Green Book Technology Summary Report

ECO II

Metasys USA, Inc., Pure Water Development, L.L.C.
5001 SW 74th Court, Suite 206
Miami, FL 33155

June 2003

Prepared for:

The Massachusetts STrategic Envirotechnology Partnership

Susan Guswa and Eric Winkler
Center for Energy Efficiency and Renewable Energy
University of Massachusetts
160 Governors Drive, Amherst, MA 01003-9265

DISCLAIMER

NOTICE FROM THE MASSACHUSETTS
STRATEGIC ENVIROTECHNOLOGY PARTNERSHIP (STEP)

STEP reports provide an independent, third party evaluation of performance and costs/benefits associated with the use of innovative environmental technologies.

STEP encourages the wide distribution of this report in its entirety. However, STEP expressly prohibits the use of any excerpt or the creation of any derivative work from the full STEP document. Consistent with this prohibition but while recognizing the report is a public record, STEP requests that no excerpt from the full document should be used without the express written consent of the STEP program. To obtain this consent, please submit your intended excerpt to the office of the Director of the STEP program for approval (http://www.state.ma.us/envir/step/program/contacts). If this procedure is not followed, STEP may remove the report from active distribution.

Table of Contents

Introduction

Dental amalgam is a metal alloy composed primarily of mercury, silver, copper, tin, and zinc and is used in dental procedures including fillings and crowns. Mercury accounts for approximately half of the dental amalgam alloy composition. The mercury found in dental amalgams is elemental mercury that is bound in the stable metallic compound (ADA, 2002). However, the mercury in amalgam particles discharged into the environment through wastewater discharge, land application of wastewater biosolids, incineration, and solid waste landfilling can undergo transformation to methyl mercury by bacteria. Methyl mercury is a bioaccumulative neurotoxin that can cause harm to the central nervous system, liver, kidneys, and immune system in humans and wildlife (Bender, 2002).

Dental amalgam has been identified both in Massachusetts and nationwide as a significant source of mercury in wastewater. The Massachusetts Water Resources Authority (MWRA), which provides sewer service to Boston and surrounding communities, found that 13% of the man-made mercury influent load in the Deer Island Sewage Treatment Plant comes from dentist offices (MWRA, 2001). Dental amalgam particles are discharged into wastewater systems through the mouth vacuums and chairside sinks in dental offices during amalgam placement and removal.

Massachusetts is actively working to reduce releases of anthropogenic mercury into the environment, including those from dentist offices. Dental amalgam separation technologies can reduce the amount of amalgam that is discharged into the wastewater system from dental offices beyond what the chairside traps and vacuum filters can typically remove (Fan, et. al, 2002). Dental amalgam separators are installed locally within a dental facility, and are designed to remove a portion of the amalgam particles and, in some cases, dissolved mercury from the dental wastewater prior to discharge from the facility. Several types of amalgam separators are now commercially available, and most are designed to be retrofitted into the dental office's existing wastewater collection system. Amalgam separator technologies can use one or more of the following processes to achieve separation: sedimentation, filtration, centrifugation, and ion exchange. Some amalgam separation technologies are designed with an upstream holding tank while others are designed as flow-through units.

Historically, dental amalgam separators have not been widely used by dentists in the United States. However, the growing concern about mercury is creating a growing demand for amalgam separators. Several states are implementing voluntary or mandatory mercury discharge reductions for dental offices. The dental industry is being challenged to understand the performance of the many amalgam separation technologies available in the marketplace. To that end, this Green Book profiles the ECO II, a sedimentation-based amalgam separator designed by Metasys, Inc. The results from available laboratory and field performance studies for the ECO II, regulatory issues, operation and maintenance requirements, and costs associated with using the ECO II dental amalgam separation technology are described in this report.

Description of Technology

Technology Description

Overview

The Economy System Type 2 (ECO II) dental amalgam separator was developed by the Metasys Group, headquartered in Austria. Metasys is certified under ISO 9001 standards, which guide the quality control processes for manufacturing the dental amalgam separator units. The ECO II technology is patented in the United States and Europe. The United States patent titled “Dental Separator for Solids from a Solids/Liquid Mixture,” US 6,276,936 B1, was granted on August 21, 2001. The United States dental market is serviced by a subsidiary of the Metasys Group, Pure Water Development, L.L.C., located in Miami, FL. Dentists can obtain ECO II units directly from Pure Water Development or approved local vendors. In addition to the ECO II, Metasys manufactures several models of dental amalgam separators including the Multisystem Type I (MST I), Multisystem Eco (MST I ECO), COMPACT Dynamic, and Superior. These units are sold primarily in Europe.

The ECO II is a flow-through unit that is designed to separate and retain amalgam particles based on the principle of sedimentation. It is designed to be installed within the vacuum system at dental offices, and is designed to treat flows up to 2 liters/minute, flow from approximately six chairs. The ECO II is constructed of six injection-molded polypropylene parts that are glued together. The separator has no moving parts and does not require any electrical input. Metasys/Pure Water Development recommends that the only cleaner and disinfectant used in conjunction with the ECO II unit should be their proprietary cleaner called “Green and Clean M2 Evacuation System Cleaner.” The M2 cleanser is biodegradable and contains enzymes, quaternary ammonia compounds, and a defoamer. Technical data for the unit are summarized in Table 1.

Table 1. ECO II Technical Data

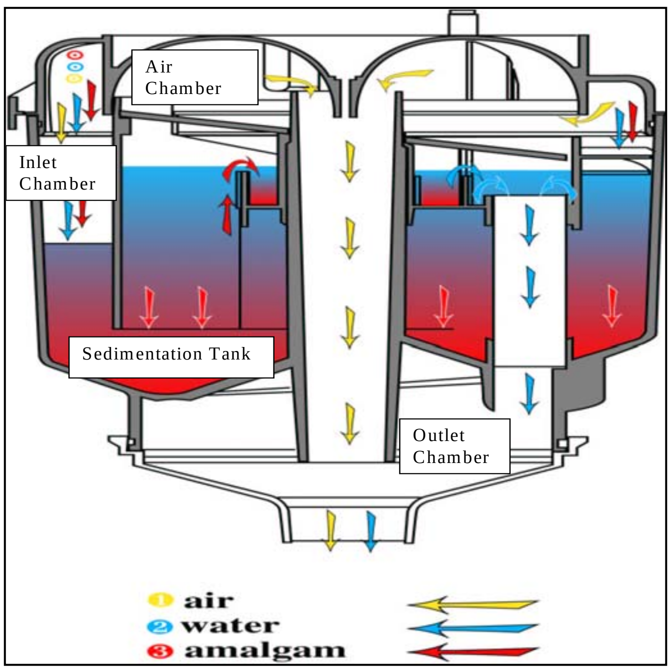
Dimensions (height x width x depth):	13.8 in x 8.7 in x 8.7 in (350 mm x 220 mm x 220 mm)
Vacuum Suction Range:	1.5 – 8.9 inches of mercury (50-300 mbar)
Maximum Water Flow Rate:	0.5 gallons per minute (2 liters/minute)
Maximum Amalgam Storage Volume:	0.4 gallons (1.5 liters)
Suitable Suction Systems:	Wet or dry vacuum suction systems

