Factors affecting human decomposition

The QUESTOR Centre

Applied Technology Unit

Report on behalf of Greengraves

Factors affecting human decomposition

Draft

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Executive summary

Initially the client (David Spiers) was interested in the possibility of QUESTOR carrying out practical research with direct relevance to human decomposition under controlled conditions. While QUESTOR have the technical knowledge and facilities to carry this work, the timeframe and funding required to complete the research was not feasible. After completion of an in depth literature review on the compounds released from the decomposition of a human body, the breakdown stages for decomposition of a corpse and the time period involved for decomposition to occur. The client was concerned about leaching formaldehyde from embalming fluids becoming an environmental concern. This study also looked at possible methods to reduce the overall quantities of formaldehyde before it escapes from the coffin and enters the surrounding sediment. An initial search for possible materials for environmentally friendly biodegradable coffins and how the presence of a concrete vault would impact on the degradation and leaching of formaldehyde was also investigated. The information was compiled using papers from established journals, textbooks and internet searches.

The client now has a much greater understanding on the underlying processes that occur after burial. As a result the client is in a much better position to proceed in the next stages of product design. QUESTOR would now consider a practical investigation to be the next step in the product development process which was agreed in principle with the client. Over the course of the research the focus in respect to certain potential products has changed from a coffin stacking system (Figure 1) to a coffin insert to aid biodegradation of formaldehyde within the coffin.

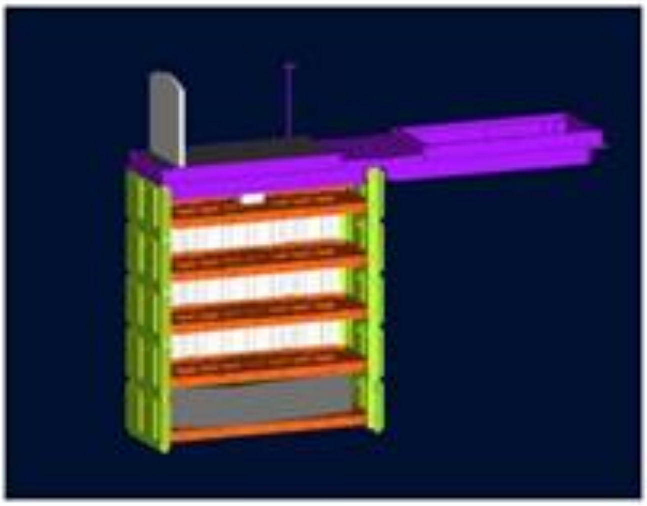

Figure 1- Proposed coffin stacking system from the Greengraves website

Greengraves 1st deliverable

1. What is in the solution which gathers in the sump?

Constituents of partial body composition:

The initial body composition is approximately 64% water, 20% protein 10% fat 1% carbohydrates 5% minerals (Pioneer burials 2008).

Protein decomposition

Continued proteolysis leads to production of phenolic compounds skatole and indole. Sulphur containing amino acids (cystine and methionine produce hydrogen sulphide gas, sulphides, ammonia, thiols and pyruvic acid. In the presence of iron a black precipitate ferrous sulphide will be produced.

The anaerobic conditions of a grave promote formation of considerable quantities of sulphide. Thiols or mercaptans are decomposition gases containing the –SH (sulphydryl group). These are acidic and react with heavy metals (mercury) to form insoluble solutions. Thiols may form from aromatic molecules and may then be converted to sulphides (Dent et al. 2004).The gases putrescine (derived from ornithine) and cadaverine (derived from lysine) are particularly prominent gases involved in body decomposition (Statheropoulos et al. 2007). Organic acids are also present which are metabolised by bacteria.

Fat decomposition

Adipose tissue is composed of 5-30% water, 2-3% proteins and 60-85% fats. The fats consist of 90-99% triglycerides. Triglycerides consist of three fatty acid molecules attached to one glycerol molecule. Due to the lack of oxygen within the coffin any oxidation of fats will be limited, the reducing conditions present will instead promote hydrolysis. Fat can be hydrolysed by tissue lipases to produce a mixture of saturated and unsaturated fatty acids. These react with sodium and potassium ions within the tissue fluids to form salts which may then be displaced by magnesium or calcium ions to form the water insoluble adipocere.

