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Amalgam and Mercury in the Dental Setting and the Efficiency of Amalgam Separators

Ulla Jacobsson-Hunt DDS, DMD

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LINKÖPINGS UNIVERSITET

Linköpings universitet, Campus Norrköping, SE-601 74 Norrköping, Sweden

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Titel

Title :
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Författare
Author : Ulla Jacobsson-Hunt

Sammanfattning

Abstract : Mercury is the only metal that is in liquid form at room temperature and it has over the years been used in various combinations to extract gold, in measuring devices, medicaments, paper industry, batteries and fluorescent lights as well as in dentistry as dental amalgam. Dental amalgam is a mixture of 50 % mercury and 50% of an alloy consisting of silver, tin, copper and zink particles and has been used in dentistry for many years. The environmental effect of mercury release into the sewer from dental practices and clinics, and the inability of the wastewater treatment plants to remove it from the sludge lead to the introduction of amalgam separators in Sweden in 1980. The ISO standard 11143 regulates the efficacy of the amalgam separators, which should be at a 95% level, but is based on a laboratory test rather than a clinical evaluation.

This study looks at the available amalgam separators in use in four areas of Sweden, Uppsala, Stockholm, Östergötland and Skåne and compares their clinical efficiency. The clinical efficiency ranged between 75 to 95%, with most units below the 90% mark. In Östergötland a new improved separator is being tried, the Capere unit, which is based on finely ground pine bark treated with a chelator sensitive to all metals and used in conjunction with a cotton filter and a regular amalgam separator. This was shown to be superior to the other separators, with a 99, 9% removal of even the smallest amalgam particles and ionic mercury from the wastewater before leaving the clinic. Otherwise, combining more than one amalgam separator of the brands available on the Swedish market did not improve the efficiency of them.

Nyckelord

Keywords : Mercury and Amalgam in Dentistry, Efficiency of Amalgam Separators

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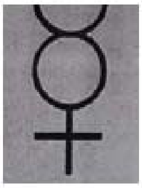

Ulla Jacobsson-Hunt DDS and DMD

University of Linköping, Department of Water & Environmental Science

Cover page

Photos taken by the author and depicts from left to right:

- ❖ The Sash from the Dental Student Union (Odontologiska Föreningen) Karolinska Institutet, Stockholm.
- ❖ The sign for mercury
- ❖ Mercury in a Petri dish

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Amalgam and Mercury in the Dental Setting and the efficiency of amalgam separators.

Introduction

Mercury is the only metal that is in liquid form at room temperature and it was known already in ancient times. There are records of the Phoenicians breaking cinnabar and enriching mercury from it at the mine at Almadén on the Iberian Peninsula around 1500 B.C. Mercury has over the years been used in various combinations, to extract gold, in measuring devises, medicaments, batteries and fluorescent lights as well as in dentistry as dental amalgam (Hylander and Meili, 2005).

Dental amalgam is a mixture of mercury with an alloy consisting of silver, tin, copper, and zinc particles and has been used in dentistry for about 150 years, although there are records of its use as a dental filling material in China as early as the 7's Century (Phillips, 1991). The toxicity of mercury has been known since long, but it was thought that it was inert when bound in set dental amalgam. It has more recently been shown that some mercury vapour is released from the fillings during mastication and excessive wear, like clenching and grinding of teeth, and end up in faeces and urine, which then make it to the waste water treatment plants and into the sludge from these plants (Hylander *et al.,* 2006).

Also, with more environmental awareness and some incidents of severe mercury poisoning, the anthropogenic sources of mercury release have been investigated more thoroughly. In Sweden the largest contributor was found to be the chlor - alkali industry, but also that dentistry was one of larger contributors of mercury to the wastewater treatment plants despite chair side amalgam traps that caught the largest amalgam particles (>0.5 mm). It was estimated that the discharge of mercury was in the region of 55 gram and above per dental chair and year before the introduction of amalgam separators (DS 1992:95).

Sweden, as the first country in the world, introduced special amalgam separating units in 1980 after the Swedish EPA set a limit to mercury discharge per dental unit, chair, at 5 gram/year. The efficacy of these units is set at 95% removal in a laboratory setting (ISO 11143 standard), but in the clinical setting they are less effective, about 60% and up. As more countries are mandating more stringent rules as to discharge and disposure of mercury and other heavy metals, amalgam separators have more recently been introduced in several European countries as well as in Canada and some states in the US. Even so, there is plenty of amalgam and mercury in the old effluent waterlines from the older practices and clinics. Especially, where there are copper and cast iron pipes with more irregularities on the inner surface walls to which the particles are prone to adhere to. All dental clinics or practices in Sweden that stop their activities are legally bound to have the waste water lines replaced or cleaned out before leaving the premises (SFS 1998:980).

Many dentists have stopped using amalgam altogether, but many patients still have amalgam fillings in their mouths, 74% of adult Swedes have at least one such filling in their mouth (SOU, 2003:53). It is estimated that 1300 - 2200 tons of mercury is present in the dental fillings of the population within the EU (15 states) and the EFTA member states (Hylander, 2002; EU, 2004), and as more states are joining the EU and their standard of living improves less extractions and more amalgam fillings will be placed. If one is to replace the present number of fillings there will still be plenty of mercury and metals to recover, but in smaller particles since better amalgam is being used as well as more efficient equipment, including burs (drills). These particles are nano size or in an ionic phase that the filters and separators cannot absorb and are most likely leave with the effluent wastewater or adhere to the bacteria and/or irregularities in the lines.

A new separating medium, Capere, has been developed and introduced in Sweden by Tekniska Verken in Linköping. It is based on finely shredded chips of pine tree bark, about 5 mm in size, coated with a chelating agent, selective to heavy metal ions. It is porous and lets the water pass through without absorbing it (Berggren, 2004; 2005).

Aim

The aim of this thesis is to evaluate what happens to the mercury used in the dental setting and to compare how efficient the amalgam separating units are when used clinically. The standard that has been set forward nationally and internationally as to amalgam separators is the ISO 11143 standard, and it is only based on a laboratory testing protocol of these units. Data has been collected from dental clinics in four different regions of Sweden. It has been evaluated and compared to see if there are any differences in between the regions as to the efficacy of the amalgam separators both as to brands and handling.
The new Capere unit, as an "add on" to the regular amalgam separator, will also be evaluated and compared to the function of the regular amalgam separators alone.

Background – the use of mercury over the centuries

Mercury is number 80 on the periodic table, but it is not a very abundant element in the earth's crust; it ranks 74:th out of a total of 90. It was known by the Egyptians who used it for its red colour, vermillion (crushed cinnabar) in paintings and cosmetics. They were also spellbound by the silvery liquid and kept it in bowls to look at. They were also familiar with the process of heating the crushed cinnabar (Hg S) and reducing it with charcoal to get the "pure" liquid mercury, although it was kept as a state secret. Later the Greeks and Romans used it to extract gold, silver and other noble metals from the metal ore (Nationalencyklopedin, 2000). During the Spanish colonization of South America 1570-1900 some 30000 tons of mercury were used in order to extract silver out of the ore, since 1 g of mercury was needed to get 1 g of pure silver and the mercury was disposed of in the rivers and the sea, when used up. The Spaniards shipped over cinnabar from the mine at Almadén and took back silver and gold on their ships (Järnelöv, 2004). Mercury is still widely used in some poorer parts of the world for local gold and silver extraction (Maxson, 2004; UNIDO-Global Mercury Project, 2006).

The alchemists thought mercury was part of every metal and gave it the name Mercurium, after the planet Mercury. The original Latin name was *argentum vivum,* vivid silver, due to the silvery appearance of the liquid metal. Cinnabar, Hg S, is the principle mercury containing ore in the world, and was mined in places like Algeria, Spain, Italy, Kyrgyzstan, Slovenia, Russian Federation, USA, Mexico and Turkey. Some of these mines were already known in the Antiques, like the ones in Spain and Italy. The Etruscans broke cinnabar at Monte Amiata in Tuscany, and it is known that the worst punishment a Roman slave could be condemned to, was to be sent to Almadén in Spain to mine cinnabar. Eventually, they all died due to mercury poisoning from the fumes and contact with the mineral in the mines (Nationalencyklopedin, 2000; Nriagu, 1979; Schroeder and Munthe, 1998).

Fig 1. Picture of the Almaden Mercury Mine in Spain, taken by the author.

Mercury has over the centuries been used in the medical field as an antibacterial and antiseptic agent, as well as in medicaments for constipation and other ailments. Syphilis came to Europe with the Spanish sailors from South and Middle America in the 1700's and became the "plague" in Europe. It was not until penicillin was introduced that doctors gave up on treating venereal diseases (syphilis in particular) with mercurial preparations like Salvarsan etc. The effectiveness of these mercurial preparations was at best, questionable. Did the patient die of the disease or the consequences of the medication? Due to the unique chemical and physical properties of mercury, it has been used in all types of measuring devices like thermometers, barometers, manometers, vacuum pumps and pressure measuring gauges and control equipment. It has been and is still used in certain light switches, batteries, and mercury lamps as well as HID, fluorescent and neon lights.

For a long time it was also used in the making of mirrors, paints and cosmetics (Vermillion or rouge, is the red pigment, cinnabar), as well as in the felt and wool industry as an antibacterial and gluing agent of the animal hairs before the product became hats and blankets (Lohm *et al*., 1997; Jonsson, 2000). Hence, the old English expression "mad as a hatter"(see e.g. Alice in Wonderland by Lewis Carroll), since hat makers became poisoned by the mercury salts that entered into the body through the skin as well as they inhaled the mercury fumes while making the hats in cramped and poorly ventilated backroom facilities of tiny shops in large cities like London. The toxicity of mercury has since long been known, but acute mercury poisoning is rare. Who would ingest or drink pure mercury? Well, some gold miners in third world countries do to prove that mercury is not a poison (Hylander, personal communication, 2006). Anyhow, inhaling the fumes is most damaging since the mercury ions in the vapour gets into the bloodstream and reaches the brain very quickly. Mercury can penetrate the blood-brain barrier as well as the placental barrier in women. The early consequences can be vomiting, diarrhoea, kidney damage, acute inflammation of the oral and throat mucosa. If the exposure continues it will lead to permanent brain damage and the person would most likely succumb to pneumonia in combination with pulmonary oedema and chock, or due to the brain damage of some fatal accident (Berlin, 1986; Eggleston and Nylander, 1987). If used on the skin, contact allergy is a given early result and with long-term use, it will also lead to brain damage, since it penetrates the skin and goes into the blood vessels (Counter and Buchanan, 2004).

The sub acute and the chronic forms of mercury poisoning are more common among cinnabar mine workers and others that have been exposed to the vapour over time or have had it in medications. Symptoms are central nervous system (CNS) disturbances, like anxiety, irritability, restlessness, which as the exposure progresses causes loss of memory, shakes, tremors and eventually death, as mentioned above. This was common during the gold rush in Alaska and western Canada in the late 19th Century, the Minamata disaster in Japan in the 1950's and the Iraqi mercury-bated seed scandal in the early1970's. The Iraqis made bread out of the seed grains instead of putting them in the soil, and the bread became pink or red. The children liked the different looking bread and ate it happily until they became sick and died. Even today, mercury poisoning is happening in the Amazonas, Brazil, the Philippines, Indonesia and certain areas of Africa, where they are extracting gold by "panning" or small-scale mining. These miners (10 to 15 million of them) release some 800 to 1000 tonnes of mercury/year into the environment (Nriagu and Wong, 1997; Jernelöv, 2004; Myers *et al.*, 2000; Mc Neill, 2001; Hylander, 2006; National Institute for Minamata Disease http://www.nimd.go.jp/english/index.html; UNIDO, 2006).

