# REPORT

# ON
# FOLLOW-UP

# RETORT EVALUATION

**Prepared by:**

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# Acknowledgement

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# 1.0 Summary

An evaluation and ranking of the retorts available in Guyana was conducted by Mr. M. Samaroo and the results were presented in his Retort Evaluation Report, dated September 27, 2000. It was concluded from this evaluation that the imported retorts required significant design modifications to operate under local condition (on a wood fire) and the acquisition cost of the efficient locally fabricated retorts may be prohibitive. During the initial testing, the modified IT retort (ED Grasshopper retort) performed creditably and was considered cheap to produce locally, since it was essentially fabricated from easily accessible galvanized pipe fittings. However, the low strength of the galvanized pipe fittings and the threaded crucible of the ED Grasshopper retort jeopardized its' durability.

These observations constituted the genesis of the follow-up retort-testing program, the main objectives of which were to develop, test, evaluate and approve a retort (local) that would have the following fundamental properties:

- Low acquisition cost
- High (acceptable) Vapour Recovery Efficiencies (>95%)
- Low retorting time
- Suitable for use on a wood fire
- Robust and durable
- Widespread acceptance
- Requiring no/minimum maintenance

In addition to the above mentioned objectives, this report provides a brief background for the use of mercury to recover gold in Guyana and describes some of the health hazards associated with the use of mercury. It also provides effective actions to minimize the risk of mercury contamination and offers some practical procedures to be followed in the use of retorts to remove and recover mercury from gold amalgam.

To achieve these objectives, four (4) retorts, variants of the ED Grasshopper retort, and identified as ED Models 1, 2, 3 and 4, were fabricated, tested and evaluated. The results of the experimental comparison of these four retorts are presented and discussed in this report.

Models 2, 3 and 4 were variations of model 1 **(Table 1)**, mainly with amendments to the crucible size, design of the permanent seal and the vapour discharge pipe (the angle of the bend above the crucible). These retort do not include a water jacket to aid the condensation of mercury vapour, however their extended vapour discharge pipe (except for Model 1) facilitates speedy condensation of the vapour. Unlike the IT retort, all the models tested were constructed from mild steel, not galvanized pipe.

**Table 1:** Summary of Design Parameters: ED Grasshopper and ED Models 1-4

| **Retort ID** | | **ED Grasshopper** | **ED Model 1** | **ED Model 2** | **ED Model 3** | **ED Model 4** |
|---|---|---|---|---|---|---|
| **Crucible** | Outer Diameter (OD), cm | 2.5 | 6 | 12 | 10 | 12 |
| | Height (H), cm | 4.9 | 6.4 | 5 | 5 | 4.5 |
| | Thickness (T), cm | 1.1 | 0.4 | 0.4 | 0.4 | 0.4 |
| | Shape | Oval depression in the centre of the bottom | Flat Bottom | Flat Bottom | Concave Bottom | Concave Bottom |
| **Vapour Discharge Pipe** | Size, cm | 1.3 | 1.3 | 1.3 | 2 | 2 |
| | Rise above crucible | 8.6 | 13 Vertically | 2.5 Vertically | 7.6 at $55^0$ | 5.08 at $32^0$ |
| | Length, cm | 58.4 | 56 | 61 | 64 | 74 |
| | Angle Above Crucible, degs | 78 | 15 | 10 | 15 | 16 |
| Permanent Seal | | Threaded crucible fitting into cover | Tapered cover fitting into crucible | Cover fitting into crucible–precisely machined surfaces | Cover fitting over crucible – precisely machined surfaces | Cover fitting into crucible – precisely machined surfaces |
| Vapour Exit | | Cylindrical | Small funnel machined into the cover | Small funnel machined into the cover | Funnel-shaped cover fitting over crucible | Small funnel machined into the cover |
| Material Type | | Galvanized pipe fittings | Mild steel | Mild steel | Mild steel | Mild steel |
| Recovery, % (with a mud seal and using Hg only) | | 93 | N/A | 90.4 | 96.3 | 82.5 |
| Cost, G$ | | 2,900 | 6,500 | 7,500 | 12,000 | 17,000 |

The crucible of Model 2 was twice as wide as that of Model 1 and 1cm less in height. The vertical rise of the condensate discharge pipe above the crucible of Model 2 was 10.5 cm less than in Model 1. When compared to Model 1, Model 2 had a less acute bend above the crucible and a 5 cm longer vapour discharge pipe **(Figures 1 and 2, Table 1)**.

The lower base of the funnel shaped cover of Model 3 essentially covered the crucible, whereas, in Models 1 and 2 the funnel base was proportionally much smaller. The crucible was a little narrower than that of Model 2 and of the same height. Unlike Models 1 and 2, the discharge pipe is generally wider and has a softer bend above the crucible **(Figures 1, 2 and 3, Table 1)**.

Unlike Model 3, Model 4 has a slightly wider crucible and a longer and more steeply bent condensate discharge pipe. The cover of Model 4 fits inside, rather than over the crucible, as in the case of Model 3 **(Figures 3 and 4, Table 1)**.

Testing of these retorts was conducted during the period May 23$^{rd}$ to June 26$^{th}$, 2002 at the Institute of Applied Science and Technology. The use of the IAST's fume hood was abandoned because of a fire during the first testing exercise. Hence, the testing detailed in this report was not conducted under laboratory conditions (under a fume hood). However, to prevent the occurrence of any health or environmental hazards, the necessary precautions were taken.

During the testing, one test was conducted on ED Model 1 retort, four on Model 2, eight on Model 3 and two on Model 4. Four replicate runs, where necessary, were conducted per retort test, in order to assess replicability of the retort evaluation method developed by the Environmental Division. The various tests reflected different experimental conditions **(See Table 2 – Combined Results of Retort Testing).** For the testing program, a total of 815.56g of mercury were used, of which 682.87g (83.7%) were recovered. This represents a loss of 132.9 g (16.3%) during the program.

To achieve the above-mentioned objectives, an evaluation of the following parameters was conducted: mercury vapour recovery efficiency (vapour recovery efficiency), time for stable recovery, the effect of different temperatures (different heat sources) on the retorting process, mercury losses during retorting, thermodynamic efficiency, the relationship between vapour recovery efficiency and thermodynamic efficiency and mass balance of the retorting process.

As a result of low Vapour Recovery Efficiencies (Models 1 and 2) and fabrication defects (Models 1 and 4), testing was discontinued on Models 1, 2 and 4.

ED Model 1 retort had an extremely low Vapour Recovery Efficiency (18.7 %), which indicates an 81.3% mercury loss when operating without a supporting mud seal. No mercury remained in the retort, since the poorly machined permanent seal (precisely machined contact-surfaces of the cover and crucible, placed in close tolerance) allowed for vapour escape. This low recovery efficiency, coupled with fabrication defects (poor seal conditions) and a low thermodynamic efficiency (60.7%) prompted immediate discontinuation of tests on this retort.

ED Model 4 retort was not fabricated to specifications. A poor permanent vapour seal caused the major deficiency of this retort. Poor machining of the cover and crucible resulted in the loss of 85.8% of the mercury vapour when operating without a supporting mud seal and 17.5% when operating with a supporting mud seal, thus rendering this retort unsuitable for field application.

The ED Model 2 retort, when tested on a wood fire, achieved recoveries ranging from 89 ± 3.76 %, without a supporting mud seal, to 90.4 ± 3.2 %, with a supporting mud seal. These relatively low recoveries, coupled with fabrication defects led to the discontinuation of tests on this retort.

Of the retorts tested, Model 3 achieved the best performance and it is recommended that this retort be introduced to miners to be employed as their retorting tool in the near future. This retort has a Vapour Recovery Efficiency ranging from 89.9 ± 6.89 %, when a mercury/gold mixture is burnt on a wood fire, to 98.5%, when the amalgam is burnt on a charcoal heat source. When consecutive tests were conducted on this retort without cleaning of the crucible and vapour discharge pipe, full recovery was achieved (more than 100% of the mercury was recovered). This indicates that the mercury that does not report to the condensate collection unit remains in the retort. Full recovery was not achieved by any of the other retorts tested during the program. These recoveries were attained within 10.3 ± 3.79 to 6.5 minutes of retorting respectively. The results of the testing conducted are presented in **Table 2.**

Experimental comparison of the four successive retorts tested successfully demonstrates that the quality of the seal between the cover and the crucible of the retorts is the critical factor in determining the effectiveness of a retort.

# 2.0 Introduction

Mercury enters our lives more frequently than we may imagine. It may be in the fluorescent lights in our office, in old cans of latex paint (remnant paint), in our batteries, dental fillings, and numerous other sources. Mercury, a naturally occurring inorganic element, was discovered centuries ago and used as a valuable component in numerous industrial processes. In very small quantities, it conducts electricity, measures temperature and pressure, acts as a biocide, and functions as a catalyst. Mercury does not degrade and is not destroyed by combustion. When released to the environment, even in small quantities, it changes into methyl mercury under the right conditions. Methyl mercury is ingested by aquatic organisms at the bottom of the food chain, and it bioaccumulates, reaching dangerous levels in fish at the top of the aquatic food chain.

Scientists believe that atmospheric deposition contributes a large portion of the mercury found in surface water and soils. Mercury emitted into the air by combustion, incineration, or manufacturing processes may later be deposited in creeks, rivers, lakes and other surface water bodies. Atmospheric deposition contains the three principal forms of mercury (elemental, methyl and inorganic). Although inorganic divalent mercury is the dominant form, methyl mercury is a more toxic form. Once in surface water, mercury enters a complex cycle in which one form can be converted to another. Mercury attached to particles can settle onto the sediments where it can diffuse into the water column, be resuspended, be buried by other sediments or be methylated. Methyl mercury can enter the food chain, or it can be released back to the atmosphere by volatilization.

Higher acidity (pH) and dissolved organic carbon (DOC) levels enhance the mobility of mercury in the environment, thus making it more likely to enter the food chain. Mercury emissions also come from natural sources including volatilization from marine and aquatic environments, as well as volcanic and geothermal activity. However, recent studies suggest that anthropogenic sources contribute the majority of mercury releases.

All forms of mercury are toxic. Mercury poisoning can result from inhalation, ingestion, and injection or absorption through the skin. Elemental mercury poses a health hazard because it is volatile. Elemental mercury, as a vapor, penetrates the central nervous system and the brain, where it is ionized by oxidation and trapped, attributing to its extreme toxic effects. Elemental mercury is not well absorbed by the gastrointestinal tract; therefore, when ingested, it is only mildly toxic. Mercury metal and mercury compounds are highly hazardous if inhaled or if they remain on the skin for more than a short period of time. Dimethyl mercury rapidly penetrates intact skin. Depending on the type of mercury and dose, symptoms may appear relatively quickly or take a number of years to appear.

Mercury vapor (i.e., elemental mercury) is readily absorbed through inhalation and can also pass through intact skin. After absorption, elemental mercury is carried by the blood to the central nervous system and the brain where it is oxidized. The oxidation product produces injury. Persons heavily exposed to elemental mercury will develop worsening tremors of the hands, shyness, insomnia, and emotional instability (e.g., the symptoms of the Mad Hatter in *Alice in Wonderland*--a caricature of hat makers who cured felt in pools of mercury.) Mercury vapors can reach very high levels when the liquid is heated. Such levels will cause adverse effects in humans almost immediately if workplace controls are inadequate.

Mercury contamination as a result of gold extraction has been a significant source of concern for both the regulatory agencies and the gold mining community in Guyana. This concern led to the evaluation and ranking of the retorts available in Guyana. The evaluation was conducted by Senior Environmental Officer, Mr. M. Samaroo and the results were presented in his Retort Evaluation Report, dated September 27, 2000. It was concluded from this evaluation that the imported retorts required significant design modifications to operate under local condition (on a wood fire) and the acquisition cost of the efficient local retorts may be prohibitive.

These observations constituted the genesis of the follow-up retort-testing program, the aim of which was to fabricate, test and evaluate a retort (local) that would have the following fundamental properties:

- Low acquisition cost
- High (acceptable) Vapour Recovery Efficiencies (>95%) – retorting of amalgam
- Low retorting time
- Suitable for use on a wood fire
- Robust and durable
- Widespread acceptance
- Requiring no/minimum maintenance

To achieve these objectives, four (4) retorts were fabricated, tested and evaluated. The results of the testing and evaluation program are detailed in this report.

Testing was discontinued on retorts with observed design defects and low Vapour Recovery Efficiencies in a worse case scenario (no supporting mud seal) and the necessary modifications were done to correct these deficiencies. Successive modification and testing led to the retort design with the best overall performance (ED Model 3), which was selected for distribution to small and medium scale gold miners. The ED Model 3 Retort has been named the GG&MC/GENCAPD Retort.

The GGMC/GENCAPD Retort is essentially made up of the following components **(Fig. 3)**:

1. Crucible – to accommodate the gold/mercury amalgam.
2. Funnel-shaped Cover fitted with a condensate pipe.
3. Condensate pipe – to collect and cool mercury vapour and discharge of the condensate.
4. Permanent Vapour Seal, consisting of two precision-machined surfaces (cover and crucible) fitting in close tolerance – to prevent the escape of vapour during retorting.
5. Locking Mechanism, consisting of wing nuts and bolts fastened to the cover and crucible of the retort - to ensure tight fitting of the crucible and cover.

## 2.1 Objectives

The main objective of the follow-up retort-testing program was to develop and approve a retort suitable for use in the local small and medium scale mining operations. This retort should have the following fundamental properties:

- Low acquisition cost
- High (acceptable) Vapour Recovery Efficiencies (>95%)
- Low retorting time
- Suitable for use on a wood fire
- Robust and durable
- Widespread acceptance
- Requiring no/minimum maintenance

To achieve this objective, testing focused on the following parameters:

- Acceptable Stable Mercury Vapour Recovery Efficiency (vapour recovery efficiency) - >90%
- Time for stable recovery
- Durability
- The possibility of full (maximum) recovery - >95%
- Effect of different temperatures (different heat sources) on the retorting process
- Mercury losses during retorting
- Thermodynamic efficiency
- Relationship between vapour recovery efficiency and thermodynamic efficiency
- Acceptance by gold miners
- Mass Balance of the retorting process
- Statistical significance of performance differences
- Nature of Seal

## 2.2 Test Procedures

Tests were conducted on modified models of the ED "Grasshopper" constructed from mild steel. All tests were conducted in a semi-enclosed space with concrete floor, generally low wind influence at floor level and good ventilation at roof level to allow for maximum dispersal of smoke and fumes.

Retorts were constructed from mild steel.

a. Four replicate runs, where necessary, were conducted per retort test, in order to assess replicability of the retort evaluation method developed by the Environmental Division.
b. Wood fire was the primary heat source used for testing. However, several heat sources (portable kerosene stoves and charcoals) were utilized to assess test parameters at different temperatures (different heat sources).
c. Tests were conducted with and without a mud seals.
d. Recovery runs were conducted on the most efficient retorts without cleaning to assess the possibility of full recovery.
e. Testing methodology was similar to that used in the previous retort evaluation program (Retort Evaluation Report by Mahendra Samaroo, September 27,2000).

i. Internal and external temperature probes were installed on the crucibles of the retorts and temperature readings (internal and external) were recorded at one-minute intervals until a stable recovery was achieved and at five-minute intervals for the next fifteen minutes.
ii. Wood fires, consisting of wood of approximately the same size, number of pieces and type (hard wood), were used as the primary heat source. Charcoal and kerosene stove were also utilized as alternative sources of heat. A fire containment structure, constructed from clay bricks, was used for each test (except when a kerosene heat source was used) to ensure that the crucibles of the retorts were located at the same distance from the fire in all tests and to increase and maintain a more or less, constant fire temperature.
iii. Separate tests were conducted using
    1. Mercury
    2. 1:1 mercury/gold mixture
iv. The amount of mercury used in each test was precisely weighed, and inserted into the crucible. The condenser discharge end was submerged in water at all times, and condensate collection, by weight, was tracked in real time (one- minute intervals until stable recovery was achieved and five-minute intervals for the next fifteen minutes) by placement of the condensate collection unit on a tarred electronic balance
v. The gold used in test (2) was assayed before and after the testing program to assess its purity.
vi. A test was considered completed when (i) internal and external temperature stabilized and (ii) real time condensate collection graph showed 15-min plateau in the weight of accumulated condensate (zero additional condensate discharge for period of 15 minutes). The retorts were cooled, tapped and flushed with water to release additional mercury trapped within system.
vii. Final recovered mass of mercury was determined by precision weighing of recovered condensate. The condensate collection unit (beaker with water) was decanted to rid the condensate of water. Water remaining in the beaker was removed by means of a pipette and the surface of the condensate was then dried using blotting paper. The condensate was then poured into a clean, dry glassware for weighing.

viii. Vapour/condensate recovery efficiency was calculated as the recovered mass of condensate/initial mass of mercury*100. The thermodynamic efficiency was assessed as the average stable internal temperature/average stable external temperature*100

ix. A mean and standard deviation of the performance of each retort was calculated to assess the statistical significance of any observed differences.

