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TREATMENT OF DENTAL AMALGAM WASTES

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ABSTRACT

Extraction and recovery of Hg from dental amalgam waste was done by retorting and gravity separation. It was found out that Hg exists in three phases in the dental amalgam waste slurry. In the first phase Hg existed as a free metal. 557.2 g of free Hg was recovered from the three 300 ml samples of dental amalgam waste. The samples were first drained of water and then filtered using a nylon or linen cloth wherein Hg was easily squeezed out. The filtrate, which is the dental amalgam alloy, was hand-panned to recover remaining free mercury that was not squeezed out of the cloth. After panning, the dental amalgam alloy was air dried to remove excess water and to prepare it for retorting. In the second phase, Hg existed in the dental amalgam waste alloyed in the amalgam. The set amalgam will ideally consist of 50% Hg but it may contain as high as 60% and as low as 40% by weight. Overall, 617.7 g of dental amalgam was collected from 900 ml of sample waste. The dental amalgam was retorted, using a ThermEx® retort, for 30 min per 100 g of dental amalgam. There was an average of 88.53% recovery. From the expected recovery of 150 g, only 132.8 g were collected from the three trials. This perhaps is an indication that the time of retorting may have been insufficient to ensure 100% recovery. Moreover, the original amalgam alloy's Hg-alloy ratio could have been lower than the ideal 1:1 ratio. In addition, the manner or method of mixing of Hg with the dental alloy probably did not promote complete mixing during preparation thus failing to provide optimum absorption of Hg. The third phase of Hg in the dental amalgam waste consists of the dispersed Hg in water. Extraction of Hg from this phase will require a separate study.

I. INTRODUCTION

Amalgam is an alloy of one or more metals with Hg. It is dentistry's main therapeutic agent for restoring decayed teeth. The oldest written record, according to the American Dental Association, of the use of amalgam in dentistry is a publication in 1528. For years, dentists have employed amalgam for dental fillings and restorations because of its remarkable properties. This metal, once alloyed, inserted and finished in the teeth, will harden to a structure that can withstand the rigors of the oral environment. Properly condensed amalgam exhibits compressive strength as high as some cast irons. The amalgam can withstand the corrosive environment in the mouth but are bland to the host. The combination of all these properties makes amalgam the most universally used restorative material.

The modern dental alloy consists of four metals: Silver (Ag), Tin (Sn), Copper (Cu), and Zinc (Zn). The composition of a dental amalgam is as follows:

Traditional alloys:

Ag	66 – 74%	Sn	25 –28%
Cu	7 – 5%	Zn	0 – 2%

High Copper content alloys:

Ag	60 – 70%	Sn	23 – 27%
Cu	7 – 18%	Zn	0 – 1.5%

The alloy described above is triturated with pure Hg until a coherent, plastic mass is formed. The amounts of Ag and Sn make the dental alloy essentially a Silver-Tin alloy. Silver and tin amalgamates easily with Hg at room temperature and even more readily on warming. In fact, practically all metals will form alloys or amalgams with Hg.

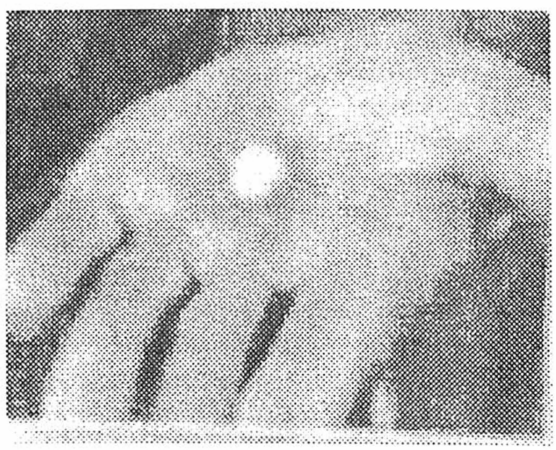

Figure 1-1. Set dental amalgam alloy

Many factors are involved in obtaining the most desirable combination of physical properties in a dental amalgam. One of this is Hg content of the restoration, a very important factor in the control of strength. If mercury is less and is not enough to coat the alloy particles, the resulting amalgam will be dry, grainy, rough, pitted, and prone to corrosion. On the other hand, if Hg is in excess, it can produce a marked reduction in strength. The ratio of Hg to alloy has much influence on the mechanical properties of the amalgam. The recommended Hg-alloy ratio for most modern amalgam alloys is in the realm of 1:1 or 50% Hg by weight. The amalgam though, may have a Hg-alloy ratio that could reach up to 1.6 – 1.75:1.