In the early 1960's there was a massive death and failure of reproduction among wild birds in Scandinavia. It was then linked to the mercury-bated seeds that were used by the farmers on the fields. The mercury was added in order to prevent fungal attacks to the seeds and was a standard procedure at the time (see the Iraqi disaster above) The Swedish stock of eagles and other wild birds is now starting to recover. This led to that Sweden and Finland started to look into the toxicity of mercury compounds and their environmental influence not only on the birds, but also the effect the chlor-alkali industry had on the environment. These industries released some 30 metric tons of mercury per year into the air and water in the 1950's and 1960's before being decommissioned or other chemicals were used in the procedure, and the release in the year 2000 was down to 0.1 ton (Westermark *et al*, 1975; Solonen and Lodenius, 1984; Notter, 1993; Statistics Sweden, 2005; Wihlborg, 2006). The Swedish mining company Boliden also is a large producer of mercury as a by-product in their precious metal production.

Recently the United Nations Environmental Program, UNEP, and the European Union, EU, have started to look into the use, exposure and emissions of mercury worldwide and within the European Union. The EU have decided on an export ban, as well as a reduction in use by prohibiting products that contain mercury and they are looking for a safe storage of the decommissioned mercury before the year 2011 (http://www.europa.eu.int/comm/environment/chemicals/mercury/pdf/report.pdf; http://www.chem.unep.ch/mercury/mandate,2003; EU-IP/05/114, 2005; SEC, 2005/101; Eckley Selin, 2005; Hylander and Meili, 2005).

The EU is now specially concerned with the amount of methyl mercury (CH3-Hg-CH3) in fish, both in the Mediterranean Sea and European lakes. In 1967, the Swedish Medical Board (now renamed the Social Welfare Board) prohibited the sale of fish from certain lakes and rivers, due to the high levels of methyl mercury they contained. People who were fishing for their own use in these waters were also advised not to eat that fish too often. Much of the mercury that settles in the forests and waterways comes with the winds as vapour from coal burning power plants on the continent, brown coal is very rich in mercury, and crematories in many countries surrounding the Baltic Sea, as well as Britain (the people in Great Britain has a lot of amalgam in their teeth, thanks to the National Health Service). But the largest contributor of mercury vapour and liquid mercury was still the Swedish paper industry and the chlor-alkali process, and as late as in 2003, Sweden was still using 400 metric tons of Hg (Maxon, 2004).

Mercury has a high affinity to combine with organic matter in the soil and forests, which will find its way after rains and runoffs in the rivers and lakes. Micro- organisms, normally occurring in the water methylate the mercury to methyl mercury. It is then incorporated into the water system or the bottom sediment and accumulates in living organisms in the water and ends up in the fish, since it is soluble in the fatty tissues in animals and bio accumulates (Hintelman *et al*, 1995). The situation in Sweden has improved since the 1960-1970's, but there are still restrictions as to how much fish one should consume and pregnant women ought still not have any to be on the safe side, since the developing nervous system and brain of the foetus is particularly sensitive to mercury in any form.

Dental use

In metallurgic terms, an amalgam is an alloy of any metal with mercury. In dentistry the word amalgam, or dental amalgam, is used to describe the material obtained by mixing an alloy, which today consists of about 70% silver, 20-30% copper and some tin as well as zinc with mercury (ISO 24234:2004). In the old days it used to be just silver in the alloy, and in the 19's Century the patient was asked to bring their own silver coin to the dentist so that he could make it into filings to be mixed with the mercury for the filling. The mercury content is about 50% in modern amalgams used in dentistry (Frykholm, 1957; Phillips, 1991; Mc Donald and Avery, 1987; Wei, 1991; Lohm *et al.*, 1997; Sviden, 2002).

In China there are records of the use of amalgam for dental restorations from the 7's Century. In Europe and the USA amalgam has been used to restore carious lesions in teeth for over 150 years and worldwide it is still the most commonly used material, comprising approximately 60% of all restorations. This, despite the rapid development of alternative materials, as composites, glass ionomers or hybrids there of (Phillips, 1991; Wei, 1991).

The clinical success of amalgam as a filling material in dentistry is due to many factors, but in particular to the ease with which it can be placed into the tooth even under adverse conditions (presence of some moisture), and the germicidal (anti bacterial) properties of the metallic ions that constitutes the material. (Frykholm, 1957; Phillips, 1991; Mc Donald and Avery, 1987; Wei, 1991). Also, the microleakage around the margins tends to decrease with age of the filling, due to corrosion products that form and lead to a seal in the interface between the tooth and the filling. The more modern composite materials are more moisture sensitive and marginal leakage increases with time, as well as they are less wear resistant than amalgam (Phillips, 1991). Professor G. V. Black of Northwestern University in Chicago, USA, was a dentist who in the mid-late 19's Century popularized amalgam by improving the amalgam alloy and coming up with the cavity designs which were most favourable to retain the filling in the tooth following caries removal. These are still taught today in most dental schools around the world with minor modifications. Since amalgam restorations require removal of a lot of sound tooth structure to get the right depth, width, retention and resistance form, there have been many attempts to develop other materials that would not need such a substantial removal of tooth structure and without damaging the nerve in the tooth (Baum *et al.*, 1985).

The amount of mercury used in dentistry in Europe, the year 2000, was 70 metric tons and worldwide it was 272 metric tons, where the American dentists, alone, were responsible for 51 tons. The worldwide demand for mercury in dentistry is still predicted to be 250 metric tons by the year 2020 (Maxson, 2005), as more people worldwide get access to dentistry. The only way the worldwide use of amalgam would decrease further, apart from using more composite resins, is if the ART, Alternative (formerly called Atraumatic) Restorative Treatment, gains more popularity. This was developed as an alternative when "traditional" restorative techniques could not be performed. Either the patient is young and uncooperative, or like in many third world countries where you have situations with no access to ordinary dental equipment. The technique is based on that one uses hand instruments to remove the caries in the tooth and then fill it with glassionomer cement, which contains fluoride (Frencken *et al*., 1994; WHO, 1994; AAPD, 2003). This is, though, taking the dental establishment and dental education to task as the old established principles, as per Dr. Black, for cavity design and "extension for prevention" will have to be totally revised. What will come instead, one may ask, but gold and porcelain fillings still require same cavity design, while with composites one can modify this somewhat. The problem with gold and porcelain fillings is mainly the price, while the problems with composites, compomers and related filling materials are that they are not as durable, more expensive, more equipment requiring, as well as more "operator sensitive" than amalgam.

The pros and cons of the use of dental amalgam is not only a scientific question, but also an emotional one for many people, both among lay people as well as dentists and other scientists.

The alternatives to amalgam are a matter of patient cost and convenience as mentioned above. If you look at the environmental cost, the figure is different and not so favourable, it runs well into the $ 1.00.000 level to exchange fillings and dispose of the mercury safely (Hylander and Goodsite, 2005).

The Environmental Administration Office in the City of Linköping did an inventory of the dental practices in that city in the autumn of 2005 and spring of 2006 and found that 32% of the dentists are still using amalgam to some extent (1-20 fillings/year), while 68% never use it. The majority of those that use it, were all in private practice (Nilzén, 2006).

Removal of old well functioning amalgam fillings can be detrimental both to the tooth and the environment, unless it is called for, for other reasons like mercury sensitivity (Langworth *et al.*, 2002).Certain people are more sensitive to metals than others and are unable to tolerate having amalgam fillings in their mouths, and the term "DAMS", dental amalgam mercury syndrome has recently been coined in Canada and the United States although their Dental Associations have for the longest been negating there is a problem with amalgam fillings and many still do. It has been considered an entirely endemic Scandinavian population. According to a review study done by Life Sciences Research Office of the NIH (National Institutes of Health, USA) there is little scientific evidence to link amalgam fillings or mercury vapour from these to health problems in humans (http://www.lsro.org/amalgam/content_amalgam_distributed.htm), although some Swedish researchers would claim otherwise (Nylander *et al.*, 1987; Eggleston and Nylander, 1987; Berlin, 2002; Nylander, 2004; http://www.amalgam.se; http://www.amalgamskadefonden.se).

One can remove the fillings in these patients under very strict and careful ventilation and evacuation and replace them with composites or porcelain inlays or crowns, but it does not cure all and everyone. Some patients end up even becoming sicker initially as a result, especially if they inhale the dust and it gets into the bloodstream (http://www.kunnskapscentret.no). The composites can also very well lead to other allergic reactions in these very sensitive patients, since they all contain some amount of acrylic acid, which has been known as a potent allergen since the 1950's (Hensten-Pettersen, 1998). Many patients have become sensitized and have complained of a burning sensation in the mouth or surrounding tissues, the so called burning mouth syndrome, as well as redness in the mucosa of the mouth and/or blisters when they have been fitted with dentures made of acrylic (Phillips, 1991). Also many dentists have had their career terminated by the contact allergies that they have developed by being in contact with the acrylic acid. The use of latex gloves does not protect the fingers and hands as one might think, the acrylic acid tend to react with the gloves and make them dissolve slowly and the contact between the acrylic and the skin can be aggravated by unintentional prolonged and close exposure to these materials inside the gloves (Ekstrand *et al.*, 1998; Karlsson and Hensten, 2004). Also these composites are not as durable as amalgam fillings, 3 to 5 years versus 10+ years (KemI, 2004). This poses a problem for many patients economically in the long run, as well as when they are removed they are ground to a very fine powder that cannot be trapped by any filters and goes out with the effluent water or stays in the lines so that bacteria can grow on these deposits.

In dental school I was taught how to mix amalgam and that was by hand. One dispensed certain amounts of the metal alloy and mercury into a mortar and used a pestle to mix the two together to an even mix. The alloy was cut from an ingot (lathe cut alloy) and had with today's standard very large irregular shaped particles of silver, copper and tin. Then you used a squeeze cloth of cotton to express the excess mercury before the amalgam was inserted into the tooth, packed and condensed in small increments at the time, to ensure all parts of the cavity would get filled and more of the excess mercury could rise to the surface and be removed before the next lot was added. The cavity had to be slightly overfilled, then it was carved back to follow the natural anatomy of the tooth and finally the restoration was burnished to improve and seal the margins between the amalgam and the enamel and to give the amalgam a smooth shiny surface more resistant to corrosion (Frykholm, 1957; Phillips, 1991; Berry *et al*, 1998). Later the fillings were polished, which made more mercury come to the surface and vaporise into the environment, but it made them smoother.

The people most at risk for the mercury vapour and the direct contact with the mercury rich mixture has always been the dentist and the dental assistant. This was already reported as a hazard in the literature as early as the beginning of the 20's Century, when the amalgam was squeezed with bare fingers and the excess mercury often ended up on the floor or in the cracks between the floorboards where it laid and slowly evaporated. Better mercury hygiene, ventilation and floor coverings made chronic mercury poisoning of the dental personnel rare from the 1920's onwards. With the introduction of fitted carpets in dental offices for soundproofing in the 1960's, when the water-cooled high-speed turbine drills were introduced, which emit a high pitch noise, there was a rise in mercury poisoning again, since accidentally spilled mercury disappeared into the carpets. The dental personnel were not informed or knowledgeable about the hazards of mercury and mercury vapour in most instances, since it had been so long since it had been an issue (Frykholm, 1957; Phillips, 1991; Langworth *et al.,* 1997).