As the burial conditions will prevent oxidation of the fats the adipocere may remain indefinitely. The intestine residing *Clostridium perfringens* possesses potent enzymes which aid anaerobic hydrolysis and hydrogenation of fats (Dent et al 2004).Hydrolysis of fatty acids such as oleic acid, linoleic acid and palmitoleic acid form stearic acid, oleic acid and palmitic acid. Stearic acid, palmitic acid, myristic acid, hydroxy-fatty acids and oxy-fatty acids will either be present within the sump or as part of the adipocere (if present).

Palmitic acid generally accounts for 50% of adipocere formation, stearic acid makes up ~33%, myristic and 10-hydroxystearic acid make up less than 10%. Oleic acid (unsaturated fatty acid) accounts for less than 5% of the adipocere.

Carbohydrate decomposition

Carbohydrate breakdown occurs during the early stages of decomposition and primarily in the liver (Evans 1963). Glycogen is attacked by microorganisms to form glucose monomers which can then be used as carbon sources for fungi, aerobic bacteria and anaerobic bacteria. Fungi metabolise sugars to form organic acids such as glucuronic acid, citric acid and oxalic acid (Waksman and Starkey 1931, Dent et al 2004). Under aerobic conditions glucose is broken down via the intermediates pyruvate, lactic acid and ethanol leading to the complete oxidation products carbon dioxide and water. Under anaerobic conditions acids such as lactic acid, acetic acid and butyric acid are produced as well as a number of alcohols which include butyl alcohol, ethyl alcohol and acetone. Methane, hydrogen and hydrogen sulphide are also formed during the anaerobic degradation of glucose (Dent et al 2004).

Table 1- The potential contaminant release (in kg) from a single 70kg burial (Pioneer burials 2009)

Year	TOC	NH4	Ca	Mg	Na	K	P	SO4	Cl	Fe
1	6.0	0.87	0.56	0.010	0.050	0.070	0.250	0.210	0.048	0.020
2	3.00	0.44	0.28	0.005	0.025	0.035	0.125	0.110	0.024	0.010
3	1.50	0.22	0.14	0.003	0.013	0.018	0.063	0.054	0.012	0.0005
4	0.75	0.11	0.07	0.001	0.006	0.009	0.032	0.027	0.006	0.003
5	0.37	0.05	0.03	--	0.003	0.004	0.016	0.012	0.003	0.001
6	0.19	0.03	0.02	--	0.002	0.002	0.008	0.006	0.002	--
7	0.10	0.01	0.01	--	0.001	0.001	0.004	0.003	--	--
8	0.05	--	--	---	---	--	0.002	0.001	--	--
9	0.02	--	--	--	--	--	0.001	--	--	--
10	0.01	--	--	--	--	--	--	--	--	--

2. What are the breakdown stages for decomposition of a corpse e.g. exit of liquids first followed by fat cells?

Pallor mortis-post-mortem paleness of skin caused by a lack of capillary circulation throughout the body (15-120mins after death).

Algor mortis-the reduction in body temperature after death until it reaches the surrounding body temperature (Initial hours after death).

Rigor mortis- incomplete muscle contraction caused by a lack of ATP leading to the myosin filaments becoming locked in position with the actin filaments. (12hrs-3 days after death). General tissue decay and leaking of lysosomal intracellular digestive enzymes cause the muscles to relax.

Livor mortis- The blood pools into the interstitial tissues of the body causing a purplish red discoloration of the skin. When the heart is no longer agitating the blood, heavy red blood cells sink through the serum by action of gravity. This discolouration does not occur in the areas of the body that are in contact with the ground or another object, as the capillaries are compressed. (starts 20 minutes to 3 hours after death and congeals in the capillaries in 4 to 5 hours, Maximum lividity occurs within 6-12 hours).