## 2.3 Equipment and Test Requirements

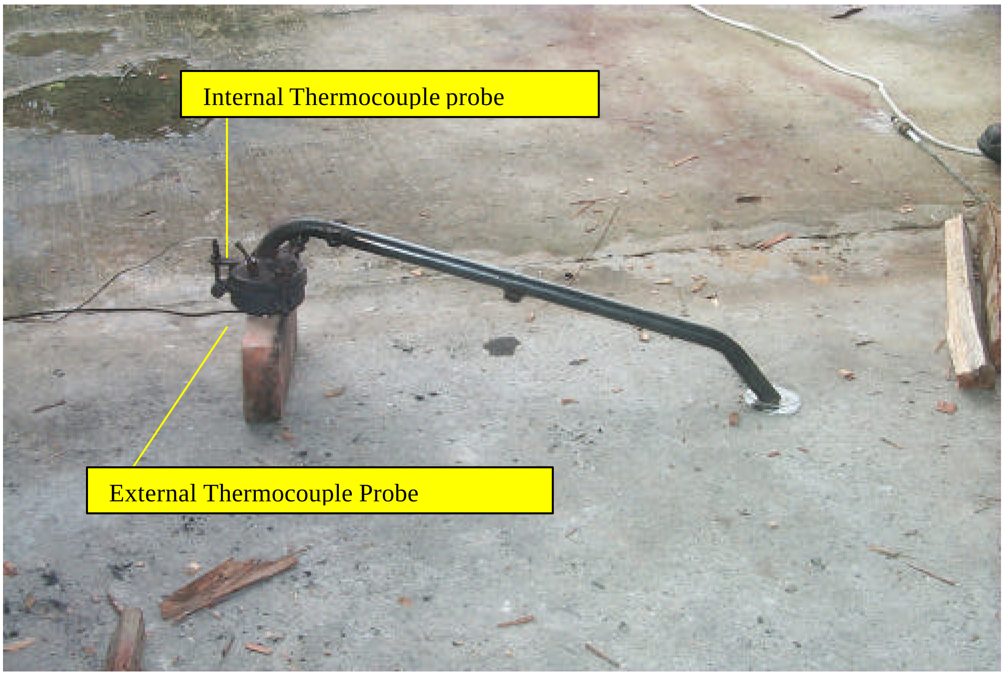
- Dual channel temperature logger
- Four high temperature RTD thermocouples (Type "K" fine gauge thermocouple probes – sustains up to 1250 $^{0}$C)
- Electronic balance sensitive to 0.001 g
- Copious amount of hard wood of a consistent size and genre
- Single burner kerosene stove and kerosene.
- Semi-enclosed space with concrete floor, low wind influence at floor level and good ventilation at roof level (dispersal of smoke & fumes)
- Refractory tiles for heat insulation of electronic equipment and concrete floor
- Safety Equipment consisting of two pairs of rubber gloves and three mercury respirators
- 4 pounds (1814.4g) of mercury
- Assorted glassware for handling, weighing and storing mercury, grinding and mixing of gold with mercury
- Boss head and clamp
- Blotting paper

# 3.0 Test Parameters and Methodology of Evaluation

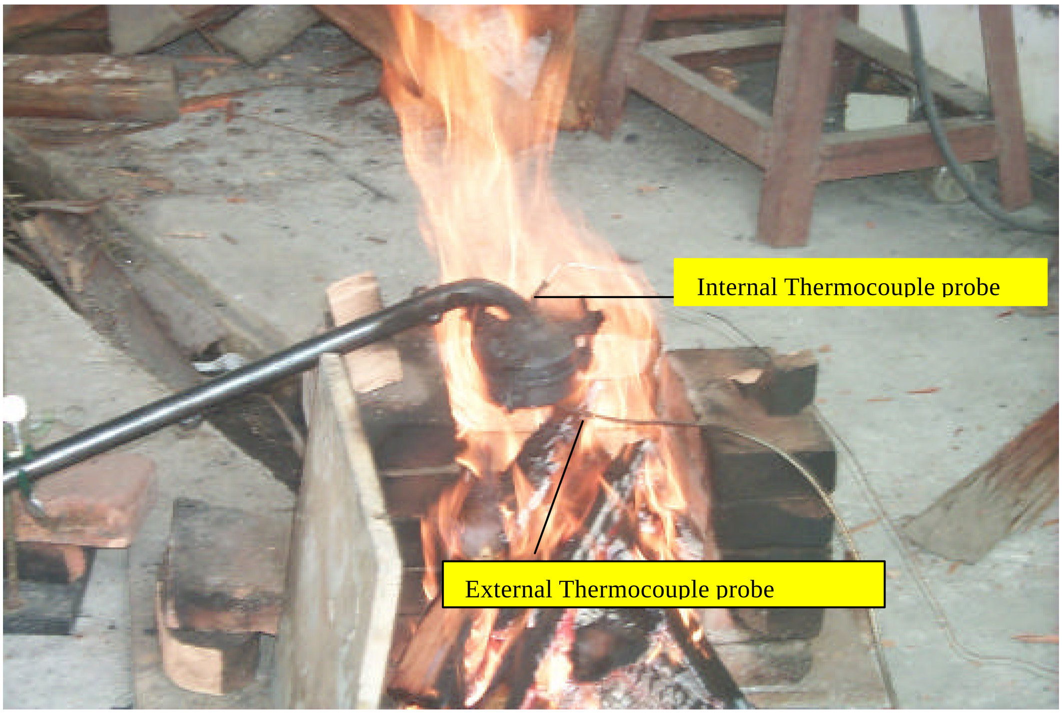
## 3.1 Thermodynamic Efficiency

This is an assessment of the quantity of the heat transferred from the heat source to the interior of the crucible (thermal gradient).

Two stainless steel (inert) thermocouples were used, one to measure the external temperature and the other to measure the internal temperature. Temperature measurements were taken simultaneously from the time of placement of the retort on flame, at one-minute intervals until a stable mass of mercury was indicated on the balance and at five-minute intervals for the next 15 minutes. The upper part (cover) of the crucibles of the retorts were drilled and tapped to ¼ NPT thread type, in order to accommodate the internal thermocouple probe and mud was used as a sealant around the probe, to provide a vapor-proof seal for the internal thermocouple. The external thermocouple was attached to the bottom of the crucible being tested with the aid of copper wires. Both probes were wired to mini-connectors via 2' long heat-insulated platinum-alloy wires, which were further insulated with 0.5cm thick fiber-reinforced asbestos fabric. A DuaLogr thermocouple thermometer was used for real-time tracking of both temperatures. **Pictures 1 and 2** show the placement of the thermocouple probes, with respect to the crucible and the heat source.




**Picture 1:** Placement of thermocouple probes with respect to the crucible




**Picture 2:** Placement of thermocouple probes with respect to the heat source.

Thermodynamic Efficiency is evaluated on the basis of several parameters. A reference temperature of $357^0$C (boiling point of mercury) is selected and three of the parameters are based on this temperature. The parameters are as follows:

1. The time lag between the external temperature attaining $357^0$C and the internal temperature achieving this level – $\mathbf{t_{357}}$.
2. The time lag between the internal temperature attaining $357^0$C and a positive change in mass in the condensate receptacle (time for the first appearance of condensate) – $\mathbf{t_C}$.
3. The time required for a stable condensate mass (stable recovery) to develop, calculated after the internal temperature has attained $357^0$C – $\mathbf{t_{Opt}}$.
4. The stable difference in operating temperatures calculated as the difference between the stable external temperature and the stable internal temperature – $\mathbf{T_{Ext.\,-\,Int}}$.

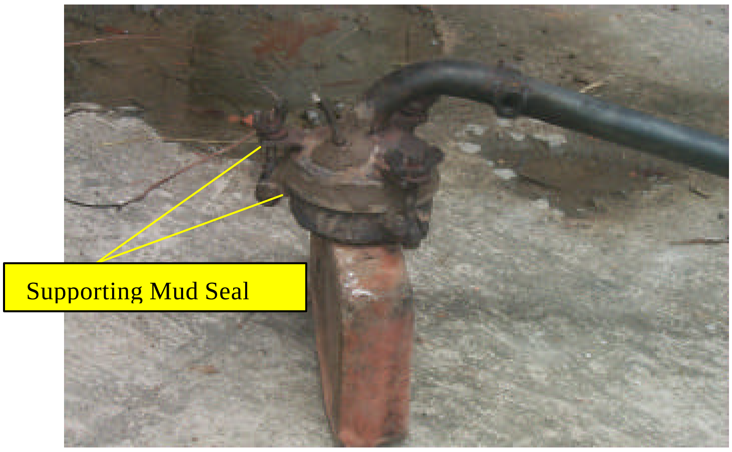
The Thermodynamic Efficiency (TE) is calculated as the Average Stable Internal Temperature ($T_{int}$) expressed as a Percentage of the Average Stable External Temperature ($T_{ext}$).

$$TE = \frac{T_{Int.}}{T_{Ext.}} * 100 \ (\%)$$

## 3.2 Mercury Vapor Recovery Efficiency

Mercury Vapour Recovery Efficiency is a measure of the percentage of the initial mass of mercury recovered (prevented from entering the surrounding environment) after the retorting process is completed.

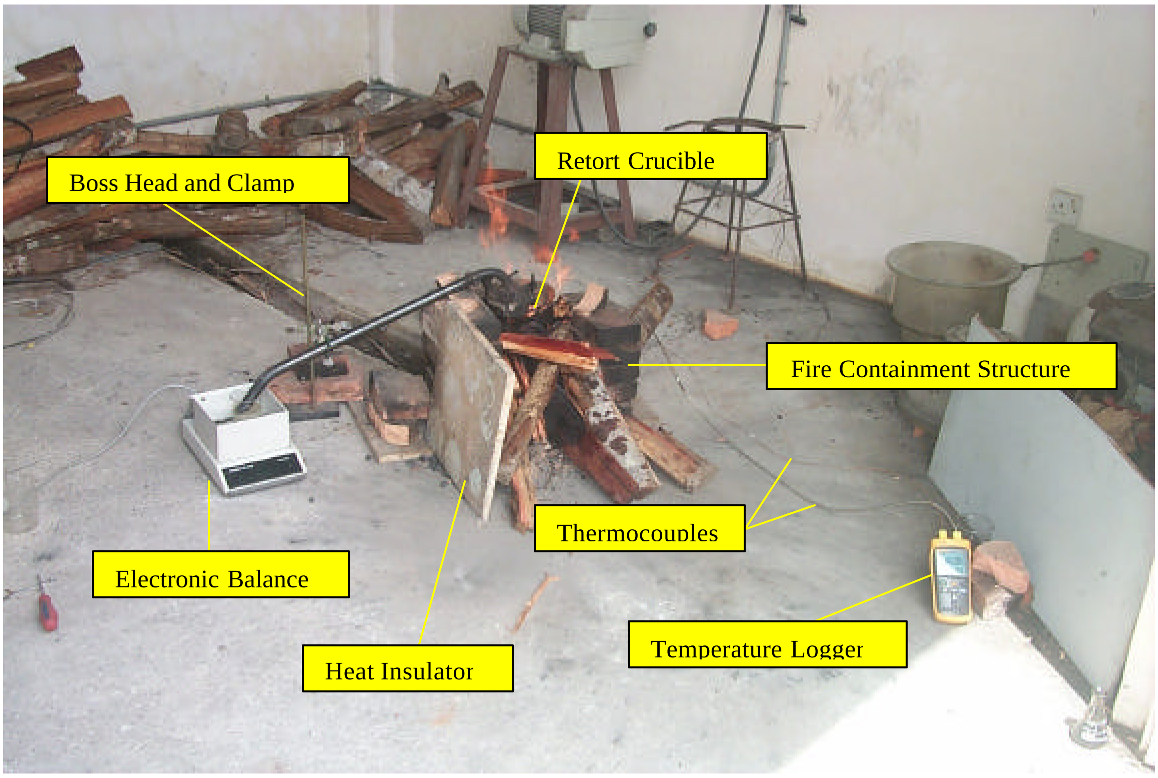
A measured mass of mercury (>50 g) was added to the crucible of the retort being tested. The retort was immediately closed via wing nuts and bolts attached to the sides of the crucible. Depending on the specified conditions under which a given test was conducted, the retort was either placed over the flame as is, or sealed with mud **(Picture 3)** before placement over the heat source. Wood (depending on test requirements) was used to prepare a flame of (approximately) constant size for each test (the average size of the flame used is shown in **Picture 2.** A charcoal heat source is shown in **Picture 3 A**.




**Picture 3:** GG&MC/GENCAPD Retort showing placement of mud seal.

**Picture 3A:** Charcoal heat source.

The flame was ignited and allowed to stabilize before the retort was positioned above it ($357 \pm 5^0$C). The condenser discharge end of each retort was submerged in a beaker of tap water, which was placed on an electronic balance (360g capacity, 0.001 gram sensitivity). The retort, with its crucible positioned over the heat source and the condenser discharge end submerged in a beaker of water, was kept stationary by the use of a boss head and clamp **(Picture 4)**. Immediately after set-up was completed, the scale was tarred (zeroed) and deviations from the initial mass of the beaker were recorded at one-minute intervals (simultaneously with the internal and external temperature measurements). The test was considered concluded after the mass of the mercury accumulated in the condensate beaker was constant (at approximately the mass of mercury added to the crucible) for a minimum period of fifteen minutes.




**Picture 4:** Showing testing in progress and placement of retort relative to fire containment structure and condensate collection unit

Mercury Vapour Recovery Efficiency is defined as the percentage of mercury recovered after the initial retorting process i.e. retorting by the application of heat to the exterior of the crucible of the retort and was calculated as follows:

$$\mathbf{V_{Hg.}} = \frac{\mathbf{M_{Hg\,cond.}}}{\mathbf{M_{init.\,Hg}}} * 100 \quad (\%)$$

Where

$V_{Hg}$ = Mercury Vapour Recovery Efficiency (%)

$M_{init.\ Hg}$ = Initial Mass of Mercury Used (under laboratory conditions, $M_{init.\ Hg}$ is found by weighing the mercury before mixing the amalgam)

$M_{Hg\ cond.}$ = Mass of mercury condensate recovered in the condensate collection unit

## 3.3 Time for Stable Recovery

The time required for a stable accumulative condensate mass to develop, calculated after the external temperature has attained $357^0$C.

## 3.4 Maximum Recovery

The total percentage of mercury recovered after additional heat (using a blow-torch) is applied directly to the surface of the amalgam subsequent to the initial retorting process. This parameter was not evaluated during this phase of testing. This parameter is expected to be evaluated by a team consisting of representatives from Guyana and Suriname.

## 3.5 Time for Maximum Recovery

The time required for a stable accumulative condensate mass to develop after the immediate application of additional heat to the surface of the amalgam. This parameter was not evaluated during this phase of testing.

## 3.6 Mercury Losses during Retorting

The amount of mercury retained in the retort (bound to surfaces), attached to the gold and lost due to leaks in the seals.

## 3.7 Durability

The durability of the retorts will be tested under field conditions on mine sites. Field-testing will be conducted subsequent to laboratory testing. Field-testing will assess and report on the performances of seals, welded joints and material type, and the relationship between mercury loss during retorting and the increasing use of the retort. Attempts will be made to identify the sources of mercury loss (i.e. seal, condensation pipe fittings, etc) during the retorting process.

## 3.8 Acceptance by gold miners

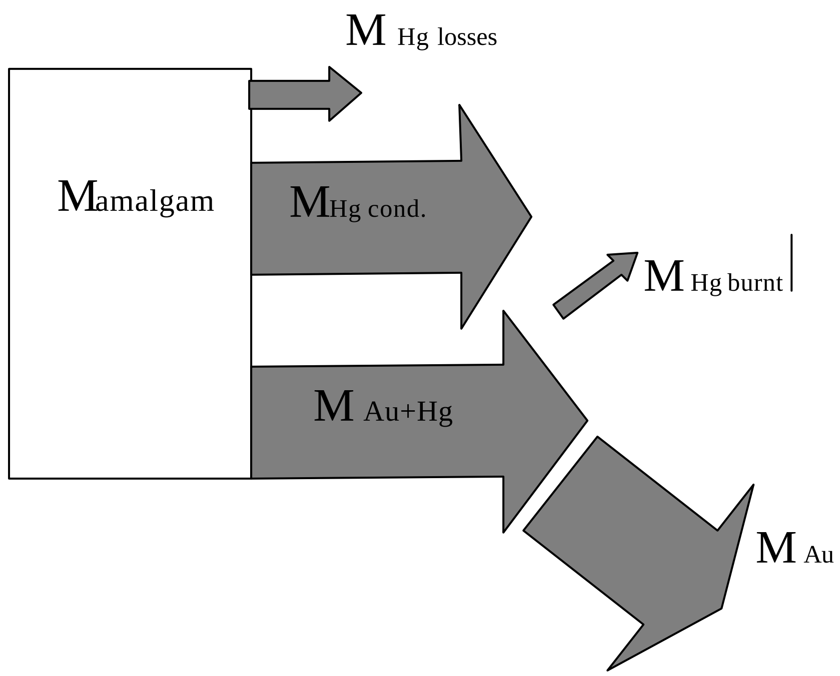
A multiple-choice questionnaire will be developed in English and Portuguese to query the acceptability of the retort by the gold miners.

**Questions will include:**

- Do you think the retort is useful?
- Do you think the retort will benefit your health?
- Do you think the retort will increase your profit?
- Will you use the retort?
- What do you think is a fair price for it?
- Is the retort easy to handle?
- Are there any defects in the construction of retort?
- What would you change on the retort to make it more applicable to your work?
- What quality (purity) of gold do you get when the retort is used?

## 3.9 Mass Balance of the Retorting Process

The mass balance of the retorting process can be depicted and described as below:



$$\mathbf{M}_{\mathbf{amal.}} = \mathbf{M}_{\mathbf{Au + Hg}} + \mathbf{M}_{\mathbf{Hg\ cond.}} + \mathbf{M}_{\mathbf{Hg\ losses}} \qquad \mathbf{(1)}$$

The gold from the retort still contains molecular bound mercury, which the miners separate by burning the Hg away with a blowtorch. Thus:

$$\mathbf{M}_{\mathbf{Au+Hg}} = \mathbf{M}_{\mathbf{Au}} + \mathbf{M}_{\mathbf{Hg\ burnt}} \qquad \mathbf{(2)}$$

Where:

$M_{amal}$ = Mass of Amalgam (gold/mercury mixture)

$M_{Au+Hg}$= Mass of gold (Au) and molecularly bonded mercury (Hg) after retorting

$M_{Hg\ cond.}$ = Mass of mercury (Hg) condensate

$M_{Hg\ losses}$ = Mass of mercury (Hg) lost in the retorting process by evaporation (leaks in the seal) or adherence to the inner surface of the retort

$M_{Au}$ = Mass of gold of maximum purity achievable by burning off final remnants of mercury

$M_{Hg\ burn}$ = Mass of burnt off (evaporated) Hg after direct application of heat to the surface of the gold/mercury mixture remaining after retorting

## 3.10 Statistical Significance of Performance Differences

Each replicate run was treated independently. The parameters of interest were calculated for each run and then combined to find a mean value and standard deviation.