More hygienic handling of the material and less waste came with the introduction of mechanical mixers "amalgamators". ”Dentamat” was one of the first, introduced in the late 1960's; it dispensed a preset amount of mercury and alloy from refillable closed containers within the unit corresponding to size of the filling and mixed it. This meant use of squeeze cloths to get excess mercury out of the mixture was largely eliminated, but the problem here was that one could easily spill material when refilling the containers. Later came the sealed preweighted capsules with separate compartments for the metal alloy and the mercury, which meant an even better and safer handling of the material. Upon activation the components came into contact with each other and was mixed (triturated) to the right consistency in an "amalgamator" that shook the capsule. Since mercury vapour was released into the air during the trituration, the amalgamators now have lids, but some vapour will still escape when the lid and the capsule are opened (Phillips, 1991; Wei, 1991).

With the capsules came also improvements in the metal alloy used in the amalgam mixture, as mentioned earlier, with the addition of copper and zink to the silver to give it better properties (more plastic, less creep, ditching and corrosion). The modern alloys can be lathe cut, spherical or admixed (which is a blend of the traditional alloy and an Ag-Cu eutection), and what they have in common is a much smaller particle size than earlier alloys, which means they require a smaller amount of mercury in the amalgamation (Phillips, 1991). Then the mixture is inserted into the tooth, still in increments, condensed and carved to the proper shape and form and finally burnished. The excess amalgam is eliminated with high-speed suction into the dental unit and hopefully also the mercury vapour that is released during condensation. In the dental unit there is a trap or screen filter that collects the larger particles (> 0.5 mm), there maybe also a bottle that collects the solid waste by sedimentation, before the wastewater is further treated or discharged into the sewer. The same goes for the amalgam particles that are formed when you remove an old filling (Berglund and Diercks, 2002; SRAB, 2004)).

<u>Amalgam waste treatment</u>

Sweden is the only country that today has a law that mandates that the larger crematories (over 200 cremations/year) have to have a special filter that traps the mercury (Åkesson, 2004). Still, it is estimated that 100 – 200 kg of mercury from dental amalgam fillings in deceased people escapes into the air during cremation every year in Sweden due to inefficient or lack of traps (Åkesson, 2004). In Denmark where no filters are in place, it is estimated that even larger amounts of mercury are emitted into the air from the crematories every year. Due to the prevailing winds a large amount of that comes in over Southern Sweden and is an additional source of pollution of forests, rivers and lakes in the area (Munthe *et al*, 2001; KemI, 2004). The EU parliament as late as March this year wanted to get some strategy on how to handle and possibly limit the use of dental amalgam, and decrease the emissions of mercury from the crematories in the whole of EU as soon as possible, but nothing has been agreed upon as of yet and it now seems it is postponed to 2007 (Andersson, trainee at EU environmental committee, personal communication).

In Sweden as well as in most countries around the world, the wastewater from the dental units and offices was for many years discharged into the sewer without much thought to the effect it would have on the environment. But in 1979, the Swedish Environmental Protection Agency, recommended a yearly limit of mercury discharge per dental unit at 5 gram (SEPA, 1979). Out of this, came an agreement in 1980 between the Swedish EPA, the Swedish Dental Association, the Swedish Dental Trade Association and the Federation of Swedish County Councils to have some kind of amalgam-separating unit that collects the solid particles, attached to the dental unit before the wastewater enters the main drain. They can work by centrifugation, filtration or sedimentation of the waste, although some newer models that have been introduced in the last couple of years have an ion exchange as an additional feature. It has never become law, but the Swedish EPA and the local environmental agencies have, since 1985, not allowed anyone to open a new dental office without having an amalgam-separating unit attached to the dental unit's effluent water before it gets to main waste water outlet.

Older established dental practices have either followed the recommendations as the older dentists retired and sold out to younger colleagues, or not bothered to install amalgam-separating units since there is no law (pers. experience). Most dentists in Sweden today do not question the "mandate" to have an amalgam-separating unit in their private practice. Although, most premises where dentistry is performed in the larger cities, like Stockholm, are rented (pers. experience). There, the property owner is the one responsible for the pipes that leaves the dental practices and there is still a lot of mercury and amalgam in many of these old pipes. Those working in the Public Dental Health Clinics do not have to worry about them, since the area or regional dental administration takes care of the separating units and the pipes. At the same time as the amalgam-separators came into use, waste amalgam and mercury containing waste material also became classified as environmental hazardous waste, which needs special handling and collection (Swedish EPA, 1979) and according to the Swedish law, SFS 1998:899, any clinic, practice or industry that closes down and has had anything to do with mercury in the past, the effluent pipes have to be checked and cleansed of mercury and amalgam remnants.

This can be a costly procedure as was seen when a Dental Public Health Clinic closed in Norrköping in 2004 after 50 years of use. The pipes were cleansed and 737 kg of amalgam was recovered, which means 368,5 kg of mercury was in the pipes (FTV-Östergötland statistics, 2005). Until 1976 the clinic was located on the 2:nd floor, had 9 dental units and a laboratory that used a lot of amalgam, and no amalgam separators. Then the clinic was enlarged and on the 2:nd floor to14 dental units. The dental laboratory was moved to the 5:th floor and on the 5:th and 6:th floor 25 units were installed for generalists, specialists and hygienists. Due to the lay out of the clinic the configuration of the effluent water lines had to be put in a drop ceiling with sharp bends, which made the retention of amalgam higher than normal in the lines despite amalgam separators that were installed during the remodelling (S. Paulsson, personal communication).

In the analysis of what was recovered yearly from 1997 through 2004 the average was 15 kg amalgam, which gives 7,5 kg mercury per year. If the recovery efficiency of the amalgam separator was 80 %, the amount of mercury left in the pipes was about 105 kg from 1976 – 2004, which leaves another 263,5 kg of mercury prior to the instalment of amalgam separators (FTV- Östergötland, 2005).

In Stockholm from 1998 through 2004, 180 kg of mercury was recovered from 385 different private, public and school dental clinics. An additional 100 kg of mercury was recovered from other industries, many related to dentistry as producers of the components of amalgam or refiners that were trying to clean their premises of old mercury (Wystrand, Stockholm Water

AB, personal communication, 2006). Also in the central area of Stockholm, which has some very old dental practices (>90 years old), it has been a drive to replace old sewers that are clogged with amalgam and mercury in the last ten years. Still in 1999, 40% of the mercury in the sewer system at Henriksdal water treatment plant came from the amalgam fillings that people in Stockholm had gotten, or had had replaced, despite the amalgam separators (Sörme and Lagerkvist, 2000; Sörme, 2003; Johansson, 2002; http://www.miljö.stockholm.se, 2005).

The use of separating units at the wash up areas for dental instruments that have been in contact with amalgam, prior to sterilization, was overlooked for a long time as an additional source of mercury release into the drains, but a campaign lead by the Stockholm Water Department in the late 1990´s have changed that not only in Stockholm but also in most of Sweden (Johansson, 2000) and is now included in the law (SFS 1998:899**).**

The efficiency of mercury removal from the effluent after the separator was set at 95% for the earlier models. The newer models "claim" to have up to 99% efficiency according to the ISO protocol 11143. The centrifuge systems all appear to have more troubles with the separation and need more maintenance, than the particle separators (Johansson, 2000 and Sweden Recycling, protocol, 2004). The separators are collected by Sweden Recycling or Stena Miljö at least once a year, where they are disinfected, sealed and sent to Germany, where the mercury is retrieved and then sent to SAKAB (Swedish Waste Recycling/Conversion Co, now owned by ***e***-on), in Kvarntorp, Sweden, for temporary storage until a more permanent plan for mercury storage is decided by the EU. A possible site for most of the EU mercury is the Spanish state mine, MAYASA, in Almadén, which has stopped its production of mercury until further notice (Hylander and Meili, 2005). The Swedish solution, that the government has decided on, is to store it in sealed containers or to convert it into a stable mercury compound by using sulphur or selenium before encapsulate it in bentonite and depositing it in the same deep bedrock storage that is proposed for the nuclear waste close to the Forsmark or Oskarshamn nuclear power plants (SOU 2001:58).

The Swedish Environmental Code (SFS 1998:808) is the law that regulates environmentally hazardous materials. It went into effect 1998 and it is based on recommendations from Chemical Inspection Agency (KemI PM 4:1996). It includes updated and very clear instructions as to the handling of mercury and mercury containing products, even extracted teeth with amalgam fillings are now included in this group. The high-speed suction tubing has to be disinfected and cleansed of amalgam remnants, by flushing it with disinfectants, at regular intervals, preferably daily. The problem being that growth of bacteria in the suction tube and lines of the dental unit will cause smaller amalgam particles not to fall into the traps but to be floating in the midst of the wastewater whirl and get washed out with the water, or to adhere to other deposits on the tube walls, depending on the diameter and construction of the tube. They can then release some of the mercury from the particles if there are enough bacteria in the tubes and if they are left there for long enough, either as ionic Hg or as methyl mercury (Letzel *et al*, 1997; SOU 2003:53; SRAB, 2004). Certain disinfectants are less suitable for cleansing of the suction tubes and lines than others. Regular water supplies are not totally avoid of bacteria and will combine with the content of the effluent from the dental units. A way to minimize the use of these disinfectants, which all have an environmental impact, and to prevent bacterial build-up, is to clean and disinfect the water before it enter the dental unit by reverse osmosis, RO, (Berggren and Andersson, personal communication).

In between 1950 and the late 1970's Swedish dentists used on the average 2 000 kg mercury/year, where 25% went into the teeth, 37% ended up in the sewers, 33% was recycled and 5% ended up in the dry waste (Halldin and Pettersson, 1978). That meant each dentist used up about 2 kg of mercury a year, although the dental technicians used a lot in model making, too. By 1990 the use had decreased to 1700 kg and around 2.1 million amalgam fillings were placed in children and adults in the whole of Sweden (Social Dep-DS 1992:95). In 2003 this figure was down to 105 kg of mercury, but in the mouths of 74% of the adult Swedish citizens there are at least one or more amalgam fillings still present (KemI, 2004).

Most European dentists have largely stopped doing amalgam fillings by now, but there is no law forbidding the use of amalgam. Not even in Sweden. Although, the Swedish Chemical Inspection Agency has proposed a ban from 2008 (KemI, 2004) it has not been approved by the Swedish Dental Association or the Swedish Government as of yet, and 2012 has been set as a new date (SAKAB and SRAB personal communication, 2006). The EU decided on a ban of the use of mercury products in 2005, but with the REACH agreement that finally could be agreed on by the EU-member states in 2005, mercury got a low priority and the ban has not been reinforced yet, and in places like the British Isles plenty of amalgam fillings are still being placed (EU-IP/05/114, 2005). The EU Dental Liaison Committee, which consists of representatives from the Dental Associations within the EU, is to a large extent negative to prohibit amalgam (Doneus, 2006; Svensson, 2006).

The most disturbing development within the EU is that they have recently allowed copper amalgam to be used again as a “medical device”. Copper amalgam was used from the 1930’s through the late 1950’s in Sweden as a preventive filling in the grooves of the first permanent molars in children. It was supposed to have “bactericidal effect”, but it stained the teeth black and was not “bactericidal” and/or stopped further decay in these teeth as first thought when records from the school dental service were examined. Therefore it was banned in Sweden in the late 1950’s and forbidden by law in 1985 (SFS 1985:841; SOFS 1987:25). In preparation for the EU decision the Swedish law was revoked in 2005 (SOFS 2005:2). In other Scandinavian Countries, like Norway, it was used until the 1980’s, where many, over 65%, of the dental assistants today demonstrate symptoms of mercury poisoning, with CNS disturbances and many of their children were born with brain damage or other handicaps that today are known to be due to mercury poisoning in-utero (“Uppdrag granskning”, Swedish Television, March 2006). The technique for mixing the material is different from “ordinary dental amalgam” because you heated up premixed pellets containing 55-70% mercury, 25-40% copper and 5% silver, until the mercury started to “creep” on the surface and then you mixed it in a mortar with a pestle before inserting into the tooth. If there were some left over you could reheat it and use it again, or keep kneading in the palm of your hand to keep it warm and plastic, which many dental assistants did. So, the mercury fumes were abundant and the kneading led to mercury entering through the skin and into the blood vessels, reaching the CNS quickly. The same has happened to many dental auxiliaries in New Zeeland, who were specifically trained to do fillings for the school children, due to the lack of trained dentists, and the main material they used was copper amalgam (“Uppdrag granskning”, Swedish Television, 2006).

