THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**SEDIMENTATION AND ADSORPTION OF MERCURY AMALGAM AND MERCURY COMPOUNDS**	
APPLICATION:	**REMOVAL OF MERCURY AMALGAM PARTICULATE AND SOLUBLE AND INSOLUBLE MERCURY FROM DENTAL OFFICE WASTEWATER**	
TECHNOLOGY NAME:	**DENTAL RECYCLING NORTH AMERICA (DRNA) MERCURY RECOVERY UNIT (MRU)**	
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NSF International (NSF), in cooperation with the U.S. Environmental Protection Agency (EPA), operates the Water Quality Protection Center under EPA's Environmental Technology Verification (ETV) Program. As part of the center's activities in verifying the performance of source water protection (SWP) technologies, NSF recently evaluated the performance of a mercury removal unit used in dental offices for removal of mercury from wastewater. This verification statement provides a summary of the test results for the Dental Recycling North America (DRNA) Mercury Recovery Unit (MRU). The NSF laboratories, in conjunction with Scherger Associates, performed the verification testing.

The Environmental Technology Verification Program was created by EPA to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with testing organizations and stakeholder advisory groups consisting of buyers, vendor organizations, permitters, and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in

accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

ABSTRACT

Verification testing of the DRNA Mercury Recovery Unit (MRU) was conducted during a seven-week period, at a dental office in Michigan that had three operatory rooms and two hygiene rooms. The office operated four days per week and averaged approximately eight (8) mercury amalgam surfaces removed/placed per day. The MRU was installed in the vacuum system ahead of the air/water separator, and operated continuously over the verification test period. During an eleven-week period prior to the verification test period, a baseline characterization test was conducted with the total volume of untreated wastewater generated at the office being sampled and analyzed. The characterization data provided representative influent data for comparison with the treated water effluent data collected during the verification test. Mercury removal was calculated by two methods. One approach used the data collected during the characterization test to represent the influent wastewater quality. The second approach used a mass balance that measured all of the mercury captured and discharged by the MRU during the verification test. The MRU achieved mercury removal, on a total mass-loading basis, of 98.3 to 99.4 percent depending on the approach used. The removal of settleable mercury, which represented 77 to 81 percent of the mercury in the wastewater, averaged 99.6 to 99.9 percent. Mercury present in the liquid fraction after settling (soluble and suspended particulate) was removed by the adsorption media in the 92.3 to 94.0 percent range. Both settleable mercury and mercury present in the liquid after settling (soluble and suspended particulate) were effectively removed from the wastewater. The system operated throughout the verification test with no maintenance or down time. There was evidence that the activated carbon adsorption media was breaking down and exiting the unit during the verification test. DRNA indicated this was due to excess bleach being fed to the unit. The concentration of the bleach solution was subsequently decreased during the verification test, and reflects the recommended bleach concentration in the Operations and Maintenance Manual currently being supplied with their units.

TECHNOLOGY DESCRIPTION

The DRNA Mercury Recovery Unit is designed to remove mercury from dental wastewater using a two-step process to address both the insoluble and soluble mercury present in wastewater. Soluble mercury is defined as the mercury, whether in solution or fine particulate, that can pass through a 0.45 micron filter. The verification testing was performed using a full scale, commercially available MRU. The test unit was received as a self-contained system that included all of the parts needed for installation. The equipment included the BullfroHg™ Air/Water/Amalgam Separator, an adsorbent column with particle filter, pump timers, twin peristaltic pumps with waste sensor, and a 10-liter bleach reservoir. The unit came with all of the tubing and fittings to connect the unit to the dental office vacuum system.

The BullfroHg unit is designed to remove mercury amalgam particles from dental wastewater by gravity settling. It is a combined solid and air/water separator that is installed on the suction side of a dental vacuum pump. Three-phase flow (air/water/solids) enters the BullfroHg, where the entrained solids and liquids are retained within the unit and the air flows out to the system vacuum pump. Particles are allowed to settle for several hours after the vacuum system is shut down at the end of the operating day. At the conclusion of settling, a timer-activated pump transfers wastewater from the settling chamber to the adsorbent column, where it passes through adsorbents and a fine particle filter. Amalgam particles remain trapped within the gravity separator unit, while soluble mercury and mercury associated with suspended fine particles are adsorbed onto the column media. A particle filter is located at the end of the column to capture fine particulate not adsorbed by the column media. The treated wastewater is discharged to the sewer system. Approximately 200 mL of bleach solution is pumped into the adsorbent column each day to control biological growth within the column. Mercury captured within the MRU is

typically returned to DRNA for recycle. DRNA has arrangements with mercury recovery companies to recycle the mercury trapped or adsorbed by the MRU, as well as from the chair side traps that are part of a typical vacuum system. The mercury recovery/recycling process used by DRNA was not part of this verification process.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test was performed at a dental office in Southeast Michigan. This general dentistry practice was representative of a small dental office with one or two dentists. The office had five chairs, with two chairs being used for dental hygiene work and three chairs for general dentistry procedures, and typically operated four days per week. During the initial characterization period, there was one dentist in the office. During the verification test period, a second dentist was added on a part time basis. The office uses a dry vacuum system.