Initial decay – 0 to 3 days after death

As cells of the body are deprived of oxygen, carbon dioxide in the blood increases, pH decreases and wastes accumulate which poison the cells. Concomitantly, unchecked cellular enzymes (lipases, proteases, amylases, etc.) begin to dissolve the cells from the inside out, eventually causing them to rupture, and releasing nutrient-rich fluids. This process begins and progresses more rapidly in tissues that have a high enzyme content (such as the liver) and a high water content such as the brain, but eventually affects all the cells in the body. At the same time gut bacteria begin to break down the intestines and start to invade other parts of the body.

Putrefaction – 4 to 10 days after death

Microorganisms (bacteria, fungi and protozoa) break down tissues and cells into gases, liquids and simple molecules. This usually occurs under anaerobic conditions, releasing fluids into body cavities. Bacteria break down haemoglobin (in blood cells) to sulfhaemoglobin causing the green colour change of the skin. Various gases (hydrogen sulphide, carbon dioxide, methane, ammonia, sulphur dioxide, cadaverine (pentamethylenediamine) putrescine (butanediamine) and hydrogen) are formed within the abdomen forcing various liquids and faeces out of the body and causing swelling of the mouth lips and tongue. Bacteria enter the venous system causing the blood to haemolyse causing red streaks followed by colour change to green caused by marbleisation. Blisters form on the skin filled with various body fluids. The skin starts to slip off the body.

Black putrefaction - 10 to 20 days after death

The bloated body cavity eventually ruptures and collapses as the gases escape. The body darkens from green to black. The muscles are broken down via bacterial action from protein to amino acids which is converted to volatile fatty acids. Further protein and fat decompostion leads to phenolic compounds, indole, 3-methylindole and glycerols.

Butyric fermentation - 20 to 50 days (possibly many years under anaerobic conditions)

The body begins to dry out (mummification) and has a cheesy smell, caused by butyric acid. Adipocere formation (or saponification) may occur producing a yellow/white greasy wax-like substance. Adipocere develops as a result of fat hydrolysis releasing fatty acids. All the remaining flesh is removed over this period.

Dry decay or diagenesis- 50 days to 365 days (for the body at surface, can last hundreds of years under certain conditions)

The slow deterioration of organic components (collagen) and the inorganic constituents (calcium phosphate, hydroxyapatite) making up the skeletal remains allow the dissolution of the mineral phase caused by a low pH permits access to the collagen by extracellular microbial enzymes allowing further microbial attack.

3. Michael mentioned a mesh to filter out the fat cells - is there any indication of what mesh size would be required?

A typical fat cell is 0.1mm in diameter with some being twice that size and others half that size. Adipose (fat) cells with a diameter of more than 200µm are rarely seen. An average adult has 30 billion fat cells with an approximate weight of 30 lbs or 13.5 kg. In a decomposing body the fat cells will lose water retention and shrink as a result. Adipose cells are connected together to form relatively large clumps of tissue-visceral fat deposits such as a 'beer belly' (Sjostrom et al. 1971).

4. Does formaldehyde leach first?

There is currently little information regarding when formaldehyde leaches out of the body during decomposition. There is more information regarding the effects of formaldehyde (as formalin) on human decomposition and the leaching of formaldehyde into groundwater. Formaldehyde is considered to be very toxic to many bacteria particularly in concentrations of 200mg/L and above (Omil et al. 1998). Formaldehyde is a strong inhibitor of methanogenic bacteria as well as other microorganisms involved in the decomposition of volatile fatty acids. The presence of this compound will slow down the degradation of the surrounding tissues, especially the arterial system and adipose tissue. Very little of the formaldehyde will be aerobically degraded due to finite amount of oxygen present within the coffin. Formaldehyde may be degraded anaerobically via hydrogen and methanol before being converted into methane (Omil et al. 1998).