Amalgam Separators

The amalgam separators are placed in connection to the suction system, which is a vacuum system and can be of a wet or dry type, with either separation of the particles by centrifugation or sedimentation. The most common are the wet systems, where the air and water slurry is vacuumed away from the dental chair to a tank, which separates the air from the liquid. The larger particles are first caught in a filter and the smaller are allowed "to settle", by sedimentation, in the amalgam-separating tank before the liquid is going out with the wastewater. The dry systems of amalgam separators are directly attached to the dental unit and have a secrete separator. They are often relying on centrifugation to eliminate the particles, which means they require more maintenance, as well, as it makes them a lot more sensitive to clogging and problems with the filters (Johansson, 2002; SRAB, 2004).

Sweden was the first country to introduce amalgam separators in dental practices, but by now other European countries like Austria, Denmark, Finland, France, Germany, the Netherlands, Norway and Switzerland have followed suite (Hylander *et al*., 2006). In Britain the issue is being discussed, but no decision has been made. The British Dental Association is not keen to recommend them and it is up to the individual dentist if they want to invest in an amalgam separator, but no mandate exists on a local or national level (R. Hunt, personal communication, 2006).

The efficacy of these amalgam-separating units has been set at 95%, but this is in a laboratory setting (ISO - standard 11143). Clinically, the efficacy has shown to be anywhere from 60% to 99,4 % (Arenholt-Bindslev and Larsen, 1994; Hylander *et al*, in press). The Germans have introduced a 95% level in their amalgam separating units but with a separating code for the different size of particles, while the Danes more recently have introduced a clinical norm, which limits the amount of mercury in the effluent to 1-2 mg Hg/chair /day. The Council of European Communities directive (84/156/EEC) was supposed to have set the limit of mercury release into the sewage from dental clinics, but the figures are not coming until 2008 (Hylander, personal communication, 2007). The ISO directive of 95% efficacy translates to 1, 1-2, 3 mg Hg /chair/day as the maximum limit in effluent from dental practices (Adegbembo *et al*, 2002, Sweden Recycling AB, 2004). The problem with the ISO directive is that it has largely not been changed since it was introduced in the 1980's. Last revision was in 1999. Meanwhile the removal of amalgam now produce much finer particles that easier pass through the separators without getting caught and goes out with the waste water, so the absolute amount of mercury/amalgam is harder to estimate and catch.

Table 1. Amalgam separators available in Sweden and looked at in the study.

Amalgam Separators	**Manufacturer/Distributors**
Sedimentation/Filtration	
SRAB 95*	Sweden Recycling AB
SRAB 99 wet/dry	Sweden Recycling AB
SRAB 99B wet/dry	Sweden Recycling AB
Rash 890 wet/dry	Rash Dental ApS, Denmark (for Sie Dental AB, Sweden)
Mercury Master wet/dry	Stena Miljö AB
Stena Scanfors*	Stena Miljö AB
Capere Dental wet	Tekniska Verken, Linköping
Centrifuge Separators	
Siemens dry	Sie Dental AB, Sweden
Sirona dry	Sie Dental AB, Sweden
Final wet/dry	Sie Dental AB, Sweden
Dürr dry	Dürr Sweden AB
Metasys dry	Metasys AG, Austria

***discontinued older models**

In Sweden there has been a new improvement in amalgam separators and it is called Capere Dental (Tekniska Verken, Linköping). This is a way of getting to the very fine amalgam particles and the ionic mercury and other metals in the effluent after the particle separator and before it goes into the sewer. This unit consists of finely shredded pine tree bark (5-7 mm pieces) with a coating of a chelator, that is sensitive to ionized metals, but not to calcium or magnesium ions. The effluent which has passed the amalgam separator is then going through a cotton filter, with a mesh size 5-10 micron, before it is finally reaches the bottom of the circular bark container and is pushed upwards through the bark like in a coffee percolator. The cotton filter and the bark catches the minute particles and the metal ions and together they end up cleaning the effluent of 95-99% of not just the mercury, but also the silver, zinc, copper and tin from the amalgam as well as other metals when crowns, bridges and other prosthetic dental work are replaced. The first large-scale working unit of this kind was installed in a clinic in Norrköping in 2004, after a trial run at a smaller clinic in Linköping, where it was shown to be very effective. Since the results have been very promising, other units have been installed in a few more clinics in the region and more installations are on the way (Berggren, 2004, 2005 and 2006; FTV-Östergötland, 2006).

Fig.2 Capere Dental Separating Unit, cotton filter to the right, bark container on the left, photo by the author.

In 1995, the Swedish dentists were using amalgam in less than 15% of the teeth they restored in adults, while dentists in the US were still using amalgam in 76% of the cases. Amalgam fillings were in principle outlawed for children in Sweden that same year (Governmental decision, S95/2214/S), while in the US 73% of the fillings done in primary teeth (baby teeth) were amalgam. As late as 1999, 71 million amalgam fillings were placed by US dentists (Berry *et al*, 1998; http://www.lsro.org/, 2004), and there has been an estimate that the US dentists release 231-251 mg Hg per dentist and operating day (Berglund and Diercks, 2001) or a total of 51 tons of mercury per year into the wastewater.

In the US there have been some preliminary laboratory studies at West Virginia Dental School on how to separate mercury from the dental wastewater by micro filtration. The results were good in the laboratory setting. A 97-98% removal rate was achieved and the mercury concentration was down to less or equal to 10 µgram/l (Reed *et al*., 2002), but it has not been introduced clinically due to the cost and complexity of the equipment (Ngan, personal communication). Other systems have been tried and are in use in Minnesota (Berglund and Diercks, 2001) and a laboratory evaluation of the available amalgam separators on the USA market was first published in the Journal of the American Dental Association, JADA, in 2002, and then a more comprehensive study as well as an assessment of the practical issues regarding the amalgam separators was published in the same journal in 2003 (Fan *et al.*, 2002; Mc Manus and Fan, 2003).

USA and Canada have looked into the amalgam question, but the Dental Associations in both countries have been reluctant to ask for a ban on amalgam, although Canada has started to require amalgam separators through a "MOU" (memorandum of understanding). The American Dental Association, ADA, has to date not wanted to take a stand on this issue and is only recommending "Best Management Practices"(BMP) for amalgam waste, but no limits, laws or regulations as to the use of amalgam or amalgam separators have been proposed (http://ww.ada.org/goto/amalgambmp). They are warning about the effect amalgam separators could have on the configuration and operation of the dental office infrastructure as well as the operation and maintenance of the installed equipment, short and long term costs as well as legal issues and state regulations, which differ from state to state (Mc Manus and Fan, 2003; http://www.ada.org/prof/resources/pubs/adanews) Some US municipalities in states like Maine, Connecticut, Colorado, New Hampshire, New York State, Minnesota, Virginia, Washington State and Wisconsin have asked for a ban of amalgam and mercury in the wastewater leaving dental practices and the installation of amalgam separators, but in most places it has been a voluntary action (Reindel, 2005; ADA, 2005). The Environmental Protection Agency, USEPA, has been looking at the mercury levels for some time and has revised and lowered the limits on discharge of mercury into the environment. The USEPA regulate and recertifies the local water treatment plants, POTW (Publicly Owned Treatment Works) on a regular basis and if the USEPA standards are not met it means heavy fines for the POTW's. Therefore they have had to look at the sources of mercury pollution and where they originated before entering their plant. This is how they found out that dentistry was and still is a main source of mercury found in the wastewater. The POTW's have put the pressure on the dentists to be more attentive of how they handle the amalgam waste and would like to see a tighter control by state agencies over the discharges in all the 50 US States (NACWA), 2002; 2006).

Another problem is also that the major dental insurance companies in the United States will only pay for amalgam fillings and not for alternatives. This can be a problem for those who want to switch to some environmentally friendlier filling materials.

The Chain of Amalgam

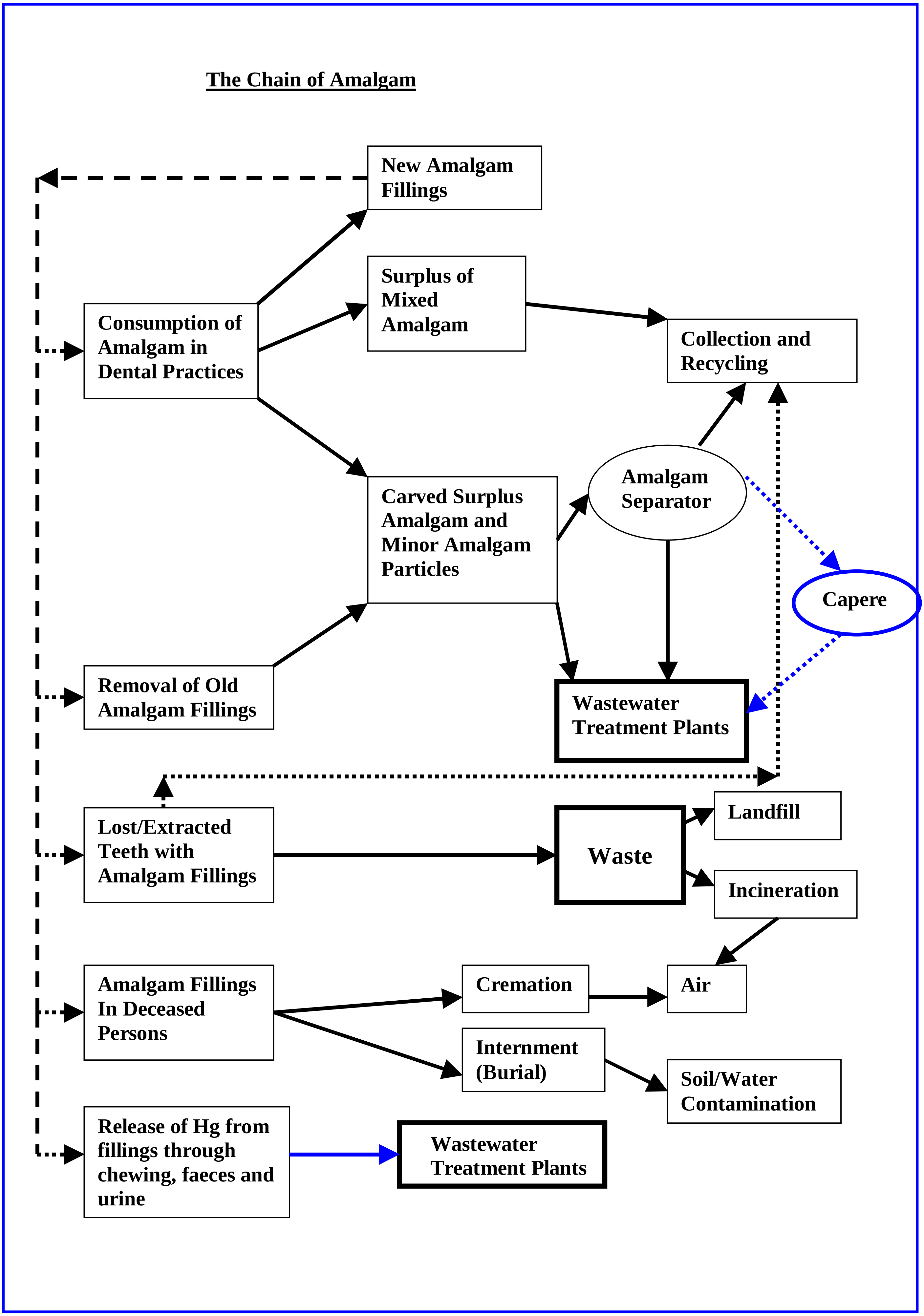
During my background research on mercury and amalgam and its impact on the nature and our environment, I found that the problem is more serious and complex than I first thought. Therefore I have tried to summarize in a chart, below, where the mercury in dental amalgam ends up in the environment, see **Fig. 3**. It can not only pollute the water but also enter the environment through soil deposition through burials, landfills, deposition of sludge from the wastewater treatment plants as well through the air, i.e. atmospheric transport and eventual deposition. What is meant with atmospheric transport is that the mercury vapour released from various industrial processes**,** coal combustion, volcano eruptions etc. is being carried around the globe with the jet winds and may get deposited in very different areas from where it was produced and cause severe environmental disturbances (Eckley Selin, 2005; Mercury, 2006).