The Student's t test is a common test of statistical significance. The test is commonly used in comparing the means in 2 samples or in correlations. It can be performed knowing just the means, standard deviations, and number of data points.

To establish if two mean values have a statistical significance, the following equation was used:

$$| X_{M1} - X_{M2} | < t_{(0.05,\ f)} * \sqrt{s_1^2/n_1 + s_2^2/n_2}$$

where $X_{M1}$ and $X_{M2}$ are the observed means for a parameter to be compared in different tests, t is Student’s t, here at a level of significance of 5% (probability level, p=0.05), $s_1$ and $s_2$ are the standard deviation of the parameter and $n_1$ and $n_2$ are the number of replicates in each test; and f is the effective degrees of freedom which is given by :

$$f = [s_1^2/n_1 + s_2^2/n_2]^2 / \{ [ s_1^4/n_1^2(n_1 + 1)] + [ s_2^4/n_2^2(n_2 + 1) ] - 2 \}$$

The mean values and standard deviations were calculated for the following parameters:

1. **Parameter 1:** The time lag between the external temperature attaining 357°C and the internal temperature achieving this level – $\mathbf{t_{357}}$ for those runs in which the thermocouples were functioning.
2. **Parameter 2:** The time lag between the internal temperature attaining 357°C and a positive change in mass in the condensate receptacle (time for the first appearance of condensate) – $\mathbf{t_C}$ for those runs in which the thermocouples were functioning.
3. **Parameter 3:** The time required for a stable condensate mass (recovery) to develop, calculated after the internal temperature has attained 357°C - $\mathbf{t_{Opt}}$ for those runs in which the internal thermocouple was functioning.
4. **Parameter 2:** The time lag between the commencement of the test and the first appearance of condensate for those runs in which the internal thermocouple was not functioning.
5. **Parameter 3:** The time required for a stable condensate mass to develop, calculated from the first appearance of condensate for those runs in which the thermocouples were not functioning.
6. **Time for Stable Recovery:** The time required for a stable accumulative condensate mass to develop, calculated after the external temperature has attained 357°C for those runs in which the internal and external thermocouples were functioning.
7. **Time for Stable Recovery:** The time required for a stable accumulative condensate mass to develop, calculated from the commencement of the test for those runs in which the thermocouples were not functioning.
8. Vapour Recovery Efficiency.

The results for Retorts 2, 3 and 4 are shown in **Appendix A**. The results were based on “whole minute” values with no attempt to interpolate to obtain more accurate values of “minutes”. This has only a minor effect on the interpretation of the results in view of the relatively large values for the standard deviation of the various parameters.

It is important to note that when the retort was placed on the heat source (wood fire) the external temperature was at the 357 ± $5^0$ C level. It was therefore assumed that this temperature (external = $357^0$C) marks the beginning of a test. Hence, the sum of Parameters 1 and 2 (Time for Stable Recovery), when the external thermocouple is functional, equals the sum of Parameters 2 and 3 (Time for Stable Recovery), when it is not functional.

The following tables summarize the results of the testing of statistical significance for various parameters under different test conditions for a given retort or for different retorts under the same test condition:

## 3.10.a Summary Tables of Statistical Significance of Parameter Differences

**1. Retort 2: With and without seal, wood using Hg only**

| | Statistical Significance |
|---|---|
| Parameter 1 | **No** |
| Parameter 2 | **No** |
| Parameter 3 | **No** |
| Time for Stable Rec. | **No** |
| Thermodynamic Eff. | **Yes** |
| Vapour Rec. Eff, | **No** |

**Conclusion:** Retort 2 is thermodynamically more efficient when a mud seal was used.

**2. Retort 3: With and without seal, wood, using Hg only**

| | Statistical Significance |
|---|---|
| Parameter 1 | **No** |
| Parameter 2 | **No** |
| Parameter 3 | **No** |
| Time for Stable Rec. | **No** |
| Thermodynamic Eff. | **No** |
| Vapour Rec. Eff, | **No** |

**Conclusion:** The mud seal had no effect on Retort 3.

**3. Retort 3 – With Seal and without seal, coals, using Hg only**

| | Statistical Significance |
|---|---|
| Parameter 1 | **N/A** |
| Parameter 2 | **No** |
| Parameter 3 | **No** |
| Time for Stable Rec. | **No** |
| Thermodynamic Eff. | **N/A** |
| Vapour Rec. Eff, | **No** |

**Conclusion:** The mud seal had no effect on this Retort 3.

**4. Retorts 2 and 3 – Without seal, wood, using Hg only**

| | Statistical Significance |
|---|---|
| Parameter 1 | **No** |
| Parameter 2 | **No** |
| Parameter 3 | **No** |
| Time for Stable Rec. | **No** |
| Thermodynamic Eff. | **Yes** |
| Vapour Rec. Eff, | **Yes** |

**Conclusion:** Retort 3 showed slightly better Vapour Recovery and Thermodynamic Efficiencies than Retort 2.

**5. Retorts 2 and 3 – With seal, wood, using Hg only**

| | Statistical Significance |
|---|---|
| Parameter 1 | **No** |
| Parameter 2 | **No** |
| Parameter 3 | **No** |
| Time for Stable Rec. | **No** |
| Thermodynamic Eff. | **No** |
| Vapour Rec. Eff, | **Yes** |

**Conclusion:** Retort 3 showed slightly better Vapour Recovery Efficiency than Retort 2.

## 6. Retort 3 – With seal and with seal + wet rag, wood using Hg only

| | Statistical Significance |
|---|---|
| Parameter 1 | **N/A** |
| Parameter 2 | **N/A** |
| Parameter 3 | **N/A** |
| Time of Stable Recovery | **N/A** |
| Thermodynamic Eff. | **N/A** |
| Vapour Rec. Eff, | **No** |

**Conclusion:** No statistically significant difference could be observed on the basis of the Vapour Recovery Efficiency.

## 7. Retort 2 and 3: With seal + continuous, wood using Hg only

| | Statistical Significance |
|---|---|
| Parameter 1 | **N/A** |
| Parameter 2 | **No** |
| Parameter 3 | **No** |
| Time for Stable Rec. | **No** |
| Thermodynamic Eff. | **N/A** |
| Vapour Rec. Eff, | **Yes** |

**Conclusion:** Model 3 performed better than Model 2 when continuously operated with a mud seal.

## 8. Retort 3: Wood and coals with seal, using Hg only

| | Statistical Significance |
|---|---|
| Parameter 1 | **N/A** |
| Parameter 2 | **N/A** |
| Parameter 3 | **N/A** |
| Time for Stable Rec. | **Yes** |
| Thermodynamic Eff. | **N/A** |
| Vapour Rec. Eff, | **No** |

**Conclusion:** Model 3 attains a stable recovery faster on a charcoal heat source than a wood fire.

**9. Retort 3: Wood and coals without seal, using Hg only**

| | Statistical Significance |
|---|---|
| Parameter 1 | **N/A** |
| Parameter 2 | **N/A** |
| Parameter 3 | **N/A** |
| Time for Stable Rec. | **Yes** |
| Thermodynamic Eff. | **N/A** |
| Vapour Rec. Eff, | **No** |

**Conclusion:** On a charcoal heat source, Model 3 attains stable recovery faster than on a wood fire.

## 3.10.b Impact of statistical significance of results

Analysis of the statistical significance of parameter differences allows the following main conclusions:

1. The effectiveness and efficiency of a retort is variable subject to ambient conditions. The present study proves one "real world" measure of this variability. Given by the standard deviation of the parameters **(Appendix A)**.

2. The goodness, that is, tightness, of the seal between the cover and the crucible of the retort is the critical factor to determine the effectiveness of a retort. This observation was clearly demonstrated by the behaviour of Models 1 and 4 compared to Models 2 and 3.

3. A mud seal is helpful for retorts with poorly machined permanent seals. It is ineffective above a certain level of goodness of seal, as was demonstrated by the improved behaviour of Model 4 and no improvement for Models 2 and 3 **(Summary Tables 2 & 3 and Table 2: Combined Results of Retort Testing)**.

4. The impact of the other design parameters on the efficiency of the retorts was not statistically assessed (only slightly lower effectiveness of Model 2 compared to Model 3 - observed only for the amount of mercury recovered and attributable to the difference in the quality of the seal). Hence, the information presented on these parameters was drawn from visual observations during the retort-testing program.

5. It cannot be concluded that higher recovery is attained with a hotter heat source since the evidence is conflicting. Model 3 gave no improvement for Hg alone in changing from wood to coals whereas it did so for gold amalgam **(Table 2: Combined Results of Retort Testing)**.

6. Higher Thermodynamic Efficiency was demonstrated by Model 2 when a mud seal was used **(Summary Table 1)**.

7. The higher the temperature of the heat source, the faster the achievement of full recovery of mercury from amalgam by Model 3 **(Summary Tables 8 & 9)**.

   This observation is noteworthy if the time for full recovery is considered to be an important factor in assessing the efficiency of a retort or its acceptance by users, since their interests are the efficiency of mercury recovery and the time it takes to recover it.

# 4.0 Retort Testing

The retort-testing program was conducted under conditions similar to that in the field under which miners operate i.e. testing was not conducted under laboratory conditions (under a fume hood). However, to prevent the occurrence of any health or environmental hazards, the following precautions were taken:

- Testing was conducted in a Semi-enclosed area with concrete floor, generally low wind influence at floor level and good ventilation at roof level (dispersal of smoke & fumes)
- Officers conducting the tests were each equipped with mercury respirators, rubber gloves and long-sleeved shirts to prevent inhalation of mercury vapour and contact with the skin.
- At the end of each day of testing, it was mandatory that officers wash all areas of their bodies that were exposed during the testing.
- No eating on the test site was allowed and all containers (bottles) containing water/beverages for consumption were tightly closed and kept in a nearby room.
- Visitors were not accommodated for extended periods if they were not equipped with the necessary protective gears.
- Testing was discontinued on any retort if the Vapour Recovery Efficiency was less than 50% after the first test run (with or without a supporting mud seal).
- Mercury stored on the test site was kept in tightly closed plastic bottles.

In the event of a mercury spill, a general clean-up exercise will be conducted at the test site. Below is the proposed clean-up procedure:

- Push small mercury beads together with a card, stiff paper, or squeegee to form larger droplets and then push them into a plastic dustpan or use an eye dropper to pick up the balls of mercury. Collect all mercury and ALL mercury-contaminated items into a leak-tight plastic bag or wide-mouthed sealable plastic container. Save the bag or container to take to a mercury-recycling center (IAST?).

- Work from the outside of the spill area toward the center. Work over a tray or box that is lined or covered with plastic wrap when pouring mercury. Mercury's high density and smoothness cause it to roll fast.

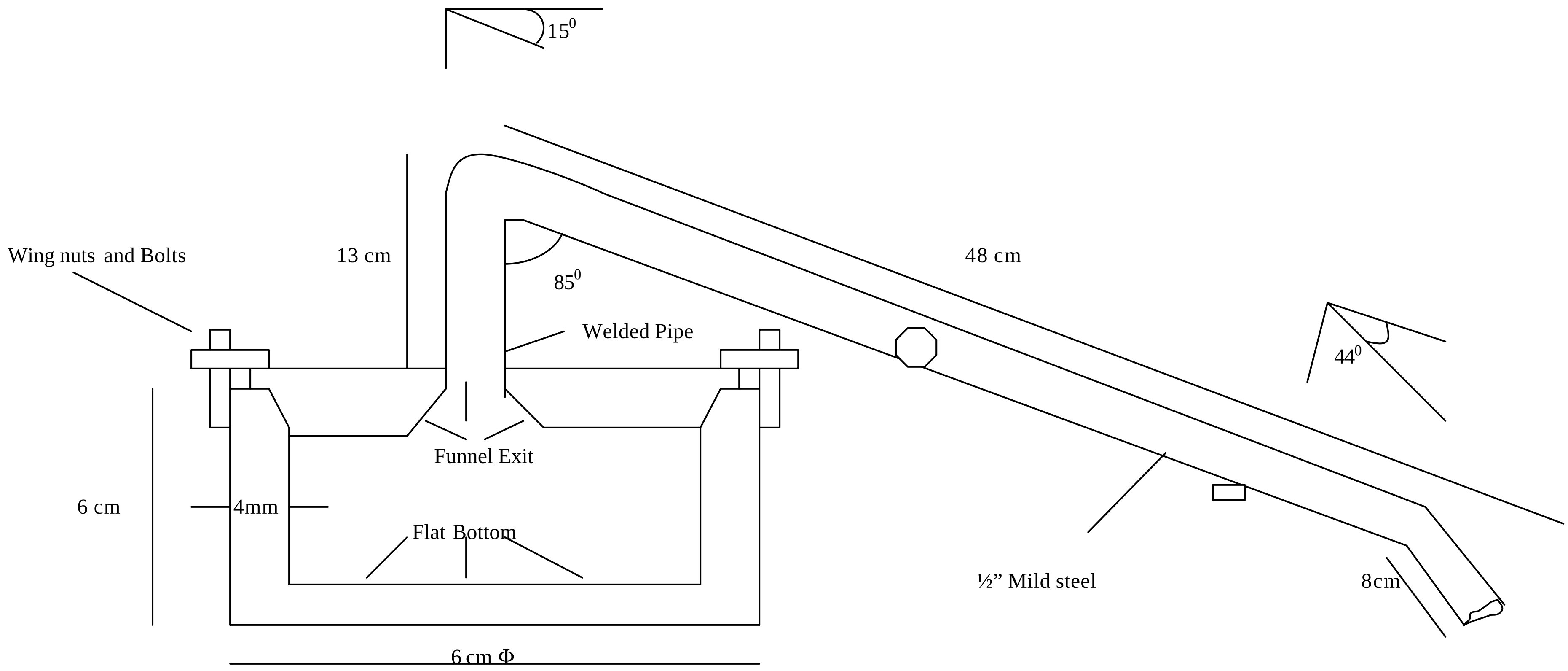
- Use a flashlight to look all around in the areas of the spill. The light will reflect off the shiny mercury beads and make it easier to see them.
- Sprinkle sulfur powder on the spill area after cleaning up beads of mercury; a color change from yellow to brown indicates that mercury is still present and more cleanup is needed.
- Sprinkle zinc flakes or copper flakes (available at hardware stores) to amalgamate (clump together) any small amounts of mercury that remain.

## 4.1 Model 1

This retort was fabricated by Rafferty's Engineering Service Guyana. It is constructed of mild steel and essentially consists of a 6cm OD (outer diameter) x 6.4cm H (height) x 4mm T (thickness) flat-bottomed crucible and a cover fitted (via welding) with a ½" (1.3cm) mild steel condensate discharge pipe. The condensate discharge pipe is 56cm long and has a 13cm vertical rise above the cover before it takes a $15^0$ (to the horizontal axis) downward slope. It also incorporates three detachable legs (threaded at the upper end). The two adjacent front legs (closer to the crucible) are each 43cm long and the back leg (closer to the end of the condensate discharge pipe) is 26cm long. The end (final 8.3cm) of the discharge pipe has a $44^0$ (to the slope of the pipe) downward curve to facilitate the immersion of the end of the pipe into a receptacle containing water. The cover is fitted to the crucible by means of wing nuts and bolts attached to the crucible. A precision-machined tapered crucible and cover facilitate vapour sealing. Vapour exits the crucible and into the discharge pipe through a small funnel-shaped opening in the cover. The retort weighs 3.742 Kg (legs – 1.01Kg, cover – 1.726Kg, crucible – 1.006Kg) and costs G$6,500. The sketch **(Fig. 1)** below shows the specifications to which Model 1 was fabricated.

**Fig. 1**

**ED Retort – Model 1: Specifications for Fabrication**

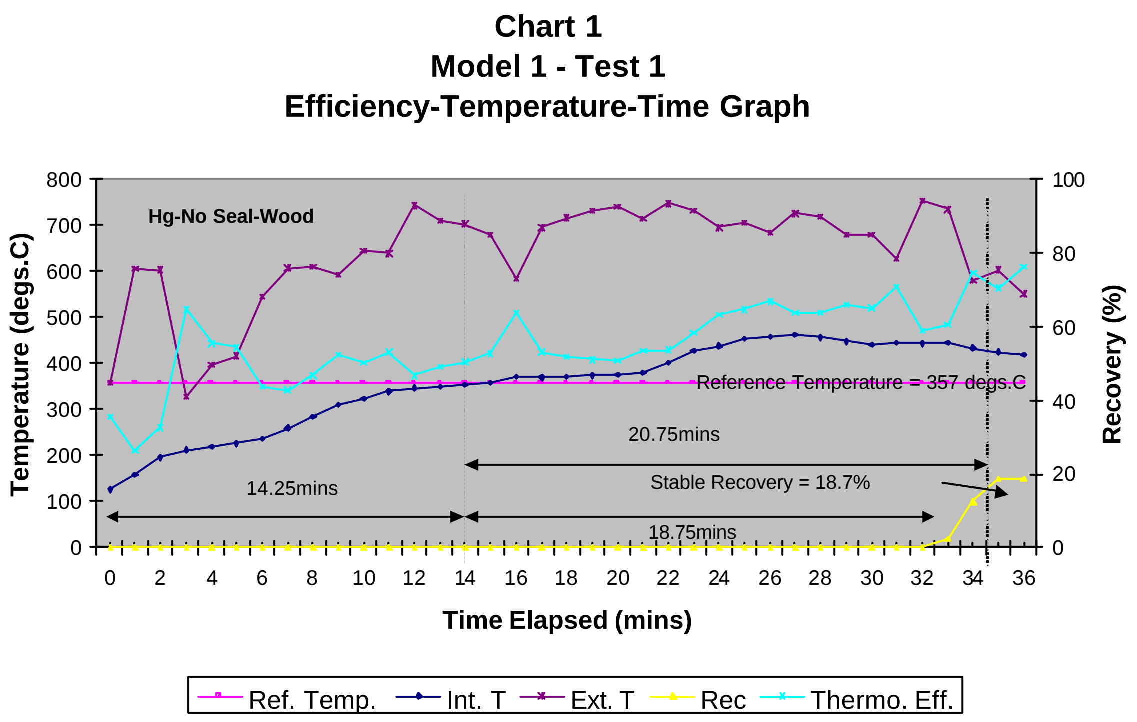



**NB.** Not drawn to scale

### 4.1.1 Test 1 (Hg – No Mud Seal – Wood)

One test was done on this retort. This test was conducted without a vapour seal (mud) and using only mercury. A mass of 50.15 g of mercury was used, of which 9.4 g were recovered in the condensate collection unit (Parameter $V_{Hg.}$ = 18.7%) after a total testing duration of approximately 35 minutes. The results obtained from this test are shown in **Chart 1** (Average results of replicate runs) below.

