Review Article

The inefficiency of sewage processing for oestrogen removal

Nicola King
The King's School, Canterbury, UK. E-mail: 07nck@kings-school.co.uk

DOI: ???

ABSTRACT

One hundred million women worldwide take the contraceptive pill. The UK's water systems do not have the capability to filter out the oestrogen introduced through the consumption of the pill. This causes problems such as the feminization of the roach fish, cancer, and infertility. Possible solutions include: incorporating biofilm into the sewage treatment process, which increases the biodegradation activity level of the microorganisms employed in the process; reverse osmosis, which filters the oestrogen out under pressure; ozonation, which uses ozone to decompose the oestrogen; and replacing the pill with the alternative contraceptive the mini-pill, which contains no oestrogen.

Source of the Problem

Currently, many of the water sewerage systems in the UK are not advanced enough to cope with the input of oestrogen into the water supply. Every day, millions of women around the world wake up and take their contraceptive tablet [Figure 1], the pill, thinking nothing more of it than as if they were simply taking any other pharmaceutical medication. However, the 17α–ethinylestradiol (oestrogen) within this tablet does not remain in the body. As the woman urinates, the drug leaves the body and enters the water system. Most of the sewerage systems around the world were built before the contraceptive pill was even invented; the thought of filtering out thousands of pharmaceuticals such as oestrogen was never a deliberation. In the society today, no fewer than 100 million women worldwide are taking the Pill and 3.5 million of those are from the UK.[1] The effect of the introduction of this hormone into the water system has only until very recently been flagged up as a problem.

Examples of the Problems Caused by the Lack of Efficient Filtering of Oestrogen

The problems caused are multifaceted; they include the following:

The feminization of the male roach fish

Vitellogenin is an oestrogen-responsive egg yolk precursor protein which is present in all female fish including the roach fish. In 1994, caged male roach fish were discovered to have excessive amounts of vitellogenin, suggesting that these fish had been exposed to high levels of forms of oestrogen; an extreme case is shown in Figure 2. Originally, this finding was put down to the existence of industrially created oestrogen replacements – for example, nonylphenol, a "breakdown product" of a variety of widely utilized non-ionic surfactants. However, it has been discovered that the natural 17α–ethinylestradiol (the oestrogen found in the Pill) as well as the natural steroids 17α-estradiol and estrone are more responsible than nonylphenol for

Figure 1: Woman taking the pill [Available from http://topnews.net.nz/content/214776-hormonal-pill-tends-alter-sexual-desire-women-says-research]

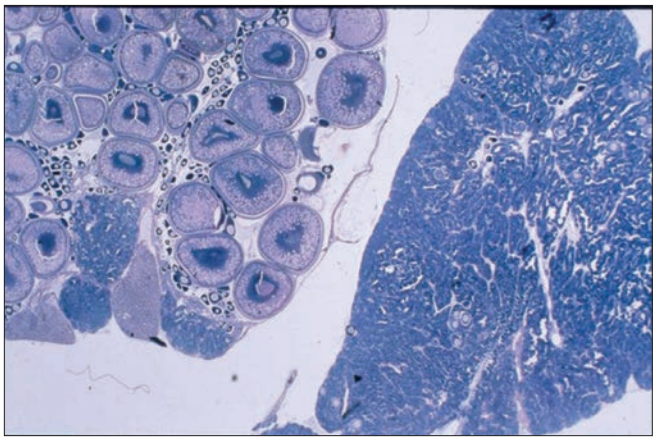

Figure 2: Testis of intersex roach showing presence of ova within the testicular tissue (tests have been done in labs which prove that oestrogen has this affect on the tissue) [Available from http://www.eng.ox.ac.uk/chemeng/pdf/oestrogens.pdf]

contributing to this effect. Overall, studies have shown that it is the 17α-ethinylestradiol that is causing most of the problems.[2]

Cancers

There are vast benefits to humans in filtering out the oestrogen in the water supply. It is well known that oestrogen is a major cause of cancers,[3] including breast, endometrial, cervical, colon, brain tumors, testicular, and prostate cancer. Elevated levels of the hormone can also cause an increase in infertility.

