1 Functioning of Ceramic Filter Candles

1.1 Introduction

Three layers of filter candles used by water4life (from Stefani Ceramics):
1 – Ceramics with fine pore size
2 – Colloidal silver impregnation
3 – Granulated Active Carbon (GAC)

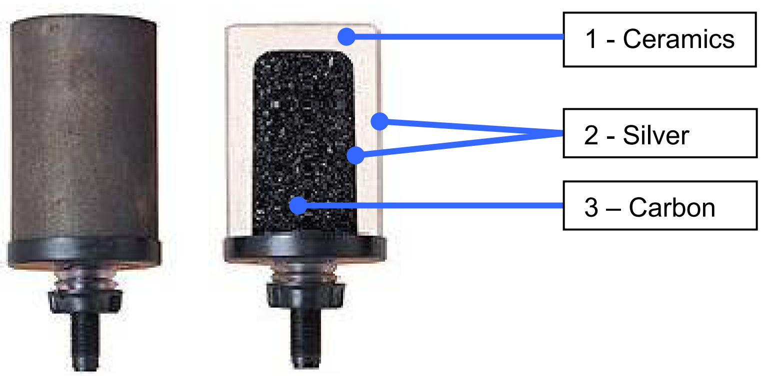


Figure 1 : 3 layers of Stefani filter candles

Each of the layers has its own distinctive functionality. The water will flow through the fine pores of the ceramics. The particles and bacteria cannot pass through the fine pores of the ceramics. Some of the contaminants will be stuck on the surface and some will be stuck inside the ceramic. These physical phenomena are called *sieving* or *surface filtration* and *depth filtration*.
The colloidal silver will prevent any bacterial build up on the layers of the candle. Silver is very toxic for viruses, bacteria, moulds, spores and fungi, as it prevents them from taking oxygen from the water. The organisms are suffocated. Any bacteria resting on the surface of the candle will be killed in this manner.
The active carbon granules have a high potential to adsorb all kinds of chemicals from the water. The molecules of these chemicals will adhere to the very fine pores of the carbon.

The functionality of each of these three layers will be discussed more extensively in the paragraphs below.

1.2 Fine pores of the ceramics

The sizes of the pores that let the water go through the ceramics are very fine. The sizes of these pores differ. But the Stefani candles can stop any particles / bacteria larger then 0.5 micrometer.

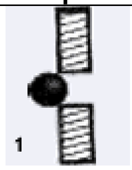
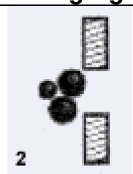
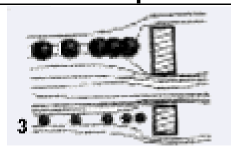
The size of common pathogens in water:

Viruses	Smallest and most complex to remove	0.02 – 0.10 micrometer (μm)
Bacteria	Most dominant	0.5 – 5 micrometer (μm)
Protozoa	May be able to from cysts	4 - 20 micrometer (μm)
Helminths / Worms	Derive sustenance at host's expense	40 - 60 micrometer (μm)

Due to the small size of the pores and the thickness of the ceramics (length of the pore channels) two physically distinctive phenomena help to remove the particles and bacteria:
1 – Surface filtration or Sieving and
2 – Depth filtration.

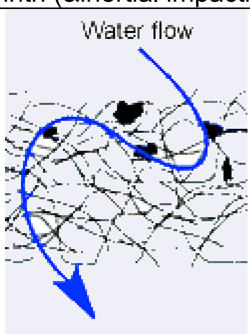
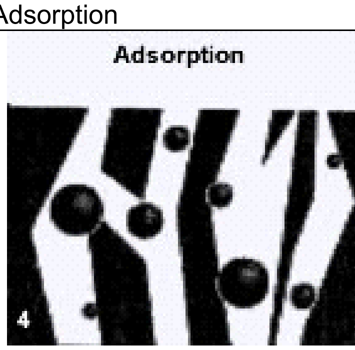
1.2.1 Surface filtration

A surface filter can be visualized as a screen that is covered with particles that are too large to pass through. Surface filtration is also known as sieving or dead end filtration.
Generally it is thought that this type of filtration is only applicable for particles larger then the larges size of the pores. However this is not completely the case. The table below (source: www.doultonusa.com) illustrates the three physical phenomena that form surface filtration:

Direct interception (sieving)	**Bridging**	**Inertial impaction**
		
Particles that are larger then the pore size cannot pass. The retention of particles will be absolute.	Smaller particles may be too small to be intercepted however two particles hitting the obstruction at the same time will form a bridge across the pore adhering to each other. Bridged particles may not plug the pore creating even smaller pore gradually forming a "filter cake". This "cake" creates a finer filtration for subsequent interception at the cost of decreased flow rate and eventually no flow rate.	Due to their inertial mass particles cannot follow the water flow. These particles hit none porous surface barrier. The particles become captured while the water flows around the barrier.

1.2.2 Depth filtration

Depth Filtration is the physical phenomenon that lets particles penetrate the ceramic filter and get captured throughout the depth of the candle wall.
Again there are several ways in which particles/bacteria will be captured in the depth of the filter wall (source: www.doultonusa.com):

Labyrinth (&inertial impaction)	Cluster formation	Adsorption
		
Particles intercepted within the ceramic depth can be much smaller than the pores. This is because particle laden water has to navigate through intricate maze of labyrinths. The path through the filter twists and turns trough sharp angles due to complicated ceramic structure and so the particles	Small particles can combine with other particles to form a cluster of particles large enough to become trapped as a group or individual in dead end cavities. This process is comparable to the bridging process mentioned before.	Weak Van der Waals forces (adsorption fig. 4) attract the small particles to the ceramic, causing them to be adsorbed onto the wall of the ceramic.

that may have penetrated the topmost layer become trapped within the structure. To appreciate the distance and how difficult a path the water has to follow, consider that the wall thickness of the ceramic is 1000-2000 times greater than the pore size of the ceramic filter and the pores are sharp and jagged rather than smooth and round.		

1.3 Colloidal silver

The Stefani candles have been impregnated with colloidal silver. Colloidal silver is actually a mixture of water and very tiny particles of silver.

In relatively simple words the functioning of colloidal silver is as follows; (source: www.doultonusa.com). Free silver ions (Ag+) have a toxic effect on micro-organisms even in relatively low concentrations. They have a highly fungicidal, bactericidal and algaecidal effect. Medical studies describe silver ions a catalyst that disable the enzymes that microorganisms depend on to "breathe".

In the presence of air (oxygen in water), metallic silver forms silver oxide, which also has a bactericidal effect due to its adequate solubility. To primitive life forms (such as viruses, bacteria, moulds, spores and fungi), colloidal silver is as toxic as the most powerful chemical disinfectants. This, coupled with its relative harmlessness to animate life (i.e. mammals), gives colloidal silver great potential as a disinfectant.

A more deep understanding about the functioning of colloidal silver is given below (source: http://educate-yourself.org). Richard Davies and Samuel Etris of The Silver Institute, in a 1996 monograph entitled The Development and Functions of Silver in Water Purification and Disease Control, discuss three mechanisms of deactivation that silver utilizes to incapacitate disease causing organisms. They are Catalytic Oxidation, Reaction with Cell Membranes, and Binding with the DNA of disease organisms to prevent unwinding.

1 - Catalytic Oxidation:
Silver, in its atomic state, has the capacity to absorb oxygen and act as a catalyst to bring about oxidation. Atomic (nascent) oxygen absorbed onto the surface of silver ions in solution will readily react with the sulfhydryl (-S-H) groups surrounding the surface of bacteria or viruses to remove the hydrogen atoms (as water), causing the sulfur atoms to form an R-S-S-R bond; blocking respiration and causing the bacteria to expire. Employing a simple catalytic reduction/oxidation reaction, colloidal silver will react with any negative charge presented by the organism's transport or membrane proteins and deactivate them.

2 - Reaction with Bacterial Cell Membranes:
There is evidence that silver ions attach to membrane surface radicals of bacteria, impairing cell respiration and blocking its energy transfer system. One explanation is based on the nature of enzyme construction: Specific enzymes are required for a given biochemical activity to take place. Enzyme molecules usually require a specific metallic atom as part of the molecular matrix in order to function. A metal of higher valance can replace a metal of lower valance in the enzyme complex, preventing the enzyme from functioning normally. Silver, with a valance of plus 2, can replace many metals with a lower, or equal valance that exhibit weaker atomic bonding properties.