An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 1** shows that there was a delay of approximately 18.75 minutes between the internal temperature achieving 357 $^{0}$C and the appearance of mercury condensate. A stable mass was attained approximately 20.75 minutes after the internal temperature had reached 357 $^{0}$C. The chart also shows that there was a delay of approximately 14.25 minutes between the external temperature attaining 357 $^{0}$C and the internal temperature attaining that temperature and the difference in stable external and internal temperatures was approximately 270.6 $^{0}$C representing a thermodynamic efficiency of 60.7%.



The achieved performance of this retort was obtained at average sustained internal and external temperatures 417.9$^0$C and 636.4$^0$C.

The extremely low Vapour Recovery Efficiency of this retort is attributed to the following deficiencies in fabrication:

1. Poor sealing mechanism – the tapered cover and crucible were not precisely machined, thus allowing for the escape of vapour (81.3%).

2. Extended vertical rise of the condensate tube – a 13cm vertical rise above the crucible results in condensation of the vapour in the vertical section of the condensate tube.

3. Acute bend (85$^0$) on condensate discharge pipe – the bend on the condensate tube above the crucible is too acute. This restricts the flow of mercury vapour from the crucible to the condensate pipe, hence causing condensation of vapour back into the crucible.

4. Small funnel exit – small funnel-shaped opening in the cover restricts the free flow of vapour to the condensate discharge pipe.

5. Flat-bottomed crucible – hindered the flow of vapour directly into the funnel exit since mercury was dispersed over the entire surface, rather than concentrated at one point.

6. Rough (corroded) internal surface of the crucible and condensate discharge pipe – served as vapour and condensate traps and hence reduced the quantity of condensate discharged at the end of the condensate pipe.

## 4.2 Model 2

This retort was fabricated by Janico Industrial Engineering Ltd. It is constructed of mild steel and essentially consists of a 12cm OD x 5cm H x 4mm T flat-bottomed crucible and a cover fitted with a ½" (1.3cm) mild steel condensate discharge pipe. The condensate discharge pipe is 61cm long and has a 2.5cm vertical rise above the cover before it takes a $10^0$ (to the horizontal axis) downward slope. It also incorporates three detachable legs (threaded at the upper end). The two adjacent front legs (closer to the crucible) are each 43cm long and the back leg (closer to the end of the condensate discharge pipe) is 35cm long. The end (final 7.6cm) of the discharge pipe has a $38^0$ (to the slope of the pipe) downward curve to facilitate the immersion of the end of the pipe into a receptacle containing water. The vapour seal consists of two precision-machined surfaces (cover and crucible) fitting within very close tolerances. The cover is fitted to the crucible by means of symmetrically located wing nuts and bolts attached to the crucible. The cover is machined to fit tightly into the crucible to facilitate vapour sealing. Vapour exits the crucible through a small funnel-shaped opening in the cover. The retort weighs 3.639 Kg (legs – 1.01Kg, cover – 1.729Kg, crucible – 0.9Kg) and costs G$7,500. The sketch **(Fig. 2)** below shows the specifications to which Model 2[1] was fabricated.

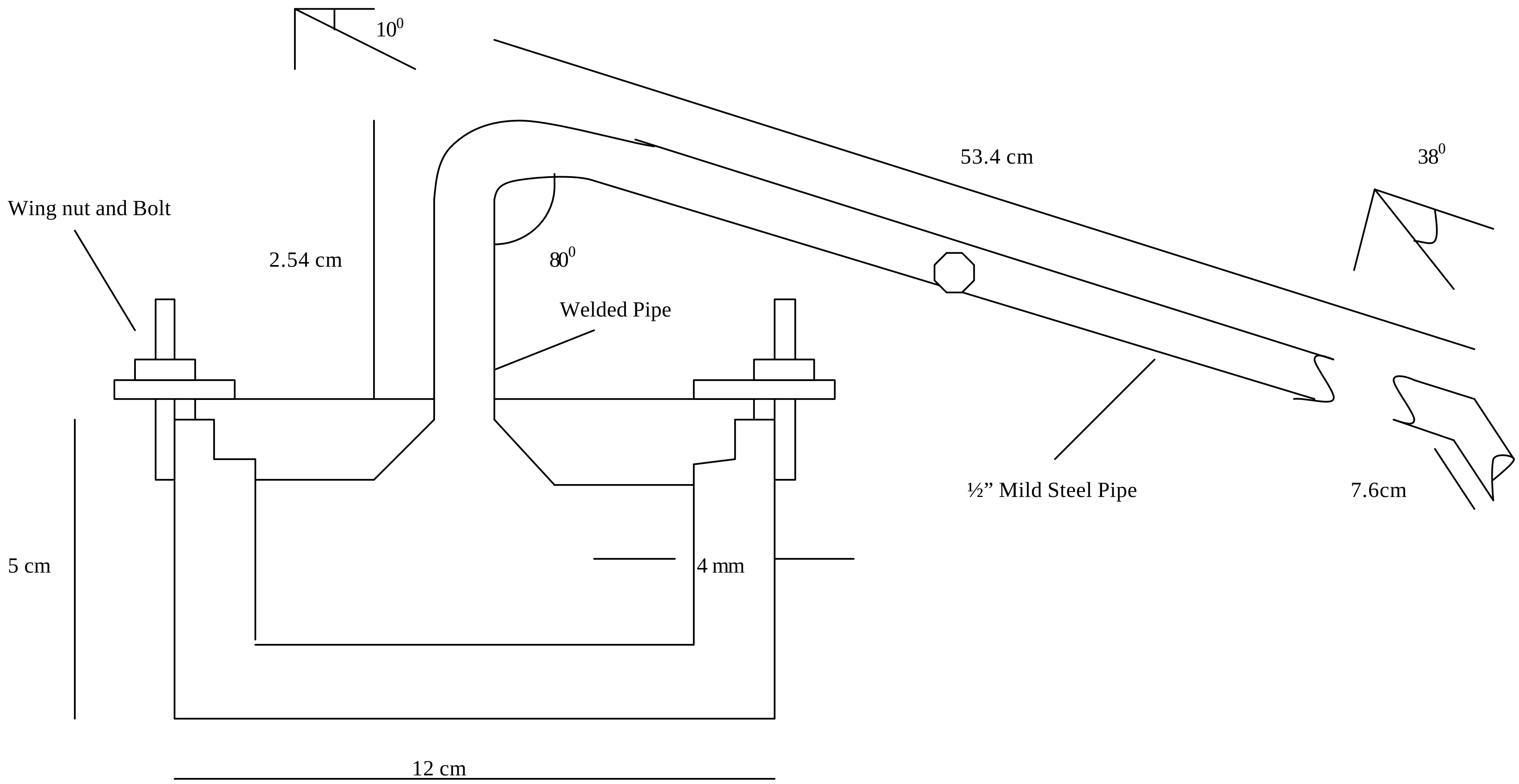
Four tests were done on this retort, three of which were conducted on a wood flame and one on a kerosene stove.

Damaged thermocouples, as a result of direct exposure of the asbestos coated platinum-alloy wires to flame temperature above 800 $^0$C, did not allow for internal and external temperature readings to be recorded in Test 3.

**NB.** Tests were not conducted in the same order as documented in this report.

**Fig.2**

**ED Retort - Model 2[1]: Specifications for Fabrication**

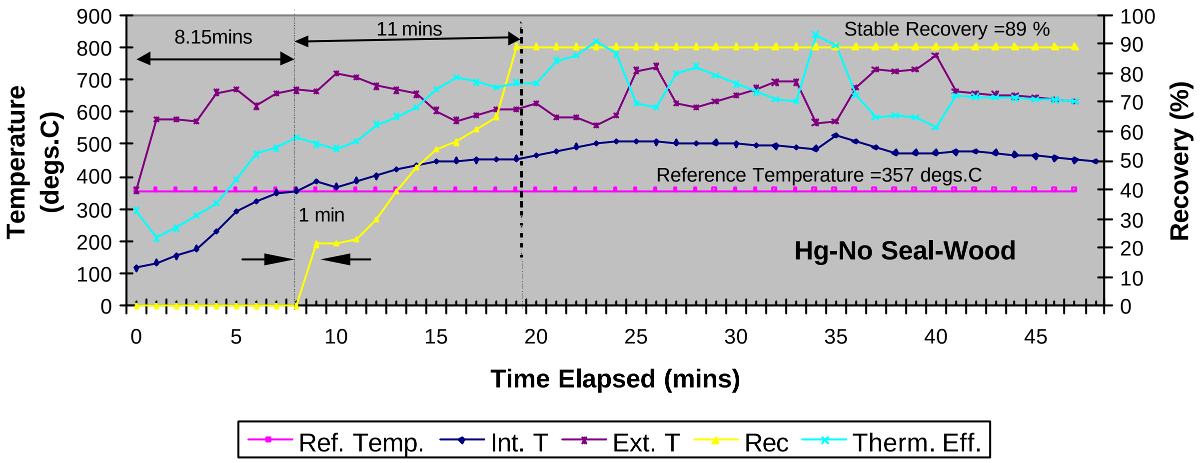



**NB.** Not drawn to scale

### 4.2.1 Test 1 (Hg – No Mud Seal – Wood)

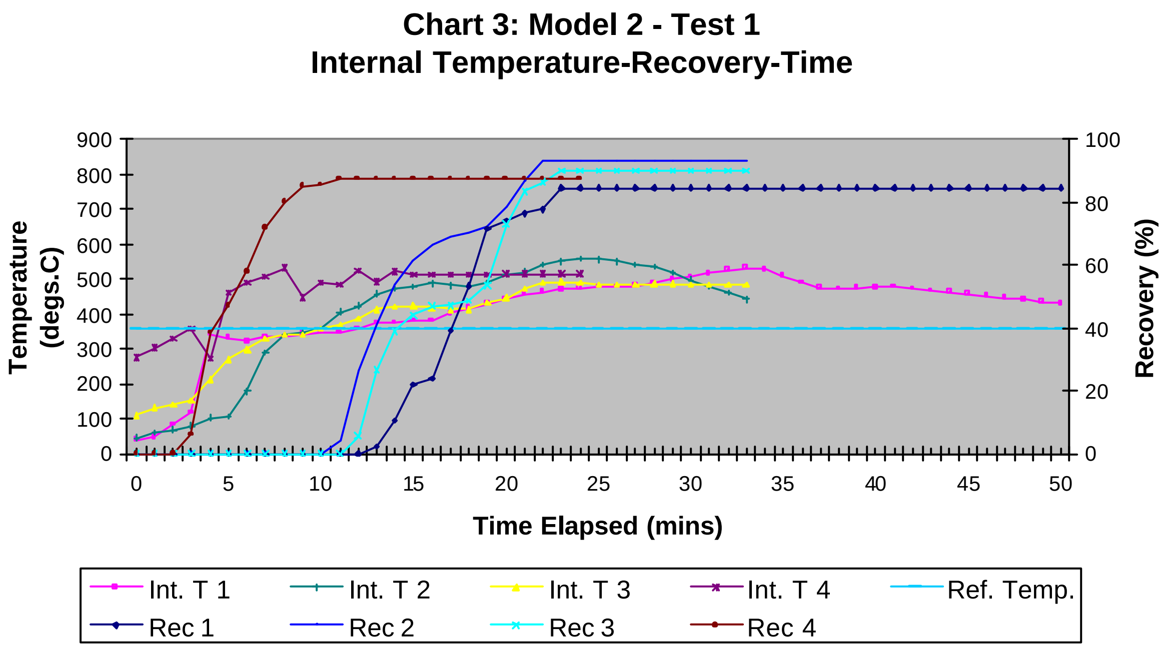
This test was conducted without a vapour seal (mud) and using only mercury. The test consisted of four replicate runs and an average mass of 60.9 g of mercury was used, of which 54.2 g were recovered (Parameter $V_{Hg}$ = 89 ± 3.76 %) after a total testing duration of approximately 50 minutes. The results obtained from this test are shown in **Chart 2** (Average results of replicate runs) below.

**Chart 2**
**Model 2 - Test 1**
**Efficiency-Temperature-Time Graph**




An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 2** shows that mercury condensate appeared approximately 1± 0.82 minute before the internal temperature attained 357 $^0$C and a stable condensate mass was attained approximately 11± 2.16 minutes thereafter. The chart also shows that there was a delay of approximately 8.15 ± 3.95 minutes between the external temperature attaining 357 $^0$C and the internal temperature attaining that temperature and the difference in stable external and internal temperatures was approximately 191.45 $^0$C representing a thermodynamic efficiency of 70.65 ± 4.16%. Stable recovery was achieved 19.8 ± 5.85 minutes after the external temperature had reached 357 $^0$C.

The graph shows that there were continuous fluctuations in the internal and external temperatures throughout the test. These variations were a direct result of the windy weather conditions experienced during the test. However, a direct relationship between internal temperatures and recovery can be observed **(Chart 3).**



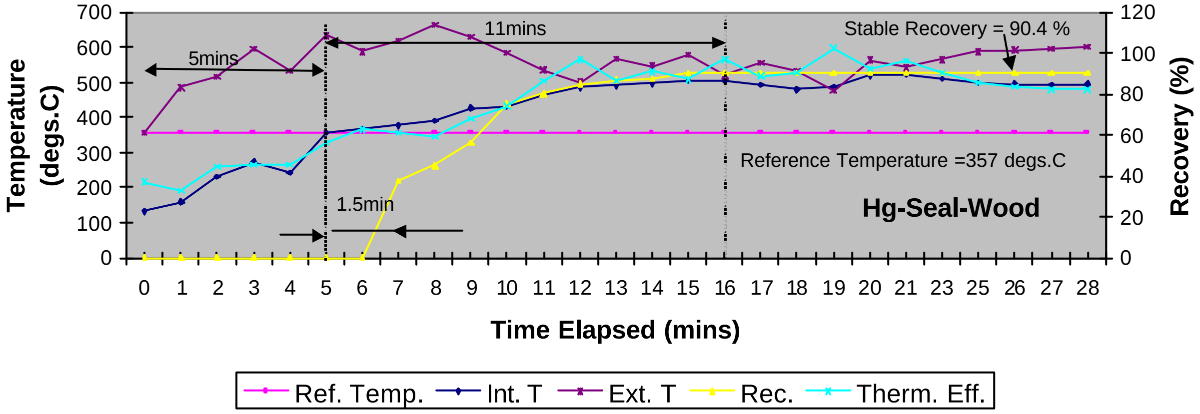

A comparison of the recovery and internal temperature shows a direct relationship between the two parameters i.e. mass accumulation mirrors closely the changes in internal temperature. This observation is clearly demonstrated in **Chart 3**. The clustered nature of the parameter graphs shown in **Chart 3** reflects the consistency in the retort performance, test procedures and to some extent the test conditions.

The achieved performance of this retort was obtained at average sustained internal and external temperatures 456.8 $^0$C and 648.2 $^0$C.

### 4.2.2 Test 2 (Hg – Seal – Wood Fire)

This test was conducted with a vapour seal (mud) and using only mercury. The test consisted of four replicate runs and an average mass of 59.7 g of mercury was used, of which 53.97 g were recovered (Parameter $V_{Hg}$ = 90.4 ± 3.2%) after a total testing duration of approximately 28 minutes. The results obtained from this test are shown in **Chart 4** (Average of replicate runs) below.

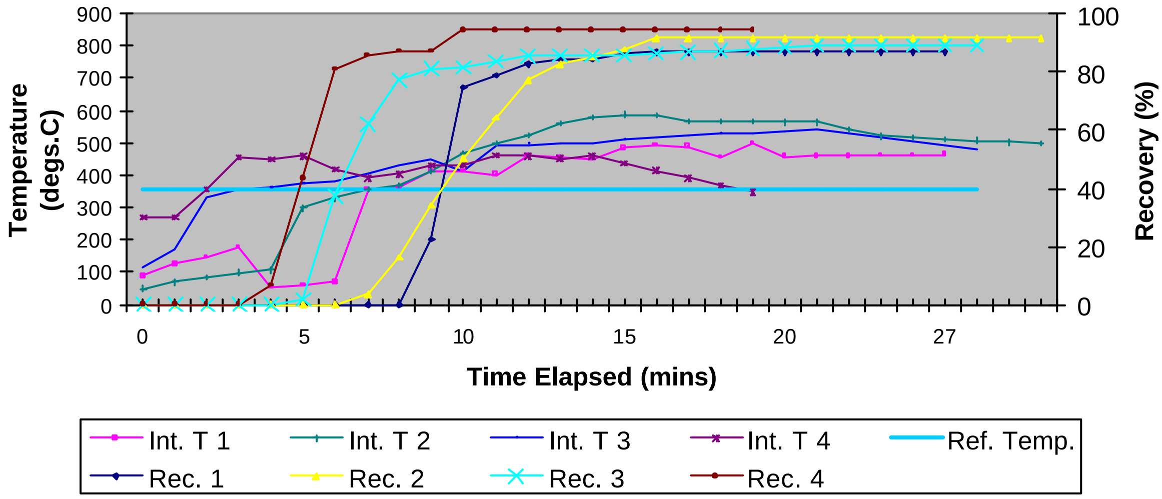
**Chart 4**
**Model 2 - Test 2**
**Efficiency-Temperature-Time Graph**




An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 4** shows that mercury condensate appeared approximately 1.5 ± 1.0 minutes after the internal temperature attained 357 $^{0}$C and a stable condensate mass was attained approximately 11.25 ± 4.57 minutes thereafter. The chart also shows that there was a delay of approximately 5 ± 2.31 minutes between the external temperature attaining 357 $^{0}$C and the internal temperature attaining that temperature and the difference in stable external and internal temperatures was approximately 101 $^{0}$C representing a thermodynamic efficiency of 85.55 ± 11.98%. Stable recovery was achieved 16 ± 4.55 minutes after the external temperature had reached 357 $^{0}$C.