after Metasys Operation and Maintenance Manual, 1999

Detailed Description

A schematic of the ECO II is shown in Figure 1. The unit consists of a series of chambers with baffles to promote the settling of the amalgam particles. Dental wastewater enters the air chamber at the top of the unit. Air is immediately diverted to a center well that leads to the outlet chamber at the bottom the unit. The wastewater and amalgam particles flow into the inlet chamber, which is a narrow annular ring around the perimeter of the sedimentation tank. The inlet chamber is lined with thin, horizontal plates that are equally spaced. The plates divide the inlet chamber into slot-like passages, which minimize turbulence. The wastewater flows downward through the inlet chamber and into the bottom of the sedimentation tank. Solids settle by gravity from the flow in this chamber. Water overtops a weir at the top of the tank and flows into a second settling area with five baffles that create vortices, which enhance gravitational settling of amalgam particles. Upon exiting the baffle chamber, the wastewater flows downward through a tube to the outlet chamber, where it rejoins the air that was separated in the initial chamber and exits the unit.

Figure 1. ECO II Process Schematic

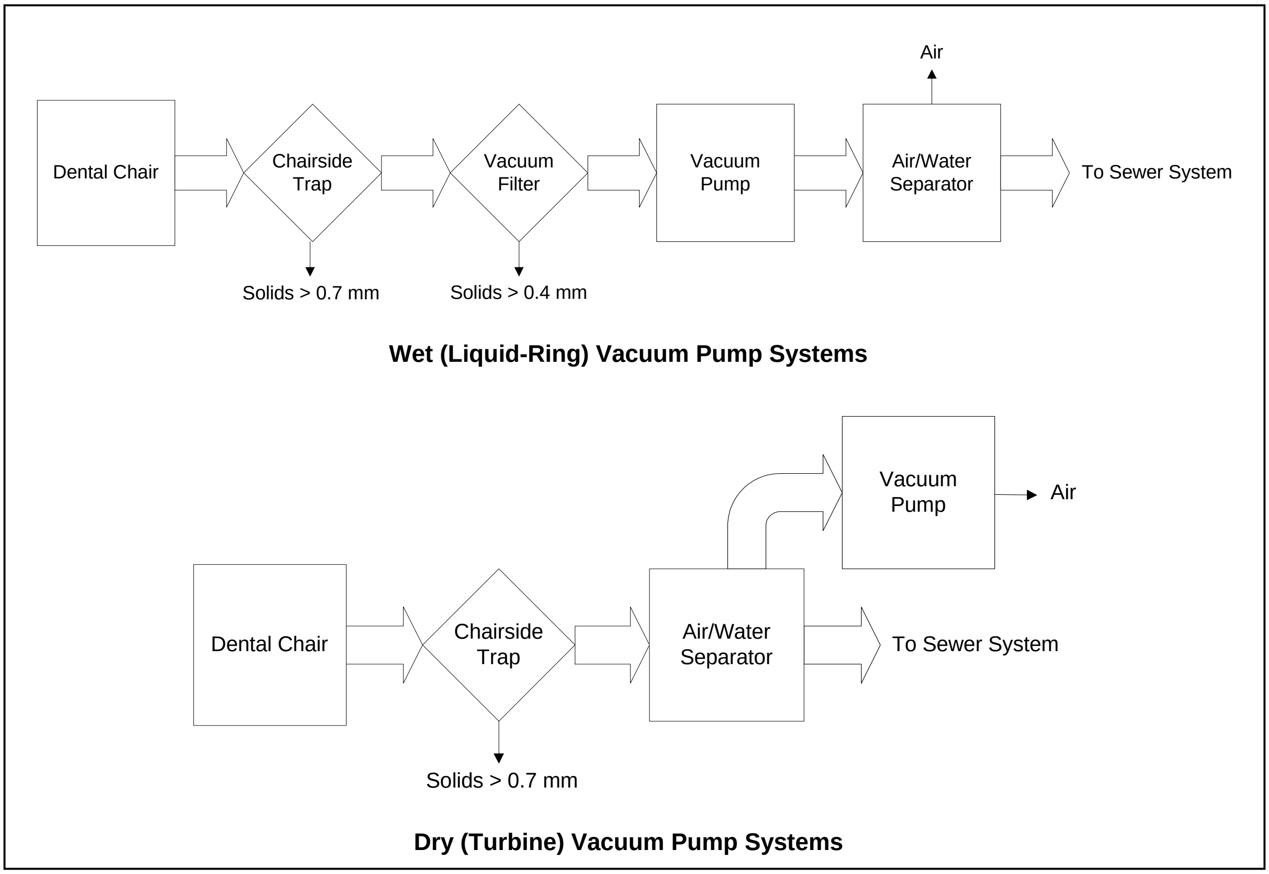


Metasys, 2002

Installation

The ECO II is shipped pre-assembled and can be installed by a licensed plumber. It is designed to be installed within the vacuum system at dental offices. Dental offices use a vacuum system to collect wastewater generated during dental procedures. Chairside sinks, mouth vacuums, and other dental equipment discharge into the vacuum system. Wet (liquid-ring) and dry (turbine) vacuum systems are the most common types of vacuum systems in the United States. Typical process flow diagrams of the wet and dry vacuum pump systems are illustrated in Figure 2.

