

Gaurab K.C

Testing different combination of personal cleaning products against activated carbon for Showerloop shower water purification system

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<p>The objective of this thesis was to test the effect of different personal cleaning products used in shower on performance of different types of activated carbon used in Showerloop's filter. There were seven responses measured namely: potassium, chloride, sulfate, phosphate, pH, conductivity and turbidity. Uncertainties were determined from preliminary batch of experiments between Carbsorb 30 activated carbon and <i>shower gel</i>. The second batch of experiments were performed as 4x4 factorial design between four activated carbons and personal cleaning products. The results were analysed by Anovamix in R and the multiple comparisons of means were determined by Tukey tests.</p> <p>The pH values were around 7 and conductivity values were well within the limit for drinking water quality, as for turbidity all the activated carbons reduced turbidity except for Carbsorb 30 against organic soap. Aquasorb Cs added phosphate into the filtrate against all the cleaning products as did Aquacarb 207 c against <i>normal shampoo</i>. Aquacarb 207 c performed similarly to Carbsorb 30 in terms of removing chloride and sulfate except for potassium which Aquacarb 207c, reduced by 6.7% against <i>organic shampoo</i>. Aquasorb 207 c also added potassium against organic shampoo but reduced chloride by 44%. Krausen removed potassium but added chloride by 11% against <i>organic shampoo</i>. Against <i>organic soap</i>, all four activated carbons reduced potassium, chloride and sulfate.</p> <p>For pH, conductivity and turbidity values all four activated carbons performed quite effectively except for turbidity for Carbsorb 30 and Krausen when used against organic soap. Aquacarb 207's performance for phosphate makes it unsuitable for Showerloop. Krausen and Carbsorb 30 could be the options although, Krausen added ions against normal shampoo. If the cleaning product is organic, the performance of all the activated carbons is more effective than when used against non-organic products. Cheaper products like Krausen perform quite similarly compared to more expensive products. Future research could be done on interaction effect of responses as well as vulnerability to bacterial growth on activated carbon because of accumulation of nutrients form cleaning products.</p>	
Keywords	activated carbon, personal cleaning products, Showerloop, AnovaMix, Tukey HSD test

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List of abbreviations

K	Potassium
Cl	Chloride
SO ₄	Sulfate
PO ₄	Phosphate
Con	Conductivity
Tu	Turbidity
AC	Activated Carbon
BAC	Biological activated carbon
GAC	Granular activated carbon
PAC	Pelletized activated carbon
SG	Shower gel
NS	Normal Shampoo
OSH	Organic shampoo
OS	Organic soap
IC	Ion Chromatography
AES	Atomic emission spectrometer
ANOVA	Analysis of variance
vdc	volt direct current
USDA	United States Department of Agriculture
UV	Ultra violet
Kwh	Kilo watt hour

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1 Introduction

The world is rapidly changing and every day we are faced with new challenges. There are over 7.35 billion people in the world (World Bank, 2016). Population growth has led to mass migration to urban areas; this in turn has led to critical shortage of clean drinking water in the cities. Access to clean drinking water is one of the major challenges we are facing at the moment, and significant steps have to be taken in terms of tackling global warming and building new infrastructures to ensure clean water for all people.

Over 1.8 billion people drink water that is faecally contaminated (WHO, 2017). The sustainable approach to providing the population with clean water requires efficient and intelligent use. There is huge disparity in water usage in developed countries compared to developing countries. USA has the highest per capita use of water at 215 m³/ year, which is more than 53 times higher than Mali's per capita usage. In USA, more than 40% of the 215 m³ of water is used for toilet and shower, and usually this is the same water that is perfectly drinkable water. (World Business Council for Sustainable Development, 2006).

The behavioural aspect of water usage is another problem in the developed countries where abundance means waste. This has led to acute water shortage in places like California during the drought. Water saving can be done in various ways; rain water harvesting and reusing water for toilets are all proven concepts. However, recycling water from shower hasn't been done before. Considering that about 20% of the water is used in the shower alone, recycling shower water not only could save large amounts of water but also would save energy. Showerloop is a shower water purification system that recycles water from the shower and purifies it as drinkable. The prospect of recycling shower water to drinkable quality would also be useful in places where water is scarce and personal hygiene may not be the priority compared to drinking. Shower water could also be recycled in places where water is abundant and where there are people who are environmentally conscious but also want to enjoy long showers. Showerloop could provide a solution to the people to enjoy long guilt free showers or people who simply want to save water and save energy.

The important parts of the Showerloop purification system are sand filter, activated carbon and UV radiation system. Activated carbon is responsible for removing turbidity, odour and ions from the water. There are wide varieties of activated carbons in the market; therefore, it is crucial to find the right one that works for the system and that is preferably cheap.

Activated carbons also called charcoal are widely used in drinking water systems to remove odour, turbidity and organic contaminants. Activated carbons are mostly made from two base materials: coconut shells and coal. There are many qualities and characteristics of activated carbon that might be suitable for one purpose but not for the other. Shower-loop's system is highly specific meaning which means that it deals with the cleaning products; therefore, it is important to use an activated carbon that is efficient against cleaning products and also long lasting or works considerably well for a long time. Four activated carbons namely: Aquacarb 207 c, Carbsorb 30, Aquasorb CS and Krausen were selected to be tested against four personal cleaning products: shower gel, normal shampoo, organic soap and organic shampoo to determine how well each activated carbons works against each of the cleaning product.

2 Theoretical Background

2.1 Showerloop

2.1.1 Core product concept

Showerloop is a shower water purification system that recycles and purifies shower water in real time. This shower water purification system collects, cleans and reuses water in real time utilizing series of filters and an ultraviolet disinfection system to obtain drinkable quality water. There are both environmental and financial benefits in using this product. The water reduction is 90%, and a 70-90% energy saving can be achieved for a 10 min shower at a flow rate of 10l/min (Selvarajan, 2016).

The three main principles of this product are a) to save money b) to save water c) to save environment. Formerly known as Showermagic, Showerloop has undergone several re-designs to improve usability, performance and efficiency, but the basic working principle is the same.

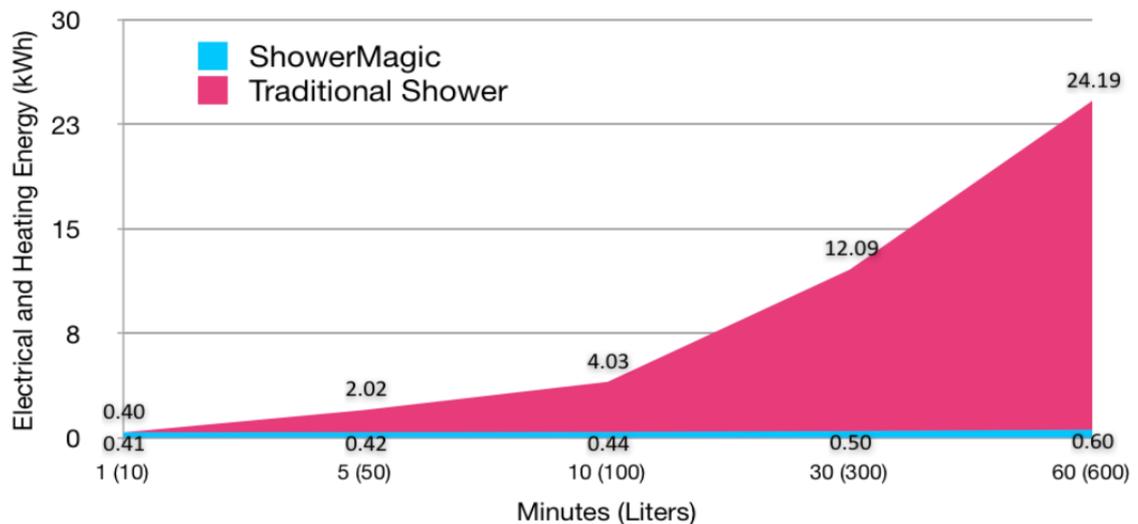


Figure 1: Energy and water saving with Showermagic vs normal shower (Selvarajan and Holland, 2013).

Figure 1 shows the savings that can be achieved with Showermagic compared to a normal shower. Showermagic recycles 10 litres of water and consumes 220 Wh power. A 10-minute normal shower will consume about 100 litres of water and 4.03 kWh. This shows that Showermagic is able to save 90 litres of water and 3.6 kWh of electricity per day per user. This corresponds to a saving as high as 300 € considering reduction in electricity and water reduction (Selvarajan and Holland, 2013).

2.1.2 Major Components

The complete set up of Showerloop is illustrated Figure 2. The major components of Showerloop are its three principle filtration and purification units given below:

- 1) Particle screen
- 2) Quartz Sand and Activated Carbon filter
- 3) Ultra violet radiation tube

Figure 2 displays all the components of Showerloop.

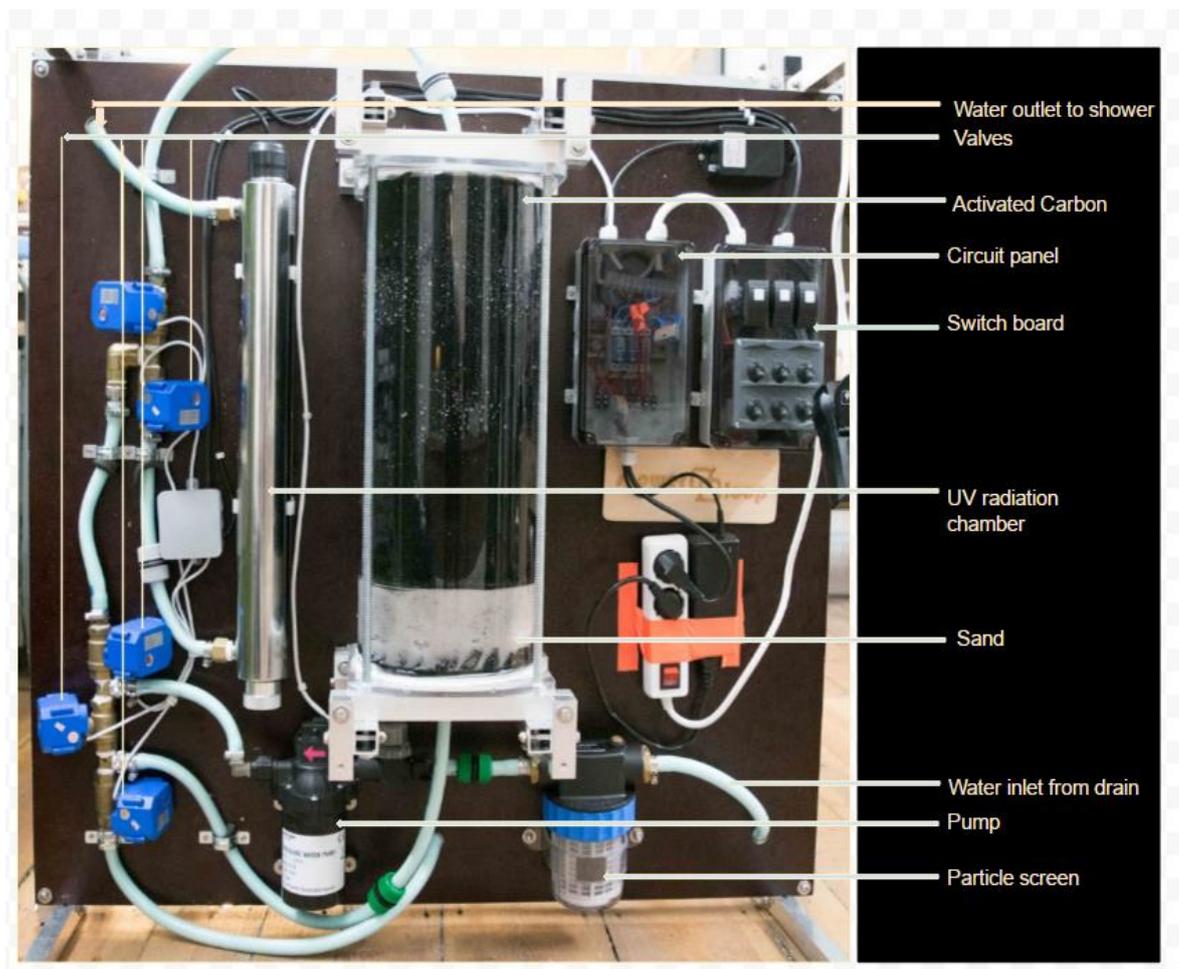


Figure 2: Labelled picture of Showerloop.

Particle screen is fitted before the pump in order to keep out hair and other particles to protect the pump. A 12 V DC powered pump is chosen in order it to be compatible with solar power. Activated carbon and sand filter are together in an enclosed acrylic cylinder tube with a sand filter on the bottom. On the inlet and outlet of the tube as well as between the sand and activated carbon, a geotextile is placed to prevent sand or activated carbon to leak into the filtrate (see Appendices)

Apart from the filtration units, all of the valves are automated, while a 12 V DC pump is chosen in order to make Showerloop usable with solar power. The UV radiation tube purifies the water before it comes out of the shower. The valves are fitted with flow and pressure sensors that are connected to the circuit panel and on to the switch that enables it to be run on different modes or switch on and off different valves.

2.1.3 Working principle

Showerloop is designed to work in real time. In the loop mode, the water is pumped in from the drain through the screen filter, then to sand filter and activated carbon filter passing through the UV tube before coming out of the shower. Figure 3 shows the complete six valve setups of the Showerloop. Showerloop has three different modes:

- 1) Showerloop mode
- 2) Back wash mode
- 3) Bypass mode

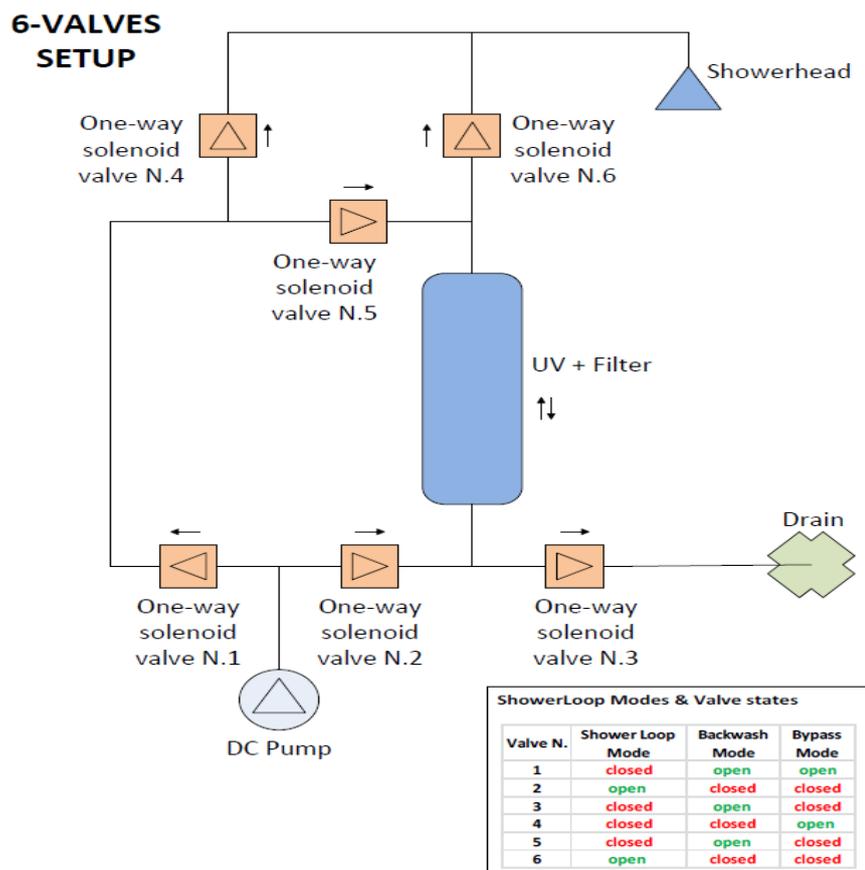


Figure 3: Showerloop modes and valve setups (Selvarajan, 2016).

The Showerloop mode is active when all the valves except for valves number 1 and 6 are open this allows the water pumped in from the drain to pass through the filters and UV tube. Activated carbon filters work as adsorbents, meaning that the longer the contact time with the water is, the higher the removal rate of contaminants is. However, the other side of the coin is to maintain the flow rate that is enough for the user to take a satisfactory shower. It has been found that the Showerloop works very well at flow rates up to 10l/min (Selvarajan and Holland, 2013).

Showerloop is continuously filtering contaminants present in the shower water that contains different nutrients, hairs, sweat as well as different chemicals of the cleaning product. The contaminants filtered in the particle filter, trapped in the sand filter and adsorbed in activated carbon need to be removed in order to ensure the desired quality of the water coming out of the shower, and also to prevent bacterial accumulation in activated carbon and in the sand filter. A Back wash mode has been designed to do this. Valves number 1, 3 and 5 are open thus allowing the flow of water counter to the regular Showerloop mode.

The bypass mode allows the user to shower as if they are not using Showerloop. This is particularly useful if the user wants to urinate in the shower so that showered water goes straight to the drain without getting the urine to the Showerloop. Valve number 1 and 4 are opened to activate this mode.

All three modes are automated which means that the user can just choose which mode is to be activated by pushing the corresponding button assigned for that mode. All the valves are fitted with sensors and are connected to the circuit board. Water quality test kits are recommended to be used at regular intervals in order to check if the system is working properly.

2.2 Personal cleaning products

Personal cleaning products are an integral part of modern life. Newer products with various ingredients and functions are being advertised and marketed all the time. Shampoos, soaps, shower gels, natural soaps and organic soaps can be found in abundance in our nearest stores; therefore, there is plenty of choice for the consumers although manufacturers use the terms like natural, organic and made with organic ingredients cleverly to entice consumers to buy their product. Products used for shower mainly consist of products specifically for hair referred to as shampoos, products for body generally referred to as soaps if they are solid and shower gels if they are liquid, and then there are few products like conditioners that are used to treat and 'condition' the hair. There are also products which are similar to the above mentioned ones but are referred to as organic, natural or Eco-soaps.

2.2.1 Non-organic soap

Non-organic soap is a personal cleaning product usually used for cleaning the body or in some cases the hair as well. These products are most widely used partly because of cheap raw materials like animal fats, vegetable oils or petroleum by-products. Non-organic soap can be either solid bar soaps or liquid soaps generally referred to as shower gel.