The graph shows that there were continuous fluctuations in the internal and external temperatures throughout the test. These variations were a direct result of the windy weather conditions experienced during the test. However, a direct relationship between internal temperatures and recovery can be observed **(Chart 5)**

**Chart 5**
**Model 2 - Test 2**
**Internal Temperature-Recovery-Time**



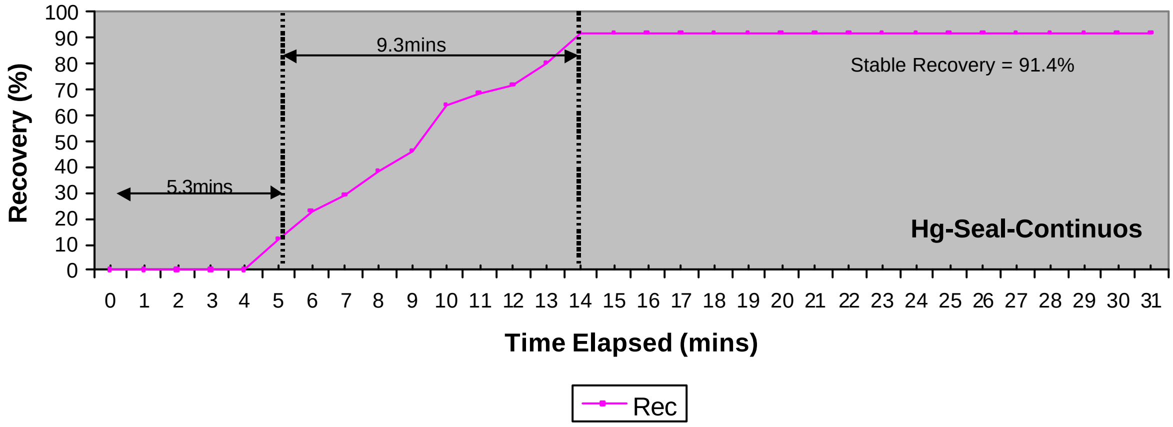

A comparison of the recovery and internal temperature shows a direct relationship between the two parameters i.e. mass accumulation mirrors closely the changes in internal temperature. This observation is clearly demonstrated in **Chart 5**. The clustered nature of the parameter graphs shown in **Chart 5** reflects the consistency in the retort performance, test procedures and to some extent the test conditions.

The achieved performance of this retort was obtained at average sustained internal and external temperatures 467.5 $^0$C and 555.3 $^0$C.

### 4.2.3 Test 3 (Hg – Seal – Wood Fire – Continuous)

This test was conducted using mercury with a vapour seal (mud). Parameters 1, 4 and thermodynamic efficiency were not evaluated during this test due to damaged thermocouples (reason given in **Section 4.3**). No temperatures were recorded in this test. The test consisted of three replicate runs and no tapping or cleaning of the retort (to remove mercury that may have been trapped in the system) between successive runs i.e. continuous retorting without cleaning. An average mass of 50.27 g of mercury was used and approximately 45.95 g were recovered (Parameter $V_{Hg.}$ = 91.4 ± 5.76%) after a total testing duration of approximately 31 minutes. The results obtained from this test are shown in **Chart 6** (Average of replicate runs) below.

**Chart 6**
**Model 2 - Test 3**
**Vapour Recovery Efficiency- Time Graph**




An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 6** shows that mercury condensate appeared approximately 5.3 ± 1.53 minutes after commencement of the test and a stable condensate mass was attained approximately 9.3 ± 3.5 minutes thereafter. Stable recovery was achieved 14.7 ± 5.03 minutes after commencement of the test.

### 4.2.4 Test 4 (Hg – Mud Seal – Kerosene)

This test was conducted with a vapour seal (mud) and using 50.77g of mercury. No condensate was recovered (Parameter $V_{Hg.}$ = 0%) after a total testing duration of approximately 36 minutes. The results obtained from this test are shown in **Chart 7** below.

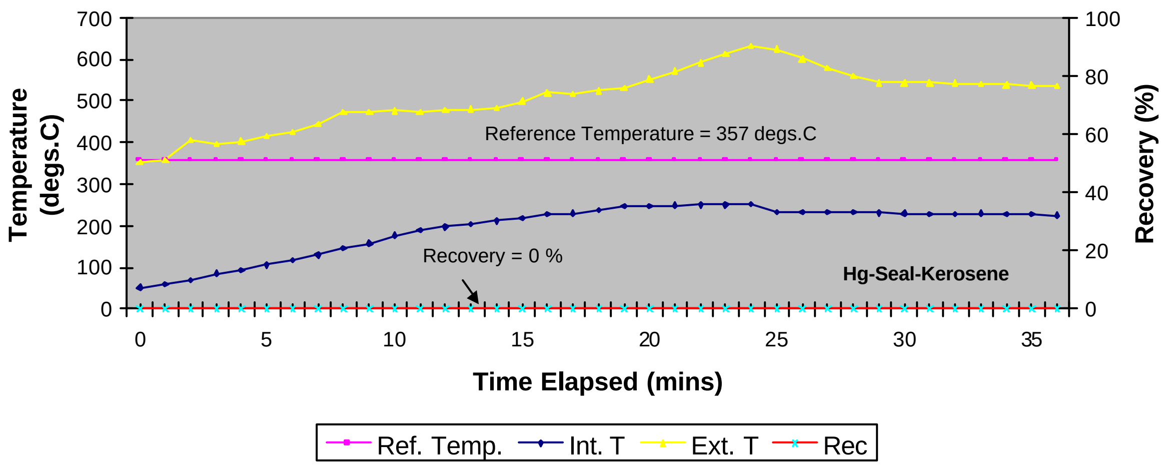
A kerosene stove was used as the source of heat for this test. **Chart 7** shows that no mercury condensate was recovered and the internal temperature did not attain 357 $^0$C. However, the mercury that did not report to the condensate collection unit remained in the crucible. The chart also shows that there was a difference of 274.1 $^0$C between the stable external and internal temperatures, corresponding to a thermodynamic efficiency of 45.7%.

The poor performance of this retort on a kerosene stove may be stated as follows:

1. The external temperature did not rise high enough nor rapidly enough to allow the internal temperature to attain the 357$^0$C level. It may therefore be assumed that heat may have been lost to the external environment faster than it was transferred to the interior of the crucible.

2. The kerosene stove provided uniaxial heating (heating in one direction), which did not allow for the crucible to be engulfed in the flame.

**Chart 7**
**Model 2 - Test4**
**Efficiency-Temperature-Time Graph**




The low Vapour Recovery Efficiency of this retort is attributed to the following deficiencies in fabrication:

1. Poor sealing mechanism – the cover and crucible were not precisely machined to fit tightly, thus allowing for the escape of vapour (approx. 10%).

The behaviour of Model 2 is perplexing. The observation that the mud seal had no effect on the efficiency of mercury recovery **(Summary of Statistical Significance 1)** suggests that a quantity of mercury is held back inside the retort. The continuous runs for this retort however suggest a loss of mercury rather than a relatively constant quantity of mercury being held back. In other words, the observed behaviour suggests that a mud seal permits an escape of up to 10% of the total mercury. Such a loss should perhaps be expected. The mud seal surrounding the leaking seal between the crucible and cover of the retort would absorb some of the potentially escaping mercury but the mercury, as its quantity increases, would increasingly permeate through the mud to be volatilized at the surface of the seal (mud). The higher temperature of the mud seal during retorting facilitates this volatilization.

2. Acute bend ($80^0$) on condensate discharge pipe – the bend on the condensate tube above the crucible is too acute. This restricts the flow of mercury vapour from the crucible to the condensate pipe, hence causing condensation of vapour back into the crucible.

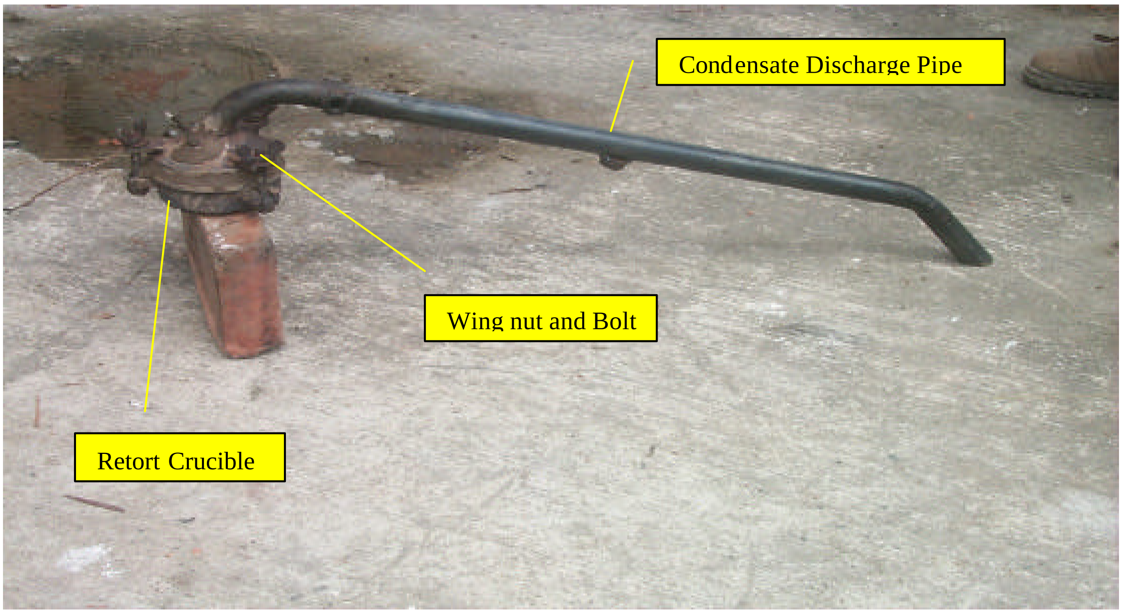
3. Small funnel exit – small funnel-shaped opening in the cover restricts the free flow of vapour to the condensate discharge pipe.

4. Flat-bottomed crucible – hindered the flow of vapour directly into the funnel exit since mercury was dispersed over the entire surface, rather than concentrated at one point.

5. Rough (corroded) internal surface of the crucible and condensate discharge pipe – served as vapour and condensate traps and hence reduced the quantity of condensate discharged at the end of the condensate pipe.

## 4.3 Model 3 (GG&MC/GENCAPD Retort)

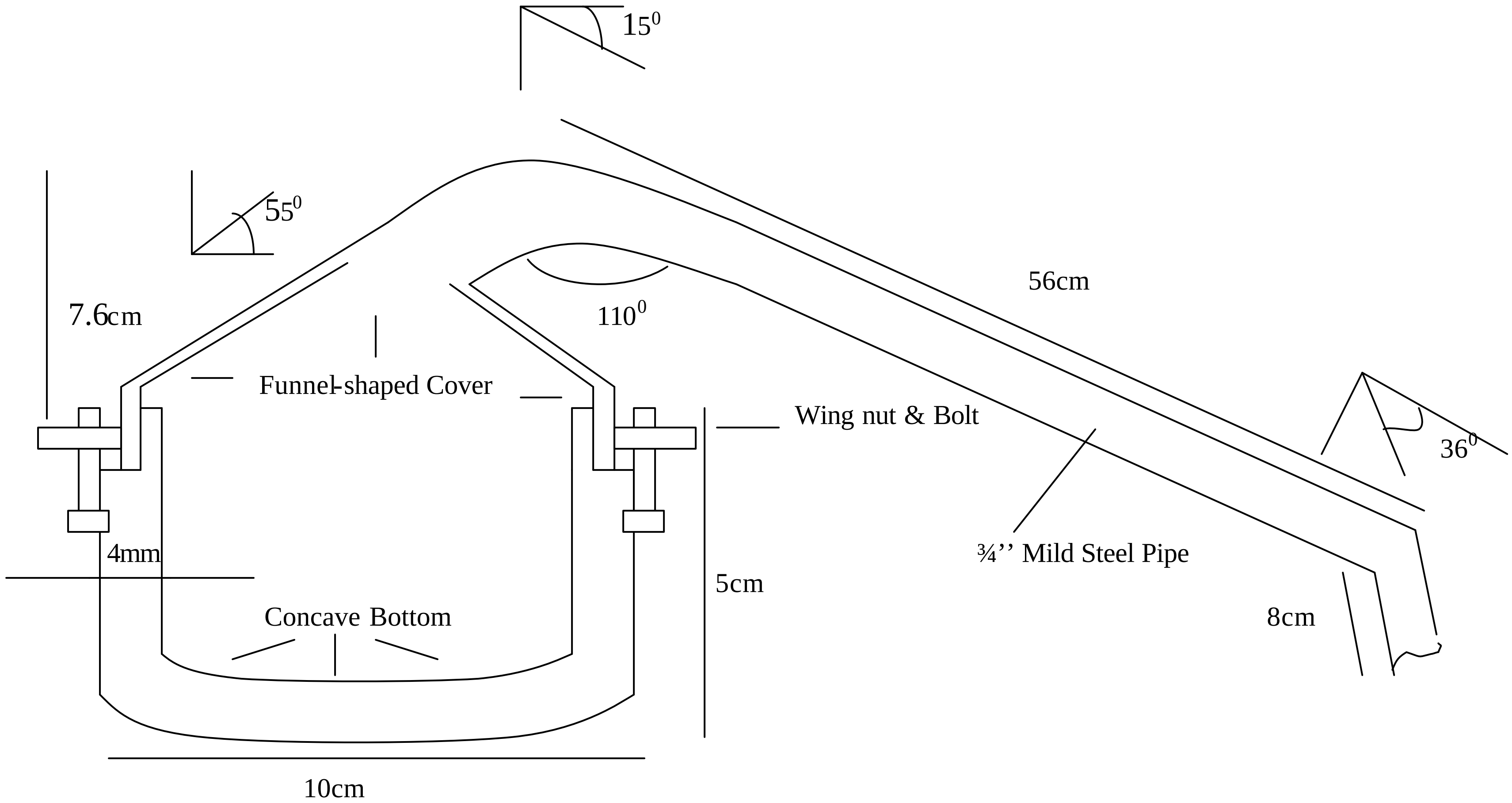
This retort was fabricated by Janico Industrial Engineering Ltd. It is constructed of mild steel and essentially consists of a 10cm OD x 5cm H x 4mm T concave-bottomed crucible and a funnel-shaped cover fitted with a ¾ ” (2cm) condensate discharge pipe **(Picture 5)**.




**Picture 5:** ED Model 3 Retort (GG&MC/GENCAPD Retort).

The condensate discharge pipe is 64cm long and rises 7.6cm above the top of the crucible at an angle of $55^0$ before it takes a $15^0$ (to the horizontal axis) decent. It also incorporates three detachable (threaded at the upper end) legs. Two of the legs (43cm in length) are situated closer to the crucible, and the other (35cm long), closer to the condensate discharge end of the retort. The end (final 8cm) of the discharge pipe has a further $36^0$ (to the slope of the pipe) downward curve to facilitate the immersion of the end of the pipe into a receptacle containing water. The cover is fitted to the crucible by means of wing nuts and bolts attached to the crucible. A male-female arrangement of the crucible and cover respectively, creates a very effective vapour seal. The vapour seal consists of two precision-machined surfaces (cover and crucible) fitting within very close tolerances. The cover is fitted to the crucible by means of symmetrically located wing nuts and bolts attached to the crucible. Vapour exits the crucible through a funnel-shaped opening in the cover. The retort weighs 2.6 Kg (crucible-0.9 Kg, cover and condensate discharge pipe-1.7 Kg), excluding legs, which weigh 1.02 Kg) and costs G$12,000. The sketch **(Fig. 3)** below shows the specifications to which Model 3 was fabricated.