Figure 2. Process Flow Diagrams



In both systems, a pump is used to create a vacuum that pulls the wastes generated at the chairs to a common location where the wastewater is discharged either into the sanitary sewer system or septic tank. Both types of vacuum systems typically include a chairside trap immediately downstream of each dentist chair. Chairside traps commonly have a screen with 0.7-millimeter (mm) openings to trap larger particles (MCES and MDA, 2001). Dry vacuum pump systems have an air/water separator upstream of the pump, and the wastewater does not pass through the vacuum pump. Wet vacuum pump systems do not have an air/water separator upstream of the pump, so the wastewater passes through the pump before it is discharged. Therefore, these systems usually have a vacuum filter that is located immediately upstream of the pump to remove particles from the flow and prevent damage to the pump. Vacuum filters typically range in size from 20 to 40 mesh (0.84 mm to 0.42 mm openings) (MCES and MDA, 2001). Amalgam particles that are too large to pass through the chairside traps and filters become trapped. Proper disposal of the collected solids from chairside traps and vacuum filters is a best management practice for the reduction of mercury releases to the environment.

The ECO II amalgam separator is designed to remove even more particulate amalgam from the wastewater than what is collected in chairside traps and vacuum filters. For dry vacuum systems, Metasys/Pure Water Development recommends that the ECO II be installed on the water line downstream of the air water separator. For wet-ring vacuum systems, Metasys/Pure Water Development recommends that their system be installed in an accessible location between the chairside traps and the vacuum filters. It is not recommended that the ECO II be installed downstream of the pump because the wet-ring vacuum pump operates with the addition of water, and flows may exceed the capacity of the unit. The ECO II is not typically installed with a bypass that would enable flow to circumvent the unit.

Operation and Maintenance

Once installed, the ECO II operates automatically and does not require day-to-day attention from the dental office staff. The units do not have any moving parts nor do they require any electrical input for operation. Metasys/Pure Water Development does not provide specific training to dentists, but the ECO II is available with an operation and maintenance manual.

Metasys/Pure Water Development sells the ECO II with an annual service contract through an approved local vendor. The contract covers the cost of replacement of the unit and amalgam recycling. The units need to be replaced when solids accumulate to the maximum capacity of the unit. The rate of accumulation of solids in the ECO II is related to the amount the quantity and types of procedures performed in the dental office. Typically, replacement is not needed more than once a year. The ECO II does not have any sensors and alarms that will notify the dentist when the unit is full. Therefore, the unit must be visually inspected by the dentist to check the solids level. The recommended frequency of visual inspections is monthly. If the solids reach the maximum level before the scheduled annual replacement, the dentist should contact the vendor for immediate replacement.

The dentist is responsible for arranging to have the local vendor change out the unit in the office. Metasys/Pure Water Development ships a replacement unit to the dentist. Change out of the unit should occur when the vacuum system is shut off. The inlet connector is detached and a packet of disinfectant provided by the manufacturer is poured into the inlet and plugged with a stopper (also provided by the manufacturer). The outlet connector is then detached, and a stopper is placed in the outlet of the unit. The new unit is then placed into the system. The manufacturer recommends that gloves and masks be worn when the unit is changed out, since the amalgam sludge in the tank is a hazardous. The dentist then ships the full unit back to Metasys/Pure Water Development for amalgam recycling. Amalgam recycling for ECO II units is performed in Austria. Guidelines and practices for amalgam recycling are beyond the scope of this assessment.

Vacuum System Cleaning

Dental wastewater systems including the dental suction equipment and chairside basins are typically cleaned and disinfected on a regular basis. Compounds used for disinfection vary widely and include cleaners containing bleach, formaldehyde, phenol and enzymes. Metasys/Pure Water Development recommends that the only cleaner and disinfectant used in conjunction with the ECO II unit should be their proprietary cleaner called "Green and Clean M2 Evacuation System Cleaner." The M2 cleanser is biodegradable and contains enzymes, quaternary ammonia compounds, and a defoamer. The M2 cleanser comes in two formulations that are packaged in red and green pouches. The cleaner serves as both a daily cleaner and disinfectant for dental suction equipment and chairside basins and prevents a buildup of biofilm within the ECO II unit. Metasys/Pure Water Development recommends that the M2 cleanser is used daily at each dentist chair station. One color-coded packet of cleanser should be used at each dentist chair station and alternated as needed.

The M2 cleanser compounds are pH neutral. An acidic pH increases the solubility of metals, including mercury. Therefore, to promote the capture of the maximum amount of amalgam particles, acidic or oxidizing (e.g., bleach) cleansers should not be used in conjunction with amalgam separators. Additionally, cleansers containing phenol and formaldehyde will cause the ECO II container to blacken, reducing the visibility of the solids.

Proper cleaning and replacement is critical to the performance of the ECO II. If the dentist elects not to follow the manufacturer's recommendations and does use bleach to clean the system, the bleach may dissolve the mercury in the amalgam and exacerbate the mercury management problem in the Commonwealth.

Technology Applicability

Applicability to Industry/User

The ECO II is specifically designed to remove dental amalgam particles from the waste stream in dental office vacuum systems. It is compatible with both wet (liquid-ring) and dry (turbine) vacuum systems. The ECO II can be installed within new systems or retrofitted into existing systems in dental offices. On average, the ECO II can serve up to six chairs, but the number of chairs served depends upon the water use within the dental office. The maximum design flowrate through the ECO II is 0.5 gpm (2 L/min).

Development/Application History

Various Metasys units have been in operation in Europe for over 15 years. The ECO II was developed in 1998, and has been installed in dental offices throughout North America. ECO II units were first installed in the United States in 1999. As of March 2003, approximately 300 units have been installed and are operating in the United States. A list of installations can be obtained from Pure Water Development, L.L.C.

Technology Applications

The ECO II has been tested both in the laboratory and in field installations. Descriptions of the testing objectives and field test applications are described below.

Laboratory Testing using the ISO Protocol

ISO 11143 is a bench-top laboratory testing protocol that was developed by the International Organization for Standardization (ISO) to determine the removal efficiency of dental amalgam separators. Efficiency is calculated from the measured mass of amalgam before and after it passes through the separator under maximum design flow rates (as specified by the separator manufacturer). In 1999 Metasys sponsored a laboratory test of its ECO II separator using ISO 11143. Tests were performed at the Technical University of Vienna, Austria in March 2000. An ISO 11143 test of the ECO II was also performed by the American Dental Association (ADA), and results are published in a JADA article entitled *Laboratory Evaluation of Amalgam Separators* (Fan, et. al, 2002). Results from these two studies are summarized in the Technology Performance section of this report.