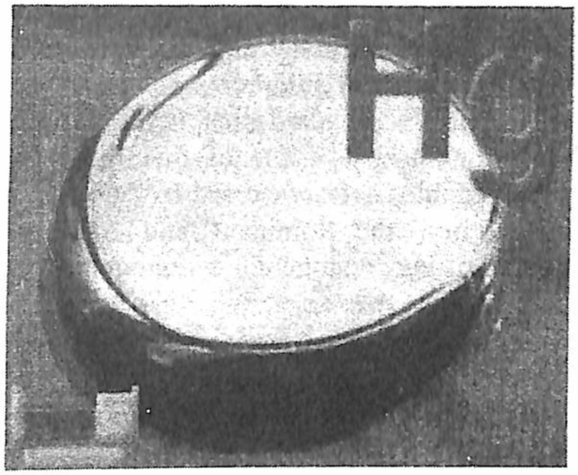

Figure 1-2 Liquid-metal Mercury (Hg)

From its earliest use, Hg's possible side effects have been questioned. It is still sometimes conjectured that Hg toxicity from dental restorations is the cause of certain undiagnosed illnesses. This raised health and environmental concerns regarding its usage and disposal. Although patients became more interested in aesthetics and environmental issues that raised the demand for alternative materials such as composites for restorative purposes, dental amalgam is still very much employed especially in the third world countries. [11]. This is because it requires less dental maintenance at a relatively low cost.

The production of excess dental amalgam for every dental restoration is difficult to avoid. The amount to be prepared can only be approximated by the dentist or the one preparing it. Excess Hg is also hard to avoid particularly when traditional methods of mixing of Hg and alloy are employed. In addition, the problem of recapturing amalgam wastes within the dental office to avoid contamination of waste water system has contributed to its accumulation.

Due to the high amounts of Hg present in the dental amalgam waste, its disposal poses a threat to health and environment since all compounds of Hg are toxic to humans. If Hg can be extracted and recovered, it will significantly reduce the level of toxicity of the dental amalgam wastes.

It was found out that Hg exists in three phases in the dental amalgam waste slurry: the free phase, the alloyed phase and the dispersed phase in the liquid medium. The objective of this study is to look into the extraction and recovery of Hg from the first two phases. The extraction and recovery of Hg from the third phase, however, will not be part of this paper and will require a separate study.

1.1 Toxicity

Elemental Mercury, both in liquid and vapor form, is known to be one of the most toxic elements to man and many higher animals. Mercury salts show a high acute toxicity, with a variety of symptoms and damages. Some mercurials, in particular low-molecular-weight alkyl mercury compounds, are considered even more hazardous to humans because of their high chronic toxicity with respect to different, irreversible, defects caused to the nervous system making it neurotoxic. Methylmercury, the dominant and one of the most avoided compounds of Hg shows strong teratogenic, carcinogenic, and mutagenic effects [12].

The more commonly accepted vehicle of Hg to man is ingestion, particularly by eating animals carrying Hg in their system but it can also be incorporated in the body by inhalation of mercury vapor. Hg is volatile at room temperature and cannot be readily detected by simple means. The maximum level of occupational exposure considered safe is 50 μg of Hg per cubic meter of air [9]. Mercury salts released into the environment may frequently be converted by anaerobic bacteria into other mercury-containing compounds that can be carried through the food chain to humans. Mercury is the only metal which undisputably biomagnifies through the food chain meaning, its concentration increases each step in the food chain due to accumulation from one organism to another [5].