**Fig. 3**
**ED Model 3 Retort (GG&MC/GENCAPD Retort)**
**Specifications for Modification**




**NB.** Not drawn to scale

Eight tests were done on this retort, five of which were conducted on a wood flame and three on coals. Damaged thermocouples, as a result of direct exposure of the asbestos coated platinum-alloy wires to flame temperature above 800 $^0$C, did not allow for internal and external temperature readings to be recorded in **Tests 3, 4, 6 and 7.**

**NB.** Tests were not conducted in the same order as documented in this report.

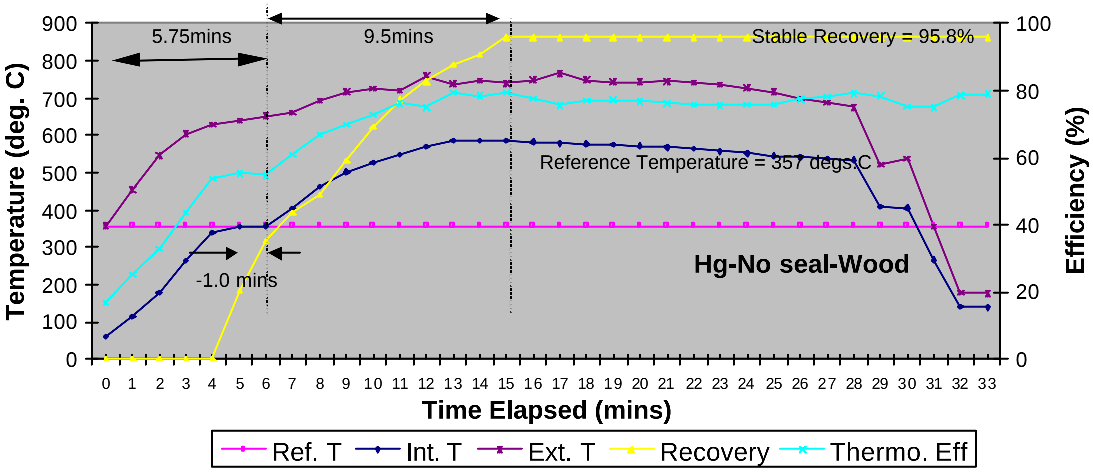
### 4.3.1 Test 1 (Hg – No Mud Seal – Wood Fire)

This test was conducted without a vapour seal (mud) and using only mercury. The test consisted of four replicate runs and an average mass of 55.45 g of mercury was used, of which 53.12 g were recovered (Parameter $V_{Hg.}$ = 95.8 ± 2.45%) after a total testing duration of approximately 33 minutes. The results obtained from this test are shown in **Chart 8** (Average of replicate runs) below.

An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test**. Chart 8** shows that mercury condensate appeared approximately 1.0 ± 1.0 minutes before the internal temperature attained 357 $^0$C. A stable condensate mass was attained approximately 8.75 ± 2.22 minutes after the internal temperature had reached 357 $^0$C. The chart also shows that there was a delay of approximately 5.75 ± 0.5 minutes between the external temperature attaining 357 $^0$C and the internal temperature attaining that temperature and the difference in stable external and internal temperatures was approximately 146.9 $^0$C representing a thermodynamic efficiency of 78.64 ± 4.15%. Stable recovery was achieved 14.5 ± 1.91 minutes after the external temperature had reached 357 $^0$C.

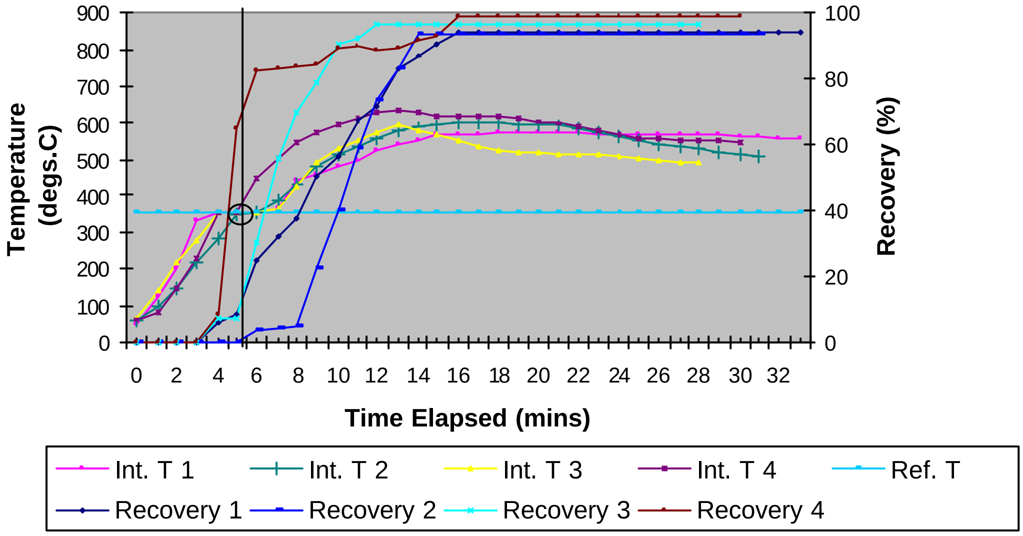
The near parallel section of the graphs of internal and external temperatures indicates a relatively constant transfer of heat from the exterior to the interior of the crucible after stable external and internal temperatures had been reached. The low intensity of the heat source at the end of the test (abrupt decrease in external and internal temperatures after approximately 28 mins) is attributed to the extremely low wind velocity experienced and small quantity of wood remaining in the fire containment structure.

### Chart 8: Model 3 - Test 1
### Efficiency-Temperature-Time Graph




A comparison of the recovery and internal temperature shows a direct relationship between the two parameters i.e. mass accumulation mirrors closely the changes in internal temperature. This observation is clearly demonstrated in **Chart 9**. The clustered nature of the parameter graphs shown in **Chart 9** reflects the consistency in the retort performance, test procedures and to some extent the test conditions.

### Chart 9: Model 3 - Test 1
### Internal Temperature-Recovery-Time

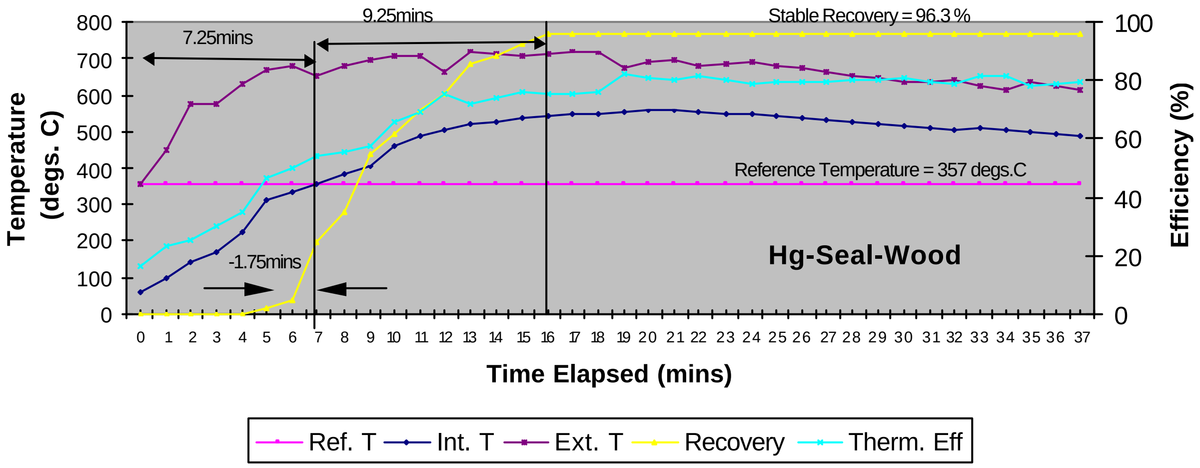



The achieved performance of this retort was obtained at average sustained internal and external temperatures 538.6 $^{0}$C and 685.4 $^{0}$C.

### 4.3.2 Test 2 (Hg – Mud Seal – Wood Fire)

This test was conducted with a vapour seal (mud) and using only mercury. The test consisted of four replicate runs and an average mass of 54.93 g of mercury was used, of which 52.9 g were recovered (Parameter $V_{Hg.}$ = 96.3 ± 0.86%) after a total testing duration of approximately 37 minutes. The results obtained from this test are shown in **Chart 10** (Average of replicate runs) below.

**Chart 10: Model 3 - Test 2**
**Efficiency-Temperature-Time**




An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 10** shows that mercury condensate appeared approximately 1.75 ± 2.22 minutes before the internal temperature attained 357 $^{0}$C. A stable condensate mass was attained approximately 9.25 ± 4.19 minutes after the internal temperature had reached 357 $^{0}$C. The chart also shows that there was a delay of approximately 7.25 ± 1.71 minutes between the external temperature attaining 357 $^{0}$C and the internal temperature attaining that temperature and the difference in stable external and internal temperatures was approximately 147.15 $^{0}$C representing a thermodynamic efficiency of 77.8 ± 5.88%. Stable recovery was achieved 16.5 ± 3.11 minutes after the external temperature had reached 357 $^{0}$C.

The near parallel section of the graphs of internal and external temperatures indicates a relatively constant transfer of heat from the exterior to the interior of the crucible after stable external and internal temperatures had been reached.

A comparison of the recovery and internal temperature shows a direct relationship between the two parameters i.e. mass accumulation mirrors closely the changes in internal temperature. This observation is clearly demonstrated in **Chart 11**. The clustered nature of the parameter graphs shown in **Chart 11** reflects the consistency in the retort performance, test procedures and to some extent the test conditions.

**Chart 11: Model 3 - Test 2**
**Internal Temperature-Recovery-Time**

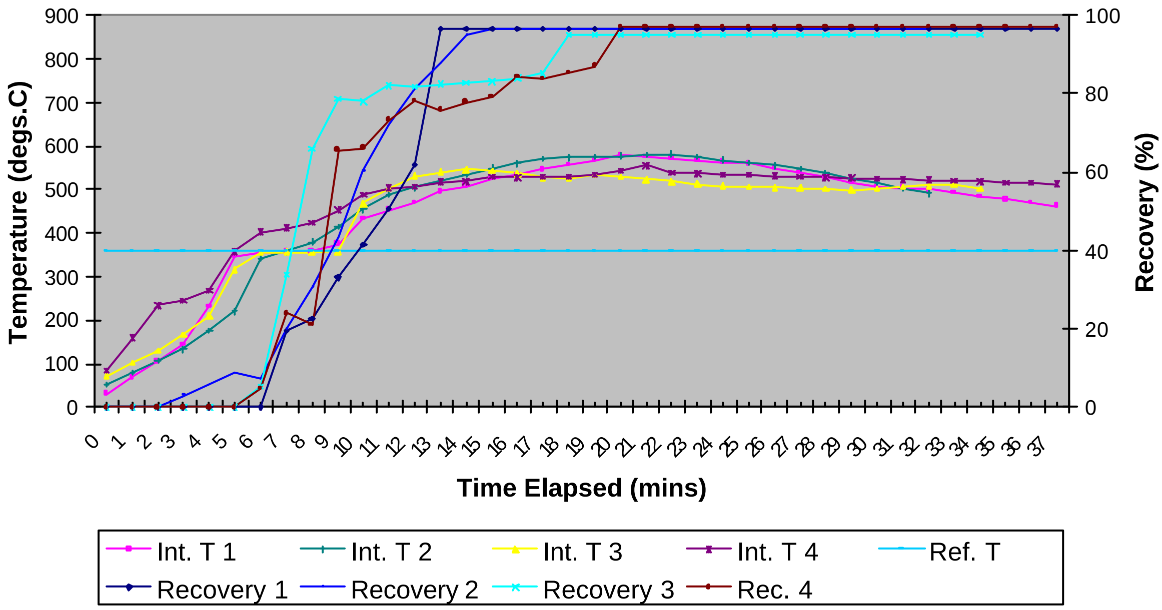


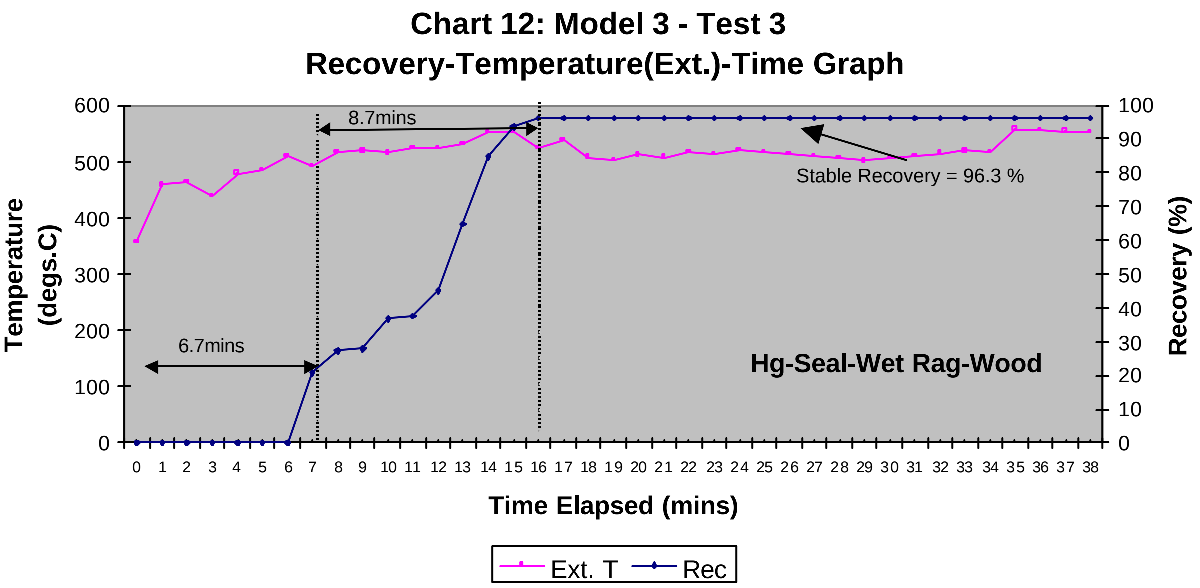

**Chart 11** also shows that the retort is most thermodynamically efficient when the internal temperature is above approximately 550 $^{0}$C (external temperature above approximately 700 $^{0}$C). Recovery peaks (optimum recovery) under these thermodynamic conditions.

The achieved performance of this retort was obtained at average sustained internal and external temperatures 506.9 $^{0}$C and 654 $^{0}$C.

### 4.3.3 Test 3 (Hg – Mud Seal – Wood Fire – Wet Rag)

This test was conducted using mercury with a vapour seal (mud) and a wet rag wrapped around the condensate discharge pipe to facilitate rapid condensation of mercury **(Picture 6)**. Parameters 1, 4 and thermodynamic efficiency were not evaluated during this test due to damaged thermocouples (reason given above). Only external temperatures were recorded in this test. The test consisted of three replicate runs and an average mass of 56.59 g of mercury was used, of which 54.48 g were recovered (Parameter

$V_{Hg.}$ = 96.3 ± 2.26%) after a total testing duration of approximately 38 minutes. The results obtained from this test are shown in **Chart 12** (Average of replicate runs) below.





**Picture 6:** GG&MC/GENCAPD Retort with wet rag.

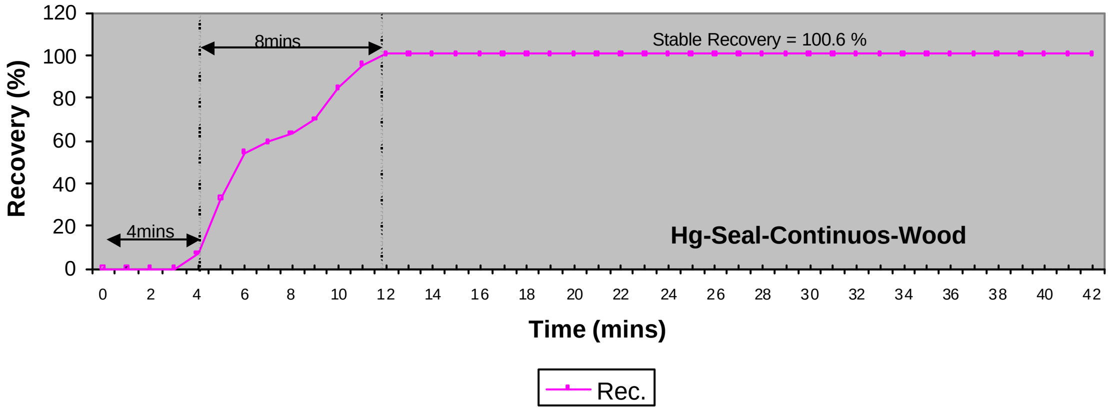
An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 12** shows that mercury condensate appeared approximately 6.7 ± 2.08 minutes after commencement of the test and a stable condensate mass was attained approximately 8.7 ± 1.53 minutes thereafter. Stable recovery was achieved 15.3 ± 2.52 minutes after commencement of the test.

The achieved performance of this retort was obtained at an average sustained external temperature of 508 $^{0}$C.

### 4.3.4 Test 4 (Hg – Mud Seal – Wood Fire – Continuous)

This test was conducted using mercury with a vapour seal (mud). Parameters 1, 4 and thermodynamic efficiency were not evaluated during this test due to damaged thermocouples (reason given above). No temperatures were recorded in this test. The test consisted of three replicate runs and no tapping or cleaning of the retort (to remove mercury that may have been trapped in the system) between successive runs i.e. continuous retorting without cleaning. An average mass of 51.16 g of mercury was used and approximately 51.45 g were recovered (Parameter $V_{Hg}$ = 100.6 ± 2.8%) after a total testing duration of approximately 42 minutes. The results obtained from this test are shown in **Chart 13** (Average of replicate runs) below.

**Chart 13: Model 3 - Test 4**
**Vapour Recovery Efficiency-Time Graph**

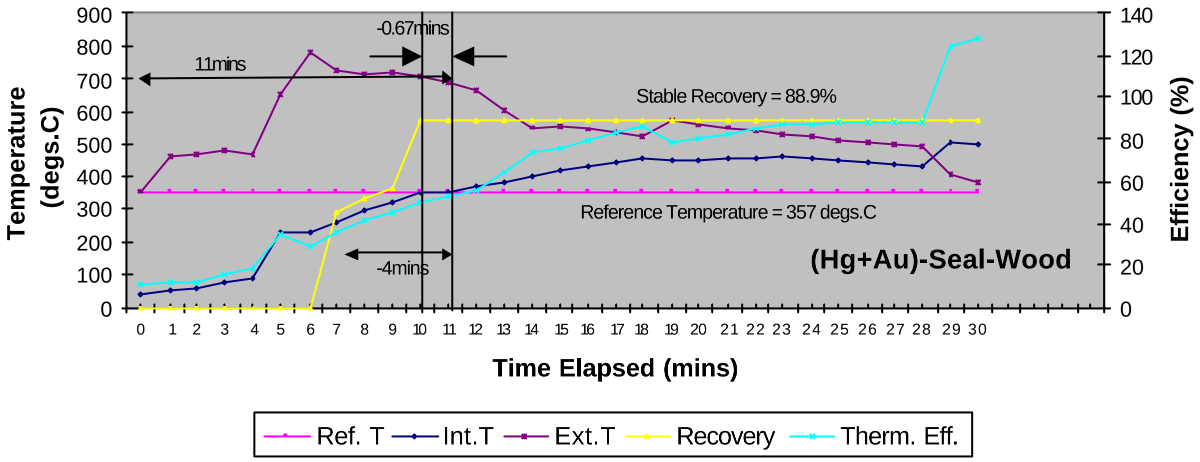



An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 13** shows that mercury condensate appeared approximately 4.0 ± 1.0 minutes after commencement of the test and a stable condensate mass was attained approximately 8.0 ± 1.73 minutes thereafter. Stable recovery was achieved 12 ± 2.65 minutes after commencement of the test.