The chemicals used in embalming repel most insects, and slow down bacterial putrefaction by either killing existing bacteria in or on the body themselves or by "fixing" cellular proteins, which means that they cannot act as a nutrient source for subsequent bacterial infections. However many bacteria are capable of metabolising the toxic formaldehyde as well as methanol and ethanol.

Formaldehyde and other chemicals used for embalming appear to pose minimal environmental concerns. It degrades quickly under most environmental situations. When formaldehyde is released into the soil, the compound will leach into groundwater. Once the compound has infiltrated into the groundwater it will be degraded by the residing microbial populations within the sub-terrestrial environment (Material data safety sheet, JT Baker).

5. What is the time period involved approx for both wet and dry conditions?

Caspers rule

The degree of degradation that has occurred to a corpse that has been lying on the surface for 1 week corresponds to that of one immersed in water for 2 weeks or about 8 weeks in the soil (Dix and Graham 2000).

Vass (2001) has developed a formula for estimating the decomposition of soft tissues in a human body on the ground.

Y=1285/X   Y= no. of days to become skeletonised or mummified X= average temperature

Ideally, the decomposition of a human body is completed within the regular resting time of 15–25 years and leads to the entire skeletalisation of the corpse (Fiedler and Graw 2003). However, decomposition rates vary greatly on the conditions present and can be very difficult to quantify. There are a number of factors that affect the rate of decomposition of a human body, these include the following:

Preservation (mummification and adipocere formation)- Two common forms of soft tissue preservation are mummification and the formation of an adipocere. The former occurs in hot very dry conditions or areas of low humidity causing rapid drying (dehydration and dessication) of the skin and internal organs- this may occur in days or weeks (arctic regions and deserts). Adipocere formation occurs in anaerobic environments with plenty of moisture. The adipocere can be formed in a period of weeks to months and may last thousands of years. Mant (1957) suggested that bodies decompose faster in coffins when compared to bodies buried directly in soil. Mant (1987) also suggested that a lower incidence and coverage of adipoceres were observed in coffin burials.

Coffin type- coffins are generally thought to speed up the decomposition process when compared to corpses buried directly into soil. Coffins are considered to accelerate the post-mortem dissolution of the body. Coffins tend not to remain airtight for long. The coffin lids may collapse or the gaps occur around the seals of the coffin. In some cases the coffin may explode due to the pressure built up within. Solid lead coffins have been found to 'sterilise' the body by poisoning the microorganisms preventing decomposition occurring past the initial autolysis stage (Vass 2001). A corpse decomposing in a non-biodegradable plastic coffin may not form an adipocere but may liquefy into a semi-liquid state, possibly due to a lack of cation exchange between salts of fatty acids (Forbes et al. 2004)

Clothing type- clothing on corpses buried directly into soil in damp conditions has been found to lead to the formation of a more extensive adipocere (Mant 1987, Mellen et al 1993 and Manhein 1999). This is most likely caused by the ability of the clothing to absorb and retain moisture, aiding the formation of the adipocere.

Depth of burial- the nearer the surface the corpse is, the more insects there will be to attack the body.

Soil type- calcium rich soils (leached from limestone) may aid the formation of an adipocere by the cation being exchanged with sodium or potassium in the fatty acids formed from the breakdown of adipose tissue. Dry sandy soils in warm conditions lead to mummification. Clay soils are better at preventing chemicals, microorganisms and viruses dispersing far from the body.

Moisture- generally aids faster decomposition. Corpses may be preserved in anaerobic peat bogs.

Temperature- the higher the temperature the faster enzymes and microorganisms will decompose the corpse. The microorganisms will also die faster once there are insufficient carbon sources to sustain them.

Air content- decomposition occurs much faster in the presence of oxygen, insects may also thrive, aerobic degradation is generally faster than anaerobic degradation. Fungal growth is greatly reduced when anaerobic conditions present.

Other factors that influence the decomposition rate of a human body include pH, cause of death (injuries- prior blood loss-leads to faster decomposition), prior embalming, humidity, rainfall, body size and weight (thinbodies are less likely to develop adipocere than fat corpses) (Fiedler and Graw 2003), the surface on which the body rests, Foods/objects inside the specimen's digestive tract (bacon compared to lettuce).