Mercury is naturally present in low quantities in all living organisms [5] but through accumulation, levels may reach an unhealthy level. The toxicity of Hg is attributed to its high affinity for sulfur containing compounds and its lesser affinity for organic ligands. Interference by mercury in the synthesis and function of enzymes and other proteins can result in a variety of adverse effects. Methylmercury also accumulates in the fetus. Symptoms of acute mercury poisoning are metallic taste, nausea, abdominal pain, vomiting, diarrhea, headache, salivation, and anuria [3].

1.2 Mercury in the dental industry

The possible side effects of Mercury have been questioned even before in its earliest use. Some undiagnosed illnesses are attributed to mercury toxicity from dental restorations and it is surmised that a real hazard exists for the dentist or dental assistant and the patient when mercury vapor is inhaled. Mercury penetrates from the restoration into tooth structure showed by an analysis of dentin underlying amalgam restorations. Small amounts of mercury were said to be released by mastication and the danger caused by this has been evaluated in numerous studies [9].

1.3 Metallurgy of dental amalgams

1.3.1 Amalgamation

An amalgam is a type of alloy with mercury as one of its constituents. Inasmuch as Mercury is liquid at room temperature, it can be alloyed with other metals in the solid state due to its propensity to form alloys with almost all metals. The process in which Mercury is combined with other metals is called amalgamation.

In restoring decayed teeth, amalgam was proven to be dentistry's main therapeutic agent. Its chief use in dental applications is as a filing for tooth cavities. Properly condensed amalgams can withstand the corrosive mouth environment and are bland to the host. In addition, once the amalgam is set, it exhibits compressive strength as high as some case metals. Such properties make the amalgam the most universally used restorative metal [8].

To make the amalgam, Mercury is mixed with a powder of the dental amalgam alloy by a procedure technically called trituration. Trituration facilitates the reaction between the alloy particles and the Mercury by exposing fresh surfaces through fracture or abrasion of the alloy particles. As the reaction proceeds the liquid mercury is replaced by various solid phases, thus producing a hardening of the formerly plastic or soft amalgam [8]. In essence, the Mercury is absorbed into the small particles of the powdered dental amalgam alloy. Enough Mercury must be added to form a cohesive plastic mass so that it can be packed into position in the tooth cavity. The phases formed possess melting points that exceed the temperature normally encountered in the mouth. The reaction between Hg and the components of the dental alloy to form a composite material is followed by the setting and hardening of the amalgam as Hg is consumed in the formation of new solid phases [9].

1.3.2 Amalgam composition

Many factors are involved in obtaining the most desirable combination of values for physical properties in a dental amalgam. Among these, the Hg-to-alloy ratio seems to have the most influence since it has a considerable influence on the mechanical properties.

Silver and Tin constitutes the largest part of the dental alloy making the dental alloy almost a Silver-Tin alloy. Silver is at least two thirds of the total composition. The main contribution of this metal to the amalgam is strength. In general, to increase the hardness of the amalgam one should increase its Ag content. Tin on the other hand tends to decrease the strength of the amalgam. In addition, excessive Sn will result in decreased resistance to corrosion and a prolonged setting time of the amalgam. In the case of Copper, its effect is similar to that of Ag in the way it adds strength. Excessive amounts of Cu will result in tarnishing which degrades the physical appearance of the amalgam. In the addition of zinc, the darkening of the amalgam mass is prevented during the trituration process [10].

Table 1. Composition of conventional dental amalgam alloys

	Range Composition (%)	
Element	Traditional Alloys	High-copper Alloys
Silver	66 - 74	60 – 70
Tin	25 - 28	23 - 27
Copper	2 - 5	7 – 18
Zinc	0 - 2	0 – 1.5

Less Mercury will also lessen plasticity, which is needed to successfully fill and pack the tooth cavity. As the Mercury content decreases, the strength and hardness of the amalgam increase up to a certain point, and a further decrease the material becomes more brittle [7]. Excess Mercury on the other hand may cause some of the Mercury to ooze out of the matrix that will lead to Hg ingestion. In the case of excess Mercury, it is removed by squeezing or wringing the mixed amalgam in a squeeze cloth prior to insertion into the prepared cavity. Although excellent restorations may be produced in this manner, the amount of Hg removed by the squeeze cloth varies and there is a considerable chance of error. Sufficient Hg is needed but it must be low enough that the Mercury content of the restoration is at an acceptable level without the need to remove an appreciable amount during condensation or setting. The recommended mercury to alloy ratio for most modern alloys is in the realm of 1:1 or 50wt% mercury [9].