Cancer affects one in three people at some time in their lives, though some tumors are much less common than others. In the UK, the commonest form in women is breast cancer, followed by colorectal, lung, and skin cancer. The Office of Health Economics has calculated that the cost to the National Healthcare Service (NHS) of treating cancer in 1998/99 was £1986 million, of which £15754 million represented hospital treatment costs, £177 million was spent on anti-cancer medicines, and £54 million was accounted for by GP and pharmacy costs.[4] I must clarify that although oestrogen is a major cause in many types of cancer, not all cancers are related to this hormone.

Current Ineffective Sewerage Treatment Process

Generally, the chief process of sewerage treatment is activated sludge. Activated sludge is a process [Figure 3] in sewage treatment in which air or oxygen is forced into sewage liquor to develop a biological floc (precipitate that appears during flocculation), which

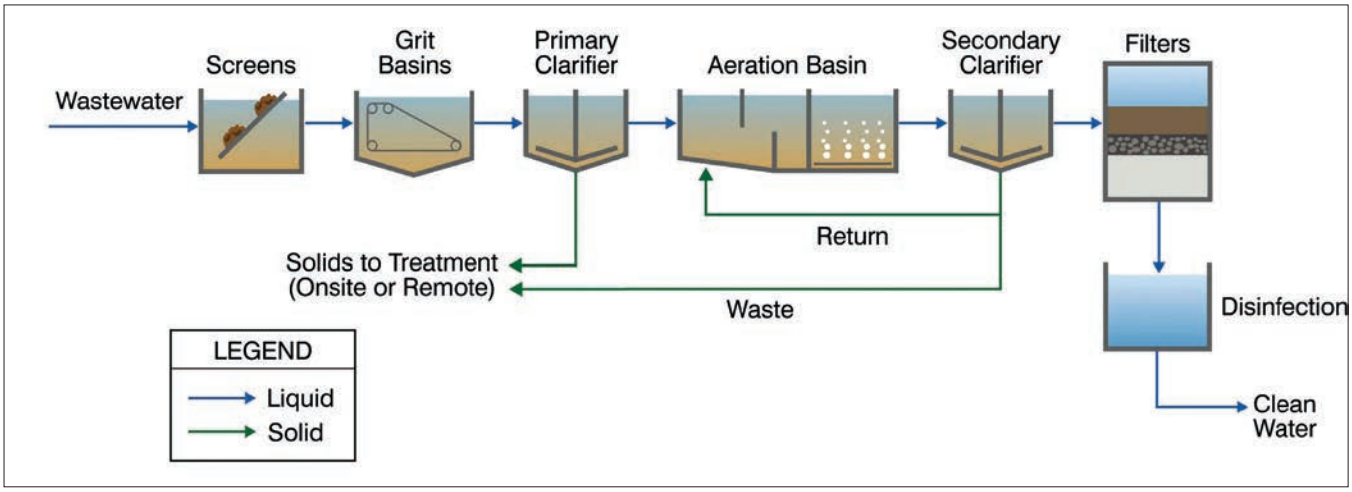

Figure 3: The current system of activated sludge plants [Available from http://www.oakharborcleanwater.org/proposed-future-treatment-facility-technologies]

reduces the organic content of the sewage. Once the sewage has received sufficient treatment, excess mixed liquid is discharged into settling tanks and the supernatant is run off to undergo further treatment before discharge. Part of the settled material, the sludge, is returned to the start of the aeration system to re-seed the new sewage entering the tank. The remaining sludge then undergoes further treatment.

Currently, activated sludge plants remove about:

- 70–88% of 17β-estradiol
- 50–75% of estrone
- 50–85% of 17α-ethinylestradiol

This appears effective but leaves about 1–10 ng/dm^3 (parts per trillion) of these harmful hormones in the water system, which, despite the small concentrations, can still have a devastating impact on the environment as stated earlier.[5]

The UK's Disadvantage

The United Kingdom has a particular disadvantage in that it has very small rivers [Figure 4] to source the supply of water in addition to the fact that it serves a high population density. As a result, the UK's Environment Agency is thinking of ways to control the output of these hormones into the water supply. It has been brought to light that in London, water has passed through eight people prior to its ingestion by any individual.[6]

What Properties Should the Solutions Have and Why?