Although most of the cleaning products are marketed as soaps, they are not exactly soaps. These products can contain a wide array of ingredients, but manufacturing processes are not usually disclosed to protect their products. There are some products that contain very little soap, i.e. saponified fats or oils, but other surfactants that are essentially detergents that are derived from by-products of petroleum production. These are therefore excellent cleaners but they are mostly non-biodegradable and bio-accumulative. The reason for their popularity besides being cheaper than the so called organic products is that they are marketed and tailored to meet the desires of all categories of customer. They are claimed to be soothing and refreshing and do not leave the skin dry. In order to achieve the various desired qualities, softeners, foaming agents, fragrance, colorants, emulsifiers, surfactants, plasticizers, lather enhancers, fillers and binders are also added to the product (Friedman and Wolf, 1996). The percent content of different constituents of toilet soap is given in Table 1.

Table 1: Toilet soap ingredients (Friedman, Wolf 1996).

Ingredients	Examples	Range (%)
Cleansing surfactants	Soap	65-85
	Synthetic detergents	0-10
Moisturizers Glycerine	Glycerine, lanolin	0.5-5
Super Fattening agent	Fatty acid	0.5-3
Bar hardening agent	Salt (NaCl)	0.3-2
Fillers	Starch	0-10
Antioxidants(preservatives)	BHT (butylated hydroxyl-toluene)	0.1-0.3
Chelating agents	EDTA	0.1-0.5
Whitening agents	Titanium dioxide (TiO ₂)	0.1-0.5
Deodorants	Triclosan, Tri-chloro-carbon	0.2-1.5
Fragrance		0.5-2.5
Dyes and pigments		0-0-01
Water		8-13

2.2.2 Organic products

According to USDA, an organic soap should contain a minimum of 70% organic ingredients by total weight. Organic soap is made from oil, water and lye but lye is completely removed when the final product is acquired. Unlike regular soaps, organic soaps do not contain petroleum-based compounds. If the product is said to be organic, it should at least contain 95% organic ingredient by weight (USDA n.d).

There are various labels such as Eco, Organic, Natural, Made with organic ingredients used to market the soaps. It is very important to realise that a product might be organic but may not necessarily be ecological. Organic soap refers to the saponification product using natural ingredients free from synthesized compounds. Basic oil blend of coconut oil, vegetable oil or palm oil is reacted with sodium hydroxide popularly known as lye along with natural herbs and oils to form an organic soap. A wide array of base oil can be used

in order to make soaps. The choice of base oil is dependent on the desired characteristics of the finished product, but most importantly the base oil has to be organic for the soap to be labelled 'Made with organic ingredients'.

Regulations and Criteria

In the EU, term organic is usually used for the ingredients and agricultural products or primary agricultural ingredients used to manufacture other products, but not the product itself. The EU Ecolabel (Figure 4) has series of categories for *rinse off cosmetic products* that include the following (European Commission, 2014):

1. Toxicity to aquatic organisms: Critical Dilution Volume(CDV)
2. Biodegradability
3. Excluded or limited substances and mixtures
4. Packaging
5. Sustainable sourcing of palm oil, palm kernel oil and their derivatives
6. Fitness for use
7. Information appearing on the EU Ecolabel



Figure 4: The Ecolabel logo for products in the EU (European Commission, 2016.)

The use of ecolabel ensures that the product has the minimum impact on aquatic ecosystem, adheres to the strict requirements of biodegradability and the waste generated from the packing is set as minimum as possible. The criteria are set to minimize the impact of the product on the environment during manufacturing, use and end-of-life (Ecolabel, 2014).

The major ingredient in manufacturing of the cosmetics and soaps are the essential oil. Most widely used oils are palm, palm kernel, coconut or their derivative; therefore, it is required that these raw materials are acquired from a sustainable source. The producer or distributors of these raw materials need to be verified by multi-stakeholder organisations. The use of fragrances is prohibited in baby products, and as for the preservatives and colorants, the BCF value should be less than 100 or $\log K_{ow}$ be less than 3, in addition, the mixture, formulation or the product itself should not contain any substances that meet the criteria for classification with hazard statements and risk phrases that are listed in the criteria document (European Commission, 2014).

Packaging the product also have a significant impact on the environment; therefore, unnecessary packaging materials are not allowed. The primary packaging should be designed to make the correct dosage easy and no more than 10% of the product can remain after full use. The packaging impact ratio should not exceed 0.28 g of packaging per gram of product. The use of plastic should be designed so as to facilitate recycling (European Commission 2016).

It is equally important to make people aware of the ecolabel and to clarify what it means when the product has a minimum impact on the environment. Therefore, the information appearing on the label should contain the following text (European Commission, 2016):

- Reduced impact on aquatic ecosystems
- Fulfils strict biodegradability requirements
- Limits packaging waste

The critical dilution volume (CDV) relates to the toxicity to the aquatic animals. The CDV should be less than 3300 (per/g Active compound) (European Commission, 2016).

2.2.3 Ingredients and Manufacturing

Organic personal cleaning products by virtue of their composition cannot be 100% organic; however, they can be made with 85% organic or natural ingredients. The simplest form of the organic soap is manufactured by saponification of oils. The oil chosen for this purpose can be either vegetable oils or animal fats. Most of the customers who choose to use organic or eco-friendly products prefer the vegetarian option. Either sunflower oil, coconut oil, palm, palm kernel oils or combination of these in different quantities are used as base oil. A wide array of natural oils and extracts such as lemongrass, rosemary, thyme, lemon, coffee, apricot, pine, juniper can be added to provide fragrance, texture and colour to the finished product. Most non-organic soap contains surfactants and foaming agents along with preservatives and colorants but organic soap does not usually contain those artificially formulated chemicals.

The eco soaps or organic soap is manufactured more or less the same way as in-organic soaps except the soap cannot contain the ingredient that exceed the values set by the EU (European Commission, 2014). The oils or fats obtained have to be obtained from sustainable source that are verified by the EU via multi-stake holder organisations. The oils can also be recycled. Many homemade soap manufacturers utilize oils leftover from restaurants and food courts to manufacture soap that are essentially recycling waste oil (see Appendices). The homemade soap follows the basic saponification route, where the waste oil is collected from restaurants, filtered and mixed with the prepared mixture lye and water. The preferred fragrance oil is added, and the mixture is then poured onto the mould and allowed to cool. In case of the liquid soaps the process is almost the same except the lye in this case is potassium hydroxide or mixture of sodium hydroxide and potassium hydroxide (European Commission, 2014).

2.2.4 Non organic Shampoo

Shampoos are special liquid that are specifically designed to clean the hair. There are many varieties of shampoo these days. The shampoos available in the market can be categorised in terms of needs they fulfil, organic or nonorganic or even the perfumes they use. Most of the popular brands have more or less similar ingredients and therefore do the basic things well i.e. washing and conditioning the hair. Shampoos can be either specifically designed for oily or dry hair, straightening and smoothing, hair thickening, clarifying. There are also few dry shampoos and shampoos specifically for dandruff control as well as for coloured hairs.

The main ingredients of a shampoo are presented in the following paragraphs.

i) Surfactants

The base material for the shampoo is surfactant which are added along with co-surfactants. Anionic surfactants are anionic in nature; these can be alkyl sulphates, alkyl sulfonates or alkyl ether sulphate. Surfactants can also be sulfosuccinate esters, amphoteric surfactants or protein-fatty acid condensates. Surfactants are responsible for breaking the physical bonds between hair and dirt, then mixing with the dirt and transporting them out of the hair.

ii) Dispersing agents

Dispersing agents are the chemicals that stabilize the shampoo during storage, prevents from settling and dumping. These are usually glycol di-stearate, acrylates, or carbomer.

iii) pH buffers

The pH buffers enable the acidic preservatives to work and maintain the pH around 5. Hair cuticles are generally pH 4.5-5.5, therefore this enables the shampoo to give shine to the hair. Weak acids like citric, tartaric, adipic and phosphoric acids and their salts are generally added to constitute pH buffers.

iv) Aesthetic additives

Aesthetic additives are mainly used to give colour, stabilize the shampoo against the light, give texture and creamy appearance as well give fragrance to the shampoo.

v) Conditioners

Conditioners function against tangling by reducing static charge. These are mainly cationic polymers e.g. Quaternary hydroxyl cellulosic, silicones and silicone derivatives.

vi) Thickeners

Sodium or ammonium chloride, along with amphoteric surfactants, betaines, polyethylene glycol as well as fatty acid monoesters and polymers like hydroxyl-alkyl celluloses and acrylates. They help to adjust the viscosity and pouring properties to prevent running into eyes.

vii) Foaming agents

Foaming agents increase the amount of foam produced contribute to the creaminess of the lather and foam. Major ingredients cocamide monoethanolamide (MEA), and cocamide di ethanolamine.

viii) Preservatives

The base material for the shampoo is water, which also source for microorganisms. Therefore, it is vitally important that microbial growth is prevented. Benzoic acid and its salts, salicylic acid and its salt, parabens (sodium methyl paraben) are added as preservatives. Organic acids and their salts are generally preferred as preservatives as they are cheap and non-harmful. Organic acids keep the pH of shampoo at 5 - 5.5.

2.3 Activated Carbon

Activated carbon is a material derived from carbonaceous material like coal, coconuts, wood. Peat, shells or any other material with high carbon content. The carbon content is activated through various physical and thermal treatment. Activated carbon can be used in various processes in water and air purification. Activated carbon removes impurities through a process called adsorption. Adsorption is a process by which activated carbon removes contaminants from liquid and vapour streams. Activated carbon has large internal surface which create attractive force to adsorb to the surface of carbon. The attractive force in these pores is stronger than attractive force binding the contaminants in the solution thus removing the contaminants (John Sherbondy, 2015).

The effectiveness and applicability of activated carbon is dependent on activity and physical properties. Pore size distribution defines the activity property of carbon. Pore size distribution is the available pore volume of carbon over three pore sizes. According to IUPAC, the three pore sizes are characterised as follows:

Macropore region > 50 nm diameter

Mesopore region > 2-50 nm diameter

Micropore region > 2 nm diameter

Figure 5 shows the arrangement of pores in an activated carbon.

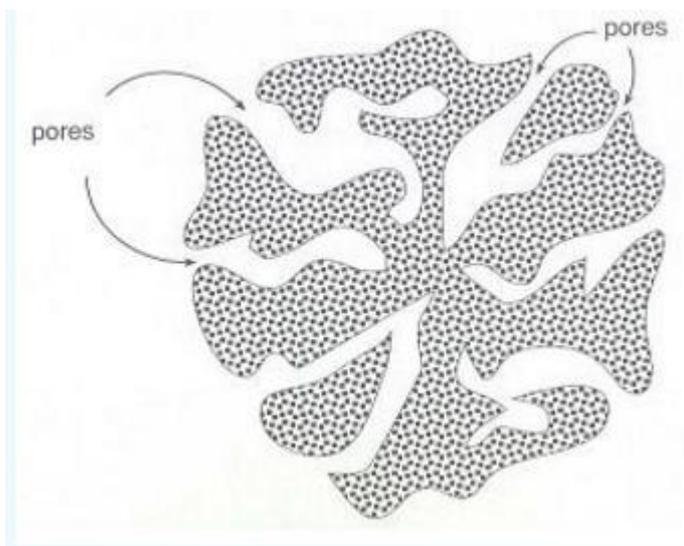


Figure 5: Pores in activated carbon (Diagram of activated carbon, 2006).

In gas phase application, most of the pores concentrated in micropore region because of the smaller size of the contaminants compared to liquid phase applications. In addition to activity property, physical properties also affect the choice and performance of activated carbon in different applications. Iodine number, surface area, product density, mesh size, ash content, hardness number are some of the physical properties that are specified by the manufacturers.

Iodine number is the standard generally used to estimate the surface area of the activated carbon by measuring iodine adsorption in standard condition, generally expressed as mgI_2 absorbed per gram carbon. Surface area is the total amount of surface available for adsorption for given mass of carbon generally denoted as m^2/g . Particle size are denoted as mesh size. Granular activated carbons are generally found in three standard sizes, 8×30 US Mesh size, 12×40 US Mesh size, and 6×16 US Mesh size (see Appendices). For example, for 8×30 US Mesh size means that at least 93% of the granules by weight are larger than 30 Mesh (0.60 mm) and at least 90% of the granules by weight are smaller than 8 Mesh (2.36 mm). Ash content refers to the non-carbon material that is produced during manufacturing in activation. Hardness number or abrasion number is the measure of carbon's resistance to attrition. This property is important indicator of activated carbon to maintain its physical integrity and withstand frictional force contributed by backwashing (John Sherbondy, 2015).

2.3.1 Types of activated carbon

Activated carbon can be manufactured from various carbonaceous base material. Materials like bituminous coal, coconuts, nut shells, peat, wood, lignite are generally used in manufacturing activated carbon. These different types of activated carbon exhibit different activity and physical properties because of base raw material and pre-treatment. Coconut shell activated carbon have high micro porosity thus contributing to high iodine number. Bituminous coal, on the other hand, have a wide array of pore diameters thus proving effective for de-chlorination and removal of organic contaminants. Coal-based carbons also have lower abrasion number compared to coconut shell carbon (John Sherbondy, 2015). Activated carbons can also be classified according to the particle size. There are mainly two types of activated carbon:

- 1) Powdered activated carbon (PAC)
- 2) Granular activated carbon (GAC)

Pelletized activated carbon as well as metal impregnated activated are also used in some applications.

Powdered activated carbon (PAC)

According to ASTM, at least 93% of the particles passing through 80 US Mesh sieve size or 0.18 mm are categorized as PAC. PAC are generally produced from wood. The average particle size of PAC derived from wood lies in between 0.15 mm - 0.25 mm. PAC are used in waste water treatment, drinking water treatment as well as in air purification systems. They can also be used coagulant particles in other liquid phase application (Cecen and Aktas, 2012).

Granular activated carbon (GAC)

GAC can be manufactured from coal, wood, lignite or coconut shells. The particle size of this type of activated carbon ranges from 0.2 mm to 5 mm. Like PAC, GAC are also used in purification process for drinking water, waste water, and groundwater. They can also be combined with microbiological film to result biological activated carbon (BAC) (Cecen and Aktas, 2012).

Pelletized and impregnated activated carbon

Pelletized activated carbon as the name suggests are created by forming activated carbon into cylindrical shaped pellets with diameter ranging from 0.8 to 5 mm. Pelletized activated carbon are mainly used in vapor phase applications where pressure drop is the priority (Pelletized activated carbon, 2015). Activated carbons are also impregnated and designed specifically to remove particular compounds; metals like silver, gold, aluminum can be used.

2.3.2 Manufacturing and Re-activation

Activated carbons can be manufactured from wide array of carbonaceous materials. Materials like coal, coconut shells or wood can be used as raw material. Carbon rich material is firstly 'Carbonized'. First, pyrolysis is done by raising temperature from 500 – 800 °C in the absence of oxygen. This is done to release volatile organic compound and realign the carbon atoms to crystalline structure. Depending upon raw material and desired final product i.e. GAC or PAC, the carbonized materials is crushed to desired particle size. The next step is activation, and it can be done either with gas or chemicals (Chowdhury and Summers et al, 2013). Figure 6 shows a typical production process of activated carbon in industrial scale.

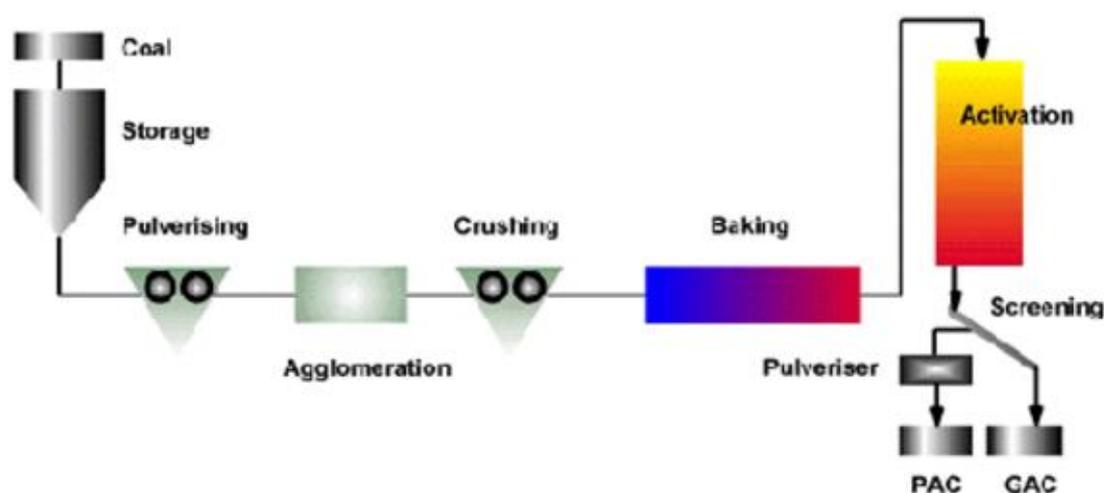


Figure 6: Activated carbon manufacturing from coal (Agglomerated Activated Carbon Manufacture, 2016).

Activation with gas is done by oxidization by oxygen, steam or carbon dioxide. If the activated carbon is to be used in water treatment applications, then the temperature is increased in the range of 850 – 1000 °C in presence of oxidizing agent. Activation process increases the pore size and suitable pore structure.

Activation with chemicals is simpler process than thermal activation or oxidization because it does not require high temperature. Activating agent like alkali, alkaline earth metal and acids are used. The use of activating agents act as dehydrating agent inhibiting the formation of tar. Chemicals like potassium hydroxide, sodium hydroxide, calcium chloride, zinc chloride are used in this process (Viswanathan and Indra Neel et al, 2009).

Activated carbon like GAC can be reactivated once they are exhausted. The reactivation process is very similar to the actual activation process with high temperature reactivation followed by off gas treatment where the adsorbed compounds are destroyed.

2.3.3 Adsorption process

Adsorption is defined as the process of accumulation of the substances on the surface or interface. In case of the water treatment applications by activated carbon the adsorption is driven by lyophobic character of solute or solvent disliking character of the solute. The solubility of the dissolved substance affects the intensity of adsorption. Therefore, a hydrophobic substance is adsorbed more than the hydrophilic substance. The other driving force is the residual force that attracts other molecular species, when they come in contact with the surface, therefore adsorption is a surface phenomenon. This unbalanced force is called London dispersion force, a type of van der Waals force. This is a type of temporary attractive force that is created by the atoms forming temporary dipoles. Therefore, when the adsorbent come in contact with the surface of the adsorbate the molecules of the adsorbent adhere to the surface of the adsorbate in this case the activated carbon the process is supplemented because of the large surface area of the activated carbon. The adsorption that are driven by van der Waals force is termed as physisorption. The other type of adsorption called Chemisorption(Cecen and Aktas, 2012). Figure 7 shows how the organic contaminants adhere to the pores of activated carbon.