II. EXPERIMENTAL METHOD

2.1 Materials acquisition and sampling

The samples used were taken from dental amalgam waste materials from dental operations in the College of Dentistry in the University of the Philippines Manila. The dental amalgam wastes were in the form of slurry containing leftover set amalgams, and excess mercury and some silver-copper alloys. The set amalgams according to the source were prepared in a 1:1 weight ratio of Silver-Copper (Ag-Cu) alloy with Mercury (Hg).

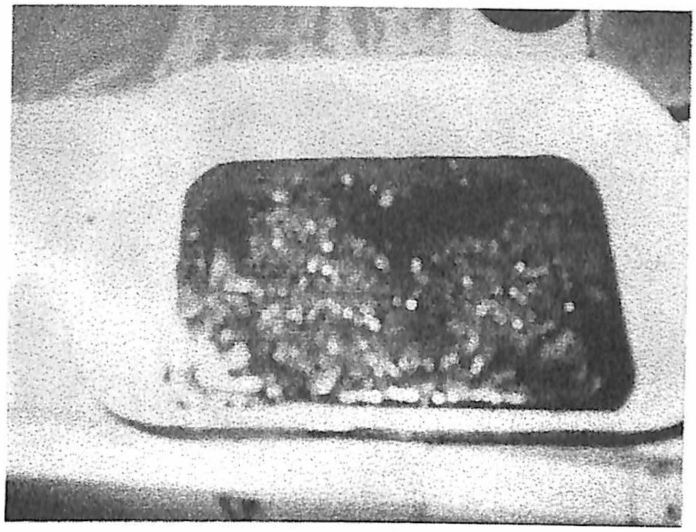

Figure 2-1. Dental amalgam-waste slurry

Three 300-ml samples were separately taken for the purpose of this experiment. Each of which was subjected to the same conditions and method of experimentation.

2.2 Extraction

Separation of the bulk of Hg from the dental amalgam waste and reclamation of Hg were effected by gravity separation and retorting.

2.2.1 Solid-Liquid separation

All samples were separately filtered using a nylon or linen cloth. Filter paper was not utilized as this may tear due to Hg's weight and Hg will not readily pass through it. Filtration was effected by pressure. The dental amalgam waste was squeezed out by hand through the strong and tight fabric. The method forced Hg out of the fabric along with most of the liquid while leaving the solids trapped in the cloth. The supernatant solution containing free Hg was repeatedly washed and decanted to recover Hg and dispose excess water.

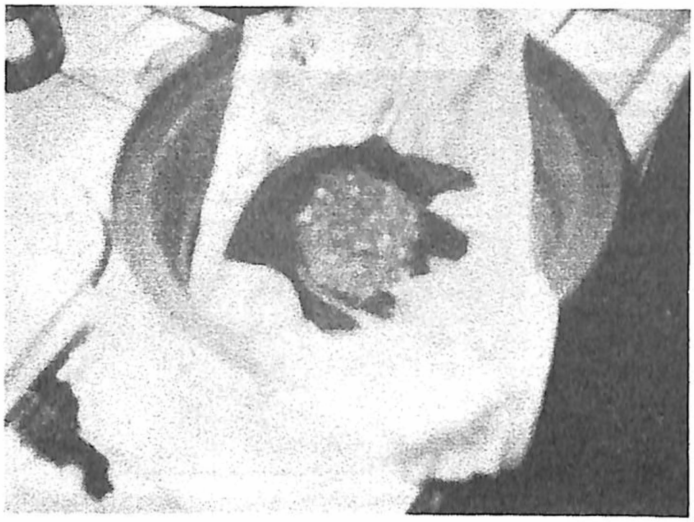

Figure 2-2. Filtration using linen cloth

2.2.2 Retorting

The filtrates on the other hand were hand panned to remove the free Hg that was not squeezed out of the fabric. The nature of the filtrate was very suitable for panning to concentrate the remaining free Hg.