Many of these harmful estrogens possess hydrophobic characteristics, so they are insoluble.

Figure 4: Image of Barlings Eau River [Available from http://www.geograph.org.uk/photo/186939]

The hydrophobic effect is fundamentally based on the tendency of (polar) water molecules to exclude non-polar molecules, which leads to segregation of water and non-polar molecules.[7]

In addition to the previously mentioned chemicals, which are endocrine disrupters, examples such as 17β-estradiol only slowly biodegrade – at the very least, it is necessary to modify the activated sludge plant to eliminate them at a reasonable rate.

Impractical Solutions to Improving the Ineffective, Current Activated Sludge Plants

- To double, triple, or even quadruple the quantities of activated sludge bacteria existing inside the last tank, where the biodegradation activity must be increased to break down more oestrogen. The last tank in many sewage works is not easily accessible and it is, therefore, difficult to place the bacteria sediment in this tank.
- Making the aeration tank much bigger will result in the tank holding water for longer, which will allow more time for the biodegrading process to take place. Again, there is a negative side to this in that the necessary large size of the treatment plant results in an increase in expenses. Furthermore, this expansion and modification can only happen in plants that have onsite space to allow for it.

As these treatments are very costly, other more practical solutions are more commonly being incorporated into sewerage systems.

Chosen Solutions

Biofilm

A biofilm is a complex aggregation of microorganisms growing on a solid substrate. Biofilms are characterized by structural heterogeneity, bacterial genetic diversity, complex community interactions, and an extracellular matrix of polymeric substances.[8] The proportion of an organic contaminant such as oestrogen that can be removed from the sewage effluent depends on the attractive power of the biofilm sorbent and the quantity of sorbent present per unit of volume.[9]

As the capability to enlarge the biological sorbent's "attractiveness" is restricted by space, it can be overcome by raising the quantity of sorbent. Activated

sludge tanks work with a biomass content ranging from 2.5 to 4 g/dm^3, as an increased concentration may create a settling problem. A biofilm, when joined onto carrier substances, does not create the same difficulties in eliminating sludge out of the effluent as a standard biofilm. A biomass of 12–35 g/dm^3 could possibly be upheld inside a separate section of the activated sludge tank using a biofilm; this is a 3–8.5 fold increase in biomass. and therefore an increase in biodegradation activity level.

Figure 5 shows how a biofilm actually lets organisms grow on it, as described in the previous paragraph. This can provide a more sorbent binding surface as well as an increased biodegradation capacity than is usually present. The ratio of high biomass and high available surface area offers the highest capability to absorb and remove the oestrogen compounds from the aqueous phase.

The process of eradication of the oestrogen contaminants is in two stages: primary adhering to the bacterial surfaces and biodegradation on the bacterial surfaces.

To demonstrate how biofilms are supported and cultivated under normal sludge plant conditions, scientists, including Andrew Johnson, carried out various studies. They obtained and positioned a large selection of different media inside cages made from stainless steel, and immersed them into the aeration tank of a standard activated sludge plant. The media were removed from the tank for analysis after some time for investigation in the lab.

The biofilm was used to start bacterial growth in a "bench-scale unit" [Figure 6]. For safety reasons, they used Ultra-High-Temperature (UHT) skimmed milk (with added nitrogen and phosphorus) instead of sewage as this has the same biomass range as regular sludge plant sewage. This fluid was then contaminated with oestrogen. The medium with biofilm fastened to it was placed in an "up flow glass bioreactor" [as seen in Figure 6]. The following passage is from the scientist who led the studies: "The feed liquor moved through the bio filter, was aerated and then overflowed to the next reactor. The typical hydraulic residence time in the bioreactors was around 20 minutes. Both the feed and effluent were constantly monitored for oestrogen using Liquid Chromatography Mass Spectroscopy."[9]