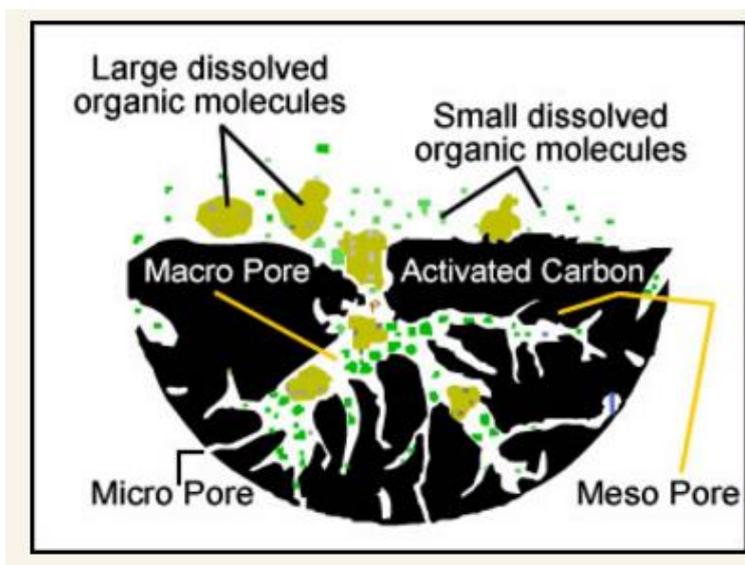


Figure 7: Removal of organic contaminant by activated carbon(Diagram of activated carbon, 2006).

There are various factors that influence adsorption. The following factors seem to affect the adsorption process (Cecen and Aktas, 2012):

- 1) Surface area – increase in surface area generally increases adsorption
- 2) Characteristics of the adsorbate- Increase in the molecular weight generally increases adsorption.
- 3) Temperature – increase in temperature of the solvent generally increases the adsorption
- 4) pH – adsorption increases with decreasing pH
- 5) Porosity – The structure, number and volumes of pores affects adsorption

2.3.4 Applications in water treatment

Activated carbon is used in drinking water as well as in wastewater treatment applications. One of the major benefits of using activated carbon in water related application is the wide range of contaminants it can remove. The use of activated carbon was mainly focused in controlling taste and odour of the drinking water, but now their scope of usability has been broadened to a wide array of contaminants like volatile organic compounds like phenols, pesticides, dyes, surfactants, herbicides and so on (Cecen and Aktas, 2012).

The most widely used activated carbon are the granular activated carbons. The powdered activated carbons are mostly used for removing non- biodegradable substances. Comparatively powdered activated carbons are less practicable and difficult to deal with compared to GACs. GACs can be used as filter beds or also as columns passing the waste water on top flowing through the column and passing out from the bottom as filtrate. However, the design needs to have the facility to be backwashed in order to prevent the filter from clogging and ensure the contaminants are removed efficiently. Several types of beds can be utilized for a water treatment plant depending upon the volume of inflow and contaminants present in the waste water. A packed or fixed GAC bed is usually utilized if the waste water has low strength and doesn't contain suspended solids. The downside of this kind of bed however is the bacterial growth that can lead to clogging and fouling of the filter. Therefore, moving beds or expanded beds can be used where the waste water is passed from bottom. In this kind of filter bed, spent carbon has to be continuously removed.

3 Methodology

3.1 Objective

The objective of the experiments was to find if the performance of activated carbon would be affected by the type of personal cleaning product (i.e. normal/regular shampoo and shower gel vs. organic shampoo and soap).

3.2 Experimental design

The independent variables for the experiments are Personal cleaning products and type of activated carbon. The following personal cleaning products were used in the experiment:

- 1) Shower gel
- 2) Organic soap
- 3) Normal shampoo
- 4) Organic shampoo

Different activated carbons from three different companies were chosen for the experiments (Table 2). Activated carbons were as follows:

- 1) Aquacarb 207 C (AC1)
- 2) Carbsorb 30 (AC2)
- 3) Aquasorb CS (AC3)
- 4) Krausen (AC4).

Table 2: Properties of activated carbons used in the experiment.

Activated Carbon	Sample Name	Base material	Mesh size	Iodine value(mg/g)	Moisture content (%)	Ball pen hardness
Aquacarb 207 c	AC1	coconut shell	8x30	1100	10	97
Carbsorb 30	AC2	coal	8x30	900	2	90
Aquasorb CS	AC3	coconut shell	20x50	1041	3.6	97
Krausen	AC4	coconut shell	8x30	1050	3	95

The controlled variables for the experiments were as follows:

- 1) Flow rate (2.4l/min)
- 2) Volume of water sample (10 l)
- 3) Volume of activated carbon (1.4.l)

- 4) Temperature of water (40 °C)
- 5) Amount of cleaning product(g)
- 6) Volume of cleaning product (ml)

A 4 X 4 factorial design with no replicates was used to carry out the experiments, due to lack of resources and time. However, in order to determine the errors, preliminary test runs for shower gel was carried out against Activated carbon filter. After that 20 litres of other three cleaning products were made with experiments made in random order.

3.3 Method of Analysis

3.3.1 Preliminary experiments

The preliminary experiments were performed between AC2 and all four cleaning products.

The explanatory variables for this experimental design were as follows:

- 1) Exp (number of replicate experiments)
- 2) BA (before/after sample)

The response variables are the following:

- 1) Potassium
- 2) Chloride
- 3) Sulfate
- 4) Phosphate
- 5) pH
- 6) Conductivity
- 7) Turbidity

A linear model of individual response was devised; a general linear model formula was $lm(response \sim r(Exp) + BA)$. The random argument was the experiment, i.e. the 5 batches of experiments with two replicates each for before and after sample. The model being a mixed effect model, AnovaMix was used to analyse the variance and goodness of model. In order to determine the goodness of model, a normality plot of residuals and a residual vs. fitted plot was made for each response variable.

3.3.2 Remaining Experiments

A factorial model was devised for remaining activated carbons and cleaning products. The design variables are the following:

- 1) Treatment (AC1, AC2, AC3, AC4)
- 2) Product (shower gel, normal shampoo, organic shampoo, organic soap)

However, no replicates experiments or measurements were made. The measurements for each response were made for *before* and *after* samples. The change in the levels of responses were tallied in different data sets and then another data set as percent change in each response between *before* and *after* samples. The percent change data set was used to depict as scatter plot of each activated carbon against each cleaning product. In order to determine whether there was difference between the activated carbon a two way anova model was used.

results.response < - aov(response~Treatment + Product) is the general formula. A post hoc-Tukey hsd test was performed for each response in order to determine the difference between the activated carbons. The results of the tests were then plotted.

3.4 Experimental setup

The activated carbon column filter was designed to emulate the actual activated filter of the 'Showerloop'. Two identical filter housings were used in order to test four activated carbons. A 12 V Dc powered pump was used for all experiments with inflow controlled before the pump with manual valve as well as the motor controller used to regulate the pump speed to get the precise flow rate for all the test.

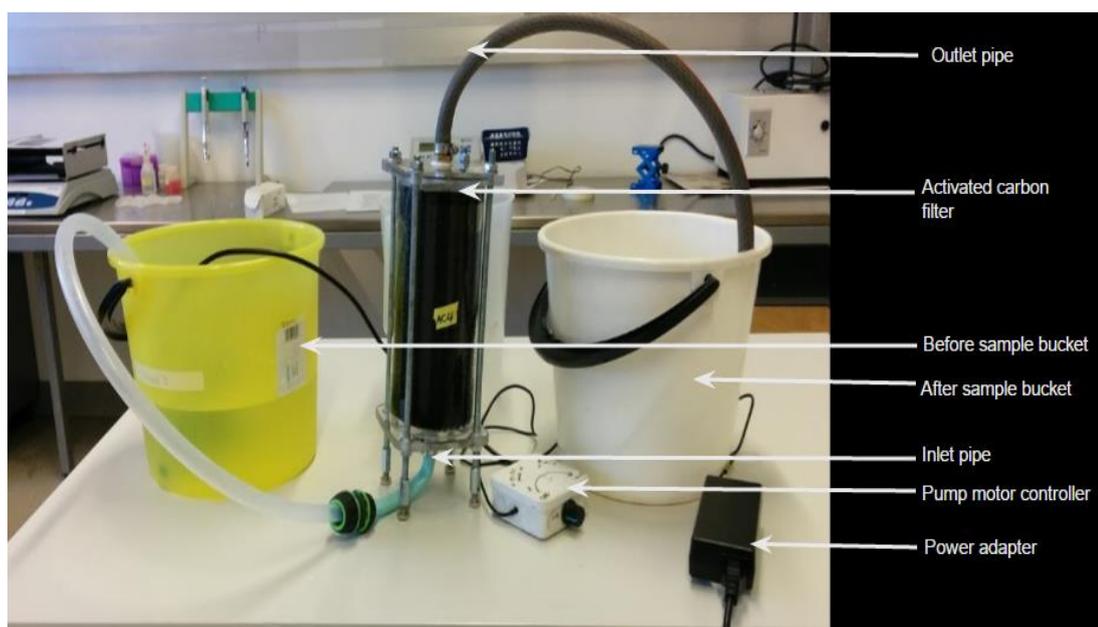


Figure 8: Complete experimental setup

All the equipment of the experiment was set up on the table as seen in Figure 8. All four activated carbons were washed for 10 minutes each, (5 minutes from each end) with the constant flow of 2.4 l/min of tap water at 40 °C, this was done to prepare the activated carbon for the experiments by removing any visible colour from the activated carbon itself. The 12 V immersible pump was used to conduct the wash the activated carbon, conduct the experiments as well as to do the back wash. The filter itself was designed to emulate the dimensions of the actual showerloop, although sand was not used in this filter. Geotextile was used along with perforated spacers on each side of the filter to allow flow of water while keeping activated carbon intact. Detachable sockets were used on both sides to swiftly switch between conducting experiments and doing back wash.

The activated carbon was tightly packed inside an acrylic tube whose dimensions are as follows:

Inside diameter(d): 9.4 cm[Radius(r): 4.7 cm]

Height(h): 24 cm

Thickness of perforated spacers: 2 cm each

Volume available for activated carbon $=\pi * r^2 * h$

$$\pi * (4.7 \text{ cm})^2 * 20$$

$$1388 \text{ cm}^3 \text{ or } 1.39 \text{ l}$$

All of the activated carbons had density of around 500kg/m³; therefore, about 700 grams of each kind of activated carbon was packed tightly inside the cylinder. The geotextile was placed inside face of the perforated spacers to allow the flow of water but preventing activated carbon getting into the filtrate or flowing back. A total volume of 20l (i.e. 10 l) for each filter was prepared at a time for each of the four personal cleaning products.

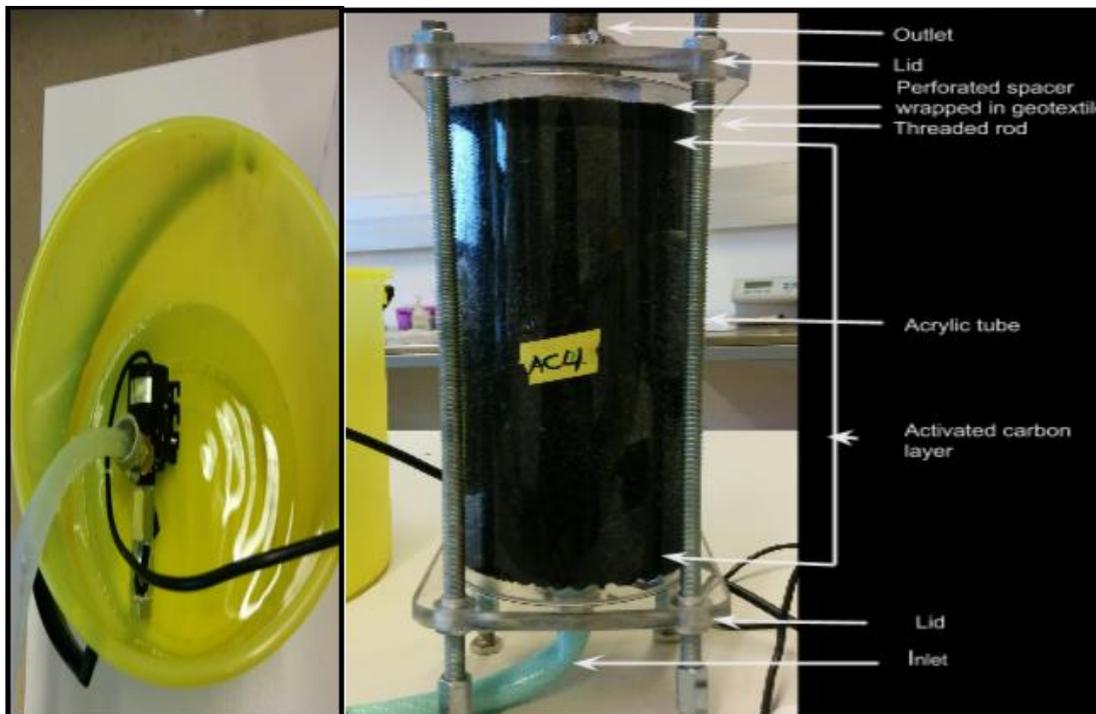


Figure 9: On the left; immersible pump used, on the right; labelled picture of one of the activated carbon filters.

3.5 Sampling

3.5.1 Naming the Samples

Following abbreviations were used to name the sample:

Before (sample taken before filtration): B

After (sample taken after filtration): A

Normal Shower gel: SG

Normal Shampoo: NS

Organic Soap: OS

Organic Shampoo: OSH

Activated carbon number: AC1, AC2, AC3, AC4

Run number: Prefix

Replicate number: Suffix

3.5.2 Concentrations

Different concentrations were used for shampoos and shower gels/soaps. The average amount of water per shower in Finland was found to be about 57 liters (European Environment Agency, 2001) and average use of shampoo is about 11.76 ml (National Center for Environmental Assessment, 2011). Therefore the average concentration is about 0.20 ml/litres for normal shampoo and organic shampoo. In one batch a total volume of 20 litres of sample was prepared for each cleaning product. 0.5 ml/l concentration was used for shower gel which was found to be about 0.345g/l, therefore 10 ml of normal showergel and 6.9 g of organic soap was mixed per 20 litres of water. The tap water was maintained at about 40 °C while the filtering was done. Table 3 gives the products used and concentrations used in the experiments.

Table 3: Concentrations of cleaning products used in experiments.

Cleaning product	Concentration
Normal shower gel	0.345 g/l
Organic soap	0.345g/l
Normal shampoo	0.20 ml/l
Organic shampoo	0.20 ml/l

3.5.3 Experiments

Preliminary runs

The preliminary test runs were carried out in order to determine the random error and systematic error. 5 separate filtrations were done with *normal* shower gel and Carbsorb 30 (AC 2) (Figure 10). Two replicate measurements were made for both before and after samples for each of the five filtrations denoted as *run*. For each run, 10 l of solution containing normal *shower gel* was prepared. Then two *before* samples were taken per each solution into two 250 ml volumetric flasks. When the temperature of the solution was about 40 °C, filtration was done for 2 minutes at 2.4 l/ min; from the filtrate two samples were collected into 250 ml volumetric flasks. After each filtration, back wash was performed for two minutes then same procedure was repeated for other four runs. Turbidity, conductivity and pH measurements were made at first; then measurements with ion chromatography for sulfate, chloride and phosphate were done after which potassium measurements were performed with atomic emissions spectrometer.

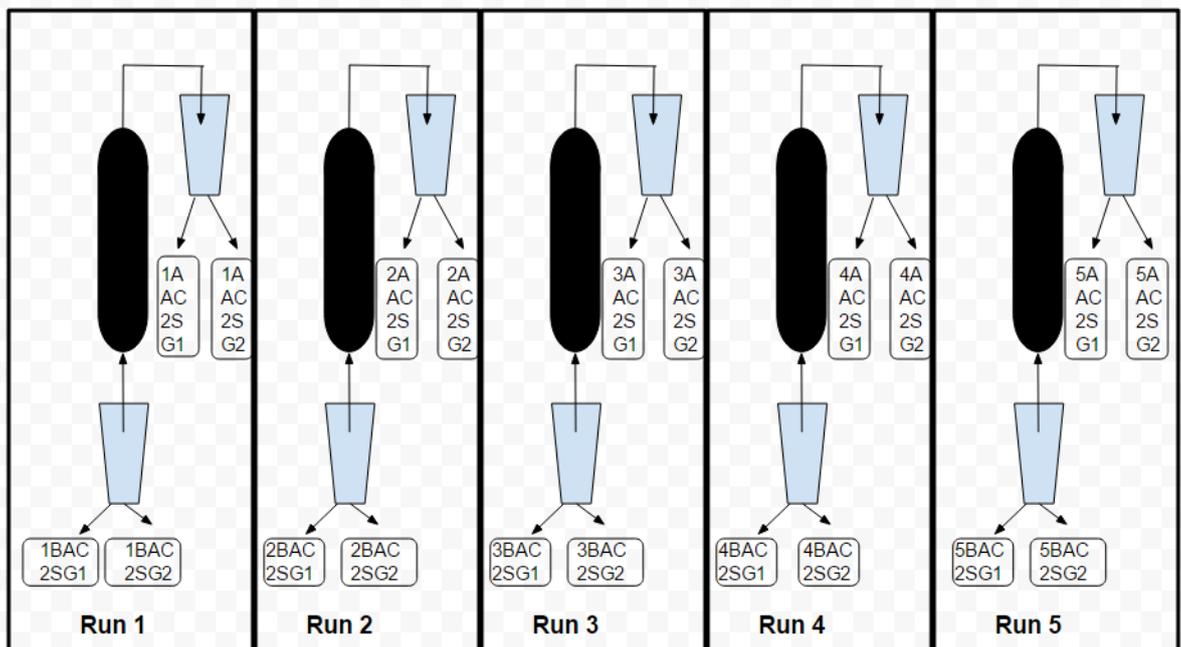


Figure 10: Preliminary test runs of normal shower gel solution against Carbsorb 30(AC2).

Remaining experiments

The rest of the experiments were made after the preliminary test runs were done, and all the measurements were finished. In the first phase of experiments, 20 l of solutions were made for each of the other three cleaning products. After that, two filtrations were made for each cleaning product solution against AC1 and AC2, respectively. Like with the preliminary tests, the temperature of solutions was kept at 40°C when the filtrations were done. *Before* and *after* samples were collected into 250 ml volumetric flasks. Immediately after the filtrations were done, the filters were backwashed for 2 minutes each. The activated carbon was then replaced from the filters with AC3 and AC4. These filters were then washed for 10 minutes (5 minutes from each end).