## 4.3.5 Test 5 (Hg+Au –Mud Seal – Wood Fire)

This test, which consisted of four replicate runs, was conducted with a vapour seal (mud) and using a 1:1 gold/mercury mixture (amalgam). Amalgamated gold (31.1 g = 1ounce) of approximately 99% purity was purchased from the Guyana Gold Board for use in all tests conducted on amalgam. An average mass of 20.6 g of mercury and 20.6 g of gold were used to produce the amalgam. After retorting for approximately 37 minutes, 18.31 g of mercury (Parameter $V_{Hg}$ = 88.9 ± 6.89%) and 20.6 g of gold (100% recovery) were recovered. The results obtained from this test are shown in **Chart 14** (Average of replicate runs) below.

**Chart 14: Model 3 - Test 5**
**Efficiency-Temperature-Time Graph**

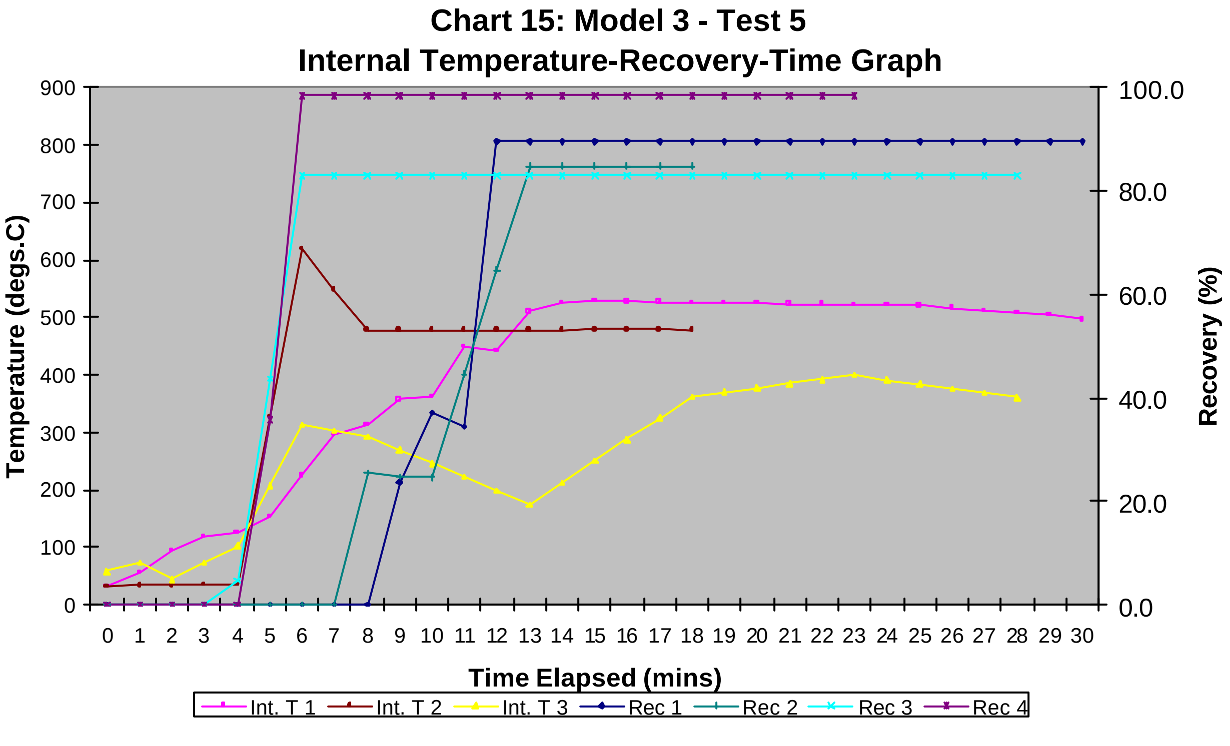



An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 14** shows that mercury condensate appeared approximately 4.0 ± 8.72 minutes before the internal temperature attained 357 $^{0}$C and a stable condensate mass was attained approximately 0.67 ± 10.02 minutes before that 357$^{0}$C level was achieved. The chart also shows that there was a delay of approximately 11.0 ± 6.24 minutes between the external temperature attaining 357 $^{0}$C and the internal temperature attaining that temperature and the difference in stable external and internal temperatures was approximately 88.93 $^{0}$C representing a thermodynamic efficiency of 79.2 ±

6.66%. Stable recovery was achieved 10.3 ± 3.79 minutes after the external temperature had reached 357 $^{0}$C.

The near parallel section of the graphs of internal and external temperatures indicates a relatively constant transfer of heat from the exterior to the interior of the crucible after stable external and internal temperatures had been reached.

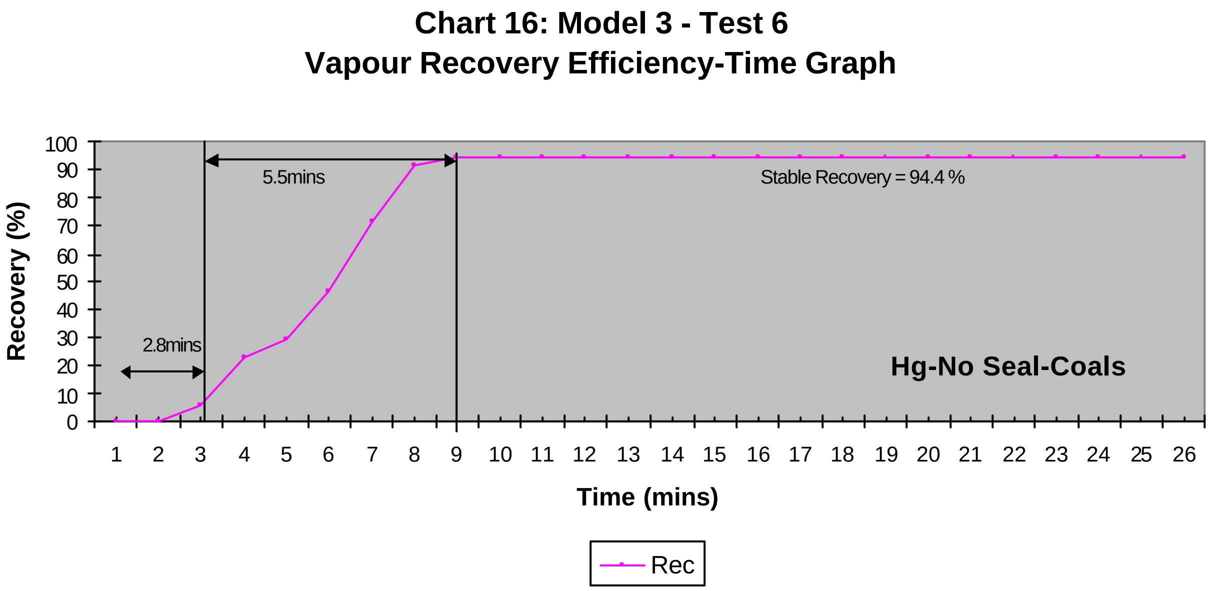
A comparison of the recovery and internal temperature shows a direct relationship between the two parameters i.e. mass accumulation mirrors closely the changes in internal temperature. This observation is clearly demonstrated in **Chart 15**. The clustered nature of the parameter graphs shown in **Chart 15** reflects the consistency in the retort performance, test procedures and to some extent the test conditions. The wider range of values of the internal temperatures achieved resulted from the introduction of gold into the system.




The achieved performance of this retort was obtained at average sustained internal and external temperatures 456.8 $^{0}$C and 575.5 $^{0}$C.

### 4.3.6 Test 6 (Hg – No Mud Seal – Charcoal)

This test was conducted without a vapour seal (mud) and using only mercury. The test consisted of four replicate runs and an average mass of 51.94 g of mercury was used, of which 49.05 g were recovered (Parameter $V_{Hg.}$ = 94.4 ± 2.6%) after a total testing duration of approximately 25 minutes. The results obtained from this test are shown in **Chart 16** below.




Parameters 1, 4 and thermodynamic efficiency were not evaluated during this test due to damaged thermocouples (reason given above). No temperature was recorded during this test.

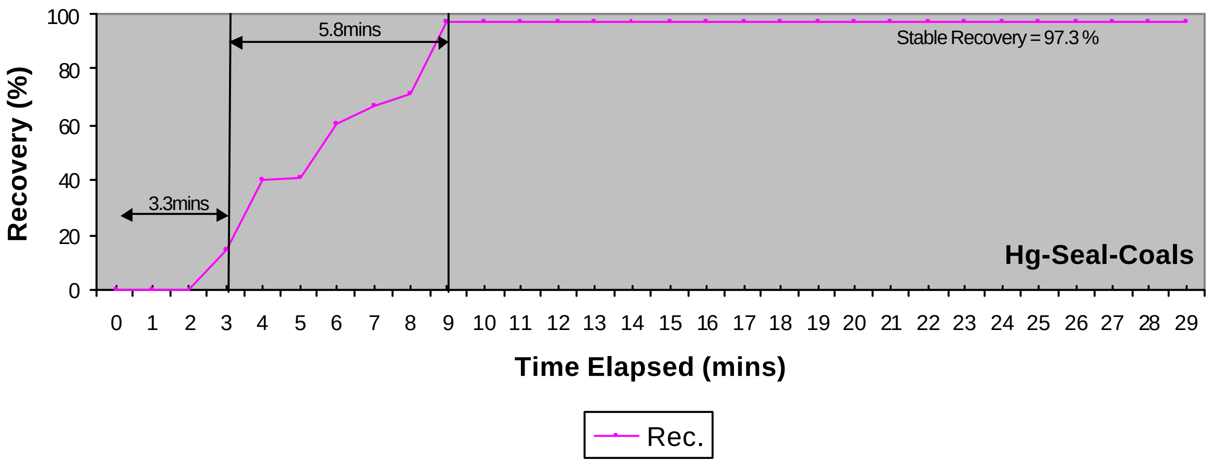
The heat source for this test consisted of a quantity of charcoal in a containment structure. **Chart 16** shows that mercury condensate appeared approximately 2.8 ± 1.71 minutes after commencement of the test and a stable condensate mass was attained approximately 5.5 ± 1.29 minutes thereafter. Stable recovery was achieved 8.25 ± 2.63 minutes after commencement of the test.

The high intensity of the charcoal heat source resulted in the exfoliation of the internal and external surfaces of the crucible and cover of the retort. It also caused the deformation of the permanent seal, resulting in reduced tightness between the cover and crucible.

### 4.3.7 Test 7 (Hg – Mud Seal – Charcoal)

This test was conducted with a vapour seal (mud) and using only mercury. The test consisted of four replicate runs and an average mass of 53.27 g of mercury was used, of which 51.85 g were recovered (Parameter $V_{Hg.}$ = 97.3 ± 1.38%) after a total testing duration of approximately 29 minutes. The results obtained from this test are shown in **Chart 17** (Average of replicate runs) below.

**Chart 17: Model 3 - Test 7**
**Vapour Recovery Efficiency-Time Graph**




Parameters 1, 4 and thermodynamic efficiency were not evaluated during this test due to damaged thermocouples (reason given in **Section 4.2**). No temperature was recorded during this test.

The heat source for this test consisted of a quantity of charcoal in a containment structure **(Picture 7)**. **Chart 17** shows that mercury condensate appeared approximately 3.3 ± 0.5 minutes after commencement of the test and a stable condensate mass was attained approximately 5.8 ± 2.5 minutes thereafter. Stable recovery was achieved 9.0 ± 2.45 minutes after commencement of the test.

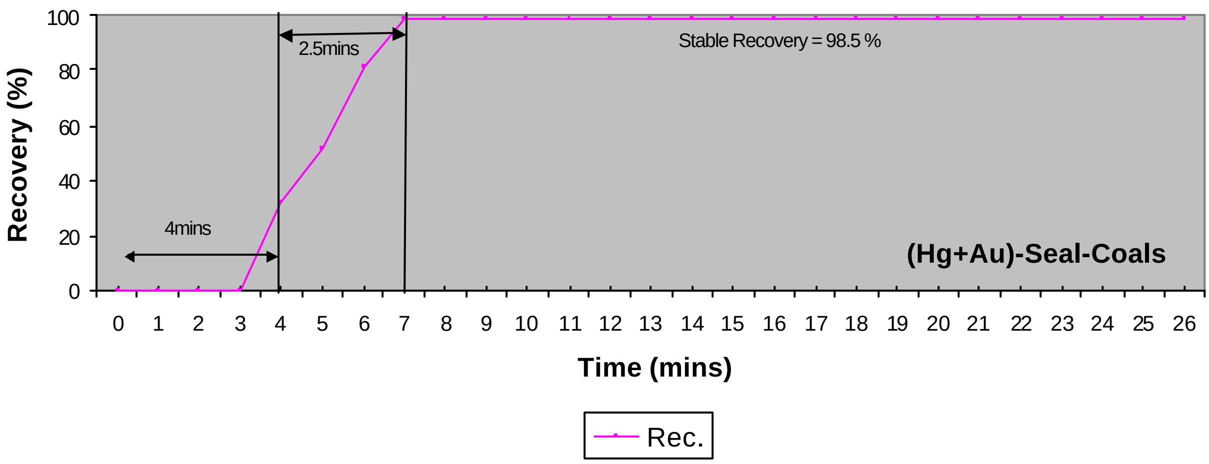
**Picture 7:** Charcoal in containment structure and retort placement for testing.

The high intensity of the charcoal heat source resulted in the exfoliation of the internal and external surfaces of the crucible and cover of the retort. It also caused the deformation of the permanent seal, resulting in reduced tightness between the cover and crucible.

### 4.3.8 Test 8 (Hg+Au – Mud Seal – Charcoal)

This test, which consisted of two replicate runs, was conducted with a vapour seal (mud) and using gold/mercury mixture (amalgam). Amalgamated gold recovered from test 5 (20.6 g), 8 g of gold of 99% purity (from the Guyana Gold Board) and 28.7 g of mercury were used to produce the amalgam. After retorting for approximately 26 minutes, 28.27 g of mercury (Parameter $V_{Hg}$ = 98.5%) and 28.3 g of gold (98.95% recovery) were recovered. The results obtained from this test are shown in **Chart 18** (Average of replicate runs) below.

**Chart 18: Model 3 - Test 8**
**Vapour Recovery Efficiency-Time Graph**



Parameters 1, 4 and thermodynamic efficiency were not evaluated during this test due to damaged thermocouples (reason given above). No temperature was recorded during this test.

The heat source for this test consisted of a quantity of charcoal in a containment structure. **Chart 18** shows that mercury condensate appeared approximately 4 minutes after commencement of the test and a stable condensate mass was attained approximately 2.5 minutes thereafter. Stable recovery was achieved 6.5 minutes after commencement of the test.

The high intensity of the charcoal heat source resulted in the exfoliation of the internal and external surfaces of the crucible and cover of the retort. It also caused the deformation of the permanent seal, resulting in reduced tightness between the cover and crucible.

A thin film of gold remained plastered to the internal surface of the retort. It is assumed that the internal temperature had risen above 1063 $^0$C (melting point of gold), hence, causing the gold to change to its molten state and initiating bonding between the gold and the internal surface of the crucible.