To prove that the biofilm could efficiently remove

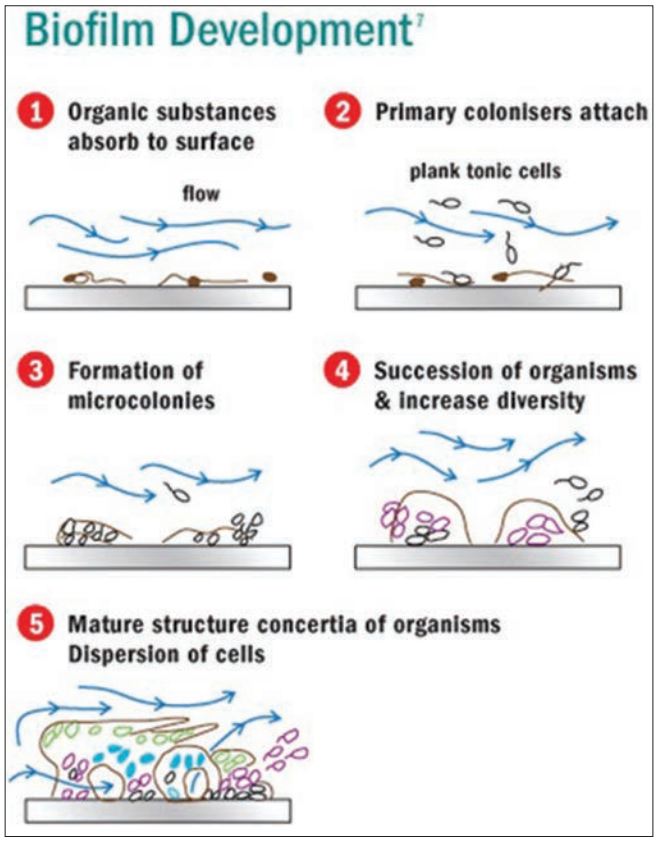

Figure 5: Showing how biofilm allows organism growth [Available from http://www.teamaquafix.com/h2s.aspx]

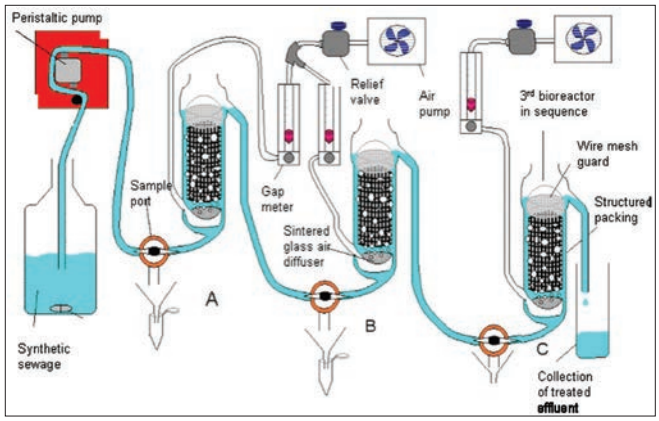

Figure 6: Showing how the experiment was carried out [Available from http://www.eng.ox.ac.uk/chemeng/pdf/oestrogens.pdf]

oestrogen, 100 μg/dm^3 ethinylestradiol (EE2), the first orally active semi-synthetic steroidal oestrogen, was inserted into and remained in the bioreactor for 20 days. During the test, 90–95% of the EE2 was removed [Figure 7].

How appropriate is this solution?

- This method is appropriate as it removes almost all of the oestrogen in the effluent. It is