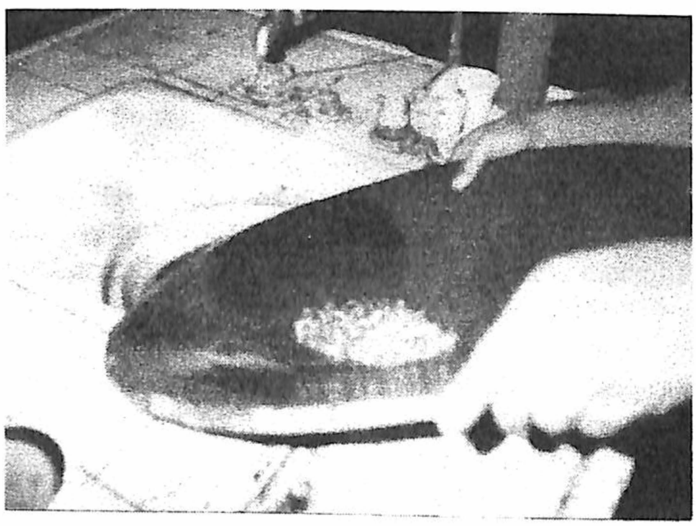

Figure 2-3. Hand panning for Hg

After panning, the filtrate was prepared for retorting. The retorting was done using a ThermEx® Retort. Prior to retorting, the filtrate was air-dried to remove excess moisture to save time and energy during retorting and to maximize the retort's capacity. Air-drying was employed to minimize Hg loss due to evaporation since Hg evaporates at room temperature.

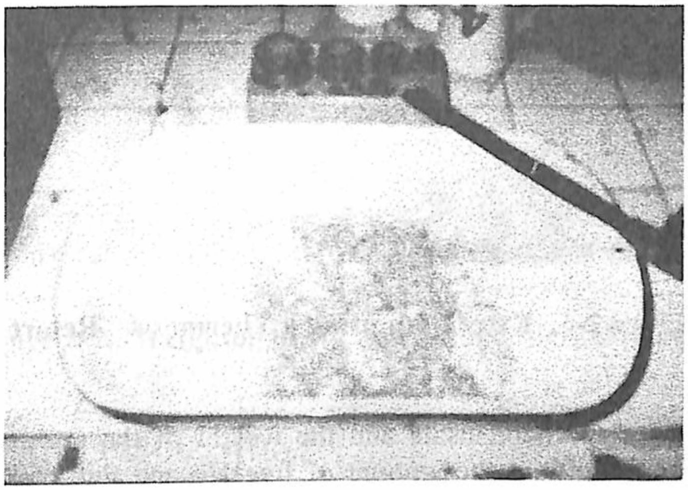

Figure 2-4. Air drying of amalgam scraps

Three trials were conducted. Each trial involved the retorting of 100 grams of dental amalgam scraps that were separated from the slurry. The scraps were continuously heated using a Bunsen burner to maintain a steady trickle of condensate, the condensed mercury, over a period of 30 minutes. After such time, the fire was withdrawn and the retort was allowed to cool until it can be opened to charge it with the next batch of dental amalgam scraps.

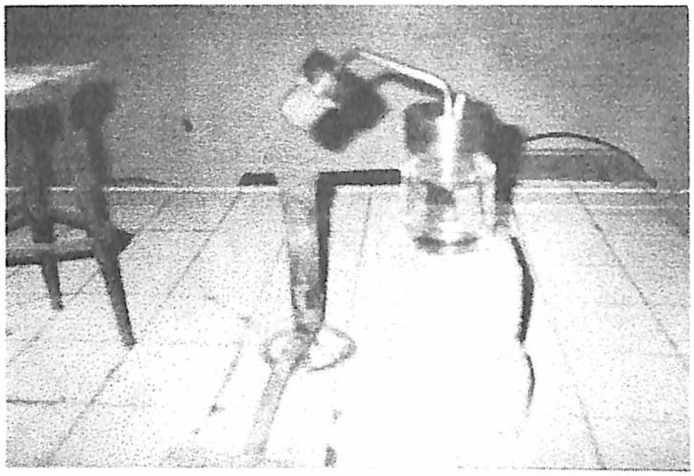

Figure 2-5. Extraction using a Thermex® Retort

The weight of the condensate and the weight of the retorted dental alloy were recorded. In addition, the amount of free Hg and the total Hg recovered were calculated for the purpose of recovery and method efficiency calculations.

