FILTRATION SYSTEMS USING NANOTECHNOLOGY

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Abstract:

Filtration systems are important all over the world in producing clean drinking water for individuals who would usually not have access to it. Most filter media are fairly limited in duration, and the rising lack of water in major cities is a growing concern, in both rich and poor countries alike — water availability in countries like India has been dropping since the early 1950s due to an explosion in population. As a consequence of this, sanitation has suffered and supplies are only available for a few hours a day. With a new system of filtering, water supplies will become not only safer but easily available. Of course, water is not the only problem in expanding countries and cities, air pollution is becoming a concern — not only in terms of global warming, but in terms of local safety too. For example, it was reported that in 2007 air pollution was responsible for 12% of deaths in the city of Manila, Philippines.

Introduction:

A nanotube is a cylinder made of atoms arranged hexagonally, stronger than steel, but more flexible than plastic. There have been a number of important developments in the field of nanotechnology which have led us to this point.

The term "nano-technology" was first coined in 1974 by Taniguchi, who uses it in a paper on ion-sputter machining. In 1985, the first Buckminsterfullerene was created, an allotrope of carbon. It was in 1991 that the first nanotube, a curled up, single atom thick sheet of carbon was discovered by Sumio Iijima. From this point on advancements in the application of nanotechnology have been pioneered at a rapid pace.

Currently carbon is the most widely used element for nanotube creation as it is both abundant and self-correcting during the bonding process. If an atom is removed, the structure changes to ensure the molecule doesn't become too active.

There are two main methods which can be used to create carbon nanotubes, in essence, both these methods require graphite as a single sheet so its shape can be manipulated, this is known as graphene, an allotrope of carbon which is only 1 atom thick.

Method one: Laser Ablation — in a high temperature reactor, pulsed lasers vapourise graphite. During this time, an inert gas such as argon is leaked into the chamber. As the carbon condenses, nanotube structures form. The cooler areas of the furnace see the majority of nanotubes forming and there is a relationship between the width of the nanotube and the temperature of the reactor.

Method two: CVD (Chemical Vapour Deposition) — This involves a substrate comprising of metal catalyst particles (ferromagnetic iron, nickel or cobalt) within a vacuum chamber, where a temperature of about 1000K is reached and two gases are leaked in. The first gas is a process gas (e.g. hydrogen) and the second gas must have a molecular structure that contains carbon (ethanol is commonly used). The dimensions of the catalyst in this case are the determining factor of the diameter of the nanotubes. The process of catalysis on the metal causes the formation of nanotubes as the gas with the molecule containing carbon is broken apart. This carbon then moves to the edges of the catalyst molecule which is where the nanotubes are formed. This method offers a cheaper alternative to laser ablation, however both methods have their strengths and weaknesses.

In 1956, Edith Flanigen invented a molecular sieve and her technology paved the way for petroleum filtration, making the process of refining oil much more efficient. These sieves operate on the simple principle of letting smaller molecules through and filtering larger molecules from the filtrate. Bacteria are a few micrometres in length and range in size and shape and viruses have a minimum diameter of around 10 nanometres. Hence, a simple ‘nano-filter’ would have to be less than 10 nanometres to effectively filter out harmful substances.

Size is a particular problem with our filtering method, in theory, we need to produce a filter which would span a pipe. One example of where the problem of size has been overcome is with the use of a so called “teabag nano-filter” that was created to tackle the issue of providing clean water to South Africa. Scientists at Stellenbosch University, in Cape Town, created this teabag nano-filter that uses ultra-thin nanoscale fibres, which the contaminated water is filtered through, as well as active carbon granules, which kill bacteria. This approach works perfectly in rural areas of South Africa, these teabags cost about 1/2 a US cent to produce and are even environmentally friendly, as they disintegrate harmlessly after use.

However it is this very reason that means they are not suitable for our water filtration system. We cannot open our water pipes every hour to replace nanofiltering teabags. However, it is from this scientific advance that we see another possible application of nanotechnology, a possibly permanent, but probably semi-permanent method of filtering water for the world's urban centres.

Of course, for an air filtration system, different methods would have to be used. In power stations, companies use flue-gas desulphurisation, a method where up to 95% of gases like sulphur dioxide are removed from emissions. However, nanotubes cannot be selective about which molecules they filter out of the air, meaning their use in this field is limited to filtering particulates. These make up a large percentage of the smog found in cities, therefore a simple nanofilter installed in an air conditioning system would work quite well in protecting the population.