3 - Binding with DNA:
Studies by C.L. Fox and S.M. Modak with Pseudomonas aeruginosa, a tenacious bacteria that is difficult to treat, demonstrated that as much as 12% of silver is taken up by the organism's DNA. While it remains unclear exactly how the silver binds to the DNA without destroying the hydrogen bonds holding the lattice together, it nevertheless prevents the DNA from unwinding, an essential step for cellular replication to occur.

1.4 Activated Carbon

The Stefani Candles have Granular Activated Carbon. Also known as GAC. GAC has a honeycombed structure with minuscule channels that branch and twist within each granule. These channels greatly increase the surface area and thereby account for activated carbon's impressive adsorptive powers. (source: www.doulton.ca)

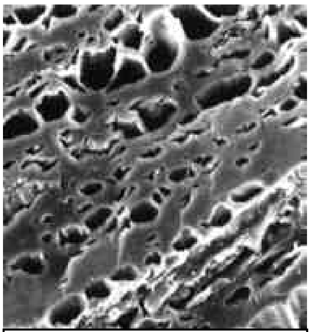


Figure 2 : Pore structure of Carbon - electron microscope

There are two principal mechanisms by which activated carbon removes contaminants from water; absorption, and catalytic reduction, a process involving the attraction of negatively-charged contaminant ions to the positively-charged activated carbon.

- Organic compounds are removed by adsorption and
- Residual disinfectants such as chlorine and chloramines are removed by catalytic reduction.

1.4.1 Adsorption

As the water passes over the positively charged carbon surface [microscopic labyrinth], the negative ions of the contaminants are drawn to the surface of the carbon granules. This is known as adsorption [to adhere] and can be closely compared in principle to magnetism.

A**d**sorption differs from A**b**sorption

A**b**sorption, in chemistry, is a physical or chemical phenomenon or a process in which atoms, molecules, or ions enter some bulk phase - gas, liquid or solid material. This is a different process from adsorption, since the molecules are taken up by the volume, not by surface. A more general term is sorption which covers adsorption, absorption, and ion exchange.

A**d**sorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or, more rarely, a liquid (adsorbent), forming a molecular or atomic film (the adsorbate). It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution. The term sorption encompasses both processes, while desorption is the reverse process.

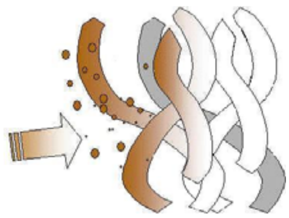


Figure 3 : Illustration adsorption

1.4.2 Catalytic reduction

Activated carbon can remove and destroy residual disinfectants (chlorine and chloramine) through a catalytic reduction reaction. This is a chemical reaction that involves a transfer of electrons from the activated carbon surface to the residual disinfectant. In other words, activated carbon acts as a reducing agent. (source: http://www.wwdmag.com/Exploring-the-Multifunctional-Nature-of-Activated-Carbon-Filtration-article1514)

Activated carbon's removal of chlorine reduces the chlorine to a non-oxidative chloride ion. The reaction is very fast. Chloramine removal by activated carbon is a much slower reaction. The predominant species of chloramine in city water supplies (pH about 7 to 8) is monochloramine. The reaction with activated carbon and monochloramine also renders a non-oxidative chloride ion.

1.4.3 Effectiveness of GAC

As a general rule the adsorption ability of GAC depends largely on a number of factors. They are as follows (source: www.doulton.ca):

Turbidity: The cleaner the incoming water (the less particulate matter it contains), the greater is the ability to adsorb. The GAC stage of the candles does not have to cope with high levels of bacteria, sediment or particulates as they are filtered by the ceramic candle in layer one.

Flow rate: Water passing at really high speeds (gushing) is not filtered as well as water flowing at slower speeds. Example, if you were to throw a nail past the head of a magnet the odds of it adhering would be slight.