4 Results

4.1 Preliminary experiments

Preliminary results were obtained, in order to determine experimental and analytical uncertainties. pH, conductivity and turbidity were measured first then, chloride, sulfate and phosphate were measured from the sample using Ion chromatography and after that potassium ions were measured using AES. Table 4 shows the preliminary results of experiment between *shower gel* and AC2.

Table 4: Preliminary results of 5 samples with two replicates each of AC2 against shower gel.

Runs	Sample	K	Cl	SO4	PO4	pH	Conductivity	Turbidity
		mg/l	mg/l	mg/l	mg/l		µs/cm	NTU
1	1BAC2SG1	10.49	4.2	11.4	0	6.8	170	11.64
	1BAC2SG2	11.61	3.76	11.13	0	6.9	173	12.2
	1AAC2SG1	7.69	3.19	10.4	0	7.5	169	5.5
	1AAC2SG2	7.45	3.24	11.21	0	7.2	170	5.5
2	2BAC2SG1	10.28	4.1	11.2	0	6.65	170	12.8
	2BAC2SG2	10.61	4	11.45	0	6.84	173	13
	2AAC2SG1	7.84	2.83	10.56	0	7.3	170	3.1
	2AAC2SG2	7.22	3.21	10.8	0	7.5	171	2.8
3	3BAC2SG1	9.97	4.1	11.8	0	6.9	168	12.2
	3BAC2SG2	10.54	4	11.8	0	6.5	170	12.5
	3AAC2SG1	7.42	3.4	11.6	0	7.3	168	2.19
	3AAC2SG2	7.36	3.2	11.1	0	7.5	170	2.8
4	4BAC2SG1	11.5	4.4	12.1	0	6.6	172	11.9
	4BAC2SG1	11.7	4.2	11.9	0	6.8	172	12.3
	4AAC2SG1	7.66	3	11.5	0	7.3	170	3.8
	4AAC2SG2	7.87	3.3	11.4	0	7.4	169	2.9
5	5BAC2SG1	11.5	4.4	11.8	0	6.8	175	12.5
	5BAC2SG2	11.56	4.7	11.8	0	6.7	173	12.2
	5AAC2SG1	7.67	3.5	11.6	0	7.2	170	3.5
	5AAC2SG2	7.5	3.2	11.33	0	7.3	168	3.5

4.2 Remaining experiments

Table 5 shows the results for pH, conductivity and turbidity for all four activated carbons against all four personal cleaning products.

Table 5: Results of water quality parameters of AC1, AC2, AC3, AC4 against shower gel, normal shampoo, organic shampoo and organic soap.

Number	Sample	pH	Conductivity	Turbidity
			$\mu\text{s/cm}$	NTU
1	BSG	6.79	171.8	11.45
2	AAC1SG	7.4	166	5.56
3	AAC2SG	7.3	169.17	4.04
4	AAC3SG	7.6	172.2	2.7
5	AAC4SG	7.7	186	8.5
6	BNS	6.6	170	5.2
7	AAC1NS	7.2	160	2
8	AAC2NS	7.4	166	3.5
9	AAC3NS	7.7	164.3	9.2
10	AAC4NS	7.6	164	4.8
11	BOSH	7.2	175.2	4.2
12	AAC1OSH	7.5	170	3.1
13	AAC2OSH	7.1	166	1.2
14	AAC3OSH	8.1	204	3.2
15	AAC4OSH	7.5	177.7	3.1
16	BOS	8.2	197.4	3.7
17	AAC1OS	7.3	204	2.2
18	AAC2OS	7.4	178	3.8
19	AAC3OS	7.6	183	3.6
20	AAC4OS	7.8	170.4	4.6

Table 6 shows the levels of potassium, chloride, sulfate and phosphate ions

Table 6: Results of potassium, chloride, sulfate and phosphate ions in mg/l unit.

Number	Sample	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Phosphate mg/l
1	BSG	10.33	4.18	11.64	0
2	AAC1SG	8.23	2.89	10.1	0
3	AAC2SG	7.57	3.21	11.27	0
4	AAC3SG	7.9	3.3	11.3	0.4
5	AAC4SG	4.1	4.5	14.5	0
6	BNS	5.2	1.6	6.3	0
7	AAC1NS	7.7	0.6	2	0.2
8	AAC2NS	8.2	1.1	5.7	0
9	AAC3NS	9.8	2.3	6.7	0.3
10	AAC4NS	6.9	3	12.7	0
11	BOSH	6.9	5.8	11.8	0
12	AAC1OSH	6.4	2.9	4.3	0
13	AAC2OSH	7.9	1.4	5.8	0
14	AAC3OSH	8	3.3	12.1	0.3
15	AAC4OSH	6.6	6.5	11.8	0
16	BOS	14.7	3.6	14.9	0
17	AAC1OS	8.5	1	2.5	0
18	AAC2OS	6.3	2.9	14.1	0
19	AAC3OS	11.4	2.9	11.7	0.4
20	AAC4OS	5.1	3.2	12.2	0

5 Analysis

5.1 Relative uncertainty from preliminary experiments

The first part of the experiments; preliminary experiments (Table 4: Preliminary results of 5 samples with two replicates each of AC2 against shower gel.) was used to calculate the uncertainties of the experiments as well as the analytical uncertainty also known as measurement uncertainty. The calculated values are given in percent in Table 9. In all the experiments except for sulfate the analytical uncertainty is higher than experimental uncertainty. The residual plots can be seen in Appendices

Table 7: Calculated relative uncertainty of parameters from the preliminary experiments.

Parameters	Relative Uncertainty %		
	Experimental	Analytical	Total
K	3.33	4.22	5.4
Cl	3.4	5.28	6.3
SO ₄	2.89	1.91	3.5
pH	0.79	1.93	2.1
Conductivity	0.32	0.9	1
Turbidity	3.2	10.14	10.6

5.2 Experiments

A 4x4 factorial design gave the following results. The values for each response are subtracted from *before* sample to get the following results. In a few samples, potassium was added, and phosphate was added to all four AC3 filtrates as well as to the AC1 filtrate of the *normal shampoo*(NS). Table 8 shows the change in responses, positive sign indicates the values were added to the after samples.

Table 8: Change in parameters after treatment with activated carbons.

Treatment	Product	K	Cl	SO ₄	PO ₄	pH	Conductivity	Turbidity
Act.Carbon		mg/l	mg/l	mg/l	mg/l		µs/cm	NTU
AC1	SG	-2.10	-1.29	-1.54	0.00	0.61	-5.80	-5.89
AC1	NS	2.54	-1.02	-4.32	0.16	0.64	-10.00	-3.20
AC1	OSH	-0.46	-2.93	-7.48	0.00	0.25	-5.20	-1.06
AC1	OS	-6.16	-2.60	-2.35	0.00	-0.87	6.60	-1.50
AC2	SG	-2.76	-0.97	-0.37	0.00	0.51	-2.63	-7.41
AC2	NS	3.05	-0.50	-0.63	0.00	0.77	-4.00	-1.70
AC2	OSH	1.04	-4.43	-6.00	0.00	-0.11	-9.20	-2.97
AC2	OS	-8.41	-0.72	-0.76	0.00	-0.77	-19.40	0.10
AC3	SG	-2.42	-0.85	-0.30	0.35	0.76	0.40	-8.75
AC3	NS	4.67	0.68	0.42	0.26	1.07	-5.70	3.99
AC3	OSH	1.05	-2.55	0.26	0.31	0.92	28.80	-0.98
AC3	OS	-3.31	-0.72	-3.15	0.44	-0.58	-14.40	-0.07
AC4	SG	-6.21	0.30	2.86	0.00	0.91	14.20	-2.95
AC4	NS	1.76	1.38	6.42	0.00	1.00	-6.00	-0.36
AC4	OSH	-0.32	0.66	0.00	0.00	0.24	2.50	-1.11
AC4	OS	-9.57	-0.40	-2.65	0.00	-0.35	-27.00	0.85

Table 9 gives the percent change of each response. Percent change was calculated with the formula; $\frac{\text{After value}-\text{Before value}}{\text{Before value}} * 100$. The positive sign indicates that the values were added to the after sample.

Table 9: Percent change in parameters after treatment with activated carbons.

Treatment	Product	K	Cl	SO ₄	pH	Conductivity	Turbidity
AC1	SG	-58.0	27.0	-44.0	10.0	-1.0	-65.0
AC1	NS	49.0	-63.0	-69.0	9.0	-6.0	-72.0
AC1	OSH	-6.7	-50.5	-63.4	3.4	-3.0	-25.4
AC1	OS	-42.0	-72.0	-16.0	-11.0	3.0	-41.0
AC2	SG	-26.7	-23.2	-3.1	7.4	-1.5	-64.7
AC2	NS	59.0	-31.0	-10.0	10.0	-2.0	-38.0
AC2	OSH	15.0	-76.0	-51.0	-2.0	-5.0	-71.0
AC2	OS	-57.0	-20.0	-5.0	-9.0	-10.0	3.0
AC3	SG	-17.0	-17.0	-1.0	11.0	1.0	-69.0
AC3	NS	91.0	42.0	7.0	14.0	-3.0	-45.0
AC3	OSH	15.0	-44.0	2.0	13.0	16.0	-23.0
AC3	OS	-23.0	-20.0	-21.0	-7.0	-7.0	-2.0
AC4	SG	-53.0	11.0	26.0	13.0	9.0	-20.0
AC4	NS	34.0	85.0	102.0	14.0	-4.0	-8.0
AC4	OSH	-5.0	11.0	0.0	3.0	1.0	-27.0
AC4	OS	-65.0	-11.0	-18.0	-4.0	-14.0	23.0

5.3 Potassium (K)

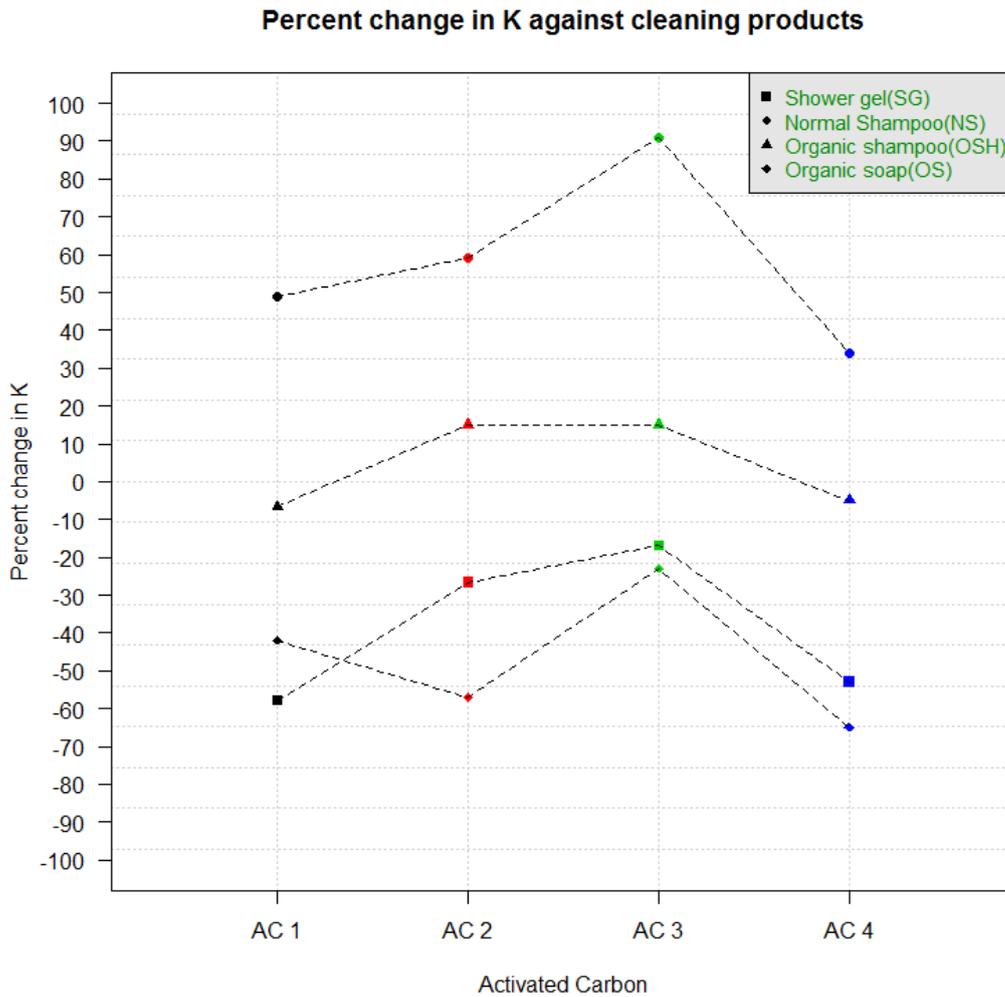


Figure 11: Scatter plot of percent change in potassium against different cleaning products.

Figure 11 shows the scatter plot of percent change in potassium ions. AC1, AC2, AC3, and AC4 all seem to add potassium into the filtrate when used against the *normal shampoo*. In the filtrates, the potassium levels increased by 49%, 59%, 91% and 35%, respectively. AC2 and AC3 both seem to add potassium into the filtrate at a rate over 10% when used against *organic shampoo*; however, AC1 and AC4 seem to reduce potassium at rate of 5%. As for *shower gel* and *organic soap*, all of the activated carbons seem to remove potassium by a significant percent.

There seems to be significant difference between AC3 and AC4 as well as between AC3 and AC1. AC4 in average seemed to be more effective than other activated carbons in removing potassium AC3 seemed to be the least effective in removing the least potassium and adding the most potassium into the filtrate.

5.4 Chloride (Cl)

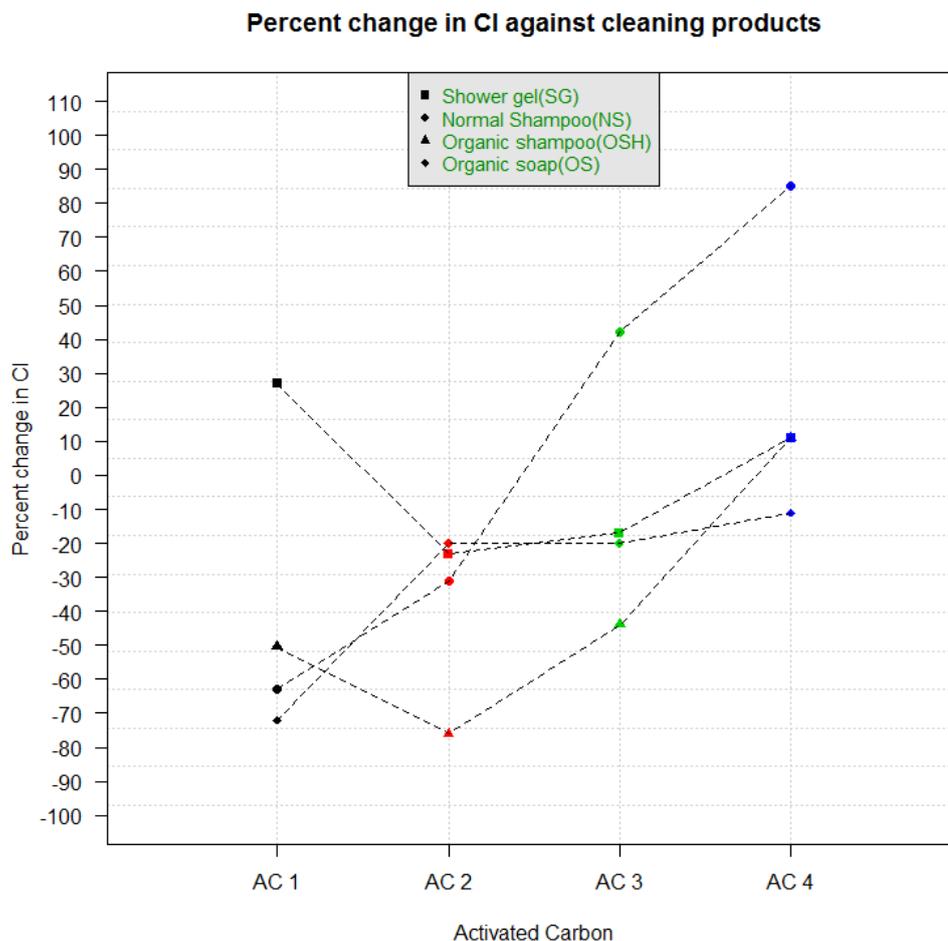


Figure 12: Scatter plot of percent change in chloride against different cleaning products.

Figure 12 shows the scatter plot of percent change in chloride ions. AC1 seems to add chloride at a rate of over 30% and AC4 by 11% to the filtrate of the shower gel sample, while AC2 and AC3 remove chloride by 23% and 17%, respectively. AC3 and AC4 added chloride to the filtrate by 42% and 85%, respectively. As for *organic shampoo* and *organic soap*, all the activated carbons seem to remove chloride, except for AC4, which adds, 11% chloride into the filtrate. Overall, the most effective in removing chloride seems to be AC2 when used against all the cleaning products. AC4 seems to be the least effective in removing chloride. AC2 and AC1 seem to be significantly better than AC4. There is no significant difference between AC2 and AC3 or between AC3 and AC1.