Discussion:

Filtering Water Supplies

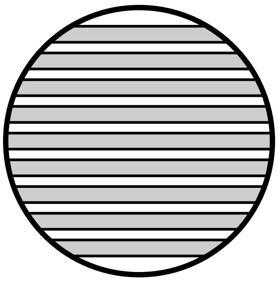

Fig. 1

If we were to place them horizontally (Figure 1), where the tubes are perpendicular to the pipe and the direction of flow, then it would be possible to transport filtrates across the tubes and out of the pipe. Again, patents have already been submitted which prove that this is theoretically possible, however, such methods use ionic charges — water molecules have dipoles induced in them for this method. It would not be technologically feasible to induce a charge in the bacteria and viruses flowing through the nanotubes — however, due to the low coefficient of friction, these compounds should easily flow.

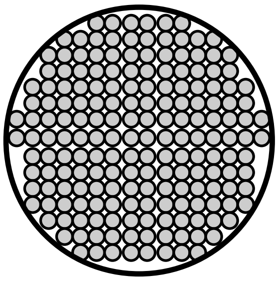

Fig. 2

Uncapped nanotubes could also be placed parallel to the direction of flow (Figure 2), allowing the water flow to maintain its speed, which has an advantage over other filtering methods in that added pressure is not required for water to pass through, and it can therefore be used without increasing the energy requirement of the filtration system. Studies have shown that some fluids, including water, can travel through nanotubes with almost no friction. The result would be a filtering system that can be integrated into large scale water supplies, or to smaller units, where accumulating enough pressure for a regular filter would be difficult.

Filtering Air Supplies

There are multiple ways to install nanofilters to filter air systems. In mega-cities, the air contains many dangerous chemicals ranging from nitrogen oxides to sulphur dioxide and even particulate matter which causes health problems such as asthma and bronchitis.

Unlike filtering water supplies, filtering air supplies requires only certain particles to be blocked out. A simple parallel-to-flow arrangement will block out any particulates, but a more intelligent system would use nanotubes in tandem with other technology to filter out molecules like sulphur dioxide.

While most buildings only require the circulation of air, certain facilities need something more advanced. The spread of infection in hospitals is a growing concern, with many examples of people going to the hospital for a trivial health problem and being infected with something worse while there. Ventilation systems that push air through nanotube filters should reduce the risk of such spread severely; Air that has been decontaminated in such a way before being recirculated will be safe for patients to breathe. This will limit the spread of infection to human contact and reduce the speed with which it spreads, allowing preventative measures to be put in place.

The Dimensions of Nanotubes

The diameter of the nanotubes has to be large enough to let the molecules of water through them, but small enough to ensure the smallest viruses do not get through. The size of a water molecule is roughly 0.2nm, whereas the smallest known virus is 10nm, so there is quite a range of diameters that the nanotubes could take — however the most common diameter of single walled nanotubes is 1nm, which would be a logical size to use in our filtering method. The same diameter is perfect for an air filtering application, as we have defined the roles of nanotubes in this instance to be removal of particulates from the air stream, and UFP, (Ultra-Fine Particulates) the smallest form of particulates, are in the range of 0.1μm.

The length of the nanotube must be kept as short as feasibly possible, as there is strong evidence to show that long nanotubes that break away can cause cancer (this is discussed below). However, the required lengths for this to be a real threat are in the micrometres, and the typical length of an open ended nanotube is a few nanometres. With this in mind, a standard open ended nanotube with a diameter of 1nm and a length of 3nm would be perfect for this application of nanotechnology. These nanotubes would act to allow ions through (without which water becomes dangerous to drink, since essential ions will diffuse out of your body) but not dangerous pathogens.

The Alignment of Nanotubes

A number of patents have been submitted which describe a ‘suspension of nanotubes’ where the nanotubes are arranged on a solvent — however, we believe that in practice, such a method wouldn’t provide a stable method for effectively filtering water. It has been proven that nanotubes become magnetised when exposed to a magnetic source, therefore we propose that it would be possible to induce a magnetic field in the nanotubes to align them in a sieve arrangement. However, this magnetic property of nanotubes was only shown for multi-walled carbon nanotubes, and the question of whether the nanotubes would need to be routinely aligned, and whether the magnetic force aligning them would be strong enough to allow them to function as efficient filters is not yet known.