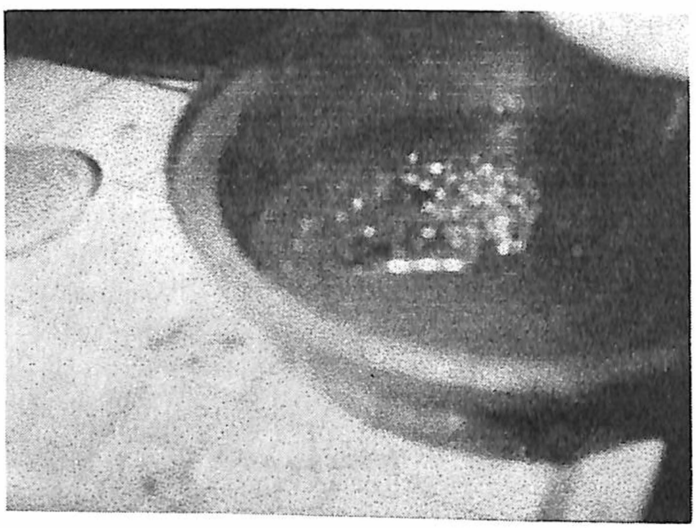

Figure 2-6. Recovered Hg from retorting

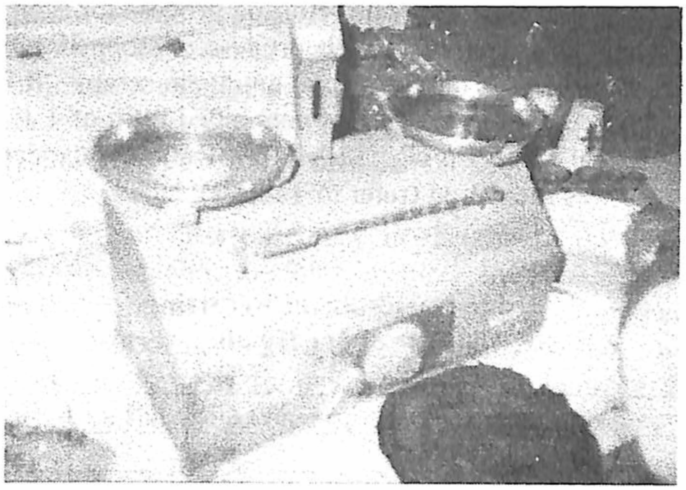

Figure 2-7. Weighing of Hg and leftover dental alloys

III. RESULTS AND DISCUSSIONS

Separation and reclamation of Mercury from the dental amalgam waste were effected by gravity separation and retorting.

It was found out that the Mercury exists in three phases in the dental amalgam waste. The first phase, with Hg existing as a free metal, constituted roughly 60% of the total Hg recovered by the overall process (refer to Table 1). Free Hg was recovered by straining and filtering the dental amalgam waste slurry to separate it from the gross impurities and dental amalgam scraps. After the solid parts of the slurry were separated, the liquid part was then decanted to remove excess water and obtain the free Hg.

Table 2. Results of Gravity Concentration
Basis: 617.7 gms of amalgam scraps

TRIAL	Weight of free Hg
1	189.2
2	191.4
3	176.6
TOTAL	557.2

Retorting facilitated the recovery of the second phase where Hg is present in the dental amalgam waste slurry. The retorting process for each trial was set to last for 30 minutes. After such time, the process is stopped. This resulted in 88.53% recovery of mercury from the dental amalgam scraps. It is assumed that the Hg-alloy ratio strictly followed the recommended ratio of 1:1, as reported by the source of the dental amalgam waste samples. From the expected 150 gms of Hg, only 132.8 gms was recovered (refer to Table 2).