The ISO 11143 test specifies pumping water through the separator at a flow rate equal to the maximum flowrate specified by the amalgam separator manufacturer. Amalgam particles are mixed with water to form a suspended solution and introduced into the flow over a period of two minutes. Water at the maximum flowrate is run through the amalgam separator for an additional eight minutes. The amount of amalgam that passes through the separator is collected and weighed. The specified amalgam test mixture is composed of the following:

- 6,000 g (60% mass fraction) ≤ 3.15 mm and >0.5 mm
- 1,000 g (10% mass fraction) ≤ 0.5 mm and >0.1 mm
- 3,000 g (30% mass fraction) ≤ 0.1 mm

$$\eta = \frac{100 \times [m_1 - (m_3 - m_2)]}{m_1}$$

Efficiency is calculated using the following equation:

Where: m_1 = mass of amalgam sample

m_2 = mass of effluent filters before efficiency test

m_3 = mass of effluent filters after efficiency test (with captured amalgam particles)

The protocol specifies that the test procedure will be run three times beginning with an empty amalgam separator and three times with the separator filled to its stated maximum amalgam capacity. The efficiency results for each of the three sets of tests are averaged. The reported efficiency is the lower average of the two series of tests.

Field Testing by Metropolitan Council Environmental Services (MCES) with the Minnesota Dental Association (MDA)

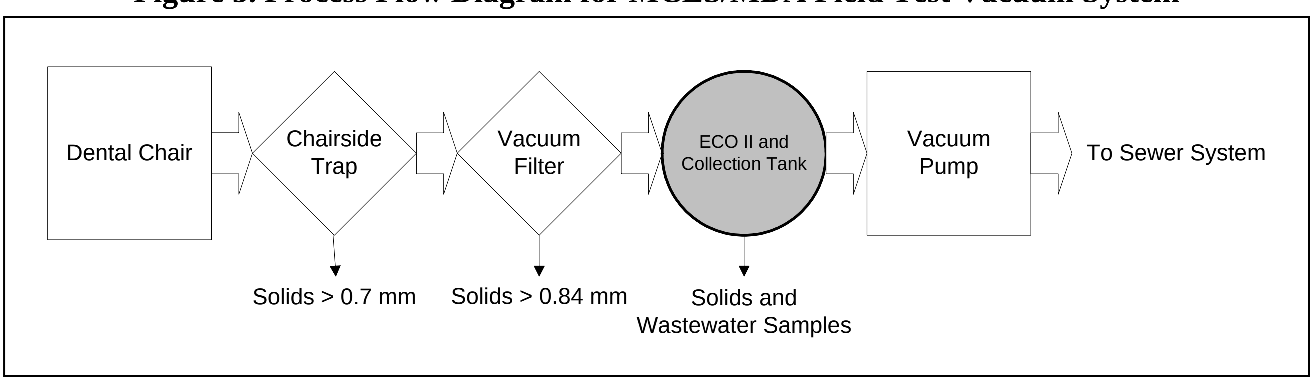
Several dental amalgam separator technologies including the ECO II were field tested for a study conducted by Metropolitan Council Environmental Services (MCES) with the Minnesota Dental Association (MDA). The goal of the testing was to determine the general performance of the ECO II (and other separators) in removing mercury from the waste stream. The results of the study are published a report titled *Evaluation of Amalgam Removal Equipment and Dental Clinic Loadings to the Sanitary Sewer* (2001) and are summarized in the Technology Performance section of this report.

The ECO II was tested at a dental clinic that had one dentist who performed general dental procedures at the clinic four days per week and no assistants or hygienists. Dental wastewater system at the clinic consisted of chairside sinks with traps, ¾" chlorinated polyvinyl chloride (CPVC) drain piping, a vacuum filter, and a wet vacuum pump. The wastewater was discharged to the sanitary sewer. Historically, the dentist flushed the wastewater system with a gallon of bleach solution daily. The bleach solution was replaced by tap water during and for four weeks prior to any sampling. Additionally, the chairside trap and vacuum filter were replaced at the start of baseline and amalgam separator test periods.

To establish a baseline, wastewater samples were collected for five weeks between July 13, 2000 and August 16, 2000 without an amalgam separator installed in the system. A 20-liter polypropylene sample collection tank was installed between the vacuum filter and vacuum pump. The sample collection tank was emptied every 2 days during the sampling period. The amalgam was digested, and samples were analyzed for total mercury.

An ECO II unit was installed within the existing wastewater vacuum system in the basement of the clinic by a professional plumbing contractor for the testing period. The unit was installed between the vacuum filter and the sample collection tank, as shown in Figure 3.

Figure 3. Process Flow Diagram for MCES/MDA Field Test Vacuum System



The ECO II was tested for five weeks between September 20, 2000 and October 25, 2000. Over the course of the sampling period, an average of 7 amalgam surface procedures were performed per day. The sample collection tank was emptied every 3 days during the sampling periods. The amalgam was digested, and samples were analyzed for total mercury. At the end of the test period, the vacuum filter and ECO II were removed and the accumulated solids were analyzed for total mercury.

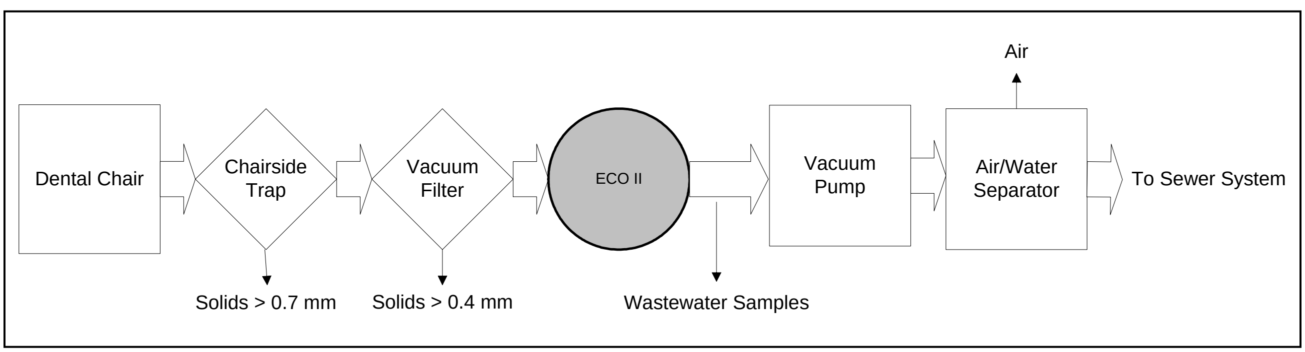
Field Testing by UMass, Boston

UMass Boston to developed and implemented a protocol for evaluating the performance of dental amalgam separators in the laboratory and the field. Several technologies were investigated in this study. Protocol development was overseen by an advisory committee, that included: the Massachusetts Executive Office of Environmental Affairs, Massachusetts Department of Environmental Protection (DEP), the Massachusetts Water Resources Authority, the American Dental Association, and the Massachusetts Dental Society. The protocol was to be used to test four dental amalgam separation technologies, including the ECO II, in the laboratory. As of June 2003, results of the laboratory testing are pending.