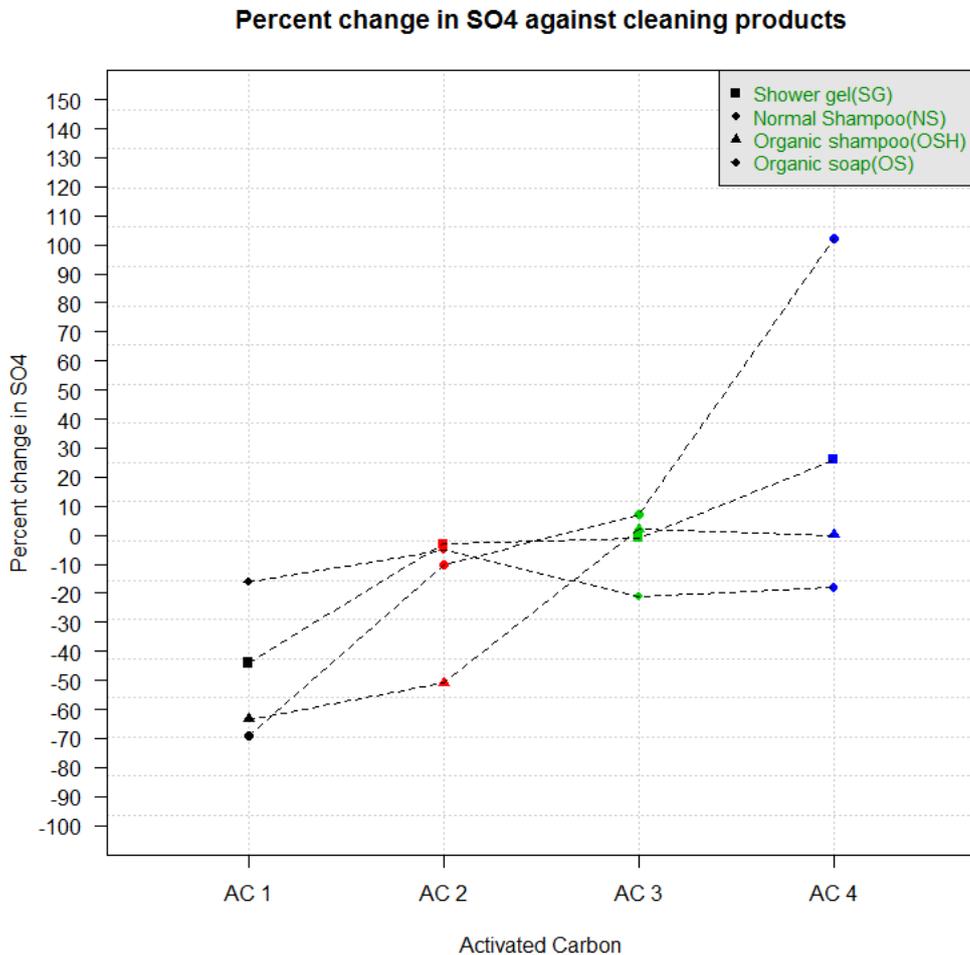
5.5 Sulfate (SO₄)

Figure 13: Scatter plot of percent change in sulfate against different cleaning products.

Figure 13 shows the scatter plot of percent change in sulfate ions. AC1 and AC2 seem to remove sulfate from all cleaning products. AC3, however, seems to remove sulfate by 1% when used against *shower gel*, but added sulfate by 7% and 2% for *normal shampoo* and *organic shampoo*, respectively. AC4 removed sulfate by 18% for *organic soap* however adding sulfate by 26% and 102% for *shower gel* and *normal shampoo* respectively. AC1 seems to be significantly better than AC4, removing 75% more sulfate than AC4. There is not much difference between AC2 and AC3. AC3 and AC2, however, perform much better than AC4.

5.6 pH

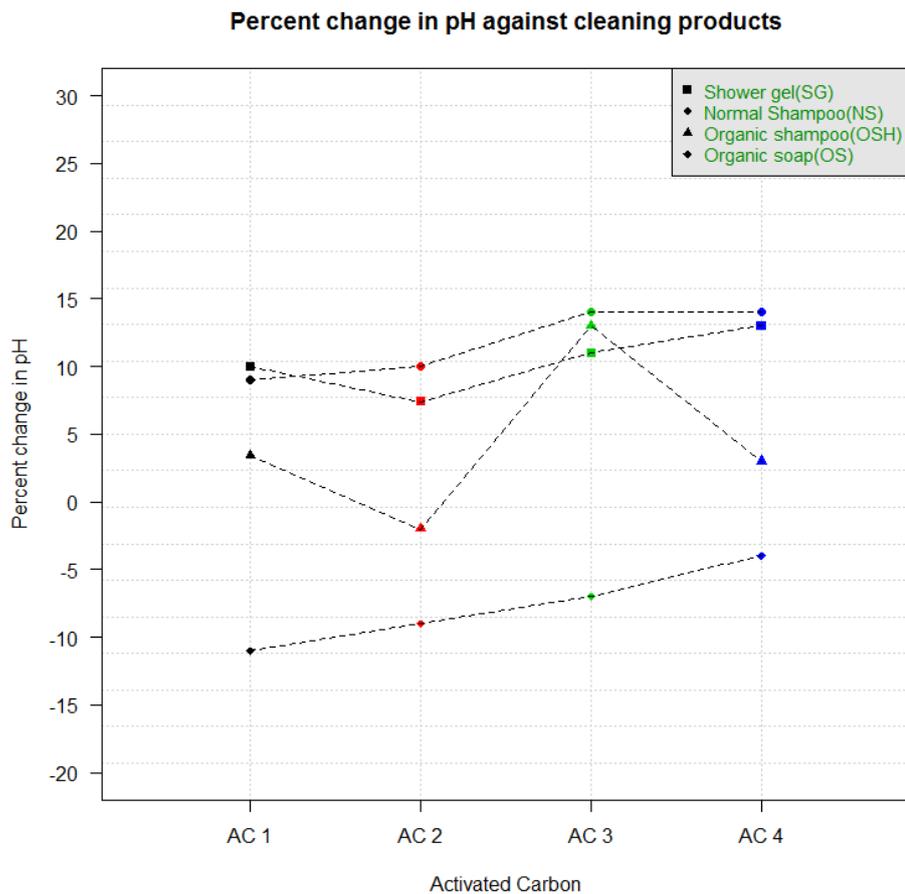


Figure 14: Scatter plot of percent change in pH against different cleaning products.

Figure 14 shows the scatter plot of percent change in pH of the samples. AC1 seems to increase pH at a rate of 10%, 9% and 3% for *shower gel*, *normal shampoo* and *organic shampoo*, respectively. AC2 and AC4 performed similarly against *shower gel*, *organic shampoo* and *organic soap*. AC3's performance against all the products is quite similar, reducing pH by over 10% except when it was used against *organic soap*.

5.7 Conductivity

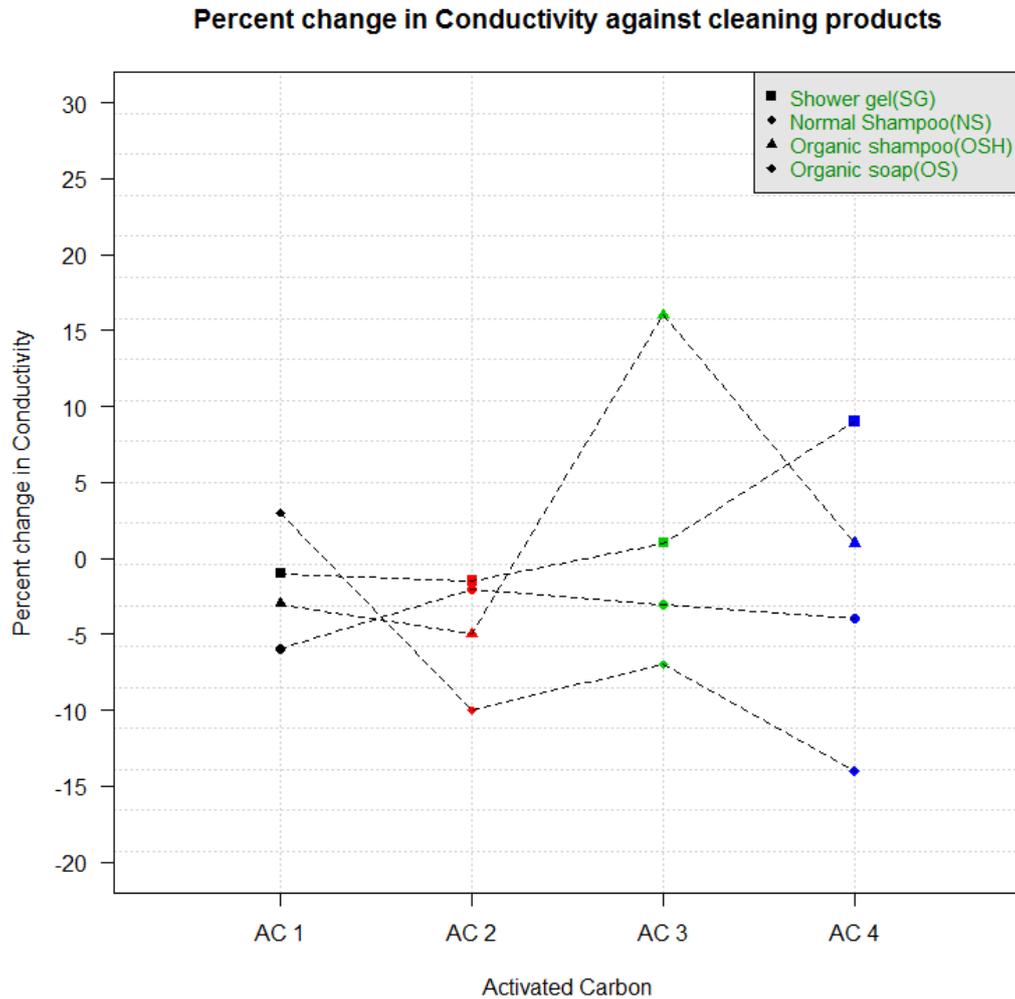


Figure 15: Scatter plot of percent change in conductivity against different cleaning products.

Figure 15 shows the scatter plot of percent change in the conductivity of the samples AC1 seemed to reduce conductivity by 1%, 6%, 3% for *shower gel*, *normal shampoo*, and *organic shampoo*, for *organic soap*, however, the conductivity increased by 3%. AC2 reduced conductivity for all cleaning products. AC3 increased conductivity for *shower gel* by just over a percent but increased conductivity by 16% for *organic shampoo* but decreased conductivity at a rate of 3% and 7% for *normal shampoo* and *organic soap*, respectively. AC4 increased conductivity by 9% and 1% for *shower gel* and *organic shampoo*, respectively while decreasing by 4% and 14% for *normal shampoo* and *organic soap* respectively. There is no significant difference between the activated carbons in terms of change in conductivity.

5.8 Turbidity

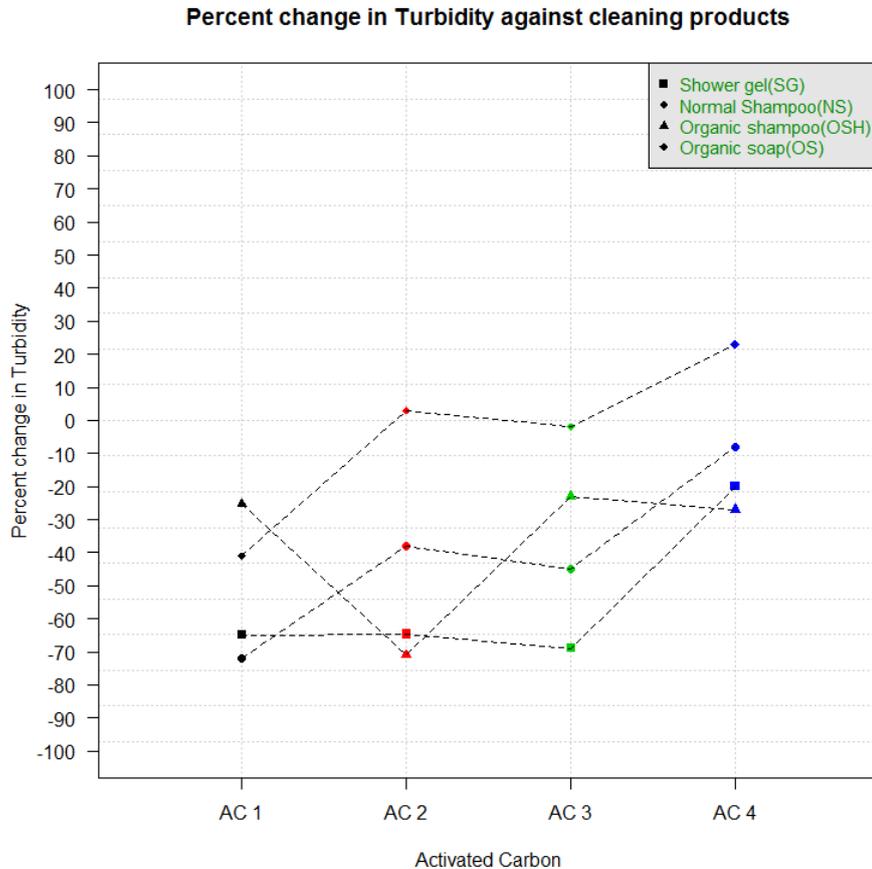


Figure 16: Scatter plot of percent change in turbidity against different cleaning product.

Figure 16 shows the scatter plot of percent change in pH of the samples AC1 and AC3 reduced turbidity against all the cleaning products, reducing the least at 25% for *organic shampoo* and most against *normal shampoo* removing 72%. AC2, however, increased turbidity slightly, adding 3 % against *organic soap* but reducing against other products. AC3 performed similarly to AC2, but AC3 removes only 23% against *organic shampoo*, while AC2 removed 71%. AC4 removed 27%, however, the turbidity increased by 23% against *organic soap*. AC4 seems to perform the worst, while AC1 performed the best. There is no significant difference between AC1 and AC2 except for performance against *organic soap*. AC3 and AC2 performed quite similarly as well.

6 Conclusion

The performance of activated carbon seems to be hugely dependent upon the type of cleaning product. Potassium was added to the filtrate for all the activated carbons used against the *normal shampoo*. In terms of anions chloride and sulfate, the performance of AC1, AC2, and AC3 does not differ significantly from each other. The only exception is AC4, which added chloride and sulfate to the filtrate when used against *shower gel* and *normal shampoo*, but added just over 0.6 mg/l of chloride when used against *organic shampoo*. Phosphate ions, however, seemed to be added to the filtrate for AC3 when used against all the cleaning products. Besides, AC3 only AC1 added phosphate when used against the *normal shampoo*. Other activated carbons did not add any phosphate into the filtrate.

The drinking water quality parameters for Finland are given in Table 10 below:

Table 10: Drinking water quality limits for the parameters (Mäkinen, 2008).

Parameter	limit for drinking water
Potassium (K)	8 mg/l
Chloride (Cl)	250 mg/l
Sulfate (S)	100 mg/l
Phosphate (PO ₄)	0.01 -0.03 mg/l
pH	6.5 – 9.5
Conductivity	250 µs/cm
Turbidity	5 NTU

The phosphate limit for drinking water is only about 0.03 mg/l, which has considerably exceeded by AC3 samples whose phosphate values were over 0.25 mg/l. The conductivity levels for all the filtrates are well within the limit, the maximum being 204 µs/cm² for AC1 against *organic shampoo*. The cleaning products do not hugely increase or decrease pH levels, the highest being 8.2 for *organic soap* and lowest being 6.6. All four activated carbons maintain the pH at around 7.

Turbidity limit for the drinking water is 5 NTU; with the exception of AC1 and AC4 against *shower gel* and AC3 against *normal shampoo*, all of the samples have turbidity values below the limit. There was not any visible foam either in any of the samples. The high turbidity value of the *shower gel sample* could be because of various substances added in order to give the product the desired colour and texture. This particular brand of *shower gel* was thick in texture as well as very foamy, which could have affected the performance of the activated carbons. However, it is intriguing why the turbidity increased against AC3.

The reason could be because the mesh size of the activated carbon is 20x50, which meant the foam could infiltrate in between the individual particle size.

The performance of all the activated carbons against *organic soap and organic shampoo* is quite good, which was also helped by the fact that both products do not have a high initial value for turbidity because they do not produce as much foam as the other products. The pH of the filtrates for AC4 are also within the limit; just over 7. AC4, however, could not remove turbidity below the limit against *shower gel*. The organic products did not contain any colouring agents either. The total relative uncertainty for turbidity, which was calculated to be 10.6%, was the highest among the results. For all the results, the relative analytical uncertainty was higher than the relative experimental uncertainty, except for sulfate given in Table 5.

7 Suggestions and recommendations

7.1 Design considerations

The activated carbons AC1, AC2, AC3 were acquired from two biggest suppliers in the world, AC4 was the cheaper product available bought from a relatively unknown seller. AC3's poor performance against the cleaning products with respect to phosphate eliminates it as a suitable active carbon filter material for Showerloop. The phosphate ions were found in the filtrate although the personal cleaning product did not contain any phosphate ions or perhaps AC3 reacted with the cleaning products to produce phosphate ions. The higher mesh value or higher individual particle size of AC3 could also be the reason why its performance was worse than that of other ACs in terms of removing turbidity. AC3 is, therefore, not suitable to be used in Showerloop.

AC1, when used against the *shower gel* solution, also added 0.2 mg/l of PO_4 in the filtrate, which leaves AC2 and AC4 as the two best choices. However, large variance is caused by the cleaning product, and especially with the *shower gel* solution, the responses behave differently. This particular brand of *shower gel* could be the reason why the ACs did not work quite as well as they did against other cleaning products. This *shower gel* had a thick texture, was very fragrant and produced large amounts of foam. Therefore, it is perhaps a good idea to recommend customers to use organic products or at least use those products that do not contain very much fragrance, not too viscous, and do not contain too much foaming agent. AC2 is the best product among the ACs used in the experiment in terms of filtration performance but AC2 could cost more than AC4, whose performance is satisfactory. Considering the cost difference, AC4 could be ideal activated carbon for Showerloop.

7.2 Future research

All the questions are not answered in this research. The interaction effect among the responses is considered because of the need to carry out large number of experiments increased by replicates. The interaction effect could be other topic for research particularly among the ions. The slowness of the ion chromatography device meant that not enough time was available to carry out such considerably high number of experiments; therefore, if alternate to this method perhaps a faster method could be a better approach. A com-

prehensive approach has to be taken because there are so many personal cleaning products that are available with very different characteristics such as texture, smell, colour, foaming agents. Therefore, substantial experimental research is required to determine what the products really contain and how different they are from each other. Another factor to consider could be that in a shower people may use different products at the same time; for example, some people use *shampoo* and *shower gel* or some may use a shampoo + shower gel combo product or even conditioners which could change how the activated carbons work. Activated carbons also have different exhaustion times. The less expensive product may work well for short time but could eventually cost more if it has to be changed frequently. The other aspect of the activated carbons to be researched could be to test, if they are vulnerable to bacterial growth because of accumulation of nutrients from the products used during the shower, and if this happens how it could be prevented.

References

Chemviron Carbon .c2016. Agglomerated Activated Carbon Manufacture. [online] Available: <http://www.chemvironcarbon.com/en/activated-carbon/activated-carbon-manufacture> [Accessed 26 May 2016].

Calgon Carbon c2015. Pelletized activated carbon. [online] Available:<http://www.calgon-carbon.com/pelletized-activated-carbon/> Accessed 25 May 2016].

Sushrut Chemicals c2016. Diagram of activated carbon. [online]. Available: <http://www.sushrutchemicals.com/activatedCarbon.html> [Accessed June 5 2016].

Cecen, F. and Aktas, Ö., c2012. *Activated Carbon for Water and Wastewater Treatment*. Singapore: Wiley-VCH.

Chowdhury, Zaid, K., Summers, R.S., Westerhof G.P., J. Leto, B., Nowack, K.O. and Corwin C.J., c2013. *Activated carbon: Solutions for improving water quality*. American Water Works Association.