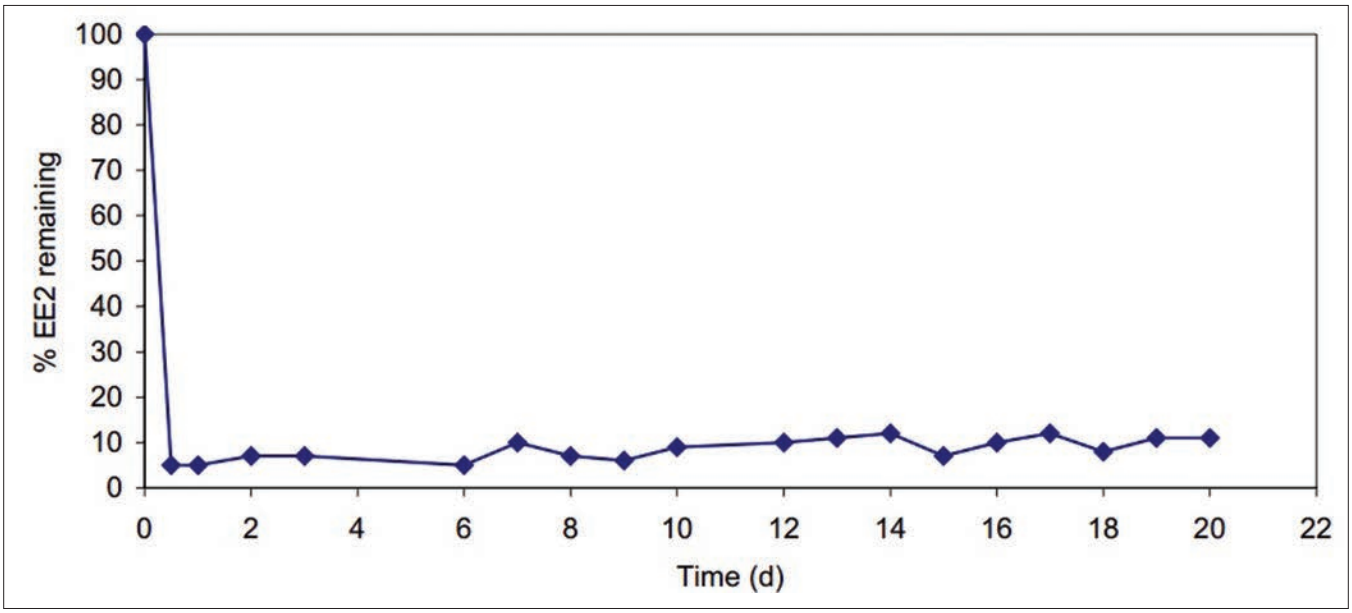

Figure 7: A table showing EE2 escape following 2 h of treatment with biofilm sustained by synthetic sewage [Available from http://www.eng.ox.ac.uk/chemeng/pdf/oestrogens.pdf]

a relatively low-cost solution compared to other more expensive approaches, as it only requires adding moderately cheap mechanisms into existing activated sludge plants. Other solutions involve building whole new plants or machinery that would be inappropriate, both in terms of cost and the environment.

- Although this solution appears to be economically superior to the other solutions, it does still involve a setup cost in correctly inserting the biofilm. There is also a time when the plant is not operative (during repairing and replacing biofilm) and one must consider where the sewage will be held during this period. Some options include: holding it in tanks, which is expensive; releasing the load into the sea and rivers, which is polluting; or sending it to other functioning plants, putting a strain on their work.
- Another flaw with this solution is that there is restricted growth of bacteria on the biofilm, and therefore with time, the ability to hold and biodegrade the oestrogen may be affected. Therefore, the biofilm may need replacement and this is inconvenient as constant inspection and repairing is required, and again, there is the problem of storing the sludge during the process.
- The risk of the method to other organisms is that the biofilm may begin to let harmful or polluting bacteria cultivate there, as there are optimum bacterial conditions. These have the threat of contaminating the effluent at a later stage, which may cause more harm than good to the organisms that use the water.
- The obvious benefit of the methodology is removing at least 80% more oestrogen from the effluent, and consequently, the environment and the population would not be exposed to the high oestrogen levels, and are therefore less likely to be prone to the negative side effects that were previously discussed.
- There is an environmental benefit to this solution in that the Earth's resources are not required in this method. It can be seen in Figure 8 that the aeration tank involved is easily accessible, so there would be no need to make a contraption to get inside it, again saving resources and conserving time.