6. What is required to neutralise the solution in terms of content, quantity and cost?

A metal casket for an above ground entombment includes a barrier material on the inner face of the casket bottom, sides and ends for preventing body decomposition liquids and vapours for contacting the inner surface of the casket bottom, sides and ends. A crystalline coating material is adhered to the barrier material and acts as a desiccant and encapsulator of the body decomposition liquids and vapours to convert the liquids and vapours into gel so that the liquids and vapours cannot migrate by gravity to the exterior of the casket (United States Patent 5666705).

Smaller particle clay-rich soils have a higher adsorption capacity than sandy soil and gravel reducing the threat of rapid seepage of decomposing products, bacteria and viruses. Graves should also be located more than 250m from boreholes, wells or springs where water drinking water is drawn, at least 30m away from other water courses and at least 10m away from field drains. Burials should not be placed into standing water and should be buried above the water table in that location (Pioneer Natural Burial 2008). By following these guidelines the risk of migration of contaminants and pathogens is greatly reduced.

7. What substance neutralises leached formaldehyde inclusive of body impurities and does not impact environmentally itself?

Formaldehyde, provided it is not leached in huge doses is not considered to cause too much environmental concern. Formaldehyde has been found to create problems in waste water works by high concentrations of formaldehyde killing the stable microbial populations used to treat the waste water. By adding a compound to try to neutralise the formaldehyde more problems may be created than are solved.

A number of methylotrophic microorganisms are able to utilise formaldehyde as a carbon source (e.g. *Hansenula polymorphawere*- a methylotrophic yeast which grows in acidic conditions) (Kaszycki and Koloczek 2004). Once the formaldehyde has dispersed to tolerable levels it will be degraded by microorganisms both inside and outside the coffin. The microorganisms may have to tolerate acidic conditions caused by leaching of the fatty acids and a number of other acidic compounds.

8. What substance if different from first neutralises next decomposite stage of corpse?

If the aim is to prevent decomposition as much as possible then attention could be drawn to stopping the wide variety of microbes from degrading the tissues. By using anti-microbial agents it is possible to retard the natural processes of decay. The possible environmental implications of any anti-microbial preservative used should be considered before use.

In a murder case a woman found near a roadside had been sprayed with insecticide and other chemicals in an attempt to mask the odour of decomposition. Unwittingly the murder had sterilised the body and prevented egg laying from insects. The corpse had some internal decomposition but it was greatly reduced by the chemicals spreading throughout the body (Vass 2001).

9. What is the potential volume of liquid in the 'sump' for the average body. We know that alive a body contains about 49 litres of water but dead but I would think this will be much less.

This depends greatly on the factors and conditions present listed in the response for question 5. Has the coffin leaked? To what extent has the body decomposed? Some anaerobic reactions require the lysis of the water molecule (H_2O). Many of the gases, liquids and solids produced from decomposition will interact with the water present, causing the formation of further products reducing the actual amount of water present.

Complete aerobic oxidation of molecules such as sugars produces water and carbon dioxide. A number of anaerobic reactions will hydrolyse water in degrading a compound (e.g. saponification).

For each molecule of glucose converted to pyruvate by glycolysis (a universal catabolic pathway) two molecules of water are formed. Acetate, ethanol, hydrogen and carbon dioxide will also be generated by *Enterobacteriaceae* anaerobically degrading glucose (Degelmann et al. 2009).

The decomposition of a body in a sealed plastic coffin will generate an abundance of gases and liquids from degradation of solid matter. As the solid matter is decreased the amounts of total gases and liquids will increase. Further degradation of some of the more complex liquids will produce further gases.

An approximation may be made concerning the total amount of liquids and gases produced from the decomposition of a corpse to a fully skeletonised state when buried in a coffin.

Mass of human body - mass of skeletonised remains = mass of liquids and gases in and permeating out of coffin + microorganisms

Assuming that the skeletonised remains of a human constitutes approximately 14-20% of the total body weight of the corpse (http://www.essortment.com/all/structureofthe_rnty.htm).