Ecolabel, c2014. The EU Ecolabel for Rinse-off Cosmetic products [Homepage of European Commission]. [online]. Available: <http://ec.europa.eu/environment/ecolabel/documents/Rinse-off%20Cosmetics%20factsheet.pdf>. [Accessed March 13 2016].

European commission. c2016. The EU Ecolabel [Homepage of European Commission], [online]. Available: http://ec.europa.eu/environment/ecolabel/index_en.htm [Accessed April 8 2016].

European Commission. c2014. Commission Decision of 9 December 2014 establishing the ecological criteria for the award of the EU Ecolabel for rinse-off cosmetic products. [online]. Available: http://www.ecolabel.dk/kriteriedokumenter/30e_2014_893_EU.pdf. [Accessed May 10 2016]

European environment agency, c2001. *Indicator Fact Sheet Signals 2001 – Chapter Households*. [online]. Available : <http://www.eea.europa.eu/data-and-maps/indicators/household-energy-consumption/household-energy-consumption>. [Accessed May 10 2016]

Friedman, M. and Wolf, R., 1996. Chemistry of Soaps and Detergents: Various Types of Commercial Products and Their Ingredients. *Clinics in Dermatology*; 14:7-13.

Mickler, J and Sherbondy, J., c2015. What is Activated Carbon? [online]. Available: <http://www.tigg.com/what-is-activated-carbon.html> [Accessed May 24 2016].

National Centre for Environmental Assessment, 2011. Exposure Factors Handbook: 2011 Edition.

Selvarajan, J. and Holland, K., 2013. *ShowerMagic: A Hygienic and Eco-Efficient Real Time Greywater Reuse System for Showers*. [online]. Available: <http://urn.fi/URN:NBN:fi:amk-201405219019> [Accessed May 10 2016].

USDA, n.d FAQ: Becoming a Certified Operation. [Online]. Available: <https://www.ams.usda.gov/services/organic-certification/faq-becoming-certified> [Accessed May 25 2016].

Viswanathan, B., Indra Neel, P. and Varadarajan, c2009. *Methods of Activation and Specific Applications of Carbon Materials*. Indian Institute of Technology Madras.

WHO, Water safety and quality. [online] Available: http://www.who.int/water_sanitation_health/water-quality/en/. [Accessed February 5 2017].

World Bank, c2015 *World Development Indicators database*. [online] Available: <http://data.worldbank.org/indicator/SP.POP.TOTL>. [Accessed January 10 2017]

World Business Council for Sustainable Development, c2006. *Water facts and trends* [online] Available: http://www.unwater.org/downloads/Water_facts_and_trends.pdf. [Accessed February 5 2017].

Appendices

Appendix 1: Homemade eco soap manufacturing

JooSoap (English)



Joo Soap
Eco Soap Studio
Finland

Taiwan Maple Community
1996
台中楓樹環保小學堂

Making your first JooSoap!!

Let's GO!

Socks Shoes Stove
Bikes Table Kitchen Glass
Floor LivingAreas Balcony Bathroom
Metal Benchtop GreaseRemover
Microwave Car Cloth
Chair Sink Toilet

for general household cleaning

Cleaning soap made from used cooking oil

1 litre used cooking oil ⇒ 10 * 100g eco-soap, or 5 litres of liquid soap



get Ready!

Take a photo of your working space.

- 1 Mix lye and water into a pot **SLOWLY**. Put something to cover the steam for 2 minutes, then start stirring. *The chemical reaction will heat up the mixture and cause some steam.
- 2 Mix until the lye has dissolved and the mixture becomes **CLEAR**.
- 3 Wait the temperature of lye water to cool down to 45-50°C.
- 4 Pour the used cooking oil into the pot. Keep **STIRRING** the soap mix until it reaches "trace".



Do this in an airy space. Be careful with the heat, splash and avoid breathing the steam!

- 5 Mix well and add few drops of scent oil you like. When the mix is getting thicker and thicker, pour them into moulds, **QUICKLY**.

Take a photo after you pour them into moulds.

- 6 Remove soaps from the moulds after 2-3 days when the soaps are solidified. (cut into small pieces if you want)
- 7 Keep it indoor in an airy space. (avoid too much direct sunshine)

Share!

JooSoap Studio

Done! & Use!

Wait to dry.....soaps will turn hard. After 4-6 weeks, the soaps are ready to use.

Take some photos of you with your soaps and share with us.

Appendix 2: Showerloop component list

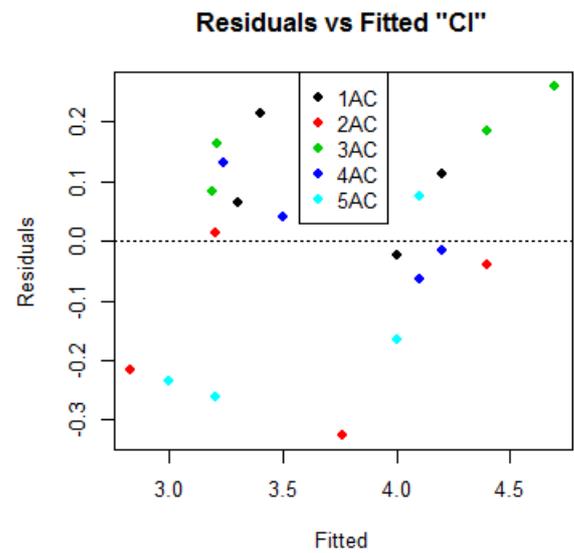
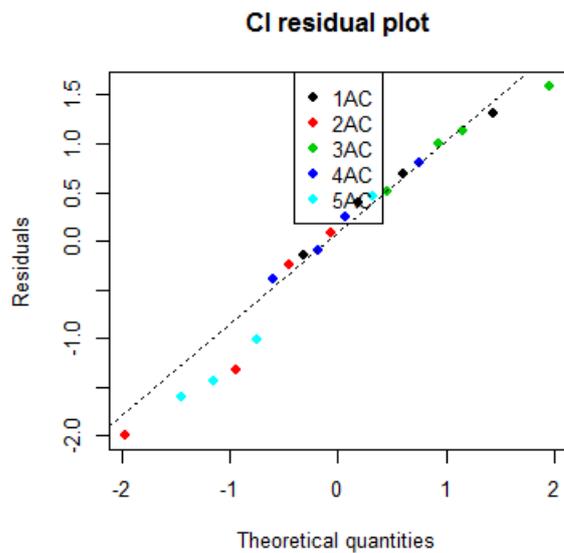
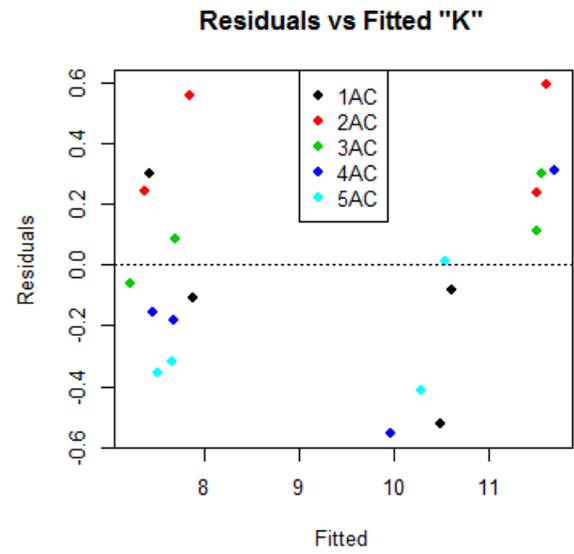
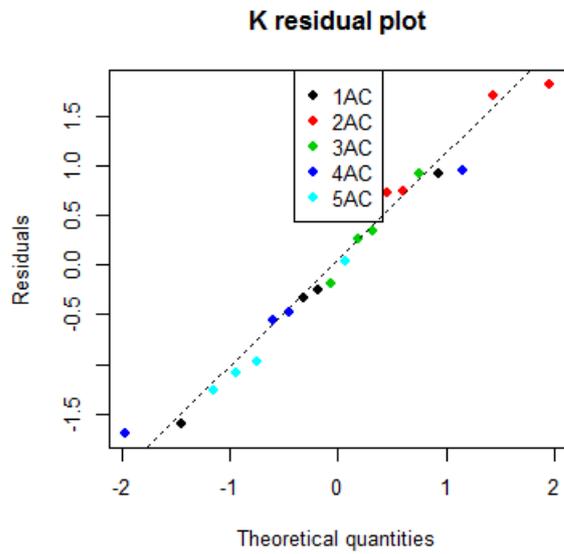
COMPONENT	PICTURE	SPECIFICATIONS	Total needed amount	Price /unit	Total Price	Usual supply amount	Where to get
Acrylic TUBE 10 cm diameter 05-10mm thickness thickness		50-55 cm	4	40	40	2m	Foiltek, can only buy 2m at a time
Acrylic plate 6 mm or more - compression disk		1 m x 40 cm	1 m x 40 cm ???	20	20		Foiltek, can only buy an entire sheet at a time
Rubber or silicone to make a gasket		silicone, ~5mm thickness	1	6	6	m2	Rubber / gasket dealer
Hose connector, female		21 mm female to 1/2" hose	6	4	24	1, 25, 50	Hardware store
Brass union + olive compression ring +		15 x 21 mm, 16mm (tube diam)	10	4	40		Hardware store
lock nut		20mm inner diam 2 / filter 3-4 / flow regulator	10	4	40		Hardware store
pipe		14 (inner) x 16 mm (outer) x 4 meters	2	15	30	1, 2, 5m	Hardware store
M10 threaded rod		8 x 60 cm, 8 x 20 cm M10	6.4m	5	30	1, 2m	Hardware store
M10 wing nut		M10	optional to replace M10 nuts	0,4	25,6	100	Hardware store
M10 nut		M10 16 / filter or flow regulator	64	0,4	25,6	100	Hardware store
Washer		M10 12 / filter or flow regulator with mounting plates	48	0,3	14,4		Hardware store
Teflon tape or hemp fiber and mineral oil		Swag	2	2	4	5m/roll	Hardware store
Hose connector M		if the whole build is with hose	11	4,5	49,5		Hardware store

Hose connector M		if the whole build is with hose	11	4,5	49,5		Hardware store
Drinking water hose (phtalate free)		for drinking water	5m	25	25	25 m roll.	Hardware store
Ring clamps		stainless steel	17	1,5	25,5	bag	Hardware store
Sand		quartz sand, sieved and washed	2	1	2	40kg sack	Aquarium store, industrial supplier
Activated Carbon		Storms Aktivit Kol 1,7l, density 0.46-0.48 g/cm ³ adsorption 1150m ² /g	6,3	6	37,8	400g/bag	Aquarium store, Home-brew store (best stuff) industrial supplier
Geotextile		Landscaping fabric	1	20	1	20m ²	Hardware store
Pump		12V / 24V Brushless DC Pump, at least 80W	80W	60	60		Ebay
UV-lamp		UV-C Min 20W, the higher the better	72W	120	120		Ebay
				in euros:	620,4	+ - 100	

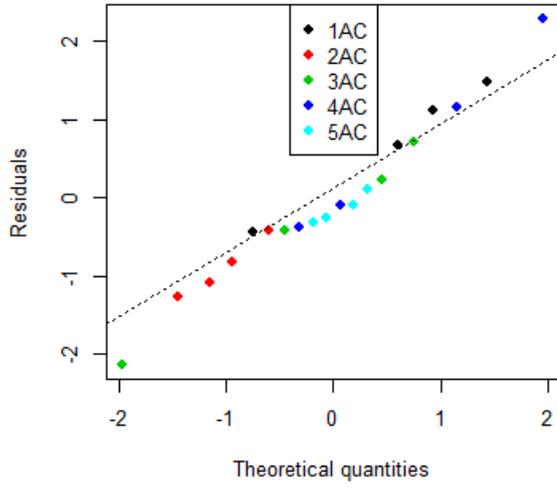
Appendix 3: US Mesh sieve size to mm sieve size

Sieve N°(ASTM E11-87)	Sieve size mm
4	4.75
6	3.35
7	2.80
8	2.36
10	2.00
12	1.70
14	1.40
16	1.18
18	1.00
20	0.85
25	0.71
30	0.60
35	0.50
40	0.42
45	0.35
50	0.30
60	0.25
70	0.21
80	0.18
100	0.15
120	0.12
170	0.090
200	0.075
325	0.045

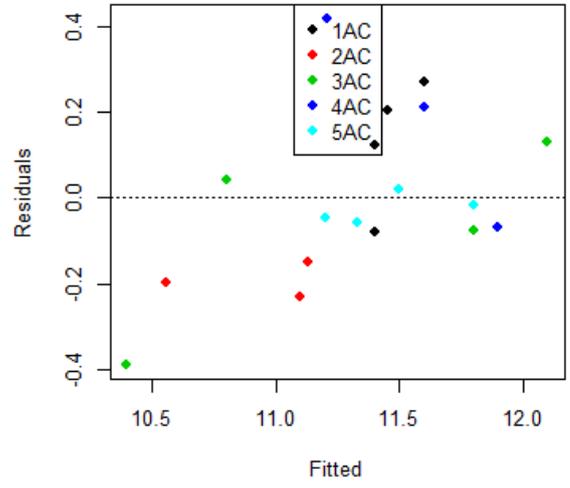
Appendix 4: Residuals of responses



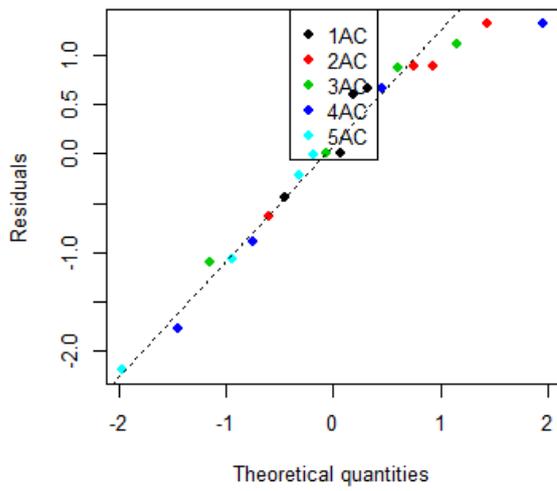
SO4 residual plot



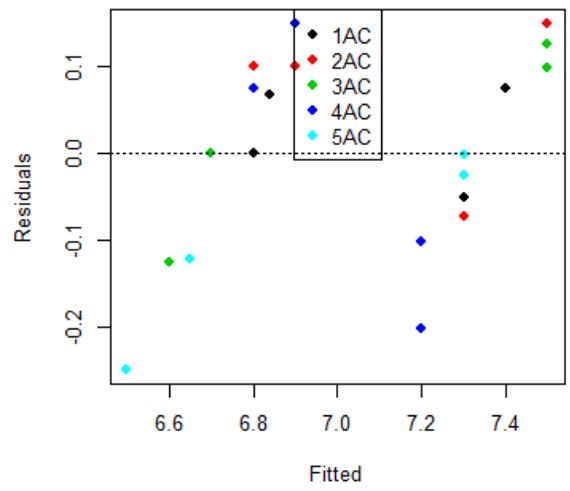
Residuals vs Fitted "SO4"



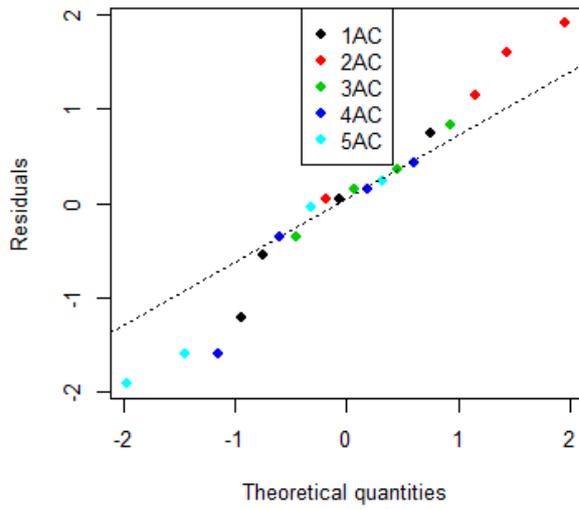
pH residual plot



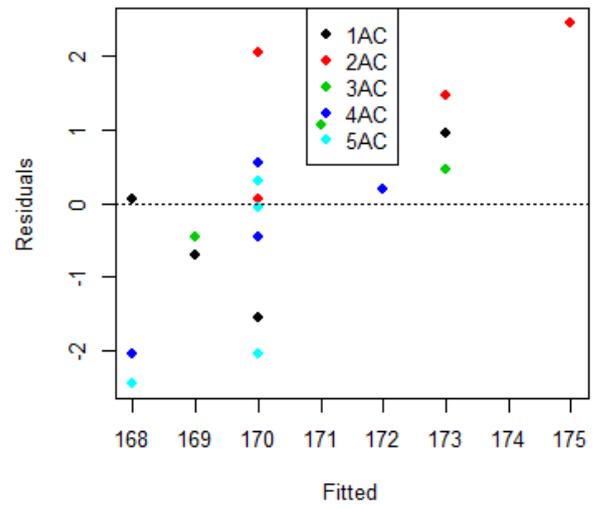
Residuals vs Fitted "pH"



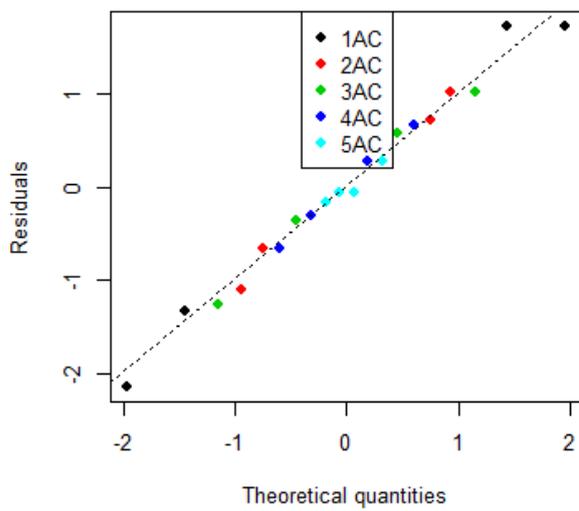
Conductivity residual plot



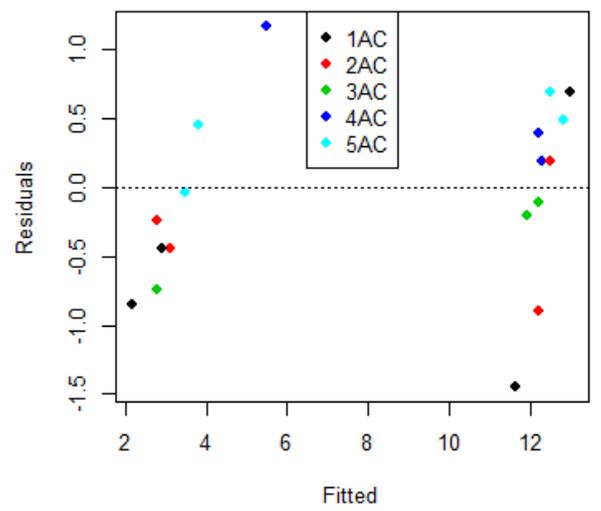
Residuals vs Fitted "Conductivity"