Methods and Procedures

During both the wastewater characterization and verification test periods, the entire wastewater flow from the vacuum collection system was collected each day the dental office was open, and was sent to the NSF laboratory by courier service in iced coolers. The samples were prepared in the laboratory and analyzed for total mercury in the settleable solids, total mercury in the decant liquid from the settling procedure and soluble mercury in the decanted liquid. The daily wastewater volume, mass of settleable solids, and pH were also determined. A special procedure was used to separate the settleable solids in the wastewater. The entire sample was placed in a large settling chamber and solids were allowed to settle for at least eight (8) hours. After settling, the liquid fraction containing suspended particles was removed from the settling chamber. The settled solids were collected, filtered, weighed and analyzed for total mercury. The liquid fraction was split into two samples. One sample was analyzed for total mercury, the other sample was filtered through a 0.45 micron filter, and the filtrate analyzed to determine soluble mercury. At the end of the verification test period, residue samples were obtained by removing the solids from the BullfroHg separator, and by removing the adsorbents and particle filter from the adsorbent column. These residues were analyzed for total mercury in order to complete a mass balance of mercury in the MRU.

All samples were preserved and analyzed in accordance with EPA approved methods. Mercury was determined using EPA Method 245.1 for liquids and 245.5 for solids, and Method 150.1 was used for pH determinations.

PERFORMANCE VERIFICATION

System Operation

The MRU was installed in accordance with the manufacturer's instructions received with the unit. The total time to install the unit was less than three hours. The system was wet tested for leaks and to verify the pumps were working properly. After this initial check, the unit operated with no mechanical changes or maintenance for the duration of the seven-week verification test period.

The bleach solution was initially made at the recommended concentration of one part bleach to one part water. After approximately three weeks of operation, the effluent from the MRU was very black in color, and the mercury levels in the effluent increased from less than 1 µg/L to between 1 and10 µg/L. According to DRNA, it was likely that the bleach solution was too strong and was causing a breakdown of the activated carbon, resulting in carbon fines passing through the particle filter and exiting in the effluent. During the characterization phase of the technology verification, DRNA revised their O&M Manual to recommend one part bleach to two parts water. However, this information was not provided

until NSF contacted DRNA about the change in the MRU effluent quality. The bleach concentration was subsequently changed to the revised recommended concentration of one part bleach to two parts water. Carbon fines continued to be discharged from the MRU at reduced levels after the bleach concentration was reduced. DRNA has since revised the recommended bleach concentration once again to one part bleach to three parts water. However, no testing was performed using this concentration.

Wastewater Characterization Results

The wastewater characterization test was conducted from July 10 through September 21, 2001, with 44 complete sample sets being collected over the eleven-week period. The dental office normally operated four days per week, and samples were collected at the end of each normal business day. Three hundred thirty four (334) mercury amalgam surfaces were removed and/or placed during the characterization test. Each wastewater sample was allowed to settle in the laboratory to separate the settleable solids from the wastewater, resulting in three samples for mercury measurement - total mercury in the settleable solids, total mercury in the liquid fraction (decant after settling, including both suspended particulate matter and soluble mercury), and soluble mercury in the liquid fraction. The wastewater flow (all flow collected as sample) averaged 2.2 liters per day, ranging from a high flow of 5.9 liters per day to a low of 0.13 liters per day.

The average total mercury concentration in the wastewater (settleable solids plus mercury in the decant liquid) was 657 µg/L, varying from a high of 1810 µg/L to a low of 73 µg/L. The average mass of mercury was 1.60 mg/day, varying from 0.05 mg/day to 6.81 mg/day. The decanted liquid fraction (after settling) averaged 192 µg/L. The soluble mercury fraction in the decanted liquid averaged 127 µg/L, and typically represented 50-70 percent of the mercury in this fraction of the wastewater. The summary statistics for the wastewater characterization are presented in Table 1.