In a 70kg burial, the mass of skeletonised remains = 9.8kg-14kg leaving approximately 56kg-60.2kg of liquids, gases and microorganisms to be expelled during the decay process.

If conditions favour adipocere formation, then a higher proportion of mass will be retained in the solid form lower the total content of gases and liquids formed from decomposition.

10. What is the estimated volume and concentration of gases we are dealing with? How much do they need diluted to be safe and odourless?

The gases present at any particular time-point in decomposition will be subject to change as the microbial communities present adapt to different carbons producing different excretory products. More complex organic carbon sources will generally be converted to simple inorganic liquids and gases (e.g. H_2S, CO_2, CH_4, NH_3, SO_2, H_2).

A study conducted by Statheropoulos et al. (2007) monitored the accumulation of gases produced during the early stages of human decomposition (after approximately 4 days decomposition). The most commonly detected compounds detected during their research were: ethanol, 2-propanone, dimethyl disulphide, methyl benzene, octane, 2-butanone, methyl ethyl disulphide, dimethyl trisulphide and o-, m- and p-xylenes. Inorganic compounds such as carbon dioxide, carbon monoxide, ammonia and hydrogen sulphide. The sulphur compounds are known for their foul odour and their evolution is usually linked to bacterial fermentation.

Other gases detected include: hexane, heptane, octane, decane, tetramethyl hexane, 1-Undecene, trimethyl decane, 2-propanol, 2 ethyl 1-hexanol, phenol, 4 methyl phenol, 3-methyl butanal, 1-phenyl ethanone, 2-butanone, 2-nonanone, dimethyl sulphide, 1,2,3-trimethyl benzene, di-limonene, 2 ethyl-1,4-dimethyl benzene, naphthalene, styrene, 1-methylethenyl benzene.

Due to the experiment being carried out at such an early stage in decomposition the quantities of gases detected would not be representative of a decomposing body after burial.

11. In terms of the material used for the trays is there a polymer that breaks down in an environmentally friendly manner with similar duration to that of a corpse decomposition?

Funeral costs are rising in the UK as cemeteries continue to reach capacity. Disposable eco coffins made of wicker or cardboard are considered eco-friendly, while enabling families to engage in traditional funeral practices. Biodegradable compostable materials currently used to package organic fruit could also be implemented. Pine and spruce coffins seem to allow more rapid decomposition than oak coffins (Fiedler and Graw 2003). Plant bedding favours the processes of decay and appears to prevent adipocere formation.

In July 2007 the first American was buried in an Ecopod. An Ecopod is 100% biodegradable coffin made of recycled paper. The seedpod-shaped coffin is designed to be planted in the ground, dissolve and replenish the earth with its nutrient-rich contents. Originally developed in England, it is sold in the United States by the Portland-based Natural Burial Company. Other coffins have been designed that consist of paper, formaldehyde-free plywood, fair-trade-certified bamboo and hand-woven Somerset willow (Dembosky 2007).

Coffins have been constructed using bamboo coffins and banana caskets which been designed to degrade naturally along with the body it holds **(**http://www.ecoffinsusa.com/Products.htm**).** Biodegradable coffins are also being produced from recycled newspapers and cardboard such as the Greenfield coffin which consists of 3 parts: an outer shell, inner compartment and lid. A biodegradable liner is also provided. These can be bought through Brighton and Hove city council.

Green graves research 2nd deliverable

1. How to aid degradation of formaldehyde in a coffin and reduce the total concentration of leached formaldehyde

Formaldehyde is a toxic compound with carcinogenic properties, due to its widespread use as an embalming agent in corpses, concerns have been raised that this chemical may be leached out of coffins in sufficient quantities as to infiltrate drinking water supplies.