There are several areas where one could introduce actions to limit the release of mercury in this chain, but in this thesis I have only concentrated on amalgam separators and their clinical efficiency, how much is collected by the separators, as well as how much mercury is present in the sludge at the wastewater treatment plant.

The release of mercury from dental fillings in the Swedish population through chewing and other oral habits (like clenching and grinding of teeth) is estimated to be 100kg of mercury/year, which ends up in the wastewater plants as an additional source of mercury (Hylander *et al*., 2006). The daily “normal” intake of mercury by the average person from food and other sources is estimated at 3-7 µg, which gives a urinary secretion of mercury up to 5µg per day. In people with amalgam fillings intake levels of up to 100µg Hg have been measured and their excretion have been as high as 50µg per day, which is higher than levels where clinical symptoms have been reported in workers who are exposed to mercury. The urine levels reflect the exposure to mercury in the recent weeks-months, but should be measured on a 24-hour basis, since the concentration varies with urinary concentration during that time span. The normal level in whole blood is 3 µg/l, and in plasma 0, 9-1, 1µg/l, which reflects the present exposure (Berlin, 2002). The faecal excretion can contain mercury released from fillings, as well as pieces of amalgam that breaks off from a filling, to particles swallowed when a filling is placed or removed. This is more difficult to estimate, but in a study done by Skare and Lagerkvist in 1994, they calculated it to be 60µg Hg per day in the faecal matter (Skare and Lagerkvist, 1994).

The ISO standard is mainly used to get the amalgam separators their ISO certification, which is valid for 5 years, and is only carried out at two laboratories, RWTÜV, in Essen, Germany and SP-Swedish National Testing and Research Institute in Borås, Sweden. The ISO organisation does not oversee or certify the laboratories doing the tests, nor do they involve themselves in issues as to the choice or installation of separators. They just determine how the standard test procedure should be done and carried out for the various types of separators (centrifugation, filtration, sedimentation or combination). The German and Danish standards are more clinically applicable and seem to be gaining in popularity, although the German standard is a laboratory test, it identifies a gradient in particle size, where the ISO uses an amalgam slurry in one of the test and amalgam scrap $\leq$ 0,3 mm in the other. The Danish standard is the only one that has a clinical standard, where the separator can release a maximum of 20 mg Hg/day, with a flow of water of 10-20 l/day through it, which gives a concentration in the effluent of 1-2mg Hg/chair/day. This would correspond to 5g Hg/chair/year, which is still a lot.

The Capere unit is a promising tool to add to the regular amalgam separator in order to prevent the release of the ultra small amalgam particles and the ionic phase of mercury into the effluent from dental facilities, which the regular ISO certified amalgam separators do not seem to be able to do at present. Further improvement of the Capere unit, where it would replace the regular amalgam separator is under consideration.


The Chain of Amalgam
New Amalgam Fillings
Surplus of Mixed Amalgam
Consumption of Amalgam in Dental Practices
Collection and Recycling
Amalgam Separator
Carved Surplus Amalgam and Minor Amalgam Particles
Capere
Removal of Old Amalgam Fillings
Wastewater Treatment Plants
Lost/Extracted Teeth with Amalgam Fillings
Waste
Landfill
Incineration
Amalgam Fillings In Deceased Persons
Cremation
Air
Internment (Burial)
Soil/Water Contamination
Release of Hg from fillings through chewing, faeces and urine
Wastewater Treatment Plants

Material – Data gathering

The data in the present study come from SWEDAC (Swedish Board for Accreditation and Conformity Assessment) accredited laboratories at Eurofins Danmark A/S, Copenhagen, Denmark, Me Ana-Konsult, Uppsala, Sweden, Uppsala University, Uppsala, Sweden, Sweden Recycling AB, Hovmantorp, Sweden, Stockholm Vatten AB, Stockholm, Sweden and Tekniska Verken, Linköping, Sweden, and were analyzed according to the ISO/IEC 17025 protocol. The validity and reliability of the data is based on the stringent control that SWEDAC has on their accredited laboratories and the people doing the tests at the clinics and in the laboratories. The amount of mercury was calculated as 50% of the collected amalgam in the amalgam separators or the sludge/water samples, since amalgam consists of 50-53% mercury. The data from Skåne was collected differently since they had the chair amalgam collectors "flushed" with water and samples taken from the effluent.

The regions, Uppsala, Stockholm, Östergötland and Skåne were selected because they had the most complete and reliable data available (SWEDAC). What I have done is to compile, evaluate and compare the data obtained from these areas. This is the first time, that this has been done, as well as the evaluation of the efficiency of the new Capere unit.

Obtaining data from dental clinics as to the use of amalgam (number of fillings inserted, replaced and/or removed, as well as the amount of amalgam purchased per month) showed to be impossible. The only data available was from the Uppsala area and was from 1992. Most dentists that still use amalgam do it very sporadically, as seen in the report done by the Environmental Administration Office in Linköping, which was mentioned earlier, or they do not want it known openly.

The data from **Stockholm** is from two studies done by Stockholm Water AB, and analyzed by them, as to the efficiency of amalgam separators in private practices in Stockholm City and Huddinge, a suburb of Stockholm, and a study done at Henriksdal wastewater treatment plant which looked at mercury in sludge from 1996 through 2005. The Henriksdal plant receives wastewater from 690 000 households and 375 dental practices that have a total of 630 amalgam separators. Over 60% of these practices were started before 1980, which means before the amalgam separators were first introduced. The data comes from numbers provided by Stockholm Water AB (http://www.stockholmvatten.se) and I have compared it to the figures published in the articles of Sörme and Lagerkvist, 2000 and Sörme, 2003. The average flow of wastewater to the plant is 10042 cubic meters per hour (241000 cubic meters per day). Also, the function/ malfunction of the various brands of amalgam separators was looked into in the first studie mentioned above.

The data from the **Uppsala** area, which was analyzed by Me Ana-Konsult and/or the laboratory at University of Uppsala, come from dental public health clinics and are from the years 1992, 2002 and 2003.The data from 1992 were published by Gahnberg *et al* in 1993 and I have compared it to the later data from the study of Hylander *et al.* The amalgam separators were based on the wet sedimentation technique and of different brands including a new experimental and more efficient unit the "LEX", which stands for Low Emission Experimental Separator. This is not on the market at present and not ISO certified, as of yet.

The data from **Östergötland** cover the years 1997 – 2005 and 46 dental public health clinics. These amalgam separators were also based on the wet sedimentation technique, SRAB 99. Five of these clinics are as of 2005 using the new Capere method of cleansing the dental wastewater, after it has passed through the SRAB 99 separator. For four of these clinics there are data available from before the Capere unit was added, as well as after. The fifth clinic "Druvan" in Norrköping is new as of late 2004 and has therefore no before data. The data comes from unpublished internal reports. The SRAB 99 units were all collected by Sweden Recycling AB and analyzed by them. The Capere units were all collected and analyzed by Eurofins Denmark A/S and Tekniska Verken, Linköping.

The data from **Skåne**, was analyzed by SRAB for FTV- Skåne as an internal report and dates from 2003. It covers 221 amalgam separators from 10 dental public health clinics. Dry centrifugal amalgam separators of the brands Siemens, Sirona, Dürr, Mercury Master and dry sedimentation separators SRAB 99, Final and Metasys were the systems used at these clinics. Here the system (separator) was flushed for 15 seconds with water by the chair, of which 0.1-0.2 litres was then collected and checked for amalgam and mercury after the same quantity had been flushed through the effluent suction tube or other outgoing tubes from the chair. The SRAB wash up area separator is different, since it is a wet sedimentary type of separator, located below the sink and only used with running water during the clean up of instruments.

Table 2. Areas looked at in this study.

Study Areas	**Source/Author**
Stockholm **Stockholm/Henriksdal Watertreatment Plant** **Mercury in Sludge from private and dental public health clinics** **Efficiency and working order of amalgam separators**	**Stockholm Water AB** **Sörme&Lagerkvist 2000** **Sörme 2003** **Johansson 1998, 2000** **Wystrand 2006**
Skåne **Chair Collectors Flushed and Hg measured from effluent at dental public health clinics**	**SRAB 2004/ FTV Skåne**
Uppsala **Mercury emission caused by dental care** **Efficiency of Amalgam Separators at different dental public health clinics**	**Gahnberg *et al* 1993** **Hylander *et al* 2006**
Östergötland **1. Amount of Hg collected at dental public health clinics 1997 – 2005** **2. Efficiency of the Capere units installed at 5 dental public health clinics**	**FTV Östergötland/ SRAB** **Internal report from Tekniska Verken & Eurofins Danmark A/S**

All values in this study are based on following assumptions: **220 working days per year and a use of 14.4 litres of water per dental chair and working day.**

Results

The data obtained from the four different regions was run through the Microsoft Excel program and analyzed. Each region has been looked at separately and comparisons in between the regions have been done where possible.

- ### Results from Stockholm

Fig 4 depicts the amount of mercury in the sludge, dry weight, from 1996-2005 at Henriksdal wastewater treatment plant.
Stockholm Water AB has been having an active campaign to reduce the mercury in the waste water pipes in Stockholm since 1996, by either cleaning them but more often replacing them. In-between 1975-80 the sludge contained 1500 kg Hg/year, and it decreased to 85 kg during the period 1981-90. A further decrease was seen during the years 1991-96 from 56 to 36 kg/year (Sörme, 2003). The peak of 31 kg Hg in 1999 came when closed down old school clinics had their pipes cleaned out. This was done under the supervision of Stockholm Water AB, but some released mercury still ended up in the wastewater treatment plant at Henriksdal. Stockholm Water AB hopes to have the level of mercury down to 5 kg or less by the end of 2006.