Contact time: Water must be in contact with the GAC for a sufficient period of time to allow the GAC to effectively adsorb the contaminants. The contact time is closely related to the flow rate. The faster the water flows, the less contact time. But also the shape/design of the filter candle determines the contact time.

Amount of carbon granules: There must be a sufficient amount of GAC in any filter cartridge to be able to effectively remove contaminants from water. A lab standard formula is used to determine how much carbon is required to filter a known quantity of water depending on the style of GAC being used.

Granular size: Filters that use only one style of GAC will be effective in removing high percentages of only certain contaminants as varying styles are more efficient on certain chemicals than on others.

1.4.4 Concerns for the use of GAC

Maintenance: Poor quality systems will all too often exaggerate the volume of water that their filters can process. Common statements such as; it's time for a change if the bad tastes and odours return or if the water flow is severely reduced because sediment has clogged the filter are very poor methods of monitoring. Once the tastes have returned, it is already far too late. A carbon cartridge may be able to control taste and odours long after the carbon has lost its ability to effectively reduce toxic contaminants. The real life of GAC is strictly limited to the number of litres it can effectively process. This should be stated and either calculated for you based on your average consumption, or monitored via a flow control device.

Bacteria: The major problem associated with carbon in any form is bacterial contamination. Wet activated carbon, richly infused with trapped organic matter, provides an ideal breeding ground for bacteria. High bacterial levels occur when the carbon is fully saturated and then let to stand [e.g., overnight]. As the water temperature inside the carbon cartridge rises, bacteria breeding escalates. Silver impregnated GAC does reduce the amount of bacterial growth that occurs, but even the silver can be overcome by the increased rate of growth. Granulated Carbon cannot hold onto bacteria, so when water flow is reintroduced a highly contaminated sample can be output. Bacteria gets into the GAC filter in the first place because disinfection at the water treatment plant does not guarantee the destruction of all bacteria. It is for this reason that many health officials consider GAC filters to be a potential health hazard. The EPA has concluded that carbon filters of any type, even those impregnated with silver show no significant bacteria reduction effect on drinking water. It is specifically for this reason that the ceramic candle filters ensure physical removal of bacteria by the ceramic wall before the water is allowed to come into contact with the inner stage GAC element. The stefani candles then also uses silver to control bacteria growth on the outer wall of the candle.

2 Maintenance of the candles

There are three effects that affect the performance of the candles over time:
1 – Build up of 'dirt' on the outside and inside the outer layer of the ceramic of the candle.
2 – Saturation of the carbon.
3 – Washing out of the silver

These three effects have a completely different effect on the performance of the filter and also have different consequences for the actions to take.

2.1 Build up of dirt on outside of ceramics

Due to the filtration as described in paragraph 1.2, a layer of dirt is formed on and in the outside layers of the ceramics. The built up layer of dirt will gradually block the water flow, until it is fully blocked. Clogging the filter in this way is not affecting the safety of the water coming out of the filter, it only reduces the flow!
The dirt layer on the outside may be an ideal breading ground for bacteria. The silver used will prevent this bacteria growth.
There are two methods of revitalizing the filter candle when dirt is blocking or reducing the water flow: Cleaning and Flow reversal. Both options are discussed below.

2.1.1 Cleaning

Cleaning the candle can be done in several ways. Depending on the persistency of the dirt one of the following techniques may be used;

- Cleaning with a cloth or brush. Rubbing the surface of the candle thoroughly with a cloth or brush with water will remove the outer layers of the dirt and the flow will return. Do NOT use any soap or detergents.
- If the dirt has penetrated the outer layers of the ceramics, it will not be removed by rubbing from the outside. The flow can only be recovered by removing the most outer layer of the ceramics. This can be done by using the back of a knife and scraping off the outer layer of the ceramics. Take care that no cracks are introduced. Once a crack is created the water is no longer safe. Do NOT use any soap or detergents.

2.1.2 Flow reversal

By reversing the flow, trapped dirt can be removed as well. This is mainly done in industrial installations. Especially with candles that have activated carbon inside, this method of revitalizing is not advisable. In case the water contains any bacteria, it will find ideal breading ground in the carbon as was mentioned in paragraph 1.4.4.