Formaldehyde can be degraded by microorganisms relatively quickly under aerobic conditions within the sub-terrestrial environment. Leached formaldehyde in an intact coffin will be degraded much more slowly under anaerobic conditions by the formation of methanol, methanoic acid and hydrogen to the final product methane, due to the limited supply of oxygen within the coffin (Oliveira et al. 2004, Pereira and Zaiat 2009). Carbon dioxide will be most likely utilised as an electron acceptor at such a low redox potential, producing methane as it is simultaneously reduced as formaldehyde is oxidised. The presence of formaldehyde may also inhibit the anaerobic degradation of other compounds such as volatile fatty acids (propionate and butyrate) within the coffin (Omil et al. 1999).

Formaldehyde exists as a gas at room temperature but is very soluble in water and will partition within the water. The aim is to reduce the total amount of formaldehyde as much as possible before it leaves the coffin. Microbial biodegradation will be the main process of formaldehyde removal. So the priority here is how to best facilitate the residing microbial populations to degrade the compound. Formaldehyde is less toxic and generally better degraded in lower concentrations, in high doses (~5g/L) it can be extremely toxic to microorganisms (Oliveira et al. 2004). In designing an appropriate method to facilitate the degradation of the compound, the main principle would be to either dilute or disperse the compound to lower concentrations making it more accessible and less toxic to the formaldehyde-degrading populations. The options include using a (trickle) filter of some description and/or a drainage system within the coffin containing a particular type of absorbent or adsorbent. Alternatively water could be used to dilute the compound to tolerable levels. The weight of any materials added to the coffin should also be considered for lifting purposes during funerals.

Types of filter- In addition to the proposed drainage basin insert within the coffin, a filter could be fitted beneath the drainage hole (Figure 2). The concept behind this is the filter will provide a large surface area for microorganisms to colonise via the drainage of leachate through the filter. The residing microbial community will utilise the compounds flowing through the filter which would include high levels of formaldehyde. The design of filter could consist of a column filled with materials such as Bio-balls (Figure 3). Although these materials were designed for usage in the biological filtration of pond water, the shape and structure of the Bio-balls could prove to be very effective in the application intended here.