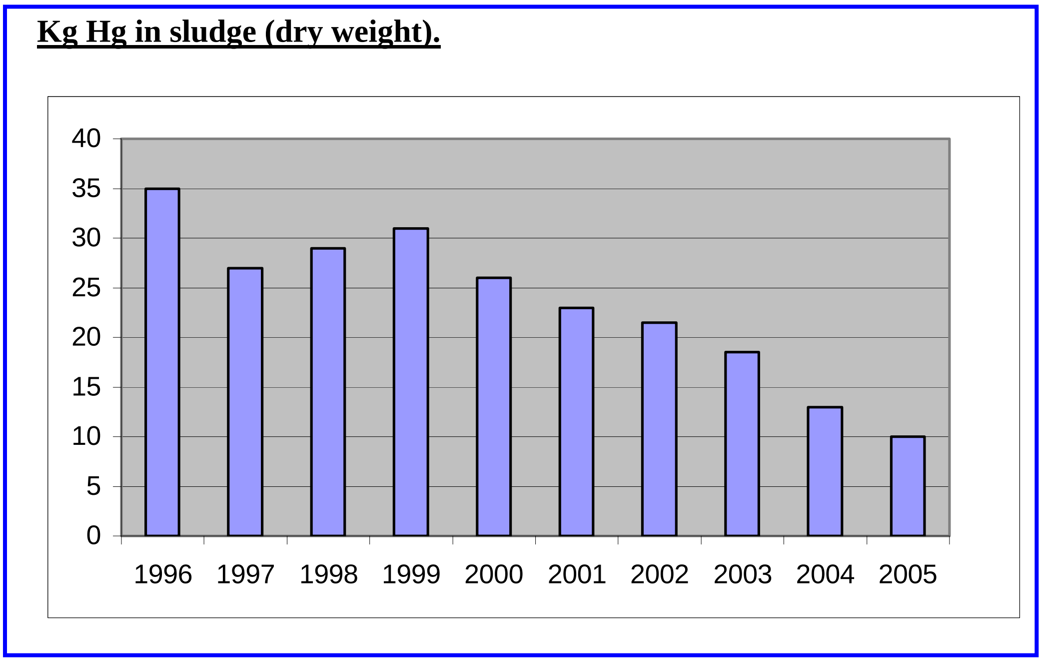


Fig 4. Hg in sludge at Henriksdal wastewater treatment plant, Stockholm.

As seen in table 3, a total of 753 amalgam separators were analyzed in 375 practice facilities. The non-acceptable separators were of older discontinued brands, not available any longer, and therefore replacement parts are hard to come by. The biggest problem, otherwise, was that many separators were wrongly installed.

Table 3. Efficiency and working order of amalgam separators by make in practices and clinics connected to Henriksdal wastewater treatment plant, Stockholm.

375 clinics and practices	total number of amalgam separators	not working correctly (%)
BRANDS:		
Dürr	***45***	***2***
Final	***63***	***43***
Mercury Master II	***72***	***36***
Meta Sys	***33***	***0***
Rash	***6***	***67***
Siemens	***61***	***39***
SRAB	***440***	***0***
NOT ACCEPTABLE:	***34***	***n/a***
MISSING:	***4***	***n/a***
Amalgam separators looked at:	**753**	**16**

- **Results from Uppsala**

As seen in table 4, the efficiency of amalgam separators varies from 79% to 90,7% and these represent some of the more common brands used in Sweden. The LEX, which stands for **L**ow **E**mission **E**xperimental **S**eparator, is a prototype for an improved amalgam separator and in the test here it showed to be very effective, 99,9% (Hylander *et al.,* 2006).

Table 4.Uppsala; efficiency of amalgam separators at two Dental Public Health Clinics, 2003. (G stands for Gottsunda and W stands for Wallingatan)

Clinic	Brand	Hg entering the am. separator (g/chair/year)	Hg in the effluent (g/chair/year)	Efficiency of am.separator (%)
G	No separator	315	103	----
7 dental units	SRAB 99	658	19	90,7
	Rash	420	12	90,3
	Mercury Master II	285	17	81,1
	LEX*	n/a	16	99,9
W	No separator	805	230	----
5 dental units	SRAB 99	830	35	87,5
	Rash	635	34	82,0
	Mercury Master II	461	33	79,0

Average both clinics	No separator	485	164	----
	SRAB 99	737	26	90,6
	Rash	505	23	86,6
	Mercury Master II	353	25	81,8

In table 5 it can be seen that based on the emission of Hg/chair and dentist/day, only the clinic at Bryggmästargatan had a lesser output of mercury, 2,8 g Hg, than the Swedish recommended limit of 5 g Hg/chair and year. The other clinics had an output of 16,5 g and 77,3 g of Hg respectively.
All these clinics had the older sedimentary type of amalgam separator from SRAB, and if one compare these results with the ones in table 4. It is interesting to see that the efficiency of the separators at the clinic at Gottsunda has improved since this study from 75% to about 90% (except for the Mercury Master II unit, which was installed after this study was carried out); while at the clinic at Wallingatan no improvement has been seen.

Table 5. Amalgam use in three Dental Public Health Clinics in Uppsala, 1992.

Clinic	**no. of dentists**	**fillings per dentist and day**	**emission of Hg in mg/ chair and dentist/day**	**efficiency of am.separator**
Wallingatan 5 dental units	2,75 (2-4)	1,6	74,8	**85 %**
Byggmästaregatan 6 dental units	3,91 (3-5)	2,56	12,73	**95 %**
Gottsunda 7 dental units	6,40 (3-7)	2,1	351,21	**75 %**

❖ Results from Östergötland

In table 6 a comparison between the SRAB amalgam separator alone and the SRAB plus the Capere filter has been carried out. Skäggetorp is the oldest and most heavily utilized of these 5 clinics, where the Capere units have been installed, so far. The equipment is older and the configuration of the pipes may not be optimal, which can contribute to the lesser rate of mercury removal by SRAB. Borensberg was not in full operation and the installed unit was not functioning properly; despite this a 99,6 % degree of removal of mercury was achieved.

Table 6. **Results from Östergötland with and without Capere filter, October 2005.**

Clinic	after SRAB alone (mg Hg/l)	after Capere filter (mg Hg/l)	Efficiency of SRAB alone (in %)	degree of cleansing after Capere (in %)
Österbymo 3 dental units	0,32	0,0100	91,0	**99,9**
Finspång 12 dental units	2,20	0,0032	93,0	**99,9**
Borensberg 5 dental units	0,16	0,1200	95,0	**99,6**
Druvan 20 dental units	0,24	0,0040	93,4	**99,9**
Skäggetorp 8 dental units	1,10	0,1200	83,0	**99,8**

Fig 5 shows the values before and after the insertion of the Capere filter. The blue is SRAB separator alone and the yellow is SRAB plus Capere filter.

The Capere Unit can on the average trap up to 277g of ionized Hg before getting saturated, which is equal to 2.1mg Hg/chair/day (ISO 11143 and the EU directive limits the amount to < 2.5 mg Hg/chair/day in the effluent). The pine bark is changed every 6 months and heating it, or lowering the pH of the bark to 1-2, retrieves the metals trapped in it. The cotton filter is also changed every 6 months and cleansed; the metal residue is recovered and recycled.
These tests were run mid October 2005 (FTV-Östergötland; Tekniska Verken).

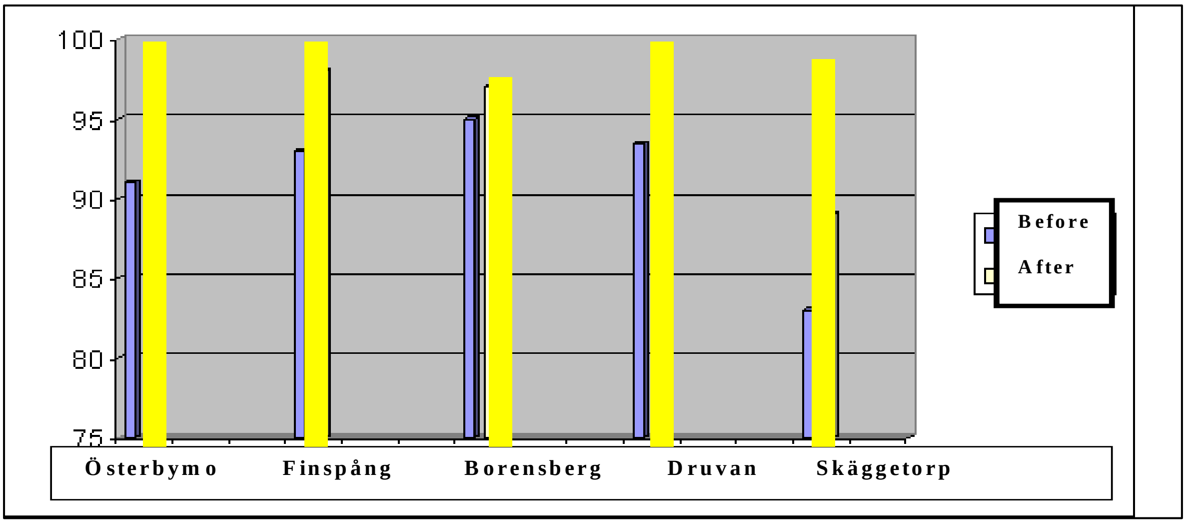


Fig 5. Before and after the insertion of the Capere filter.

Some of the early figures in table 7, before the year 2000, were not available or unusually low, as can be seen from the clinic at Skäggetorp, specially, but also from Finspång. Both these clinics have a high degree of utilization, (high patient flow), so one would have expected more mercury in the effluent. There are also large variations over time, with the highest levels during the years 2001 through 2003 and with the peak of 4264 g Hg in 2002 from the four clinics in operation at that time. The high values from the year 2000 through 2003 are most likely due to some drive to exchange amalgam fillings for composites.

Table7. Mercury in amalgam separators from 1997 to 2005 in: g Hg/yr/chair. The Capere filter was installed in 2005. The red figures are the additional collected amount of Hg in the Capere filter, after the SRAB separator.

Table7. Mercury in amalgam separators from 1997 to 2005 in: g Hg/yr/chair. The Capere filter was installed in 2005. The red figures are the additional collected amount of Hg in the Capere filter, after the SRAB separator.	1997	1998	1999	2000	2001	2002	2003	2004	2005	2005	%
Österbymo 3 dental units	183,3	358,3	142	840	957	1510	1538	1407	1006	968	96
Borensberg 5 dental units	410	120	856	563	573	753	713	938	576	513	89
Finspång 12 dental units		67		316	965,4	345,4	439,6	429	451	442	98
Druvan 20 dental units*								224	440	431	98
Skäggetorp 8 dental units	50	13	720	219	264	1628	419	538	513	466	89

*Estimate for the year based on the collected amalgam for September 2004. The clinic was not in full operation until October 2004.
All figures are based on collected amalgam in the separator, minus 50%, which is considered the amount of mercury in the amalgam particles.

In table 8 Borensberg has not been included due to malfunctioning unit.
"Before filtration" means after amalgam separator SRAB and before it enters the cotton "particle filter".
"After particle filter" is when the effluent has past through the cotton particle filter.
After filtration" is when the effluent has gone through the Capere bark medium.
"Reduction" figure is the amount of metals recovered by the cotton and the Capere bark medium after the amalgam separator, SRAB.

The reduction of mercury is high except at the Skäggetorp clinic, which is the oldest of these clinics and have had some problems with their equipment. The high levels of copper can be due to newer types of amalgam have been used since the alloy in these contain up to 30% copper, but the low level of silver in the filters is interesting, since the alloy contain 70% silver (ISO 24234). The recovery of other metals is also high which means very little is discharged to the main drain after it has passed the Capere system.

Table 8. Measurements from Östergötland, the week 49, 2005.