Four separator technologies were temporarily installed in dental office in the Boston, MA area and monitored for effluent mercury concentrations. Results of the field testing are summarized in a project report titled *Development, Evaluation and Implementation of a Testing Protocol for Evaluation of Technologies for Removal of Mercury from Dental Facilities: Part I – Field Studies* (Wallace et. al., 2003) and are summarized in the Technology Performance section of this report.

The ECO II was installed in a dental office with one practicing dentist who performed an average of 2.4 amalgam procedures per day (Wallace et. al., 2003). Initially, a 20-liter polyethylene wastewater collection tank was to be installed immediately downstream of the ECO II to collect all of the effluent flow. However, flows were larger than anticipated, and the sampling setup was changed to include a sampling port in the waste line downstream of the ECO II. An ISCO automated sampler was connected to the sampling port and time-paced composite samples of the effluent wastewater from the ECO II were collected. The samplers were programmed to collect 336 +/- 4mls every five minutes. Samples for which data are available were collected for 10 weeks between December 21 and March 8, 2002. Baseline sampling was not performed at this site. Changing of vacuum filter and chairside traps was not monitored. A diagram of the ECO II test setup is shown in Figure 4.

Figure 4. Process Flow Diagram for UMass Boston Field Test Vacuum System



Technology Performance

Performance Goals

The ECO II has been tested in the laboratory and in the two separate field studies. Results of these studies are described in this section. Laboratory tests were performed using the ISO 11143 test protocol, which measures dental amalgam particle removal efficiency for the separator. Meanwhile the results of the two field tests were based directly wastewater sampling and chemical analysis to determine mercury removal efficiency and effluent concentrations.

Paired influent and effluent samples are prohibitively difficult to collect in the field because the volume of flow is small and highly variable making it challenging to obtain representative samples. Thus, the field test protocols differed from the approach specified in the ISO 11143 protocol for laboratory tests. The MCES/MDA study was designed to determine removal efficiency of the dental amalgam separator by capturing the effluent wastewater as well as the deposited mercury in the vacuum filter and amalgam separator. The UMass Boston field test was designed to measure average mercury effluent concentrations from time-weighted composite effluent samples.

Due to differences in the test protocols, the results of these laboratory and field tests cannot be statistically combined to determine single removal efficiency value for the ECO II. However, the results of all of the tests support the goal of amalgam separators to substantially reduce the amount of mercury that is released from dental offices.

Laboratory Testing using the ISO Protocol

The results of laboratory testing using the ISO 11143 test protocol are summarized in Table 2.

Table 2. ECO II Removal Efficiency Based on ISO 11143 Laboratory Test Results

	TU Vienna	**ADA**
Efficiency Empty	Not Reported	98.17% (SD 0.43%)
Efficiency Full	Not Reported	97.51% (SD 0.74%)
ISO 11143 Efficiency[1]	96.7% @ 2 L/min	97.51% @ 3 L/min

1. The ISO 11143 Efficiency is the lower of the measured empty separator and full separator efficiencies.

SD: Standard Deviation

The results of both laboratory tests indicate the particulate dental amalgam removal efficiency of the ECO II is high, and exceeds 95%. ADA reported no statistical differences between the removal efficiencies for empty and full separators (Fan, et. al, 2002). The ISO protocol may overestimate the unit's efficiency because amalgam separators are typically installed downstream of chair side traps and vacuum filters, which remove a significant portion of the amalgam particles. Chair side traps typically retain particles larger than 0.7 mm and vacuum traps may retain particle larger than 0.4 mm. While the protocol was designed to simulate actual conditions, greater variability of amalgam particle sizes, concentrations, and flow rates in actual installations are possible than those measured during the ISO 11143 testing. Thus, removal efficiencies for the unit when tested using the ISO 11143 protocol may not be indicative of removal efficiencies of the unit for all installations.

In addition to the ISO 11143 efficiency test of the amalgam separator, the ADA study also analyzed the amalgam in the separator effluent to estimate total and dissolved mercury concentrations. Total mercury was estimated from the mercury particles retained on the effluent filters and the mercury in the effluent filtrate. Dissolved mercury was calculated from the effluent filtrate that passed through a 0.45-um filter. Results of the mercury tests are shown in Table 3.

Table 3. Total and Dissolved Mercury Concentrations in Effluent from ADA ISO 11143 Testing

	Range of Total Mercury Concentration from Amalgam in Effluent (mg/L)	Range of Dissolved Mercury Concentration from Amalgam in Effluent (mg/L)
Empty Separator	16.3 – 23.4	0.01 – 0.03
Full Separator	2.3 – 39.7	0.04 – 0.16

Total mercury concentrations ranged between 2.3 and 39.7 mg/L. Dissolved mercury concentrations were very low, ranging between 0.01 and 0.16 mg/L. The researchers attributed the ranges in concentrations to the variation in the number of small-sized amalgam particles in each of the ISO test runs (Fan, et. al., 2002). It should be noted that the ISO 11143 test protocol is not designed to simulate dissolved mercury concentrations in dental wastewater. The results presented above may not be indicative of dissolved mercury concentrations in actual installations.

Field Testing by Metropolitan Council Environmental Services (MCES) with the Minnesota Dental Association (MDA)

The total volume of wastewater effluent was collected from the dental office and transported to MCES for analysis every 2-3 days during the five-week baseline monitoring and during the five week ECO II demonstration. Upon receipt at the laboratory, the samples were subdivided into solid and liquid fractions. The solid fractions were obtained by gravitational settling for 24 hours. The solid fractions were predigested using a method based on Standard Method 3030 E and then analyzed for total mercury using EPA Method 245.1. The liquid fractions were analyzed using EPA Method 245.1. At the end of the sampling periods, the vacuum filter and ECO II unit were removed and the residual amalgam particles were predigested using Standard Method 3030 E and then analyzed for total mercury using EPA Method 245.1. Results are summarized in Table 4.