The filter will reach the end of its life when:

- It is not possible anymore to revitalize the flow of water

OR

- The ceramics have become thin

In these cases new candles must be installed.

2.2 Saturation of the carbon

As was explained in paragraph 1.4.1, carbon derives most of its functionality from adsorption of various molecules. Once all surface of the carbon has been covered by contaminants, it can no longer adsorb any more substances. The carbon is then saturated. In severe cases it may even release some of its adsorbed materials.

There is in contradiction to what some other sources mention no reliable and safe method to re-activate the saturated carbon on a household scale.

The filter candle will reach the end of its life when:

- The carbon is fully saturated. It is without any specialized equipment not possible for a user to determine this moment. Once the taste of the water is changing, it can be assumed that the carbon is saturated.

In this case new candles must be installed.

2.3 Washing out of the silver

Little is known about the speed at which the colloidal silver will wash out of the candles. This may also depend on the method of application (coating from the outside by soaking it in a bath or mixing silver with the production of the ceramics). Once the silver is washed out, the bacterial growth can no longer be stopped on the outside (and inside the outer layers) of the ceramic. Once the number of bacteria become really large, it may be possible for bacteria to pass the ceramic layer and thereby making the filtered water unsafe.

It is not possible for a user to revitalize the filter candle once the silver has washed out.

The filter candle will reach the end of its life when:

- The silver has washed out in such amounts that it can no longer block bacterial growth on the outside and in the outer layers of the ceramics. There is no reliable method for a user to detect this moment. The amount of silver in the candle should be such that it will be able to outlive any of the other effects that determine the life of a candle. Only thorough testing by the supplier can assure this.

In this case new candles must be installed.

2.4 End of life

As has been mentioned in the previous paragraphs, there are several effects that may determine the end of life. The effect that occurs first determines actual end of life.

- Irreversible clogging of the filter ceramics
- Saturation of the activated carbon
- Washing out of the silver

Which one of these three effects will occur first depends on the quality of the water that is added to the water filtration unit. These moments are very difficult to determine for an average household. Therefore most manufacturers will mention the amount of water which can pass through the filter on average.
For Stefani filter candles this is 700 litres. Each water4life water filtration unit contains 2 candles. Assuming a family has 4 members, and they will drink each 1.5 litre of water each day from the filter, this means as an average the filter candles will last for 7 months. Taking into account varieties in water quality, family size and water usage, it is safe to mention that the **candles need to be replaced each 6 to 9 months.**

2.5 First use

During first use of a new set of filter candles, some tiny particulates of carbon will ooze out of the filter. This is because during production and transportation, the carbon granules may break and from very small particles that can pass through the holes of the small sieve inside the candle that holds the carbon granules. Therefore it is advised to not drink the first 4 to 8 litres of water coming out of a new candle.
The carbon particles coming out of the candle are in no way harmless to humans not even when consumed with the drinking water.

If small particulates keep coming out, one can try to do the following: Boil a pan of water for minimum of 10 minutes. Keep the pan covered and cool it down to ambient temperature. Submerge the filter candle in the water and leave it for 2 hours. Then start using the candle regularly. This process should wash out the smallest carbon granules.

There are some risks related to this procedure:

- If the water used is not completely sterilized, the bacteria may nestle in the carbon and will form new colonies. After that when using it inside the purifier unit, the filtered water will not be free of bacteria and therefore not safe for consumption!
- If the candles are put in water that is of too high temperature, the glue between the plastic end cap and the ceramics may soften en eventually get loosened. If this happens, leaks will be created. Through these leaks, source water is able to go straight to the bottom container, while not passing through the layers of the filter candle. Thereby the filtered water may contain bacteria and therefore is not safe for consumption!

So in general it is not advisable to communicate these options widely.

3 APPENDIX: General background

3.1 Ceramics

(source: www.wikipedia.org) The word ceramic is derived from the Greek word κεραμικός (keramikos). The term covers inorganic non-metallic materials whose formation is due to the action of heat. Up until the 1950s or so, the most important of these were the traditional clays, made into pottery, bricks, tiles and are like, along with cements and glass.