Turbidity residual plot



Residuals vs Fitted "Turbidity"



Appendix 5: Analysis of Variance table for preliminary experiments

Potassium(K)

Response: K

	Mean Sq	Sum Sq	Df	F value	Pr(>F)
Exp	0.53	2.14	4	3.50	0.0352
BA	58.07	58.07	1	380.09	0.0000
Residuals	0.15	2.14	14	-	-

	Err.term(s)	Err.df	VC(SS)
1 Exp	(3)	14	0.0954
2 BA	(3)	14	fixed
3 Residuals	-	-	0.1528

(VC = variance component)

Chloride (Cl)

Response: Cl

	Mean Sq	Sum Sq	Df	F value	Pr(>F)
Exp	0.10	0.41	4	2.66	0.0770
BA	4.79	4.79	1	125.60	0.0000
Residuals	0.04	0.53	14	-	-

	Err.term(s)	Err.df	VC(SS)
1 Exp	(3)	14	0.0158
2 BA	(3)	14	fixed
3 Residuals	-	-	0.0382

(VC = variance component)

Sulfate (SO4)

Response: SO4

	Mean Sq	Sum Sq	Df	F value	Pr(>F)
Exp	0.48	1.93	4	10.13	0.0005
BA	1.19	1.19	1	25.06	0.0002
Residuals	0.05	0.67	14	-	-

	Err.term(s)	Err.df	VC(SS)
1 Exp	(3)	14	0.1085
2 BA	(3)	14	fixed
3 Residuals	-	-	0.0475

(VC = variance component)

pH

```

Response: pH
      Mean Sq Sum Sq Df F value Pr(>F)
Exp      0.006   0.02  4    0.33 0.8519
BA      1.806   1.81  1   97.78 0.0000
Residuals  0.018   0.26 14      -      -

      Err.term(s) Err.df VC(SS)
1 Exp              (3)   14 -0.00308
2 BA              (3)   14    fixed
3 Residuals        -    -   0.01847
(VC = variance component)

```

Conductivity

```

Response: Con
      Mean Sq Sum Sq Df F value Pr(>F)
Exp      3.55  14.20  4    1.52 0.2499
BA     22.05  22.05  1    9.44 0.0083
Residuals  2.34  32.70 14      -      -

      Err.term(s) Err.df VC(SS)
1 Exp              (3)   14   0.304
2 BA              (3)   14    fixed
3 Residuals        -    -   2.336
(VC = variance component)

```

Turbidity

```

Response: Tu
      Mean Sq Sum Sq Df F value Pr(>F)
Exp      0.91   3.63  4    1.40 0.2850
BA    384.13 384.13  1  592.16 0.0000
Residuals  0.65   9.08 14      -      -

      Err.term(s) Err.df VC(SS)
1 Exp              (3)   14  0.0647
2 BA              (3)   14    fixed
3 Residuals        -    -  0.6487
(VC = variance component)

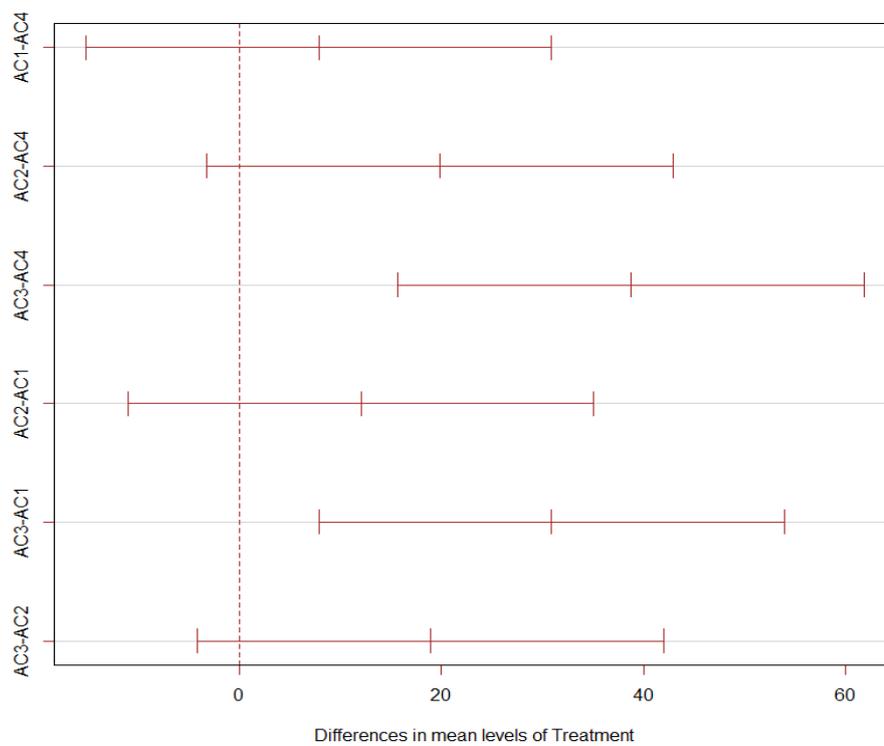
```

Appendix 6: Summary of Tukey tests for the responses

```
Fit: aov(formula = K ~ Product + Treatment, data = percent.removal)
```

```
$Treatment
      diff      lwr      upr    p adj
AC1-AC4  7.825 -15.271  30.92  0.7219
AC2-AC4 19.825  -3.271  42.92  0.0970
AC3-AC4 38.750  15.654  61.85  0.0025
AC2-AC1 12.000 -11.096  35.10  0.4142
AC3-AC1 30.925   7.829  54.02  0.0105
AC3-AC2 18.925  -4.171  42.02  0.1162
```

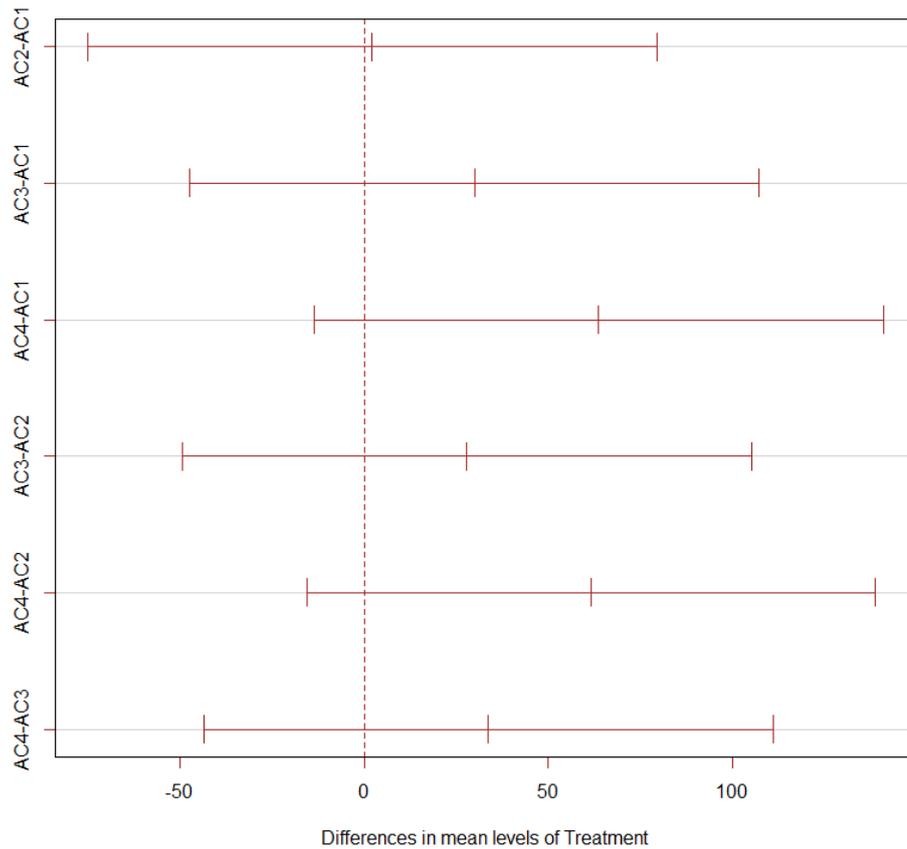
95% family-wise confidence level



```
Fit: aov(formula = c1 ~ Treatment + Product, data = percent.removal)
```

```
$Treatment
      diff      lwr      upr  p adj
AC2-AC1  2.075 -75.18  79.33 0.9998
AC3-AC1 29.875 -47.38 107.13 0.6378
AC4-AC1 63.625 -13.63 140.88 0.1140
AC3-AC2 27.800 -49.46 105.06 0.6853
AC4-AC2 61.550 -15.71 138.81 0.1290
AC4-AC3 33.750 -43.51 111.01 0.5495
```

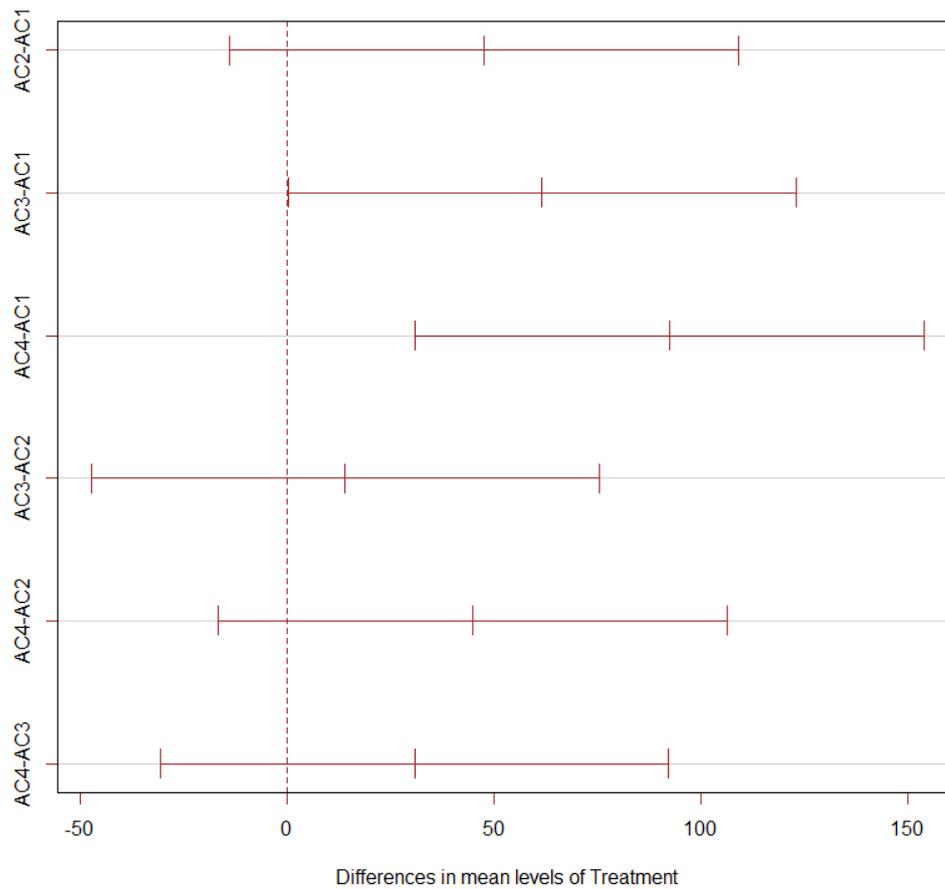
95% family-wise confidence level



```
Fit: aov(formula = S ~ Treatment + Product, data = percent.removal)
```

```
$Treatment
      diff      lwr      upr  p adj
AC2-AC1 30.82 -40.429 102.08 0.5569
AC3-AC1 44.85 -26.404 116.10 0.2690
AC4-AC1 75.60   4.346 146.85 0.0376
AC3-AC2 14.02 -57.229  85.28 0.9249
AC4-AC2 44.77 -26.479 116.03 0.2702
AC4-AC3 30.75 -40.504 102.00 0.5588
```

95% family-wise confidence level



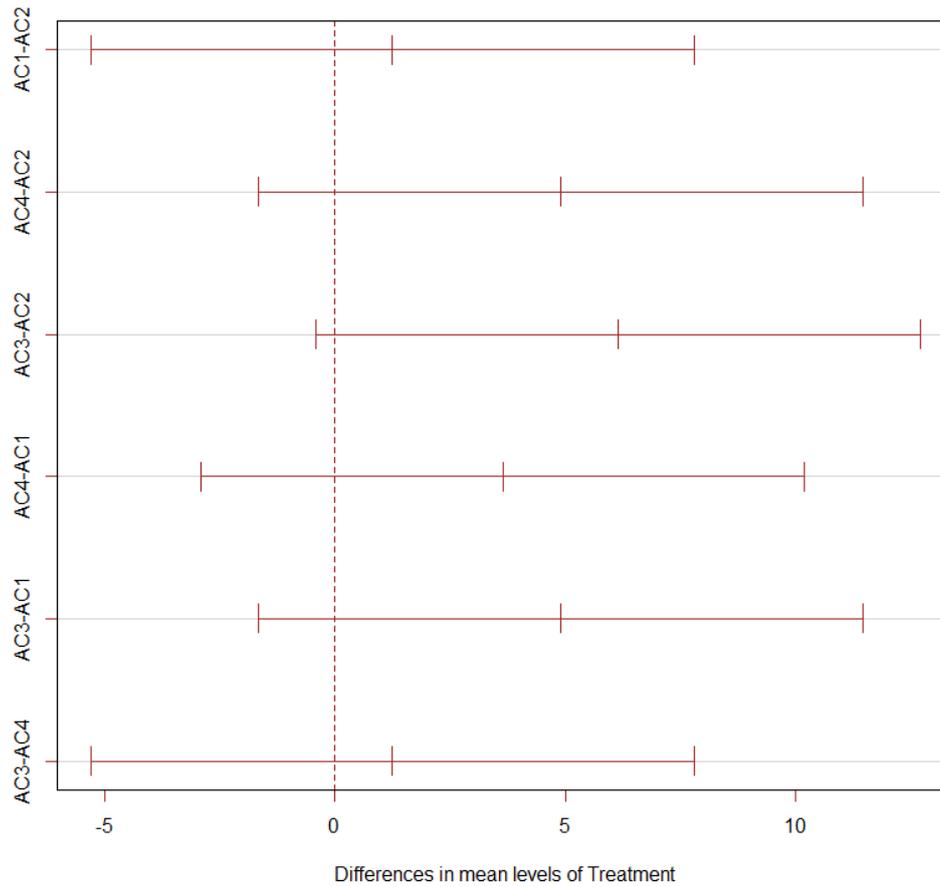
Fit: aov(formula = pH ~ Treatment + Product, data = percent.removal)

```

$Treatment
      diff      lwr      upr  p adj
AC1-AC2  1.25 -5.3045  7.805 0.9310
AC4-AC2  4.90 -1.6545 11.455 0.1611
AC3-AC2  6.15 -0.4045 12.705 0.0668
AC4-AC1  3.65 -2.9045 10.205 0.3599
AC3-AC1  4.90 -1.6545 11.455 0.1611
AC3-AC4  1.25 -5.3045  7.805 0.9310

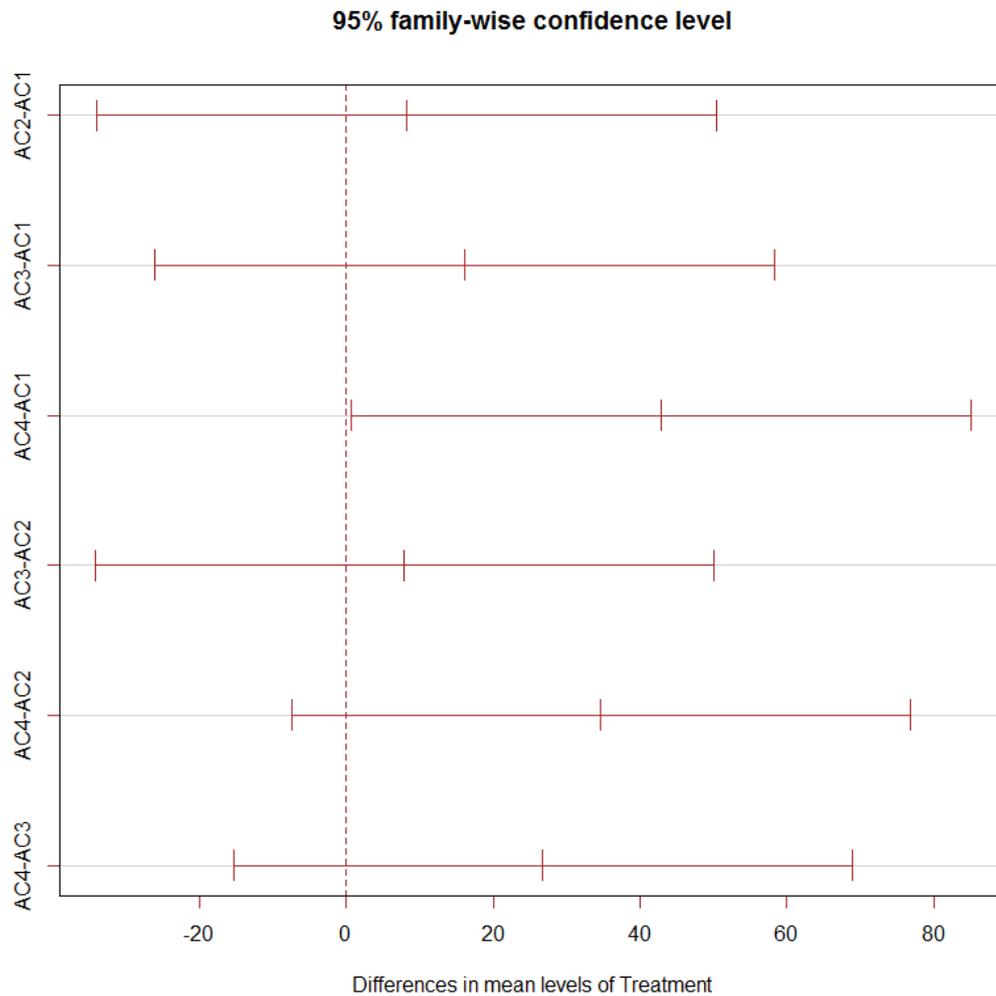
```