Clinic:	Before filtration	After particle filter	After filtration	reduction
Österbymo				
Ag	0,48 mg/l	0,38 mg/l	0,14 mg/l	**71%**
Cu	1,9 mg/l	0,39 mg/l	0,057 mg/l	**97%**
Hg	0,32 mg/l	0,076 mg/l	0,01 mg/l	**97%**
Sn	0,11 mg/l	0,029 mg/l	0,0069 mg/l	**94%**
Zn	1,5 mg/l	1,1 mg/l	0,13 mg/l	**91%**
Total:	**4,31 mg/l**	**1,975 mg/l**	**0,3439 mg/l**	**92%**
Finspång				
Ag	0,65 mg/l	0,02 mg/l	0,012 mg/l	**98%**
Cu	2,8 mg/l	0,22 mg/l	0,19 mg/l	**93%**
Hg	2,8 mg/l	0,045 mg/l	0,032 mg/l	**98%**
Sn	0,83 mg/l	0,01 mg/l	0,0083 mg/l	**99%**
Zn	4,2 mg/l	0,19 mg/l	0,17 mg/l	**96%**
Total:	**10,58 mg/l**	**0,485 mg/l**	**0,4123 mg/l**	**96%**
Druvan				
Ag	0,089 mg/l	0,003 mg/l	0,0016 mg/l	**98%**
Cu	2,3 mg/l	0,2 mg/l	0,064 mg/l	**97%**
Hg	0,035 mg/l	0,0095 mg/l	0,004 mg/l	**98%**
Sn	0,036 mg/l	0,00069 mg/l	0,0005 mg/l	**98%**
Zn	1,7 mg/l	0,26 mg/l	0,22 mg/l	**87%**
Total:	**4,364 mg/l**	**0,47319 mg/l**	**0,2901 mg/l**	**93%**
Skäggetorp				
Ag	0,24 mg/l	0,04 mg/l	0,038 mg/l	**84%**
Cu	2,2 mg/l	0,57 mg/l	0,45 mg/l	**80%**
Hg	1,1 mg/l	1,0 mg/l	0,12 mg/l	**89%**
Sn	0,47 mg/l	0,038 mg/l	0,038 mg/l	**92%**
Zn	1,7 mg/l	0,78 mg/l	0,63 mg/l	**63%**
Total:	**5,71 mg/l**	**2,428 mg/l**	**1,276 mg/l**	**78%**

In table 9 are the results from the initial testing as the clinic just had opened, and was carried out in order to see how the equipment was functioning. The bark medium and the flow through it was adjusted, but as seen by the December figures further adjustment was needed to improve the degree of cleansing. The test in 2006 uses the newly installed reverse osmosis clean water unit, rather than tap water, as the water supply to the dental units. This appears to further improve the cleansing of the effluent, due to decreased build up of biofilm in the lines, which can trap small amalgam particles and bind mercury.
Degree of cleansing after the Capere filter is based on the percentage of amalgam separator alone, see column 2

Table 9. Tests at the Dental Public Health Clinic "Druvan" in Norrköping.

DRUVAN Dental Clinic Norrköping Testing dates:	**Mercury levels after amalgam separator in mg Hg/l**	**Effectivity of amalgam separator alone in %**	**Mercury levels after Capere filter in mg Hg/l**	**Total degree of cleansing in %**
2004-09-27	**0,023**	**93**	**0,0011**	**95**
2004-12-21	**0,1**	**88**	**0,0018**	**96**
2005-10-15	**0,24**	**93,4**	**0,004**	**98**
2006-04-04	**0,12**	**95**	**0,005**	**99**

❖ Results from Skåne

As can be seen in fig 6, two separators of older discontinued models (one SRAB 95 and one Stena-Scanfors) were excluded from the figure. The SRAB wash up area separator was 100% effective, which is to be expected since it deals with washing instruments contaminated with mercury/amalgam and the water from the sink goes straight into the separator and can sediment out. Of the dry centrifugal separators the Dürr had the highest number of separators that emitted less than 1 mg Hg/l/chair/year, 83% as seen by the green staple, but at the same time 17% of their separators emitted more than 1 mg Hg/l/chair/year, the red staple. There is no data as to which brands were in which clinic, or if they were of centrifugal or sedimentary type. Of the dry sedimentation type of separators the SRAB 99 had 81% that emitted less than 1 mg Hg/l/chair/year, but also here you had a group of 19% separators that released Hg above this level. Still all in all, 25% of the separators had outgoing levels of Hg higher than 1 mg Hg/l and chair, which is above the acceptable limit (SRAB amalgam separator protocol, 2004, based on the ISO-11143 standard and the EU directive, 84/156/EEC). Siemens and Metasys had both more separators that were releasing more Hg than the acceptable limit than below, 65% vs. 35% for Siemens and 46% vs. 54% for Metasys, while the Final separators had just as many above as below the acceptable limit.

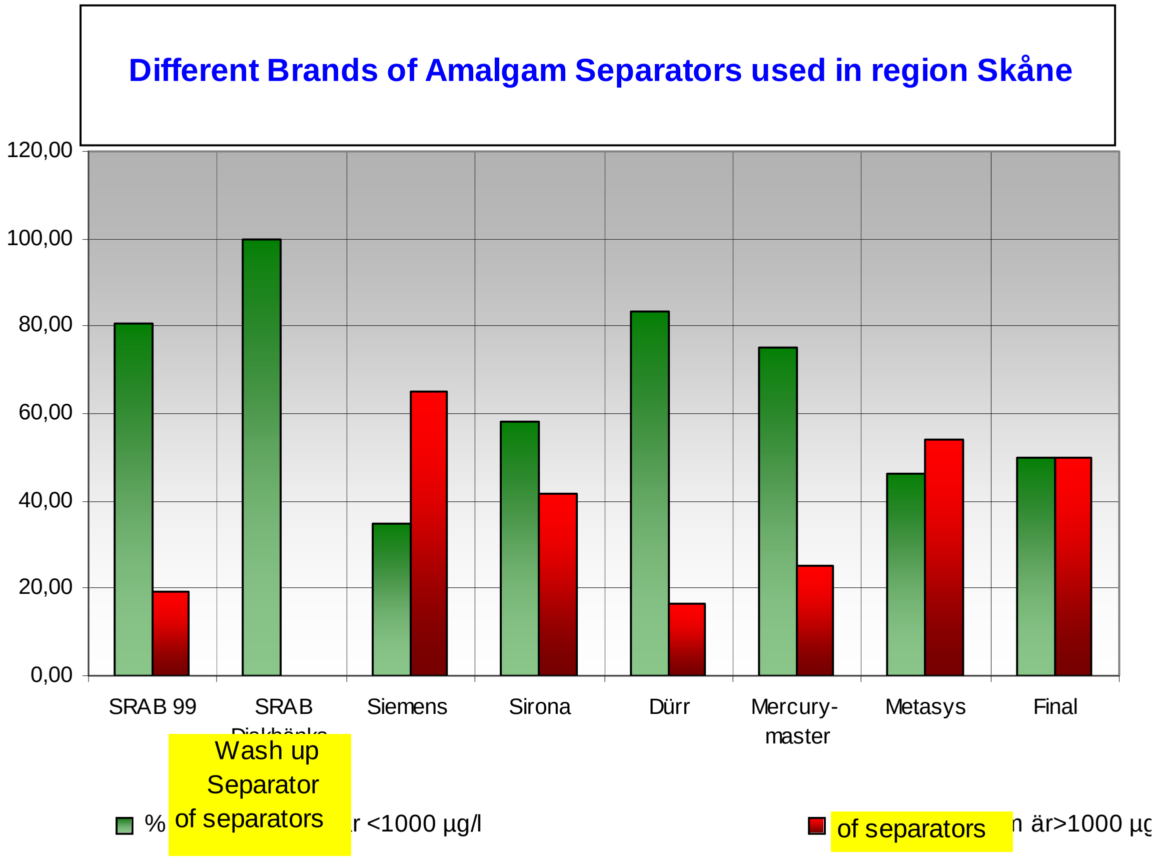


Fig6. depicts mercury in the effluent from different clinics using different brands of amalgam separator

Discussion

Mercury is a ubiquitous element, which worries both regulators and the public today more than ever in many places around the globe. It is well known that mercury is a bio accumulative neurotoxin; despite this it has been used in many applications and continues to be so in some fields, even if people are more aware of the dangers with mercury, many are still not or ignore them.

It is expected that the mercury use in amalgam fillings will only see "a gentle decline" in between now and 2020, due to more frequent dental visits and an increase in fillings rather than extractions in certain countries. Most dentists are familiar with the material, which has a long history of use, follow up and documented success rate, which composites does not have to the same extent. The cost both to the patient and the dentist is another factor, but the environmental cost is more worrisome, as mentioned earlier.

The Swedish use of mercury in dentistry was down to 110 kg in the year 2000 and by 2003 it was even less, 105 kg, and it continues to decrease further (KemI, 2004). Still, the largest contributor to the Swedish dental mercury "reservoir" are the fillings that are removed or replaced in the 74% of the Swedish population that have amalgam fillings in their mouths. Some 40 metric tons of mercury is still present in this group, and will end up in the amalgam separators or via the wastewater in the water treatment plants (KemI, 2004), if it does not eventually end up in air from the crematories.

The amount of mercury recovered from three of the four areas studies appears to be mainly from removal of amalgam fillings. In Stockholm it was recovered from the sludge at the wastewater plant at Henriksdal and is of mixed sources, but mainly from dental practices as mentioned earlier.

The amount of mercury in the sludge at Henriksdal wastewater treatment plant has decreased considerably since the 1970's (Sörme, 2003) and the introduction of amalgam separators. The decreased use of mercury not only in dentistry but also in other applications and instruments has helped in lowering the load of mercury in the sludge. As seen in Fig 4 the drive by Stockholm Water AB to clean out and/or replace old pipes in the Stockholm region clogged with amalgam and mercury has been very effective. The other initiative was to check the efficiency and working order of the amalgam separators, see Table 3, and it was very interesting to find that many separators, about 22%, were not acceptable (older, less efficient and/or discontinued models), and 16% of the separators were not working correctly (see under malfunctions, below).

As seen in Table 7, there was a large variation in the recovery of mercury from the amalgam separators in Östergötland over time, 1997-2005. Unfortunately, the data was not complete and similar figures from the other regions were not available, but it appeared that a large number of amalgam fillings were replaced in the years 2001 through 2003. This can be due to several factors, new dentists are more prone to promote composite fillings and at various times there have been campaigns to exchange fillings and/or media reports on the danger of amalgam fillings, although the pressure to exchange amalgam fillings for other materials were more intense in the 1980's and 90's (pers. experience).

As to the Capere results, one can look at them from two sides, either how much they reduce the mercury content in the effluent from the original amount of mercury in the waste water leaving the dental unit, as seen in Table 6, thus comparing it to what the amalgam separator can eliminate, or to compare it to the amount that the amalgam separator cannot eliminate, which is seen in Table 8 and Table 9. Therefore you can come up with two different amounts and percentages of mercury recovery from the effluent. In Table 6-9 the differences can be depicted, either the effluent that leaves the Capere system have taken care of 99,9% of what was in the original amount of waste water leaving the dental unit or 89-99% of what the amalgam separator did not eliminate, which gives a more exact figure of what the Capere unit can accomplish.

Table 8 shows the recovery of all the metals in dental amalgam, and if you just look at the mercury reduction as in table 6, it would have been 99, 9% at all clinics, but by looking at it from the other point of view as mentioned above the reduction is more differentiated. The reason for this can be attributed to several factors as lay out of clinic and pipes, age of pipes, water quality of in-water, maintenance, patient flow and to some extent the “human factor”(the staff and their interest and awareness).