Figure 8: Aeration tank of an activated sludge plant [Available from http://www.alcosan.org/Education/HowitWorks/HowItWorks2/tabid/95/Default.aspx]

- An additional environmental benefit is that aqueous plants and underwater habitats will be much less polluted by oestrogen.
- The only input of greenhouse gases into the atmosphere is in the transport of the materials to each of the sludge plants, when CO_2 will be released.

Reverse osmosis

"Reverse osmosis," as the name suggests, involves the opposite action to osmosis and is shown in Figure 9. Osmosis is the movement of a solvent through a selectively permeable membrane into a solution of higher solute concentration that tends to equalize the concentrations of solute on the two sides of the membrane.

In reverse osmosis, the membrane is used as a very fine filter to produce pure water from water contaminated with the oestrogen. The polluted water is kept on one side of the membrane and then pressure is applied to stop, and then reverse, the osmotic process.[10]

- There are many advantages to reverse osmosis. It is environmentally friendly because the process does not create or use harmful chemicals. Moreover, the process does not require many raw materials and in this respect, it is considered to be "green." It is also very effective in oestrogen removal.
- However, a major disadvantage in the process is that reverse osmosis requires a vast quantity of water as well as pressure. Such systems typically return as little as 5–15% of the water pushed through the system;[10] this means that the process is very time consuming, and the method very inefficient. This enormous volume of water also has to be free of bacteria; to create a system to carry out all this would require time and money. The outcome of removing oestrogen is beneficial though, so there is a decision to be made as to whether the amount of money required to be spent on this system is worth the benefit of the oestrogen removal.

Ozonation

Ozone (O_3) is an "unstable gas" containing three oxygen atoms; the gas will easily convert back to oxygen, and during this conversion a free oxygen atom or "radical" is created. The free oxygen radical is extremely reactive but has a short half-life. In normal circumstances, it can only last for milliseconds, and in this time, it will oxidize practically any chemical, including oestrogen. It has seven times the oxidizing capability of free chlorine atoms, but does not create toxic waste (which the majority of other chemicals do).

Role of ozone in water treatment

As ozonation has the ability to break up virtually any chemical, oestrogen in the water is also broken up. As ozone degrades back to oxygen and free radicals,