Another possible method of alignment is to grow them in a specific way which produces a “forest” of nanotubes, These forests can then be compressed to increase the density so that they are more aligned and with gaps too small to allow molecules through. A more in depth discussion of how such methods work and the potential drawbacks are included within *Quantities of Nanotubes*.

The Danger of Nanotubes

Of course, there are associated dangers with using nanotubes. It has been reported that when there are defects in the carbon chain, high stress levels are introduced when the nanotubes are bent. Such a defect was found in 1986, whereby rather rather than creating a series of hexagons, every so often a pentagon and heptagon pair would appear.

If nanotubes were to break off and enter the water or air supply then this would result in many small nanotubes entering peoples’ bodies. It has been shown that nanotubes trigger a similar reaction to asbestos in mice. However, only longer chains cause a problem as they are insoluble in the lung. The mesothelium, which lines the lungs, becomes paralysed and is unable to remove longer chains from the body — eventually, they cause inflammation and can cause the cells to become cancerous.

With slower water flows, under a lower pressure, the nanotubes are less likely to fragment and enter the water supply. The matter of safety is still a primary concern, especially if the filters are to be put to use in medical scenarios.

Scientists at the Rensselaer Polytechnic Institute have shown that this holds true. They tested the strength and durability of carbon nanotubes by compressing them to 25% of their original height 500,000 times. After this test was completed the physical properties of the nanotubes were identical to their original variants. Although the force exerted to require to induce the desired compression lessened slightly during the initial phases of the experiment it soon plateaued and this test conclusively shows the durability of nanotubes and aids the credibility of our method as an efficient filtering technique.

Is it possible to prevent nanotubes from entering water and air supplies completely? In theory, a simple solution to the problem of carcinogenic particles is a second filtration system that will collect these fragments. Activated carbon filters are effective at adsorbing organic molecules. There has been concern that activated carbon filters can encourage bacterial growth, but the previous filtration through nanofilters will mean that there is nothing in the water to use the filter as a growing medium. Studies have also shown that activated carbon filters do not increase microbial content of water.

The Quantities of Nanotubes

Due to advances in the creation of large area quantities of nanotubes and the ability to compact nanotubes into a more dense “forest”, water flows, and the pressure they create, are less of an issue. In a medical situation, we would have to use a method which produced the highest quality nanotubes at the lowest price. With both methods described in the introduction, the instruments required to create the nanotubes cost millions of pounds.

For this method of filtering to be feasible it must not have to be perpetually replaced and upgraded to retain the same level of filtering quality, therefore the lifetime of the nanotubes, that is, how long they will last without breaking or needing to be replaced, is a very important factor. The creation of the vast amounts of nanotubes for this technique will be expensive and for this method to be cost effective they must have a long lifetime. This is especially true if it is implemented over a city wide water supply.

Being of such a small physical scale, the amount of nanotubes needed to cover any practical are will be large. The average pipe fitting to a household tap is about 2cm, which is 20,000,000nm. Pi x $(2E7nm)^2$ gives an area of roughly Pi x $4E14nm^2$. Given that our nanotubes will have a radius of 0.5nm, their area will be Pi x $0.25nm^2$, we will therefore need 1.6E15 of our nanotubes for a single household appliance. This is 1,600,000,000,000,000 nanotubes. Clearly advances in the creation of nanotubes need to be made before this quantity is realistic.

One such pioneering method is Super Growth CVD. This method creates what is known as a “single walled nanotube forest (SWNT)” which can stretch to metres in dimensions of area. This synthesis process is 100 times more efficient than Laser Ablation, the most expensive method of synthesis. Furthermore, because this is a variant on the standard CVD method, the properties of the nanotubes can be altered by tuning the growth conditions. After being placed in a solvent and dried, the nanotubes are packed into a dense material, which can then be moulded into various shapes and thicknesses by compression during the process. Following this method, sheets of highly compacted, aligned SWNT Forests (with a carbon purity of >99.9%) can be formed, which is precisely what we require.

However, the length of the nanotubes formed this way is greater than 1mm, indeed, in many cases the actual length is closer to 2.5mm. This is too long by a factor of a million, should we want our nanotubes to have lengths in the nanometres. However, the fact remains that there will have to be a compromise between length (which must be below micrometres to avoid the complications of cancer) and structural integrity, which will require slightly longer lengths to ensure the appropriate amount of nanotubes can actually be created, and they are durable enough to last as a long-term application.