- **Efficiency of amalgam separators**

Arenholt-Bindslev and Larsen (1996) were the first to look into the effectivity of the amalgam separators in the early 1990's. They looked at clinics in Denmark that had amalgam separators and clinics that did not, ten of each. Their aim was to analyse how much mercury the separators discharged with the wastewater during a normal working day. They found that clinics that lacked amalgam separators discharged a mean of 57g Hg/chair/year (range: 7-185g Hg/chair/year), while clinics with amalgam separators discharged a mean of 9g Hg/chair/year (range: 2,6-22g Hg/chair/year), based on 220 working days/year. From this early study it was found that the amalgam separators removed approximately 85 to 90% of the mercury from the effluent leaving dental practices when compared to those that had no separators. They also found that the amount of mercury in the effluent did not correspond to the amount and type of amalgam work that was carried out in the practices on a daily basis, since it largely came from amalgam particles that had settled in the suction hoses and pipes, and became dislodged at peak flow (Arenholt-Bindslev and Larsen, 1996).

These early separating systems had a special no-return valve at the outlet of the separation tank or after the amalgam separator to make sure the suction kept going while work was being done. This had a tendency to create a surge in “back suction” before the valve had closed when the suction by the dental unit was turned on, which created a force large enough to push the amalgam particles back into the separation tank. When the suction was turned off again, the valve opened and a rush of water from the separation tank would pass the separator often causing it to exceed it holding capacity and the amalgam particles would not sediment, but get washed out in the “whirl” with the effluent going through the separator. Even if two amalgam separators, a pre and a main separator, were installed it did not help the problem (Arenholt-Bindslev and Larsen, 1996; Hylander *et al*., 2006). This “back suction”-problem was commonly occurring with the older amalgam separators and could be the reason for the low efficiency of the amalgam separators in two of the clinics, Wallingatan and Gottsunda, in the early Uppsala study in table 5, as well as the low efficiency of the amalgam separators looked at in the Stockholm area (85%).

The results from Skåne (Fig.6) show that about 25% of the brands of amalgam separators, used in the region and looked at, had an unacceptable high level of Hg (> 1 mg Hg/l/chair) in the effluent even if it became diluted by the test method that was used (the separator was flushed for 15 seconds with 0,1 - 0,2 litres of water and the same amount was collected from the effluent suction tube or other outgoing tubes from the chair, SRAB, 2004). According to the manual for amalgam separators issued by SRAB in conjunction with the tests done in Skåne, 1 mg Hg/l per chair was set as a limit above which remedial action of the separator was needed (SRAB, 2004). It is therefore, difficult to compare the results from Skåne with the data obtained from Uppsala and Östergötland apart from stating that many amalgam separators were not working to capacity. There was also a mix of amalgam separators, sedimentary and centrifugal as well as dry/wet systems, only separated out by brands in the results reported. After remediation, some follow up tests were done in 2004 and the levels of mercury had decreased considerably (FTV-Skåne).

The SRAB separator appears to be the most commonly used amalgam separator in the four areas of Sweden looked at, either as a wet or dry sedimentation system. The newer SRAB 99 and 99-B amalgam separator showed to have a similar clinical efficiency, about 90%, in all four areas, even in Östergötland, without the Capere unit. The increase in efficiency of the amalgam separators at the Uppsala clinic at Gottsunda from the earlier figure of 75% in 1992 to the later figure of 90,7% in 2003 is most likely due to upgrading to the newer model of separator, see table 4 and 5.

Mercury Master II appeared to be the least efficient of the amalgam separators in the Uppsala study with only 79% efficiency. In Skåne the efficiency was also low, below the 80% mark.

The Rash separator was not used in the clinics in Skåne or Östergötland, but in Uppsala and Stockholm. It had a low efficiency rate, only 82%.

The Final separator was only in use in Skåne and Stockholm, but it appeared to have a lot of problems and a low efficiency rate, below 75%.

The Dürr, Metasys and Siemens separators were also only used in Stockholm and Skåne. The Dürr faired a lot better than the Metasys and Siemens units, 89% efficiency versus 84 and 78%.

The Sirona separator was only in use in Skåne and its performance was at par with the Metasys unit.

The only well working unit, apart from the Capere and the "LEX", was the SRAB- wash up area separator, which had a 100% removal of mercury and amalgam, as can be seen in Figure 4. A lot of water is used during the wash up procedure, but on the other hand it is not in constant use. The separator is below and close to the sink, which facilitates for the amalgam to sediment out. The washing up of instruments that have been in contact with mercury and amalgam was for a long time an overlooked source of mercury release into the effluent from dental practices, which now largely has become a problem of the passed.

As shown in this study of data from the four regions of Sweden, none of the dental amalgam separators, although all ISO certified, were living up to this level of efficiency clinically, except the new separators, the Capere system and the "LEX". The factory labels stated that the separators had 95-99% efficiency according to the ISO protocol, but the results show a dismal figure of 75–90% separation clinically with the older amalgam separators, and 79-91% separation with the newer models on the Swedish market. More mercury than the recommended limit of 5 g Hg/chair and year was emitted with the units of the lower efficiency rates, which is worrisome. As mentioned before, the particle size of the amalgam removed today is much finer than that back in the early 1990's and therefore harder to catch in the separators, so there is also an unknown, but sizable amount that goes out with the effluent water.

- **Malfunctions**

The results from Stockholm show how easy it is to cause an unnecessary release of amalgam particles because of a malfunctioning amalgam separator. In the pilot study, 25% of the separators were not working properly and only 25% of the practices had wash up area separators. In the larger follow up study, 16% of the units were not working as they should despite an intensive information drive and incentive to buy wash up area separators, but now over 70 % had installed wash up area separators. The most common problems that lead to malfunction of the amalgam separators were lack of regular maintenance**,** clogged filters and/or overfilling of the separators as well as wrongly installed units. The main reason for faulty installation or configuration was disrespect for the fall height, which led to amalgam remnants remaining in the hoses and/or drainpipes (Johansson, 2000).

Hylander *et al.* (2006) looked at the mercury in the effluent from 12 dental public health clinics in the Uppsala area from 1995 through 1997, and found similar problems with the amalgam separators. These clinics were all equipped with SRAB 99 wet system amalgam separators of the sedimentary type, preceded by a chair side mesh which removed amalgam particles >1 mm. The effluent wastewater was collected on four consecutive working days and analyzed for its mercury content. The concentration of mercury ranged in between 0,77 and 74 mg/chair/day (the average was 15,8 mg, which would give a yearly discharge of 14,5 g Hg/chair, i.e. well over the recommended maximum of 5g Hg/chair and year). At these clinics approximately, 7 amalgam fillings were placed per week and 17 amalgam fillings removed, which was higher than the figures from the study carried out in 1992 and reported in table 5. Of the mercury collected from the pipes, 12 % came from between the clinic and the wastewater outlet to the municipal main drain. After revision of the systems (hoses, pipes were checked and cleaned/replaced and new amalgam separators installed) the mercury level in the effluent decreased to an average of 1,7 g Hg/ chair and year (range: 0,07-7,3 Hg/chair and year), (Hylander *et al*, 2006). The problem with fall height and sharp bends in the pipes turned out to be just as common as reported in the Stockholm region, and were all due to poor design or disregard for the pipe system by the dental equipment company or whoever did the installation. The amount of mercury collected from the pipes, excluding what was in the amalgam separators, was 5899 grams from these 11 clinics. This can be compared to the amount of mercury recovered from the pipes in Norrköping, 1997-2004, which was 1500 g per year.

The SRAB and Dürr amalgam separating units seemed to have the least problems (< 2%) as to the function, while the Rash, Final and Siemens/Sirona units appeared to have the most problems. 67% of the Rash units were not working correctly followed by 43% of the Final and 39% of the Siemens units (see Table 3 and Fig 4). The dentists and their staff interviewed in Stockholm and Skåne as to their malfunctioning amalgam separators seemed not to be fully aware of the size of the problems (Johansson, 2000 and SRAB, 2004). Therefore, they need to have better education in maintenance and early warning signals for when the amalgam separator is not working at its best and when the collection box needs changing. To do it only according to when the responsible company is scheduled to come may not be enough, more alertness and involvement from the dental personnel is needed. They should read the reports that are sent from the recycling companies as to how much amalgam and mercury has been collected each time. They should also discuss the reports, what do the figures mean, and what strategy can be needed in order to improve on them. One can only hope that the manufacturers, also, will improve their warning systems in order to prevent the overfilling from happening, and have a better control of the installation and supervision of the units, but as far as I know not much has happened on that front since these studies were done.

- **Capere**

The Capere unit appears to be the most efficient amalgam separator in conjunction with a SRAB 99 separating unit. It has now been in use for over 2 years in Östergötland and the efficiency of its separating action down to the ionic level of mercury has been well documented as seen in the tables (Table 6 through 9). The high efficiency rate of removal in a newer clinic, like “Druvan”, in comparison to an older clinic, like Skäggetorp, shows that it is very efficient in equally old and new pipes and lines, although more can be retained and not accounted for in the separators in the old one where the fall height, length of pipes and avoidance of sharp bends are not as good.

The Capere unit does not only separate out the mercury but also the other metals present in the amalgam alloy as seen in Table 8. There are plans for further improvements, but they outside the scope of this study (Berggren, personal communication).

The Capere system is one way to achieve and improve the removal of metals from the effluent, but with a better cleaner water supply to the dental units, so that bacterial build up can be minimised is another. These would together lead to a cleaner effluent from the dental clinics virtually devoid of metals and bacteria. The last results from the “Druvan” clinic, as seen in Table 9, show a cleansing degree of 99% and that was when the new clean water system just had been installed.

Another future use for the Capere bark system could be at the wastewater treatment plants, where it could be used to decrease the heavy metals in the sludge. As of 2005, there is a ban in Sweden on depositing any organic material on farmland unless it is specially treated and the heavy metals removed from it (Johansson, 2000; KemI, 2004). Otherwise, it has to be disposed of as a filling material in old mines and other pits, where it could possibly leach out into the soil and ground water. This way the sludge could come to a better and safer use either for the manufacturing of biogas or for heating purposes without causing an environmental impact and the metals recycled.

Conclusions and Recommendations

From the data obtained it can be concluded that the clinical efficiency of the amalgam separators currently in use in Sweden are not meeting the ISO 11143 standard except the Capere unit and the “LEX” experimental model, but more studies are needed as to the clinical efficiency of the “LEX” unit.

The regional differences as the use of amalgam separator brands showed that Skåne and Stockholm were the most diversified and seemed to have lower efficiency rate in separation and more problems attached to them. As to handling of the amalgam separators there seemed not to be any notable difference, although newer clinics seemed to have less problems than older.

The addition of the Capere unit to an amalgam separator as done in Östergötland, the removal efficiency of amalgam and mercury from the effluent was shown to increase considerably and with this environmentally friendly and cheap method. The bark is a bi-product from the forest industry and would be burnt if not used for this purpose.

As Sweden has been at the forefront for amalgam separators and the regulation of amalgam use in dentistry, the rest of the world can learn from our experiences and statistics and that more work needs to be done to restrict the emission of mercury from dental practices. The efficiency of the amalgam separators needs to be improved as seen by the results from this study. The ISO standard, which is based only on a serie of laboratory tests, ought to be combined with or replaced by clinical tests. A protocol of procedures for cleansing the suction hoses and pipes, including what chemical solutions are acceptable ought to be added to the ISO protocol.

Better filtering systems are needed in Sweden and its neighbouring countries in order to minimize the still abundant emissions of mercury into the air, water and soil. Specially, catching the ionic phase of mercury is difficult, and it is a disturbing "villain" in not only the effluent from dental offices, but also in the mercury that leaves crematories and incinerators in a gaseous form, as well as what comes from the combustion of fossil fuels and appears in the sludge from waste water treatment plants.

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