Chariside traps were in place during the testing, but the contents of only a limited number of chairside traps were analyzed. Therefore, calculations of percent removal of mercury for the whole system (filters and amalgam separator) are based on mercury mass in the wastewater downstream of the chairside traps.

Table 4. MCES/MDA Field Test Results

	Baseline	**ECO II**
Sampling dates	7/13-8/16/00	9/20-10/24/00
Number of operating days	21.00	20.25
Number of effluent samples collected	11	9
Volume of wastewater generated (liters)	173.5	123.0
Volume of wastewater collected (liters)	173.5	123.0
Number of amalgam surfaces placed and removed	201	146
Mass of mercury collected in vacuum filter (mg)	3,747	3,468
Mass of mercury collected in ECO II (mg)	--	3,953
Mass of mercury in effluent (mg)	9,430	749
Average concentration of mercury in effluent (mg/L)	54.4	6.1
Percent of mercury removed by vacuum filter (as compared to what passed the chairside traps)	28%	43%
Percent of mercury removed by ECO II (as compared to what passed the chairside traps)	--	48%
Percent of mercury removed by both vacuum filter and ECO II combined	28%	91%
Percent of mercury remaining in wastewater	72%	9%
Percent of mercury removed by the ECO II (as compared to what entered the ECO II)		84%

(after MCES and MDA, 2001)

The results indicate that the ECO II is capable of removing a significant portion of the mercury contained in vacuum filter effluent. The measured percent removal of mercury by mass was 84% for the ECO II, as compared to amount entering the ECO II, and was 48% as compared to the amount passing the chairside traps. The average mercury effluent concentration is approximately 6 mg/L based on the total mass of mercury in the ECO II effluent and the total volume of wastewater collected. A comparison of the mass of mercury in the effluent with and without the ECO II shows that the separator is capable of lowering the mass of mercury discharged to the sewer system by an order of magnitude. A particle size distribution of the amalgam particles collected in the ECO II was not performed. Although the dentists at the test site were instructed not to exceed the maximum flow rate for the ECO II, flow rates were not monitored.

The QA/QC analysis indicated that the analytical results were good (MCES and MDA, 2001). Recovery of the mercury was less than 100%, thus the reported results may slightly underestimate the actual mercury amounts (MCES and MDA, 2001).

Field Testing UMass, Boston

Time-weighted composite wastewater samples were retrieved weekly during the 10-week sampling period. The samples were subdivided into samples containing three size fractions:

- Settled solids – fraction of solids settling out of the sample by gravity overnight
- Suspended solids – fraction retained on 0.4 um polycarbonate membrane filter
- Dissolved solids – fraction passing through the 0.4 um polycarbonate membrane filter

Suspended and settled solid samples were digested using a microwave assisted digestion technique that recovered 93 ± 12% (N=9) (97 ± 5%, N=8) of mercury from mercury amalgam reference samples. The sample digests and dissolved samples were analyzed for total mercury using EPA Method 245.1. Average mercury concentrations in the samples are summarized in Table 5. The results indicate that the ECO II effluent mercury concentrations were typically less than 1 mg/L, but range over three orders of magnitude, from 0.4 mg/L to 3.6 mg/L. Flowrates and mercury influent concentrations were not monitored at this site, thus no direct removal efficiency calculations can be made. A particle size distribution of the amalgam particles collected in the ECO II was not performed.

Table 5. Results of the UMass Boston ECO II Field Test

Week	Composite Effluent Mercury Concentrations (ug/L)			
	Settleable	**Particulate**	**Dissolved**	**Total**
1	589	176	18	783
2	1,562	725	9	2,295
3	not measured	1,159	13	--
4	19	162	8	188
5	58	3,282	285	3,624
6	24	799	12	834
7	3	358	7	368
8	48	303	9	360
9	6	200	5	211
10	14	18	9	40
Mean	**258**	**718**	**37**	**967**
Standard Deviation	**524**	**968**	**87**	**1,206***

*excluding Week 3

(after Wallace et. al., 2003)

Dissolved mercury concentrations at the ECO II test site were typically lower than those observed at the other three monitored sites. However, the ECO II is not designed to remove dissolved mercury. The difference may be explained by the differences in pH of the wastewater.

For the ECO II installation, the wastewater pH concentration was neutral 7.3 ± 0.7, while the other sites had acidic pHs, typically less than 3. The M2 cleanser had a neutral pH as compared to bleach, which will lower the pH of the water. The low-pH environment at the other sites may have caused more mercury from the amalgam particles to dissolve because mercury solubility increases as pH drops.

Procedural blanks and replicate samples were analyzed for quality assurance and quality control. Reported mercury concentrations in the procedural blanks were negligible. Precision of replicate samples was 6.3% ± 8.1% for dissolved concentrations, 26% ± 23% for particulate concentrations, and 9% ± 10% for the settleable solids concentrations (Wallace et. al., 2003). The large variance in precision for the particulate concentrations was attributed to heterogeneity of the subsamples (Wallace et. al., 2003). Reported mercury recovery from amalgam reference material was 93% ± 12% (Wallace et. al., 2003).

Cost Information

Pure Water Development, LLC, provided cost data on the ECO II. The ECO II is available to dentists through service contracts administered by either Pure Water Development, LLC or an approved local vendor. The cost of the service contract includes initial and annual charges, and the minimum contract term is three years.

Capital Costs

The service contracts include an initial charge for equipment and installation of the ECO II equipment in the office. The equipment charge is $160. The installation is the responsibility of the dental office and the charge depends upon the particular installation. A local certified plumber performs the installation. Typical installations require a couple of hours with costs ranging $100-200.

Operating Costs

The annual contract charge is $288 ($24/month) and is paid at the beginning of the service year. The contract includes the following services:

- Repair and replacement: The whole unit is replaced annually. Any necessary repairs are also included in the service plan.

- Amalgam disposal and recycling: Upon replacement, the used ECO II units are shipped to Metasys/Pure Water Development and subsequently to Austria where the amalgam is recovered from the unit and recycled.

Metasys/Pure Water Development specifies a proprietary cleaning solution, Green & Clean to be used daily with the ECO II instead of bleach cleaners commonly used in dental offices. Estimated annual costs of the cleaner are $74.70/chair.