Table 1. Mercury Data Summary – Wastewater Characterization Test

	Decant Liquid Concentration (mg/L)		Total Wastewater Volume (mL)	Hg Mass (mg/day)		Total Wastewater	
	Total	Soluble		Settleable Solids	Decant Liquid	Concentration (µg/L)	Mass (mg/day)
Average	0.192	0.127	2180	1.23	0.364	657	1.60
Maximum	0.676	0.632	5880	6.49	1.90	1810	6.82
Minimum	0.0446	0.0044	129	<0.01	0.0094	72.6	0.0537
Std. Dev	0.152	0.139	1410	1.81	0.369	581	1.94
Total Mass/ vol.			100,000	54.2 (mg)	16.7 (mg)		

Verification Test Results

The verification test was performed from September 24 through November 8, 2001, with 32 complete sample sets of MRU treated effluent being collected and analyzed. During the seven-week verification period, the dental office added a dentist on a part time basis. The office operated on a four or five day per week schedule with 243 mercury amalgam surfaces being removed/placed on 29 operating days. The average amalgam surface removal/placement rate of 8.38 surfaces per operating day was similar to the rate during the characterization test (7.73 – 7.95 surfaces per day).

MRU effluent wastewater samples were handled in the same manner as during the characterization test, resulting in three samples for mercury measurement - total mercury in the settleable solids, total mercury in the liquid fraction (decant after settling, including both suspended particulate and soluble mercury), and

soluble mercury in the liquid fraction. The results of the analyses are presented in Table 2. The average total mercury discharge concentration from the MRU was 10.3 µg/L, with a maximum of 39.8 µg/L and a minimum of <0.2 µg/L. The average mass of mercury discharged on a daily basis was 0.036 mg/day, with the settleable solids portion representing an average of 0.007 mg/day and the liquid fraction having an average of 0.0284 mg/day. The mercury contribution from the settleable solids represented 19 percent of the mercury present in the discharge after treatment versus 77 percent in the untreated wastewater.

Table 2. Summary Statistics Mercury Results for DRNA MRU Effluent

	Decant Liquid Concentration (mg/L)		Total Wastewater Volume (mL)	Hg Mass (mg/day)		Total Wastewater	
	Total	Soluble		Settleable Solids	Decant Liquid	Concentration (µg/L)	Mass (mg/day)
Average	0.0079	0.0027	2550	0.0073	0.0284	10.3	0.0357
Maximum	0.0337	0.0135	6060	0.043	0.177	39.8	0.217
Minimum	<0.0002	<0.0002	177	0.00	<0.0002	<0.2	<0.0003
Std. Dev	0.0108	0.0037	1770	0.0103	0.0507	12.8	0.0601
Total mass			81,700	0.234 (mg)	0.909 (mg)		

Note: All Values below Detection Limit set equal to zero in calculation

The mercury concentration in the discharge was either below the detection limit (<0.2 µg/L) or in the 0.2 to 3.5 µg/L range for the first eighteen days of the verification test. During the first few days, the effluent had no settleable solids and had very low suspended solids in the liquid fraction. The effluent then began to darken in color and became very black, with noticeable suspended particulate present; however, only a small portion of these solids settled. The amount of solids being filtered from the liquid fraction began to increase and the solids were very black and fine in appearance. The bleach solution was changed to the new recommended strength about 3½weeks into the test, and over the next 1½weeks, the total mercury concentration in the effluent, the mass of settleable solids found in the separation procedure, and the amount of solids being filtered from the decant liquid reached peak levels. For the last two weeks, the mass of dry solids and the mercury concentration in the MRU effluent stabilized and began to decrease. On the last two days of the verification test, the mass of solids and the mercury concentration in the effluent again increased. It was noted that the total flow from the dental office was higher than average on these final two days. The final day's flow was impacted by the extra flushing of the vacuum system performed to clear the lines at the end of the test. On the second to last day of the test, the number of mercury amalgam surfaces removed and placed was higher than average. These factors may have impacted the performance of the MRU.

DRNA MRU Performance

As described in the general protocol for test plan development, it was not possible to collect influent and effluent samples simultaneously during the verification period due to the small volume of the influent flow, the operation of the system under vacuum, and the difficulty of obtaining representative samples (particularly of solids) from small pipes, with small intermittent flow under vacuum. The test plan was designed to obtain data that could be used for two different approaches to determine the treatment efficiency of the unit. The first approach used the characterization test data, collected for the eleven weeks prior to the verification test period, to determine the average mercury concentration and average mercury mass discharged from the dental office on a daily basis. The dental office operation was similar during both the characterization period and the verification period, which allowed the characterization data to be used as a substitute for the actual influent characteristics during the verification test period. For

the second approach, effluent quality was measured directly during the verification test period. At the end of the test period, a mass balance for the MRU was completed using the effluent data collected during the verification test period and the mass of mercury retained in the MRU.