Table 3. Results of Retorting
Basis: 100 gms of 1:1 Hg alloy scraps

TRIAL	Wt Hg	Wt alloy left	% Hg Recovery
1	42.8	56.4	85.6
2	44.7	54.4	89.4
3	45.3	54.1	90.6
AVERAGE	44.27	54.97	88.53
Total	132.8	164.9	

This outcome could perhaps be explained by putting in mind two things: first, the time of retorting may have been insufficient to recover all the mercury; second, if the time were sufficient, the Hg-alloy ratio may have been below the assumed ratio of 1:1. The attainment of the recommended 1:1 ratio may have been crudely approached particularly if the method of mixing is manual trituration. In preparing the amalgam, the quantity of Hg that will be absorbed depends upon the method of which the dental alloy and the Mercury were mixed.

If the assumed ratio is correct and only the free Hg and the alloyed Hg were to be considered, the overall efficiency of the methods employed was calculated to be 95.9%. This is of course based on the obtained average recovery of 88.53% for 30 minutes of retorting time. Thus, the method employed can significantly reduce the level of toxicity of the dental amalgam waste.

Total volume of dental amalgam waste = 900 ml
Volume of each sample = 300 ml

IV. CONCLUSION AND RECOMMENDATIONS

With an average recovery of 88.53% in retorting and an overall process efficiency of 95.9%, the method employed was proven to be effective in reclaiming much of the alloyed Hg in the dental amalgam. This in effect, has significantly reduced the level of toxicity of the dental amalgam waste.

An Hg-alloy ratio of 1:1 was assumed in recovery calculations in retorting. This assumption however, does not go far in comparison to the actual ratio as stated by the sample source and an implication thereof is that an assumption of 1:1 Hg-alloy ratio can be applied without compromising the accuracy of the recovery and efficiency calculation. To avoid such assumption, the author recommends ensuring 1:1 ratio by controlling the amalgam composition and carefully mixing and trituration of the dental amalgam.

For the overall process efficiency in reclaiming the Hg content of the dental amalgam waste, which is the form of slurry, the phases wherein Hg existed as a free metal in the slurry and as alloyed Hg were the only ones considered. The reclamation of the finely dispersed Hg in the solution was not investigated. The methods used in this study were limited only to Hg reclamation for the first two phases. A separate and an additional study will be required to investigate the third phase.

V. REFERENCES

1. U.S. Bureau of Mines Staff [Washington]; Mercury Potentials of the United States; U.S. Department of Interior, Bureau of Mines, (1965).

2. Engleston, Thomas, L.L.D; The Metallurgy of Silver, Gold, and Mercury in the United States; Offices of "Engineering", London and John Wiley and Sons, New York, (1980).

3. Sittig, Marshall; Toxic Metals: Pollution Control and Worker Protection, Noyes Data Corporation, (1976).

4. Solomons, W., Forstner, U. and Mader, P.; Heavy Metals: Problems and Solutions: Springer-Verlag Berlin Heidelberg New York, (1995).

5. Hutchinson, T.C. and Meema, K.M.; Lead, Mercury, Cadmium, and Arsenic in the Environment, Scientific Committee on Problems of the Environment, (1987).

6. Hawkes, H.E. and Webb, J.S.; Geochemistry in Mineral Exploration; Harper and Row, Publishers; New York, (1962)

7. Smith, J. and Campbell, B.SC.; The Chemistry and Metallurgy of Dental Materials, Blackwell Scientific Publications, Oxford, (1946).

8. American Dental Association; Guide to Dental Materials and Devices 6th Ed., American Dental Association, Chicago, (1972).

9. Phillips, Ralph W. .M.S., D.Sc.; Science of Dental Materials 9th Ed., W.B. Saunders Company, (1991).

10. Leinfelder, K.F., D.D.S., M.S. and Taylor, D.F., B.S.E., M.S.E., PhD; Laboratory and Clinical Dental Materials, The University of North Carolina Press, (1981).

11. *Journal of Esthetic Dentistry,* Vol. 12, No. 4, B.C. Decker Inc. (2000)

12. Alloway, B.J. Heavy Metals in Soils, 2nd Ed., Blackie Academic and Professional, Chapman and Hall, (1995)