95% family-wise confidence level



```
Fit: aov(formula = Con ~ Treatment + Product, data = percent.removal)
```

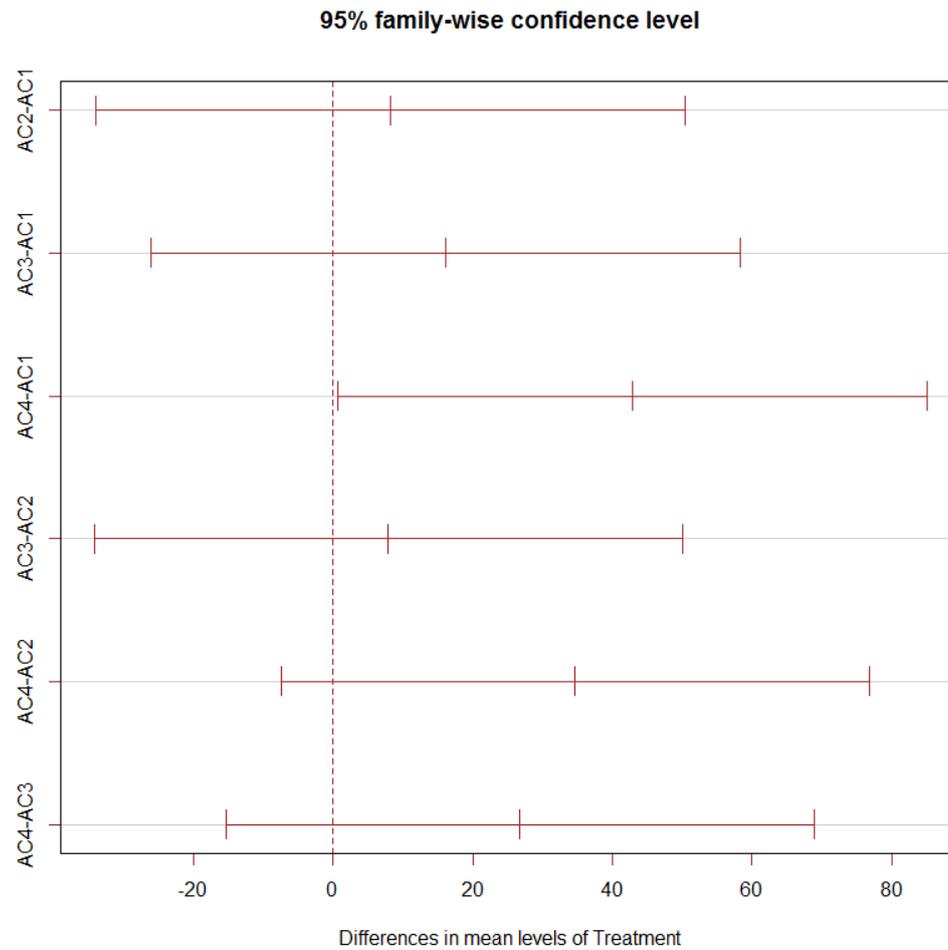
```
$Treatment
      diff      lwr      upr  p adj
AC4-AC2  2.625 -12.571  17.82  0.9471
AC1-AC2  2.875 -12.321  18.07  0.9324
AC3-AC2  6.375  -8.821  21.57  0.5798
AC1-AC4  0.250 -14.946  15.45  0.9999
AC3-AC4  3.750 -11.446  18.95  0.8658
AC3-AC1  3.500 -11.696  18.70  0.8871
```



```
Fit: aov(formula = Tu ~ Treatment + Product, data = percent.removal)
```

```
$Treatment
      diff      lwr      upr  p adj
AC2-AC1  8.175 -33.9866  50.34 0.9278
AC3-AC1 16.100 -26.0616  58.26 0.6464
AC4-AC1 42.850   0.6884  85.01 0.0463
AC3-AC2  7.925 -34.2366  50.09 0.9336
AC4-AC2 34.675  -7.4866  76.84 0.1146
AC4-AC3 26.750 -15.4116  68.91 0.2634
```

```
< |
```



Appendix 7: Rscript for determining uncertainties of responses

```

preliminary <- read.table('preliminary.txt',header = TRUE, sep = "", dec=".")
print(preliminary)

extract.var <- function(Data) {
  ## This function extracts the columns into individual variables.
  ## The names of the new variables are also displayed.
  # Make this work on lists as well!!
  if(is.data.frame(Data)) {
    for (i in 1:dim(Data)[2]) eval(parse(text=paste(names(Data)[i],'-> Data[,i]'))))
    for (i in 1:dim(Data)[2]) assign(names(Data)[i],Data[,i],envir=.GlobalEnv)
  }
  if(is.list(Data)) {
    for (i in 1:length(Data)) eval(parse(text=paste(names(Data)[i],'-> Data[[i]]'))))
    for (i in 1:length(Data)) assign(names(Data)[i],Data[[i]],envir=.GlobalEnv)
  }
  print(names(Data))
}

#K
model.K <- lm(K~r(Exp)+BA,data=preliminary)
mixK <- (AnovaMix(model.K))
print(mixK)
extract.var(mixK)
U.K.Exp <- sqrt(mixK$var.comps[1])
U.K.Ana <- sqrt(mixK$var.comps[3])
U.K.Tot <- sqrt((U.K.Exp)^2+(U.K.Ana)^2)
K.mean <- mean(preliminary$K)
U.K.Exp.rel <- round((U.K.Exp/K.mean)*100,2)
print(U.K.Exp.rel)
U.K.Ana.rel <- round((U.K.Ana/K.mean)*100,2)
print(U.K.Ana.rel)
U.K.Tot.rel <- round((U.K.Tot/K.mean)*100,1)
print(U.K.Tot.rel)

#CI
model.CI <- lm(CI~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.CI))
model.CI <- lm(CI~r(Exp)+BA,data=preliminary)
mixCI <- (AnovaMix(model.CI))
extract.var(mixCI)
U.CI.Exp <- sqrt(mixCI$var.comps[1])
U.CI.Ana <- sqrt(mixCI$var.comps[3])
U.CI.Tot <- sqrt((U.CI.Exp)^2+(U.CI.Ana)^2)
CI.mean <- mean(preliminary$CI)
U.CI.Exp.rel <- round((U.CI.Exp/CI.mean)*100,2)
print(U.CI.Exp.rel)
U.CI.Ana.rel <- round((U.CI.Ana/CI.mean)*100,2)
print(U.CI.Ana.rel)

```

```

U.Cl.Tot.rel <- round((U.Cl.Tot/Cl.mean)*100,1)
print(U.Cl.Tot.rel)

#S
model.SO4 <- lm(SO4~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.SO4))
mixSO4 <- (AnovaMix(model.SO4))
extract.var(mixSO4)
U.SO4.Exp <- sqrt(mixSO4$var.comps[1])
U.SO4.Ana <- sqrt(mixSO4$var.comps[3])
U.SO4.Tot <- sqrt((U.SO4.Exp)^2+(U.SO4.Ana)^2)
SO4.mean <- mean(preliminary$SO4)
U.SO4.Exp.rel <- round((U.SO4.Exp/SO4.mean)*100,2)
print(U.SO4.Exp.rel)
U.SO4.Ana.rel <- round((U.SO4.Ana/SO4.mean)*100,2)
print(U.SO4.Ana.rel)
U.SO4.Tot.rel <- round((U.SO4.Tot/SO4.mean)*100,1)
print(U.SO4.Tot.rel)

#pH
model.pH <- lm(pH~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.pH))
mixpH <- (AnovaMix(model.pH))
extract.var(mixpH)
U.pH.Exp <- sqrt(abs(mixpH$var.comps[1]))
U.pH.Ana <- sqrt(mixpH$var.comps[3])
U.pH.Tot <- sqrt((U.pH.Exp)^2+(U.pH.Ana)^2)
pH.mean <- mean(preliminary$pH)
U.pH.Exp.rel <- round((U.pH.Exp/pH.mean)*100,2)
print(U.pH.Exp.rel)
U.pH.Ana.rel <- round((U.pH.Ana/pH.mean)*100,2)
print(U.pH.Ana.rel)
U.pH.Tot.rel <- round((U.pH.Tot/pH.mean)*100,1)
print(U.pH.Tot.rel)

#COn

model.Con <- lm(Con~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.Con))
model.Con <- lm(Con~r(Exp)+BA,data=preliminary)
mixCon <- (AnovaMix(model.Con))
extract.var(mixCon)
U.Con.Exp <- sqrt(mixCon$var.comps[1])
U.Con.Ana <- sqrt(mixCon$var.comps[3])
U.Con.Tot <- sqrt((U.Con.Exp)^2+(U.Con.Ana)^2)
Con.mean <- mean(preliminary$Con)
U.Con.Exp.rel <- round((U.Con.Exp/Con.mean)*100,2)
print(U.Con.Exp.rel)
U.Con.Ana.rel <- round((U.Con.Ana/Con.mean)*100,2)
print(U.Con.Ana.rel)

```

```
U.Con.Tot.rel <- round((U.Con.Tot/Con.mean)*100,1)
print(U.Con.Tot.rel)
```

```
#TU
```

```
model.Tu <- lm(Tu~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.Tu ))
model.Tu <- lm(Tu~r(Exp)+BA,data=preliminary)
mixTu <- (AnovaMix(model.Tu))
extract.var(mixTu)
U.Tu.Exp <- sqrt(mixTu$var.comps[1])
U.Tu.Ana <- sqrt(mixTu$var.comps[3])
U.Tu.Tot <- sqrt((U.Tu.Exp)^2+(U.Tu.Ana)^2)
Tu.mean <- mean(preliminary$Tu)
U.Tu.Exp.rel <- round((U.Tu.Exp/Tu.mean)*100,2)
print(U.Tu.Exp.rel)
U.Tu.Ana.rel <- round((U.Tu.Ana/Tu.mean)*100,2)
print(U.Tu.Ana.rel)
U.Tu.Tot.rel <- round((U.Tu.Tot/Tu.mean)*100,1)
print(U.Tu.Tot.rel)
```

Appendix 8: Rscript for plotting residuals

```

preliminary <- read.table('preliminary.txt',header = TRUE, sep = ",", dec=".")
print(preliminary)
Activated.carbon <- preliminary$Exp
model.pH <- lm(pH~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.pH))
pH.res = rstandard(model.pH)
model.Tu <- lm(Tu~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.Tu))
Tu.res = rstandard(model.Tu)
model.K <- lm(K~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.K))
K.res = rstandard(model.K)
model.SO4 <- lm(SO4~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.SO4))
SO4.res <- rstandard(model.SO4)
model.Cl <- lm(Cl~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.Cl))
Cl.res = rstandard(model.Cl)
model.Con <- lm(Con~r(Exp)+BA,data=preliminary)
print(AnovaMix(model.Con))
Con.res = rstandard(model.Con)
K.resd <- resid(model.K);
Cl.resd <- resid(model.Cl);
SO4.resd <- resid(model.SO4);
pH.resd <- resid(model.pH);
Con.resd <- resid(model.Con);
Tu.resd <- resid(model.Tu);

#K Plot
windows(width=8,height=8)
par(mfrow=c(2,2))
plot.K <- qqnorm(K.res, ylab='Residuals', xlab='Theoretical quantities',
pch=19,col=as.numeric(unique(factor(Activated.carbon))), main = 'K residual plot')
qqline(K.res, lty=3)
legend('top', legend=levels(factor(Activated.carbon)),
col=as.numeric(unique(factor(Activated.carbon))),pch=19)

res.plot.K <- plot(preliminary$K, K.resd, ylab= 'Residuals', xlab='Fitted',
main = 'Residuals vs Fitted "K"',
pch =19, col=as.numeric(unique(factor(Activated.carbon))))
abline(0,0, untf = FALSE, lty= 3)
legend('top',pch=19, legend=levels(factor(Activated.carbon)),
col=as.numeric(unique(factor(Activated.carbon))))

# Cl plot
plot.Cl <- qqnorm(Cl.res, ylab='Residuals', xlab='Theoretical quantities',
pch=19,
col=as.numeric(unique(factor(Activated.carbon))), main = 'Cl residual plot')
qqline(Cl.res, lty=3)
legend('top', legend=levels(factor(Activated.carbon)),
col=as.numeric(unique(factor(Activated.carbon))),pch=19)
res.plot.Cl <- plot(preliminary$Cl, Cl.resd, ylab= 'Residuals', xlab='Fitted',
main = 'Residuals vs Fitted "Cl"',pch =19,
col=as.numeric(unique(factor(Activated.carbon))))
abline(0,0, untf = FALSE, lty= 3)
legend('top', legend=levels(factor(Activated.carbon)),
col=as.numeric(unique(factor(Activated.carbon))),pch=19)

# SO4 plot

windows(width=8,height=8)
par(mfrow=c(2,2))
plot.SO4 <- qqnorm(SO4.res, ylab='Residuals', xlab='Theoretical quantities',pch=19,
col=as.numeric(unique(factor(Activated.carbon))), main = 'SO4 residual plot')
qqline(SO4.res, lty=3)
legend('top', legend=levels(factor(Activated.carbon)),
col=as.numeric(unique(factor(Activated.carbon))),pch=19)

res.plot.SO4 <- plot(preliminary$SO4,SO4.resd, ylab= 'Residuals', xlab='Fitted',

```

```

        main = 'Residuals vs Fitted "SO4"', pch = 19,
        col=as.numeric(unique(factor(Activated.carbon))))
abline(0,0, untf = FALSE, lty= 3)
legend('top', legend=levels(factor(Activated.carbon)),
       col=as.numeric(unique(factor(Activated.carbon))), pch=19)

#pH plot

plot.pH <- qqnorm(pH.res, ylab='Residuals', xlab='Theoretical quantities',
                 , pch=19, col=as.numeric(unique(factor(Activated.carbon))))
                 , main = 'pH residual plot')
qqline(pH.res, lty=3)
legend('top', legend=levels(factor(Activated.carbon)),
       col=as.numeric(unique(factor(Activated.carbon))), pch=19)

res.plot.pH <- plot(preliminary$pH, pH.resd, ylab= 'Residuals',
                  xlab='Fitted', main = 'Residuals vs Fitted "pH"', pch = 19,
                  col=as.numeric(unique(factor(Activated.carbon))))
abline(0,0, untf = FALSE, lty= 3)
legend('top', legend=levels(factor(Activated.carbon)),
       col=as.numeric(unique(factor(Activated.carbon))), pch=19)

#Conductivity plot

windows(width=8,height=8)
par(mfrow=c(2,2))
plot.Con <- qqnorm(Con.res, ylab='Residuals', xlab='Theoretical quantities',
                 pch=19, col=as.numeric(unique(factor(Activated.carbon))))
                 , main = 'Conductivity residual plot')
qqline(Con.res, lty=3)
legend('top', legend=levels(factor(Activated.carbon)),
       col=as.numeric(unique(factor(Activated.carbon))), pch=19)

res.plot.Con <- plot(preliminary$Con, Con.resd, ylab= 'Residuals', xlab='Fitted',
                  main = 'Residuals vs Fitted "Conductivity"',
                  pch = 19, col=as.numeric(unique(factor(Activated.carbon))))
abline(0,0, untf = FALSE, lty= 3)
legend('top', legend=levels(factor(Activated.carbon)),
       col=as.numeric(unique(factor(Activated.carbon))), pch=19)

#Turbidity plot

plot.Tu <- qqnorm(Tu.res, ylab='Residuals', xlab='Theoretical quantities',
                 pch=19, col=as.numeric(preliminary$Exp),
                 , main = 'Turbidity residual plot')
qqline(Tu.res, lty=3)
legend('top', legend=levels(factor(Activated.carbon)),
       col=as.numeric(unique(factor(Activated.carbon))), pch=19)

res.plot.Tu <- plot(preliminary$Tu, Tu.resd, ylab= 'Residuals', xlab='Fitted',
                  main = 'Residuals vs Fitted "Turbidity"',
                  pch=19, col=as.numeric(unique(factor(Activated.carbon))))
abline(0,0, untf = FALSE, lty= 3)
legend('top', legend=levels(factor(Activated.carbon)),
       col=as.numeric(unique(factor(Activated.carbon))), pch=19)

```

Appendix 9: Rscript for plotting residuals

```

#Tukey hsd test for K

percent.removal <- read.table('results.txt',header = TRUE, sep = "", dec = ".")
results.K <- aov(K~Product+Treatment, data=percent.removal)
tukey.k <- TukeyHSD(results.K, "Treatment", ordered = TRUE )
print(tukey.k, ordered = TRUE )
plot(tukey.k,las=0.5 ,col='brown')

#Tukey hsd test for Cl

percent.removal <- read.table('results.txt',header = TRUE, sep = "", dec = ".")
results.Cl <- aov(Cl~Treatment+Product, data=percent.removal)
tukey.Cl <- TukeyHSD(results.Cl, "Treatment", ordered = TRUE )
print(tukey.Cl, ordered = TRUE )
plot(tukey.Cl,las=0.5 , col="brown" )

#Tukey hsd test for SO4

percent.removal <- read.table('results.txt',header = TRUE, sep = "", dec = ".")
results.SO4 <- aov(SO4~Treatment+Product, data=percent.removal)
tukey.SO4 <- TukeyHSD(results.SO4, "Treatment", ordered = TRUE )
print(tukey.SO4, ordered = TRUE )
plot(tukey.SO4,las=0.5 , col="brown")

#Tukey hsd test for pH

percent.removal <- read.table('results.txt',header = TRUE, sep = "", dec = ".")
results.pH <- aov(pH~Treatment+Product, data=percent.removal)
tukey.pH <- TukeyHSD(results.pH, "Treatment", ordered = TRUE )
print(tukey.pH, ordered = TRUE )
plot(tukey.pH,las=0.5 , col="brown")

#Tukey hsd test for Conductivity

percent.removal <- read.table('results.txt',header = TRUE, sep = "", dec = ".")
results.Con <- aov(Con~Treatment+Product, data=percent.removal)
tukey.Con <- TukeyHSD(results.Con, "Treatment", ordered = TRUE )
print(tukey.Con, ordered = TRUE )
plot(tukey.Con,las=0.5 , col="brown" )

#Tukey hsd test for Turbidity

percent.removal <- read.table('results.txt',header = TRUE, sep = "", dec = ".")
results.Tu <- aov(Tu~Treatment+Product, data=percent.removal)
tukey.Tu <- TukeyHSD(results.Tu, "Treatment", ordered = TRUE )
print(tukey.Tu, ordered = TRUE )
plot(tukey.Tu,las=0.5 , col="brown" )

```