Characterization Data vs. Verification Data

Comparing the characterization data to the treated effluent data shows that the DRNA MRU was effective in removing the settleable solids and the mercury in these solids, achieving better than 99 percent removal either on an average concentration basis or on a total mass basis. As shown in Table 3, the overall removal of mercury (solids and liquid combined) was 98.7 percent on a concentration basis and 98.3 percent on a total mass basis. Removal efficiency for the mercury associated with the settleable solids was 99.6 percent. The MRU also was effective in removing the mercury associated with the decant liquid fraction (soluble and suspended mercury) showing an efficiency of 92.8 percent.

Table 3. Removal Efficiency Based on Characterization Data- Total Mass and Average Concentration

	Settleable Solids Mass (mg)	Decant Liquid Mass (mg)	Total Wastewater	
			Concentration (µg/L)	Mass (mg)
Characterization (7/30-9/20/2002)	53.3	12.7	778	66.0
MRU Discharge (9/25-11/9/2002)	0.234	0.909	10.3	1.14
% Removal	99.6	92.8	98.7	98.3

Mass Balance of Verification Data

The second approach to calculating removal efficiency is based on measuring all of the mercury retained in the unit during the verification test and calculating the total load to the MRU (retained mercury + discharged mercury = total influent mercury). Using this approach, the DRNA MRU removed over 99 percent of the mercury in the settleable solids and over 99 percent of the total mercury delivered to the MRU. The MRU was also effective in reducing the mercury in the liquid fraction by 94 percent. The results for the verification test mass balance are shown in Table 4. The removal efficiencies calculated by the mass balance are similar to the removal efficiencies found using the characterization data. In general, the mass balance approach does tend to show somewhat larger removal efficiencies because there was a greater total mass of mercury, particularly in the settleable solids, during the verification test than during the characterization test.

Under these conditions, verification testing demonstrated the DRNA MRU to be capable of removing greater than 99 percent of the mercury associated with settleable solids, 92 to 94 percent of the mercury associated with the liquid fraction (soluble plus suspended particulate), and 98 to 99 percent of the total mercury present in the wastewater.

Table 4. Removal Efficiency based on Mass Balance of Retained and Discharged Mercury

	Mass of Mercury		
	Settleable Solids (mg)	Decant Liquid (mg)	Total Wastewater (mg)
Separator-Retained	181	-	181
Filter-Retained	-	0.049	0.049
Carbon-Retained	-	4.98	4.98
Resin-Retained	-	9.24	9.24
Discharge	0.234	0.909	1.14
Total Mass Load	182	15.2	197
% Removal	99.9	94.0	99.4

Operation and Maintenance Results

The MRU was easy to operate, requiring no operator intervention except for occasionally verifying pump operation and weekly checks of the bleach solution level. Once the unit was installed and operational, there were no maintenance requirements other than replenishing the bleach solution, and the unit performed without interruption for seven weeks. DRNA's recommended maintenance interval is 6-12 months depending on the amount of material treated in the wastewater stream. Visual observations made during the verification test, and a review of the type of pumps and materials of construction used in the MRU, did not indicate otherwise. The only operational problem encountered during the verification test was the increase in solids in the MRU effluent, apparently from the bleach solution causing the carbon to breakdown and be discharged. The bleach solution to water ratio was adjusted to what DRNA recommends for units currently being sold.

Two quantifiable O&M factors that apply to the DRNA MRU are electrical usage and chemical usage. The electrical power requirement was 120VAC, 4 amps for each of the two pumps in the unit. Total electrical use can be expected to average about 2,400 watts per day. At a mix ratio of 1 part bleach to 3 parts water, approximately 1.2 liters of bleach per month will be used.

The MRU did not require cleanout or maintenance during the verification test period. Observation during the recovery of the settleable solids from the separator showed that less one percent of the solids separator volume (<100 mL of solids in a 10 liter unit) was accumulated during the seven-week test period. The separator should therefore have sufficient capacity to hold six months to one year of solids at the accumulation rate experienced during the verification test. DRNA provided proprietary information on the mercury adsorbing capacity of the adsorbent material. Measurement of the weight of adsorbent in the MRU combined with results of quality control samples that independently measured the adsorption of mercury, indicated sufficient adsorption capacity to treat soluble mercury for six months to one year, assuming no breakdown of the adsorbent material. The costs associated with cleanout of the MRU on the regularly scheduled change out (6 – 12 months) are the cost to ship the unit to DRNA and the cost associated with the recycling service. The MRU has been designed to facilitate the change out for return to DRNA, with quick disconnects and an arrangement that will assure complete containment of the MRU content during shipping.

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Availability of Supporting Documents

Copies of the *ETV Protocol for Verification Testing for Mercury Amalgam Removal Technologies* dated April 2001, the Verification Statement, and the Verification Report are available from the following sources:

Source Water Protection ETV Pilot Manager (order hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140

NSF web site: http://www.nsf.org/etv (electronic copy)

EPA web site: http://www.epa.gov/etv (electronic copy)

(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)