When filtering air, the amount of nanotubes required varies massively with application, so we shall limit it to the case of an air conditioning system. As mentioned in the introduction, nanotubes can only be used to filter particulates from the air, other chemical methods would be required to remove other harmful or toxic substances. The size of an air conditioning system’s air intake can be as small as $2cm^2$, meaning it would require no more nanotubes than a household pipe fitting.

Carbon-Silver Hybrid Nanotubes

Silver nanoparticles are well known for their anti-bacterial properties, and are currently used in many different industries. Obviously a suspension of silver nano-particles in the water itself would need replacing perpetually, and would be extremely dangerous, as they have been found to have “inflammatory, oxidative, genotoxic, and cytotoxic consequences” mainly in the liver, but also in the brain. They have also been found to, in larger than necessary quantities, remove both beneficial bacteria and harmful bacteria during waste water treatment processes.

Therefore, we suggest that they are actually formed as part of the nanotubes themselves. This would mean that we could not only control the amount present in a SWNT forest to ensure that should a failure occur, the quantities released into the water would be below harmful limits, but also that the amount is not so great that the quantities of beneficial bacteria would be adversely affected, also that no nanotube was without a single silver nanoparticle as part of its chemical composition.

It has been shown that it is possible to insert silver atoms into a carbon chain and multiple methods have been successful in this approach. The average diameter of the nanotubes where silver atoms have been inserted into the chemical composition is 1.22nm, perfectly within our range of feasible diameters for our proposed application.

However, we have to consider how this would affect the strength of the nanotube — as mentioned, defects in a nanotube can cause large stresses across the structure. The addition of silver particles would indeed weaken the structure of the nanotube, rigorous testing would be needed to ensure that this weakened structure would still be able to maintain structural integrity. This is necessary because, as mentioned above, silver nanoparticles are toxic to humans, so special care must be taken when inserting them into a water filtration system.

Conclusion:

As we have shown, we believe that nanotechnology can be relatively easily implemented into filtration systems, not only in industry but also for personal, medical use.

Nanotubes can be used effectively when placed parallel to the flow of water in small pipes and would filter out any bacteria and viruses. However, we have to consider that filtering out all bacteria may cause more harm than good. The introduction of silver nanoparticles in the filtration system would, as mentioned, potentially remove beneficial bacteria from the water supply.

We also face a similar problem when considering filtering air supplies — although it is relatively simple to filter out large particulates, there is no feasible way to filter out molecules such as sulphur dioxide and nitrogen dioxides. Arguably, these are the main proponent in smog and the main cause of illness from air pollution in major cities. The only way to protect against this would be to use an intelligent system which specifically selected certain molecules and removed them accordingly.

For both filtering air and water, we propose a method where the filtration level at each stage in the process becomes finer and finer.

For example, at the initial stage of water filtering, a filter fine enough to stop large stones and debris entering the water supply could be employed, then a filter to stop silt and mud, gradually getting smaller in scale until we reach the level of nanofiltering. Any smaller and the water molecules themselves would be unable to move through, making the system entirely useless. So rather than using a nanofilter as a stand alone module, if employed as part of a larger filtering strategy, the result would be very efficient.

For filtering air, large particulates would first be filtered and then if more intelligent nanofiltering systems are invented, they could be used to introduce secondary and tertiary filtering systems which remove harmful toxins such as sulphur dioxide and nitrogen dioxides. A semi-permeable membrane would which would allow oxygen, nitrogen etc., through but not toxins, would perform this task. However, a method which uses conventional filtering methods alongside nanofiltering is the only viable solution at this time.

The crux of the problem with our filtering technique appears to be to the vast quantities of nanotubes required, which initially appeared to be solved by Super Growth CVD. However, one of the severely limiting factors with Super Growth CVD was that, though it was the most able method at producing the required quantities of nanotubes, the lengths of the synthesised nanotubes were too long to be used for filtering water or air that would come into contact with humans. So, should this length problem be overcome, then it would be an ideal solution to the question of quantity.

Nanofiltration has already seen widespread use in many industries and it is hoped that the ability to strain bacteria and other pathogens from both water and air supplies will soon see a great reduction in the spread of many diseases. Not only will nanofiltration allow access to healthy supplies of these amenities, the rapid turnover of the process should help to combat future water shortages.

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