Metasys/Pure Water Development also extends their amalgam recycling service to other sources within dental offices including chairside traps and vacuum filters. The service plan covers the recycling costs of these sources, but an additional shipping charge will be applied. Typically, Metasys/Pure Water Development will coordinate FedEx pickups of the other amalgam sources with the individual dental offices.

Cost Summary

Average annual costs for one ECO II unit installed in a dental office with three under typical operating conditions is $550 - $650 based on the following assumptions:

- $260 - $360 for equipment and installation,
- $24/month service plan: amalgam disposal, unit replacement, and repairs included,
- $75/year/chair cleaner costs: 3 chairs.

Regulatory/Safety Requirements

Applicable Regulations

Most states currently do not have specific limits on mercury discharged from dental facilities. Many states are evaluating legislation that will require that dental amalgam separators be installed to reduce mercury discharges.

In Massachusetts, draft legislation has been proposed to require ISO 11143 certified amalgam separators be installed and maintained in dental offices that use dental amalgam. The Executive Office of Environmental Affairs and Department of Environmental Protection (DEP) are working with the Massachusetts Dental Society to promote the use of separators and to implement Best Management Practices in dental offices. Hazardous waste regulations applicable to dental offices are summarized below.

Regulatory Requirements[1]

At this time the Massachusetts DEP does not have sufficient information to know how much mercury leaches from dental wastes to definitively classify these wastes as hazardous or non-hazardous. Therefore, the DEP recommends that any dental waste containing mercury be recycled, to ensure that mercury is not released to the environment.

Assuming that at least some of the dental sources of mercury-bearing waste is hazardous waste, and that most dentists generate less than 100 kg of mercury-bearing waste per month, most dentists would be classified as Very Small Quantity Generators (VSQGs) and therefore should register as such with DEP. Information regarding VSQGs can be found at the website for the Massachusetts DEP, Bureau of Waste Prevention, Division of Business Compliance: http://www.state.ma.us/dep/bwp/dhm/. The website contains a fact sheet publication on VSQGs.

A VSQG may send mercury-bearing recyclable material off-site for recycling without having to obtain a Class A regulated recyclable materials permit provided that the following specific requirements are met:

- Obtain a Massachusetts generator identification number;
- Keep a record of each shipment sent off-site for recycling;
- Ship the mercury-bearing recyclable material only to authorized recyclers who have a Class A permit (unless out of state);
- Obtain a receipt of recycling certification from the off-site recycling facility; and
- Accumulate recyclable material in containers that are sealed and structurally sound and

[1] This report subsection was completed by Massachusetts DEP.

- labeled as a regulated recyclable material, if the recyclable material is accumulated on-site prior to shipping.

Applicable regulatory language is found in the Massachusetts Hazardous Waste Regulations, 310 CMR 30.000 and is included here:

"30.221: General Provisions

(3) Persons who generate one hundred kilograms or less in a calendar month of Class A regulated recyclable material, other than those regulated recyclable materials listed in 310 CMR 30.136, and accumulate at any one time no more than 600 kilograms of regulated recyclable material need not obtain a permit for the generation, management, transportation, or recycling of Class A regulated recyclable material, provided:

(a) only the Class A regulated recyclable material that is generated onsite is recycled onsite; or,

(b) the material being recycled is a characteristic sludge hazardous solely because it exhibits the Toxicity Characteristic due to the presence of mercury (D009) and the following requirements are satisfied:

1. the material is sent offsite for reclamation;

2. the generator shall keep, for a period of at least three years from the date of recycling:

a. records from the recycling facility, certified pursuant to 310 CMR 30.009, that the materials were recycled in compliance with applicable State and Federal laws and regulations; and

b. a record of each shipment sent off-site. The record shall take the form of a log, invoice, manifest, bill of lading or any other shipping document, and shall include the:

i. name and address of the facility to which the material was sent;

ii. quantity of each type of material sent; and

iii. date the shipment of material left the site; and,

3. the material, if accumulated on-site prior to shipping, must be accumulated in containers that are sealed and structurally sound, and labeled as "Regulated Recyclable Material - Toxic - Mercury".

(c) a generator of Class A regulated recyclable materials that is exempt from the requirement to obtain a recycling permit pursuant to 310 CMR 30.221(3)(a) shall comply with all other applicable standards and requirements set forth in 310 CMR 30.200 governing Class A regulated recyclable material."

Please be advised that in mid-2003 there will be at least one amendment to the preceding regulations. The Department expects that section 30.221(3)(b)2 will be amended to be more descriptive of information that must be included on the shipping paper.

Health/Safety Issues

The ECO II is designed to capture and contain dental amalgam inside the unit. The entire unit is removed and shipped off-site for amalgam recycling, thus potential exposure to amalgam is very low. However, it is recommended that best practices for amalgam handling be practiced when servicing the ECO II unit.

Lessons Learned / Implementation Issues

Design Issues

- The ECO II is a flow through sedimentation treatment unit. The unit is designed to be installed within a vacuum collection system for dental wastewater. Typical design of the installation does not include a bypass or upstream flow equalization. Therefore, flowrates through the ECO II can vary widely depending on chairside water use. The ECO II is rated to a maximum flowrate of 0.5 gpm (2 L/min), and flow rates exceeding the rated maximum will likely reduce its amalgam removal efficiency. The specific relationship of flow rates and performance can not be determined from the data that was evaluated as part of this report. However, the ADA ISO 11143 laboratory testing showed that the amalgam removal efficiency did not decline when tested at 3 L/min. When planning a new ECO II installation, maximum water use rates from the facility should be calculated to verify that they do not exceed the design maximum of the separator, taking into account flow rates from the intermittent releases from air/water separator. Water use should be carefully controlled to meet the flow requirements, especially during activities where it is possible to exceed the flowrate such as during cleaning and flushing of the vacuum system.

- Existing dental waste treatment systems could have amalgam deposits within its piping system. Thus, amalgam could continue to be discharged from these deposits if the separator is installed upstream of the amalgam deposits. Based on observations during the UMass Boston field study, the investigators recommended that amalgam separators should be placed as close as possible to the point of discharge to capture pre-existing mercury that has accumulated in waste piping system (Wallace et. al., 2003).

- Retrofitting a dental amalgam separator system into an existing facility can be challenging if the existing plumbing system is inaccessible. If piping is buried, then retrofitting the system to include an ECO II may be expensive. Additionally, some dry vacuum systems are designed with chairside air/water separators rather than a central one. In this case, the ECO II could be installed downstream of the point in the system where all the chair drainpipes connect. If this location were inaccessible, then an alternative would be to install an ECO II unit just downstream of each air/water separator. The additional cost of installing and maintaining multiple ECO II units may be prohibitive.