Many ceramic materials are hard, porous and brittle. The study and development of ceramics includes methods to mitigate problems associated with these characteristics, and to accentuate the strengths of the materials as well as to investigate novel applications.

Sintering-based production method
The principles of sintering-based methods is simple. Once a roughly held together object (called a "green body") is made, it is baked in a kiln, where diffusion processes cause the green body to shrink. The pores in the object close up, resulting in a denser, stronger product. The firing is done at a temperature below the melting point of the ceramic. There is virtually always some porosity left, but the real advantage of this method is that the green body can be produced in any way imaginable, and still be sintered. This makes it a very versatile route.

There are thousands of possible refinements of this process. Some of the most common involve pressing the green body to give the densification a head start and reduce the sintering time needed. Sometimes organic binders such as polyvinyl alcohol are added to hold the green body together; these burn out during the firing (at 200–350°C). Sometimes organic lubricants are added during pressing to increase densification. It is not uncommon to combine these, and add binders and lubricants to a powder, then press. (The formulation of these organic chemical additives is an art in itself. This is particularly important in the manufacture of high performance ceramics such as those used by the billions for electronics, in capacitors, inductors, sensors, etc.)

A slurry can be used in place of a powder, and then cast into a desired shape, dried and then sintered. Indeed, traditional pottery is done with this type of method, using a plastic mixture worked with the hands.

3.2 Silver

The best and most environmentally-friendly silver based disinfectants are capable of rendering stored water potable for long period of time as in space stations.

While silver's importance as a bactericide has been documented only since the late 1800s, its use in purification has been known throughout the ages. Early records indicate that the Phoenicians, for example, used silver vessels to keep water, wine and vinegar pure during their long voyages. In America, pioneers moving west put silver and copper coins in their water barrels to keep it clean.

Purifying Water
Silver-based water purification units for the home have been in use in Europe for more than 50 years. Royal Doulton ceramic candles combine silver within the ceramic during manufacturing to take advantage of the outstanding bacterial disinfecting properties of silver. These units meet the National Sanitation Foundation Standards covering bacteriostatic efficacy, the reduction of lead, copper and particulates and the reduction of taste and odor. They also have the approval of the US Environmental Protection Agency as a bactericidal unit.

A new European Union Drinking Water Standard in draft form has removed any upper limit for silver in drinking water following the World Health Organization's Guidelines for Drinking Water Quality which

States, "It is unnecessary to recommend any health-based guideline for silver as it is not hazardous to human heath.

Thanks to eye-opening research, silver is emerging as a wonder of modern medicine. An antibiotic kills perhaps a half dozen different disease organisms but silver kills some 650. Moreover, silver is virtually non-toxic. Dr. Harry Margraf of St. Louis, a pioneering silver researcher, says: "Silver is the best all around germ fighter we have."[1]

3.3 Activated Carbon

Carbon, in the form of ashes, has been used to treat drinking water since Biblical Times. Granular Activated Carbon [GAC] is created by exposing a carbon-containing material [usually charcoal] to high temperatures and steam in the absence of oxygen. The GAC used in most quality systems is from anthracite coal [almost pure carbon].

Activated carbon nitrogen isotherm showing a marked microporous type I behaviorActivated carbon can be manufactured from carbonaceous material, including coal (bituminous, subbituminous, and lignite), peat, wood, or nutshells (i.e., coconut). The manufacturing process consists of two phases, carbonization and activation. The carbonization process includes drying and then heating to separate by-products, including tars and other hydrocarbons, from the raw material, as well as to drive off any gases generated. The carbonization process is completed by heating the material at 400–600 °C in an oxygen-deficient atmosphere that cannot support combustion.

The carbonized particles are “activated” by exposing them to an oxidizing agent, usually steam or carbon dioxide at high temperature. This agent burns off the pore blocking structures created during the carbonization phase and so, they develop a porous, three-dimensional graphite lattice structure. The size of the pores developed during activation is a function of the time that they treated in this stage. Longer exposure times result in larger pore sizes. The most popular aqueous phase carbons are bituminous based because of their hardness, abrasion resistance, pore size distribution, and low cost, but their effectiveness needs to be tested in each application to determine the optimal product.