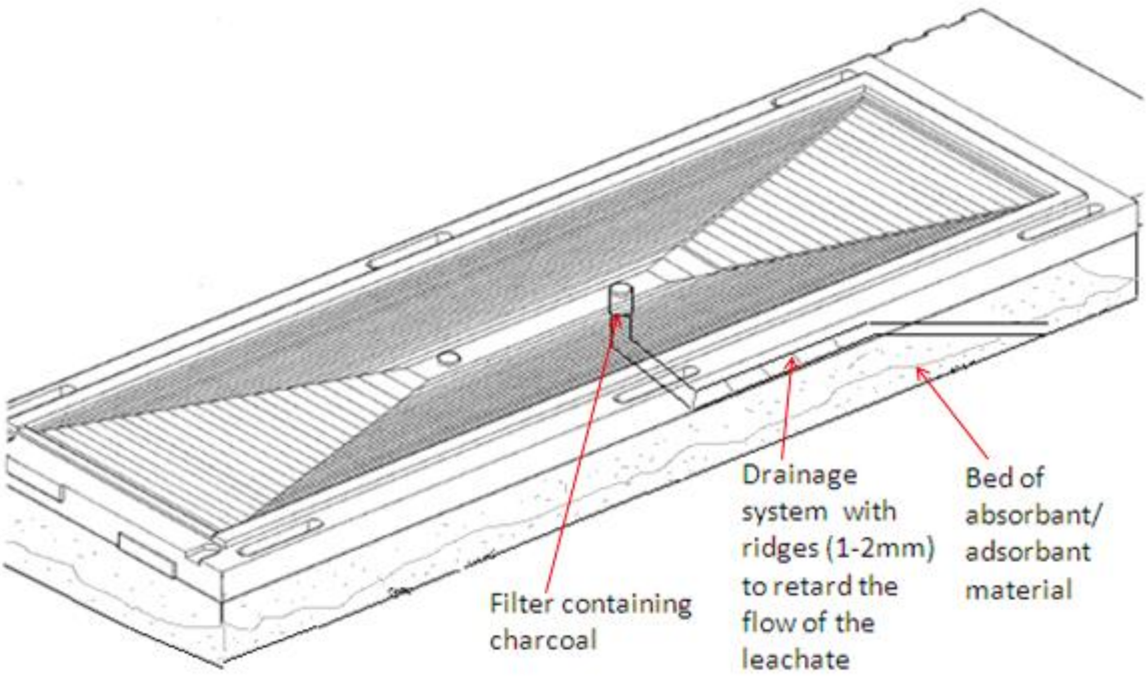

Figure 2-Initial concept of a proposed drainage system

Figure 3-Bio-balls fish tank filter media for trickle filters provide a suitable structure for colonisation by formaldehyde and tissue degrading microbes (http://www.koiandponds.com/tricklefilter.htm).

Other possible materials to be used in the construction of a filter include charcoal, sponge, sawdust, small stones or pebbles, wood chunks, biodegradable plastic spheres or organic plant material all enclosed using a wire or a suitable biodegradable alternative mesh. The aim of the filter is to retard the flow of leaching liquids without becoming blocked. The filter pore size would be in the range of 0.1mm to 2mm in diameter. From this filter a drainage pipe could be fitted possessing a succession of ridges to slow the leachate flow and allow colonisation by microorganisms. After the leachate has flowed out of the drainage basin, through the filter and down the drainage tubing an absorbent material may be used to mop up a proportion of the liquid. Any compounds/materials used to aid degradation of the formaldehyde should not negatively impact the environment and should be able to degrade at the same rate or faster than the associated corpse.

Other alternatives include small air vents in the design of the coffin which may be opened on burial to increase the airflow into the coffin. This may be activated by a weight mechanism. More oxygen equals faster and more complete decomposition. However, limited oxygen will be available between 1-2m in the sediment for aerobic degradation.

Water selective membranes could be incorporated into the design of the coffin to allow the passage of water (by osmosis) into the sump to dilute formaldehyde to tolerable levels. These thin film composite membranes (hydrophilic) are made from cellulose acetate, polyamide, nitrocellulose or nylon film (Sterlitech cooperation). Eventually the coffin will lose integrity and liquids and gases will escape from the coffin into the surrounding sediment.

Realistically any system designed to reduce the leaching of formaldehyde should be tested under controlled conditions with the relevant experimental controls before the product is finalised for release. This testing will provide quantitative analysis of the effectiveness of any product implemented within the coffin design, proving the implemented device functions as it is intended.

2. How would the degradation of formaldehyde be affected in a sealed concrete vault?

Concrete is a porous material allowing water to infiltrate the walls caused by hydrostatic pressure in the grave (burial vault patent 4128981). This barrier will slow the passage of decomposition products (including formaldehyde) from the coffin into the surrounding groundwater and sediment. The presence of water around the body will increase the overall rate of decomposition compared to the absence of water in the same conditions. The concrete vault will also prevent the indigenous microbial populations within the sediment and groundwater from coming into contact with the coffin for a prolonged period of time.

The presence of concrete barriers will slow down the degradation of the compounds that leach out of the coffin into the surrounding sediment or groundwater. This may result in a pool of hazardous by-products collecting within the vault especially if the interior of the vault is lined with metal or plastic. The decay of the coffin itself will also be retarded by less sediment (meaning less microorganisms and insects) being in contact with the coffin. Lining the vaults with impermeable material such as plastic or metal alloys will prevent the transfer of water into the grave and decomposition products out but this may pose problems in the future due to the graves persisting for hundreds of years. This will obviously contribute to graveyard over-crowding. Some concrete vaults have drainage holes in the bottom to allow the gradual release of leachate (www.forestlawnomaha.com). Concrete vaults not reinforced with steel are less secure and are known to crack open (especially the lid) under adverse conditions such as freeze-thawing and attack from tree roots. Wooden vaults are known to decompose and cave in after 3-5 years. (Nemerow and Agardy, 1998)

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