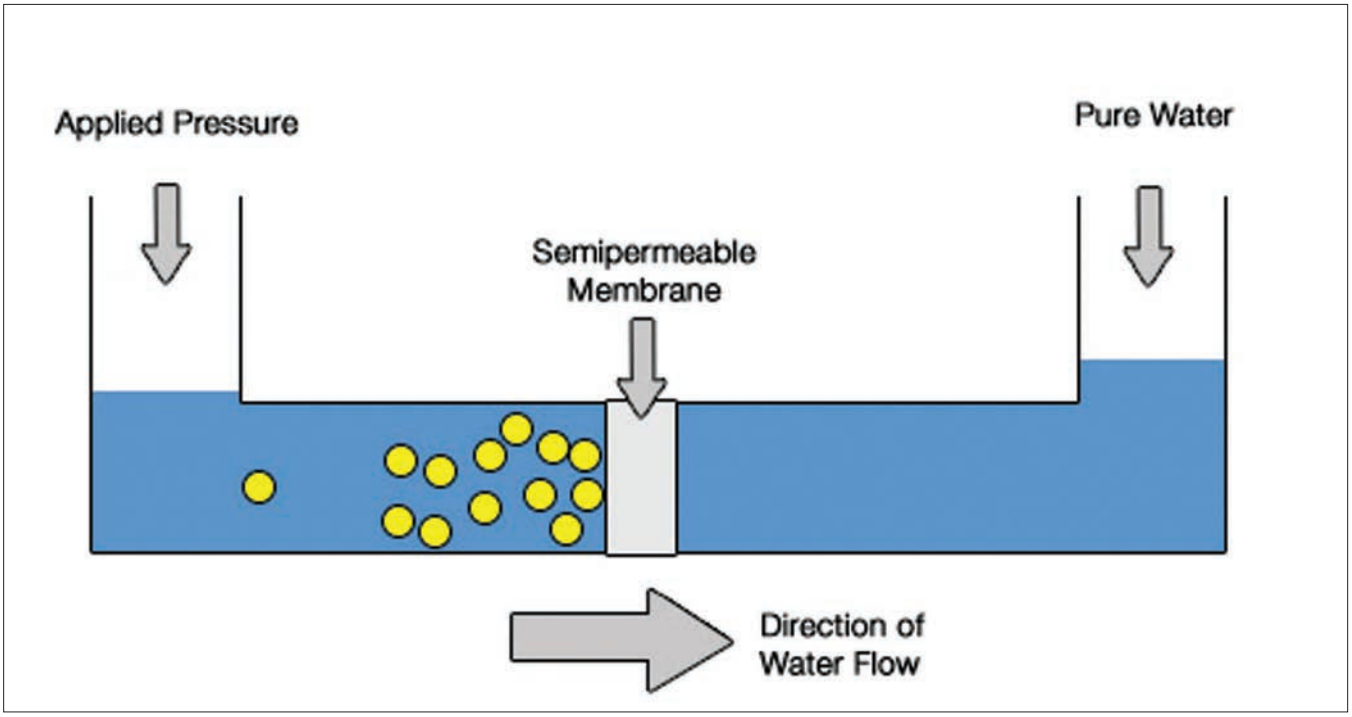

Figure 9: Image of reverse osmosis process [Available from http://bmet.wikia.com/wiki/Reverse_Osmosis_Unit]

the probability of water oxidizing other chemicals is raised. This capability to oxidize is determined as "redox" potential – the higher this potential, the greater the intensity of the free radicals. As the redox potential is increased, so is the range of chemical species that can be oxidized.

The advantages of ozonation are as follows

- Removes oestrogen
- Reduces oxygen demanding matter, turbidity and surfactants
- Removes most colours, phenolics and cyanides
- Increases dissolved oxygen
- No significant toxic products
- Increases suspended solids' reduction[11]

The disadvantages of ozonation are as follows

- High capital cost
- High electricity consumption
- Highly corrosive, especially with steel or iron and even oxidizes Neoprene[11]

The mini-pill

The mini-pill is another form of oral contraception that contains no oestrogen, as stated by the GP Dr. David Delvin: "Unlike the ordinary pill it contains just one hormone – not two. That hormone is a progestogen. A progestogen – which is an artificially manufactured hormone – is very like progesterone, which is one of the female hormones the body produces. Unlike the 'ordinary' pill, the mini-pill contains no oestrogen at all."[12]

It may be suggested that the population increase their use of this form of oral contraception rather than using the regular oestrogen pill, which is currently the most popular form of contraception.

The latest progestogen only pill (POP) "Cerazette," also known as "desogestrel," is considered as effective as the oestrogen contraceptive pill (OCP; i.e. combined pill) in protecting against pregnancy [Figure 10].

Advantages

- The first and obvious advantage is that there will be a considerable reduction in the country's oestrogen levels.Therefore, all the problems that these high levels of oestrogen create will either be terminated or significantly reduced.
- It protects the population from unwanted pregnancy.
- It has the following advantages in its primary function as a contraceptive:
  1. Effective and reversible (failure rate 0.5% in original POPs but 0.17% with Cerazette)
  2. Decreased risk of venous embolism
  3. Decreased risk of endometrial cancer, pelvic inflammatory disease, premenstrual syndrome, mastalgia and thrush.
  4. Does not interfere with breast-feeding.
  5. Not affected by antibiotics, sodium valproate or clonazepam.
  6. Causes fewer metabolic changes – does not raise blood pressure or increase cholesterol levels. Minimal effects on clotting mechanism and glucose metabolism.[13]

Figure 10: The Cerazette mini-pill [Available from http://www.2womenshealth.com/Cerazette.htm]