- During the MCES/MDA study, it was found that the fittings on the ECO II pulled apart from the plumbing system with very little force. MCES/MDA recommended that the design of the fitting be modified to use union fittings for a stronger connection (2001).

- The piping connections are standard metric sizes and require an adaptor to US piping sizes.

Implementation Considerations

- The ECO II is designed to retain the captured amalgam without washout for a year of use under typical operating conditions. However, dental amalgam loading rates have been shown to vary widely depending on the number of chairs connected to the system and number amalgam procedure performed. The use of polishing compound (“prophy paste”) will also add to the solids load within dental wastewater. The ECO II is available only in a single size, and thus the rate of solids accumulation will vary between installations and temporally within a single location. Every month, the dental office staff should perform a visual inspection of the ECO II unit to check the level of the solids accumulated. When the capacity has been reached, the unit should be replaced, even if the unit is not yet due for its annual replacement.

- The ECO II is constructed from polypropylene, and cleansers containing phenol and formaldehyde will cause the ECO II container to blacken, reducing the visibility of the solids inside the container. Metasys/Pure Water Development recommends that a pH-neutral enzymatic cleaner, such as their M2 cleanser, be used with the ECO II.

- Acidic (low pH) or oxidizing cleaners increase the solubility of metals, including mercury. Therefore, to promote the capture of the maximum amount of mercury, acidic or bleach type cleansers should not be used in conjunction with amalgam separators. The M2 cleanser compounds sold by Metasys/Pure Water Development are pH neutral.

- Removal efficiencies for the ECO II installed in dental offices will depend upon the presence of chairside traps and vacuum filters in addition to wastewater flow rates and solids characteristics. Chairside traps and vacuum filters are designed to capture solids to prevent them from causing blockages in the wastewater system or damaging the vacuum pumps. Fewer solids may be captured by the separator in systems with chair side traps and/or vacuum filters upstream of the separator. Although the amalgam separator is also designed to remove solids, having redundant solids removal equipment (i.e. chairside traps, amalgam separators, and vacuum filters) increases the likelihood of solids capture in the event any one piece of equipment malfunctions.

Benefits Derived from Application

- Based on the field and laboratory testing, the ECO II has been shown to remove significantly more dental amalgam particles than a vacuum system with just chairside traps and/or vacuum filters. The ECO II achieved a 96.7% and a 97.5% removal efficiency rating in the two laboratory tests performed using the ISO 11143 testing protocol. For the MCES/MDA study, the measured removal efficiency of the ECO II was 84%. A comparison of the mass of mercury in the effluent from the MCES/MDA study with and without the ECO II shows that the separator lowered the mass of mercury discharged to the sewer system by an order of magnitude, and the average effluent concentration of mercury was 6 mg/L. Average effluent concentrations of mercury in the time-paced wastewater samples collected downstream of the ECO II unit during the UMass Boston field study were typically less than 1 mg/L.

- Metasys/Pure Water Development’s service contract approach relieves the dentist from hands-on maintenance of the unit. Through the service contract, the dentists can call a service provider to perform the annual replacement of the unit. However, the dentist must be an active participant to assure that effective and timely service for the system is provided.

- Once installed, the ECO II operates automatically and does not require day-to-day attention from the dental office staff. The units do not have any moving parts nor do they require any electrical input for operation.

- Because of its relatively small size, the unit is easily retrofitted into existing systems. The unit can be used in with both wet and dry vacuum systems.

Limitations in Application

- The ECO II is rated to a maximum flowrate of 0.5 gallons per minute (2 L/min). Flow rates exceeding the rated maximum will reduce its amalgam removal efficiency.

- The ECO II is designed to remove particulate dental amalgam, not dissolved mercury (fraction passing through a 0.4 – 0.45 um filter). To minimize the amount of dissolved mercury in the wastewater system, acidic or oxidizing (i.e. bleach) should not be used. The M2 cleanser compounds are pH neutral and are recommended for use with the ECO II.

- The ECO II was developed in 1998, and long-term studies of its performance are not available for this system or for any other amalgam separator system on the market today.

- The system does not have an automated mechanism either to assure that dental staff will be warned of system capacity nor does the system have a mechanism to assure that dental staff will comply with best practice recommendations for the use of this system. Abuses, should they occur, are capable of defeating the intended use of this equipment and may be unobservable to regulatory agencies.

- Proper cleaning and replacement of the ECO II is critical to its performance. If the dentist elects not to follow the manufacturer's recommendations and does use bleach to clean the system, the bleach may dissolve the mercury in the amalgam and exacerbate the mercury management problem in the Commonwealth.

References

American Dental Association. July 2002. *Science Versus Emotion in Dental Filling Debate: Who Should Choose What Goes in Your* Mouth? News Release. Chicago, IL. http://www.ada.org/public/media/newsrel/amalgam0207/nr-06.html

Bender, Michael T. June 2002. *Dentist the Menace? The Uncontrolled Release of Dental Mercury*. Montpelier, VT.

Fan, P. L., Ph. D., Hanu Batchu, M.S., Hwai-Nan Chou, M.S., William Gasparac, Dip., Jim Sandrik, Ph.D., and Daniel Meyer, D.D.S. May 2002. "Laboratory Evaluation of Amalgam Separators." *Journal of the American Dental Association.* Vol. 133, pp. 577-589.

International Organization of Standardization. 1999. *Final Draft International Standard for Dental Equipment – Amalgam Separators*. Geneva, Switzerland.

Massachusetts Water Resources Authority. October 2001. *Draft Results of MWRA Testing of Dental Amalgam Separators*. Boston, MA.

Metropolitan Council Environmental Services and Minnesota Dental Association. December 2001. *Evaluation of Amalgam Removal Equipment and Dental Clinic Loadings to the Sanitary Sewer*. Report No. 01-509. St. Paul, MN.

Wallace, Gordon, Ph. D. June 2003. *(Unpublished) Development, Evaluation and Implementation of Testing Protocol for Evaluation of Technologies for Removal of Mercury from Dental Facilities and Technology Verification and Development*. Boston, MA.

Wernisch, J. March 29, 2000. *Separation-Rate Testing According to ISO 11143*. TU Vienna, Institute for Applied and Technical Physics. Vienna, Austria.