Disadvantages

- There is insufficient evidence to support the idea that the drug does not cause the same effects as oestrogen in effluent.
- It would be incredibly difficult to persuade a nation to switch to another form of contraception, if they are happy with their current choice, in a short time.
- The following are the disadvantages to its primary function as a contraceptive:
  1. Needs to be taken daily.If using any POP other than Cerazette, it must be taken at the same time every day or within 3 hours.
  2. Irregular periods, heavy periods or no periods, can occur.
  3. Interactions with enzyme inducing drugs can occur (rifampicin and some anti-epileptics).
  4. May worsen acne. Side effects – headaches, dizziness, nausea, bloating, breast tenderness, moodiness and loss of libido.
  5. Ovarian cysts may occasionally develop.[13]

Conclusion

Having evaluated the various solutions to the problems that oestrogen in the effluent creates, I conclude that biofilm in the aeration tanks of activated sludge plants is probably the best option, having considered the advantages and disadvantages of all the various solutions. The main advantages it has over the other solutions I have studied are as follows:

- Biofilm is a more cost-effective solution compared with ozonation and reverse osmosis.
- Biofilm is a comparatively easy method to remove oestrogen from the effluent.
- Once the biofilm has been installed in activated sludge plants, there is no requirement for annual replacement of materials, and aeration tanks allow for easy access.
- Biofilm does not rely on unpredictable public cooperation, whereas using the mini-Pill solution does.
- Biofilm is the most environmentally friendly solution.
- Biofilm is the most effective long-term solution for removing oestrogen from the water.

References

1. Stacey D. Top 10 Pill Myths. About.com, 2007. Available from: http://contraception.about.com/od/contraceptionmyths/tp/pillmyths.htm.[Last accessed 2011 Feb].
2. Delvin D. Contraception – The Contraceptive Pill. Net Doctor, 2011. Available from: http://www.netdoctor.co.uk/sex_relationships/facts/contraceptivepills.htm.[Last accessed 2011 Feb].
3. Oestrogen – The Killer in Our Midst. Cancer Active, 2003. Available from: http://www.canceractive.com/cancer-active-page-link.aspx?n=661.[Last accessed 2011 Feb].
4. Bartlett S. A-Z of Medicines Research. 4th ed. United Kingdom: The Association of the British Pharmaceutical Industry; 2007. [Last accessed 2011 Feb].
5. What is Activated Sludge? Bionewsonline.com, 2005. Available from: http://www.bionewsonline.com/x/what_is_activated_sludge.htm.[Last accessed 2011 Feb].
6. 10 Facts About Water in London. Watercoolersdirect.com, 2008. Available from: http://www.watercoolersdirect.com/resources/10-facts-about-water-in-london.html.[Last accessed 2011 Feb].
7. Hydrophobic Effect. Wikipedia.org. Available from: http://en.wikipedia.org/wiki/Hydrophobic_effect.[Last accessed 2011 Feb].
8. Bioscreen C. What is Biofilm? Bionewsonline.com, 2005. Available from: http://www.bionewsonline.com/n/what_is_biofilm.htm.[Last accessed 2011 Feb].
9. Johnson A,Darton R. Removing Oestrogenic Compounds from Sewage Effluent.Available from: http://www.eng.ox.ac.uk/chemeng/pdf/oestrogens.pdf.[Last accessed 2011 Feb].
10. Water Ozone Generator/Ozonator. Air Purifier's Superstore. Available from: http://www.air-purifiers-superstore.com/air_water_ozonator.html.[Last accessed 2011 Feb].
11. Rossa-Lee C.Ozonation of Wastewaters. Mountain Empire Community College. Available from: http://water.me.vccs.edu/courses/ENV149/ozonation.htm.[Last accessed 2011 Feb].
12. Delvin D. The Mini-pill--Progesterone-only Pill or POP. Net Doctor, 2011. Available from: http://www.netdoctor.co.uk/sex_relationships/facts/mini-pills.htm.[Last accessed 2011 Feb].
13. Smithson J. Progesterone-onlyPill. Gp-training.net.Available from: http://www.gp-training.net/protocol/gynaecology/contraception/pop.htm.[Last accessed 2011 Feb].

About the Author

Nicola King goes to school in Canterbury. She studies Maths, Physics, Biology, and Art, and hopes to study Biology at University one day. The interest for this article started when she read an article in the news about the male roach fish turning female.