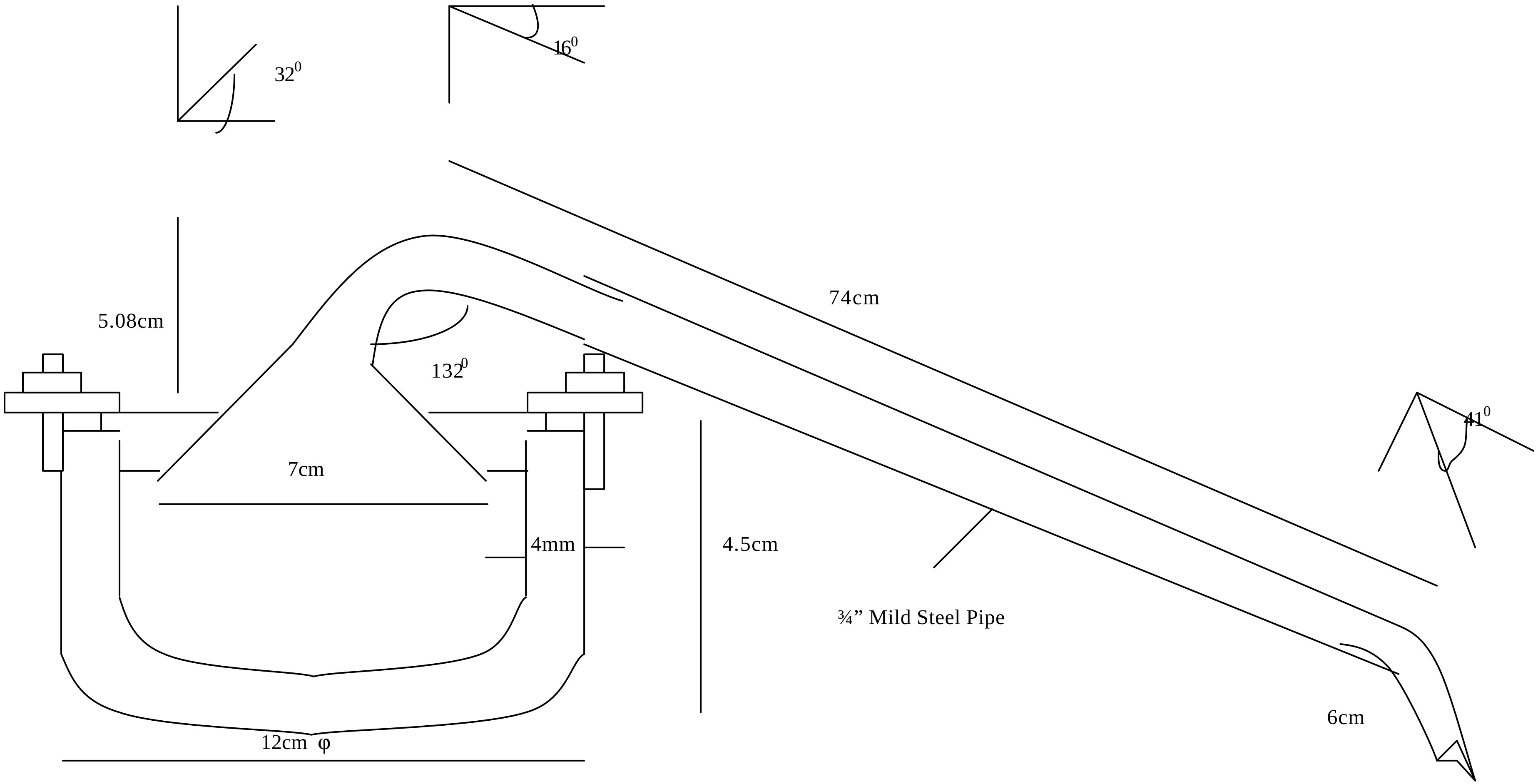
## 4.4 Model 4

This retort was fabricated by Janico Industrial Engineering Ltd. It is constructed of mild steel and essentially consists of a 12cm OD x 4.5cm H x 4mm T concave-bottomed crucible and a flat cover, fitted with a ¾ ” (2cm) condensate discharge pipe. The internal surfaces of the bottom and the cover were machined to achieve a concave shape and a funnel-shaped exit respectively. The condensate discharge pipe is 74cm long and rises 5.08cm above the top of the crucible at an angle of $32^0$ before it takes a $16^0$ (to the horizontal axis) decent. It also incorporates three detachable (threaded at the upper end) legs. Two of the legs (43cm in length) are situated closer to the crucible, and the other (35cm long), closer to the condensate discharge end of the retort. The end (final 6cm) of the discharge pipe has a further $41^0$ (to the slope of the pipe) downward curve to facilitate the immersion of the end of the pipe into a receptacle containing water. The cover is fitted to the crucible by means of wing nuts and bolts attached to the crucible. Precision machining of the lower part of the cover (lip) to fit tightly into the crucible creates a very effective vapour seal. Vapour exits the crucible through a funnel-shaped opening in the cover. The retort weighs 3.9 Kg (crucible-1.4 Kg, cover and condensate discharge pipe-2.5 Kg), excluding legs, which weigh 1.02 Kg each) and costs G$17,000. The sketch **(Fig.)** below shows the specifications to which Model 4 was fabricated.

Two tests were done on this retort and the source of heat for these tests was a wood flame.
Damaged thermocouples, as a result of direct exposure of the asbestos coated platinum-alloy wires to flame temperature above 800 $^0$C, did not allow for internal and external temperature readings to be recorded during the testing of this retort.

**NB.** Tests were not conducted in the same order as documented in this report.

**Fig. 4**
**ED RETORT Model 4**
**Specifications for Fabrication**

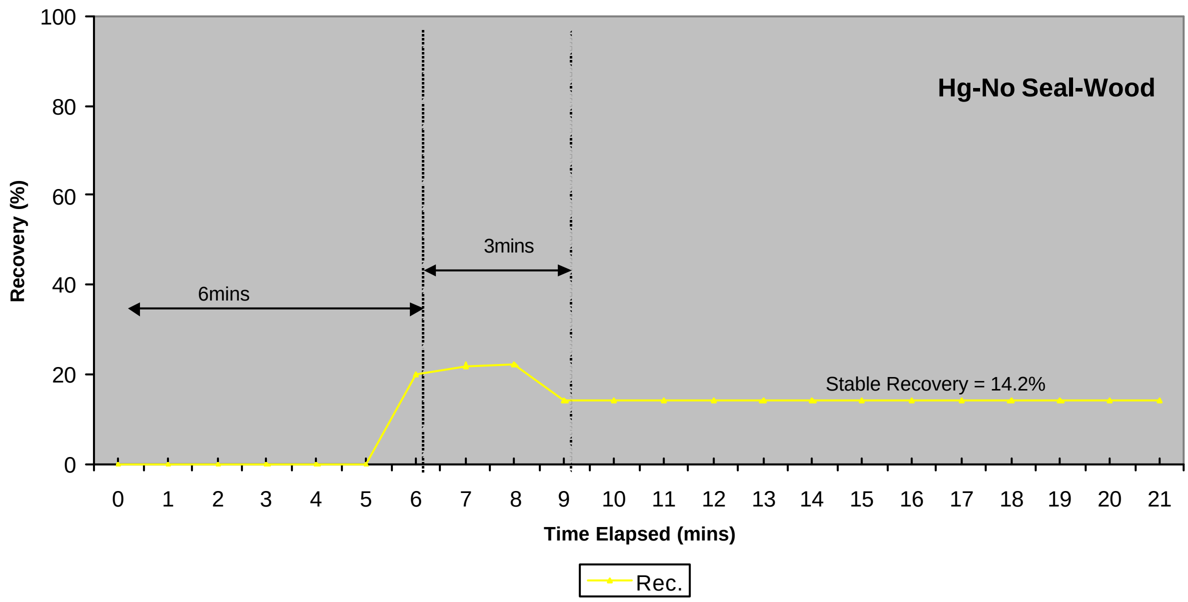



NB: Not drawn to scale.

### 4.4.1 Test 1 (Hg – No Mud Seal – Wood)

This test was conducted without a vapour seal (mud) and using only mercury. The test consisted of a single run and a mass of 54.5 g of mercury was used, of which 7.73 g were recovered in the condensate collection unit (Parameter $V_{Hg}$ = 14.2%) after a total testing duration of approximately 21 minutes. The results obtained from this test are shown in **Chart 19** (Average of replicate runs) below.

**Chart 19: Model 4 - Test 1**
**Vapour Recovery Efficiency-Time Graph**

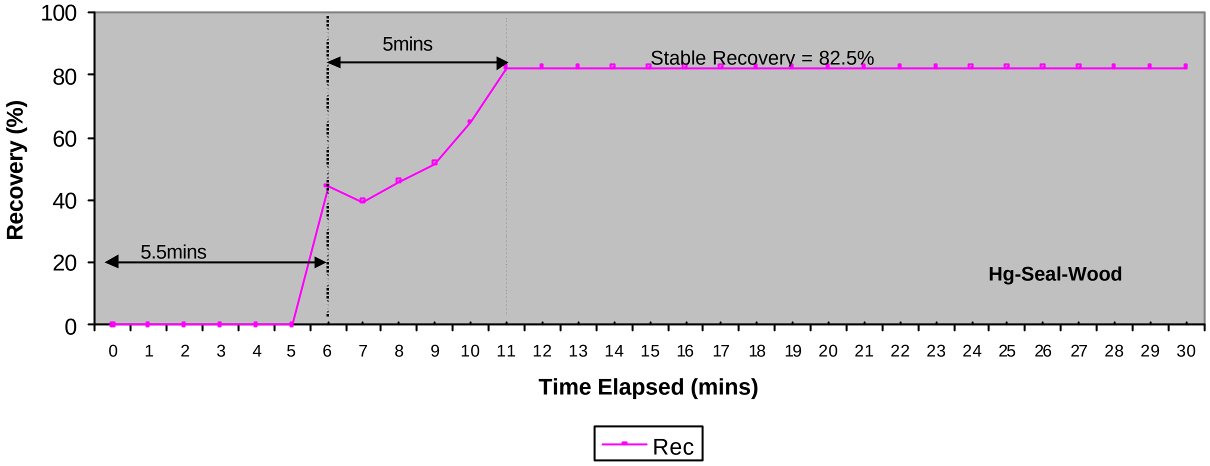



An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 19** shows that mercury condensate appeared approximately 6 minutes after commencement of the test and a stable condensate mass was attained approximately **3** minutes thereafter. Stable recovery was achieved 9 minutes after commencement of the test.

### 4.4.2 Test 2 (Hg – Seal – Wood Fire)

This test was conducted with a vapour seal (mud) and using only mercury. The test consisted of two replicate runs and an average mass of 53.9 g of mercury was used, of which 44.47 g were recovered (Parameter $V_{Hg.}$ = 82.5%) after a total testing duration of approximately 30 minutes. The results obtained from this test are shown in **Chart 20** (Average of replicate runs) below.

**Chart 20: Model 4 - Test 2**
**Vapour Recovery Efficiency-Time Graph**




An open flame, created by burning a specie of hard wood in a fire containment structure, was used as the source of heat for this test. **Chart 20** shows that mercury condensate appeared approximately 5.5 minutes after commencement of the test and a stable condensate mass was attained approximately 5 minutes thereafter. Stable recovery was achieved 10.5 minutes after commencement of the test.

This retort was not fabricated to specifications. A poor vapour seal contributed the major deficiency of this retort. Poor machining of the cover and crucible resulted in the loss of 86% of the mercury vapour **(Test 1)**, thus rendering this retort unsuitable for field application and hence, no further testing was conducted on this retort.

As in the case of ED Model 2 retort, the mud seal may have absorbed mercury (only 83% mercury recovery with a mud seal) and its' higher temperature during retorting may have facilitated volatilization at the surface of the seal.

# 5.0 Conclusions and Recommendations

## 5.1 Performance

Of the retorts tested, the best performance was achieved by **Model 3** and it is recommended that this retort be introduced to miners to be employed as their retorting tool in the near future. This retort has a Vapour Recovery Efficiency ranging from 88.9 ± 6.89%, when a mercury/gold amalgam is burnt on a wood fire, to 98.5%, when the amalgam is burnt on a charcoal heat source. These recoveries were attained within 16 minutes of retorting. Considering that this retort was designed for use on a wood fire, and locally, wood is the primary source of heat in almost 100% of the small-scale mining operations in Guyana, this retort would be widely accepted.

The results of the testing conducted are presented in **Table 1** below.

**Table 2: Combined Results of Retort Testing**

| Test # | Retort & Test Condition | Heat source | Parameter 1 (mins) | Parameter 2 (mins) | Parameter 3 (mins) | Parameter 4 (deg. C) | Thermo. Eff. (%) | Vapour Rec. Eff. (%) | Time for Stable Recovery (mins) | Hg Losses (%) | Au losses (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1(4) | Model 3 (Hg) no seal | Wood | 5.75± 0.5 | -1.00± 1.0 | 8.75± 2.22 | 146.90 | 78.64± 4.15 | 95.80± 2.45 | 14.50± 1.91 | 4.20± 2.45 | - |
| 2(4) | Model 3 (Hg) seal | Wood | 7.25± 1.71 | -1.75± 2.22 | 9.25± 4.19 | 147.15 | 77.80± 5.88 | 96.30± 0.86 | 16.50± 3.11 | 3.70± 0.86 | - |
| 3(3) | Model 3 (Hg) seal wet rag | Wood | - | 6.7± 2.08 | 8.7± 1.53 | - | - | 96.30± 2.26 | 15.3± 2.52 | 3.70± 2.26 | - |
| 4(3) | Model 3 (Hg) seal continuous | Wood | - | 4.0± 1.0 | 8.00± 1.73 | - | - | 100.60± 2.8 | 12.0± 2.65 | -0.6± 2.8 | - |
| 5(4) | Model 3 (Hg+Au) seal | Wood | 11.00± 6.24 | -4.00± 8.72 | -0.67± 10.02 | 88.93 | 79.2± 6.66 | 88.90± 6.89 | 10.3± 3.79 | 11.1± 6.89 | 0 |
| 6(4) | Model 3 (Hg) no seal | Coals | - | 2.8± 1.71 | 5.5± 1.29 | - | - | 94.40± 2.60 | 8.25± 2.63 | 5.60± 2.6 | - |
| 7(4) | Model 3 (Hg) seal | Coals | - | 3.3± 0.5 | 5.8± 2.5 | - | - | 97.30± 1.38 | 9.00± 2.45 | 2.70± 1.38 | - |
| 8(2) | Model 3 (Hg+Au) seal | Coals | - | 4.00 | 2.50 | - | - | 98.50 | 6.50 | 2.50 | 1.88 |
| 1(4) | Model 2 (Hg) no seal | Wood | 8.15± 3.95 | 1.00± 0.82 | 11.00± 2.16 | 191.45 | 70.65± 4.16 | 89.00± 3.76 | 19.8± 5.85 | 11.0± 3.76 | - |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2(4) | Model 2 (Hg) seal | Wood | 5.0± 2.31 | 1.5± 1.0 | 11.25± 4.57 | 101.00 | 85.55± 11.98 | 90.4± 3.2 | 16.0± 4.55 | 9.60± 3.2 | - |
| 3(3) | Model 2 (Hg) seal continuous | Wood | - | 5.3± 1.53 | 9.3± 3.5 | - | - | 91.40± 5.76 | 14.7± 5.03 | 8.60± 5.76 | - |
| 4(1) | Model 2 (Hg) seal | Kerosene | 35+ | - | - | 274.10 | 45.70 | 0.00 | - | 0.00 | - |
| 1(1) | Model 1 (Hg) no seal | Wood | 14.25 | 18.75 | 20.75 | 270.60 | 60.70 | 18.70 | 35.00 | 81.30 | - |
| 1(1) | Model 4 (Hg) no seal | Wood | - | 6.00 | 3.00 | - | - | 14.20 | 9.00 | 85.80 | - |
| 2(2) | Model 4 (Hg) seal | Wood | - | 5.5 | 5 | - | - | 82.5 | 10.5 | 17.50 | - |

**X** ± **S,** where **X** is the Mean value of the parameter and **S** is the Standard Deviation.
**(A),** where **A** is the number of replicate runs

***Note:***

1. **Mercury Vapor Recovery Efficiency:** *The vapor recovery efficiency is calculated as the Mass of the Condensate expressed as a percentage of the Initial Mass of Mercury in amalgam.*

2. **Stable Recovery**: *The percentage of mercury recovered after the initial retorting process i.e. retorting by the application of heat to the exterior of the crucible of the retort.*

3. **Time for Stable Recovery:** *The time required for a stable accumulative condensate mass to develop, calculated after the external temperature has attained $357^0C$.*

4. **Time for Stable Recovery:** *The time required for a stable accumulative condensate mass to develop, calculated from the commencement of the test.*

5. **Mercury Losses during Retorting**: *The amount of mercury retained in the retort (bound to surfaces), lost due to leaks in the seals and by other means.*

6. **Thermodynamic Efficiency:** *The thermodynamic efficiency is calculated as the average stable internal temperature expressed as a percentage of the average stable external temperature.*

7. **Parameter 1:** *The time lag between the external temperature attaining $357^0C$ and the internal temperature achieving this level –* $t_{357}$.

8. **Parameter 2:** *The time lag between the internal temperature attaining $357^0C$ and a positive change in mass in the condensate receptacle (time for the first appearance of condensate) –* $t_C$.

9. **Parameter 3:** *The time required for a stable condensate mass (optimum recovery) to develop, calculated after the internal temperature has attained $357^0C$ –* $t_{Opt}$.

10. **Parameter 4**:*The stable difference in operating temperatures, calculated as the difference between the stable external temperature and the stable internal temperature –* $T_{Ext.\ -\ Int}$.

11. **Parameter 2**: *The time lag between the commencement of the test and the first appearance of condensate.*

12. **Parameter 3:** *The time required for a stable condensate mass to develop, calculated from the first appearance of condensate.*

**Table 1** also highlights the effects of the amount of heat applied to the retort on the time taken to achieve Optimum Vapour Recovery. Optimum Recovery is achieved faster with a charcoal heat source than with a wood fire.

## 5.2 Retort Design

### 5.2.1 Sizes of Retorts

For a given size of heat source, a large vessel will take longer to develop a predetermined temperature than a smaller vessel, and any distillation conducted in the smaller container will be more efficient than that conducted in a larger unit (all other conditions being equal). It is therefore concluded that smaller retorts are more thermodynamically efficient, and the size of the retort must match the scale of production. This signifies that there should be retorts developed in sizes that are suitable for small and medium scale mining. Also, the significant features of retorts developed for small-scale miners are that they should be small, inexpensive, robust and have a permanent seal.

### 5.2.2 The Vapor Seal

The design of the permanent vapour seal of any retort is a critical factor affecting the Vapour Recovery Efficiency of the retort. To ensure an acceptable level of performance by a retort, an effective seal between the crucible and the cover of the retort must be maintained. While replaceable seals are preferred, the most practical seal is one that is robust and permanent i.e. one that is attained through a high level of precision machining. For a seal of lower quality, a mud seal is helpful but only up to a point, hence, retorts with poor permanent seals should be avoided.

The EDS Model 3 retort meets the requirement for a tight seal and can be recommended for wide acceptance. This retort consists of two precision-machined surfaces fitting within very close tolerance, and closed tight by means of symmetrically located wing nuts and bolts attached to the crucible of the retort. This design has been proven to be very efficient. It is also recommended that this retort be used with a mud seal as an additional safeguard against the potential loss of mercury.

Threaded crucible designs are undesirable, since constant thermal expansion and contraction associated with heating and cooling will eventually result in thread damage and in an inefficient seal. The use of charcoals (high temperature heat source – heating of the crucible to a red state) for retorting will reduce the effectiveness of the sealing mechanism of the retort in the longer term. This results from deformation of the crucible due to continuous expansion and contraction during heating and cooling for the retort."

### 5.2.3 The Discharge Pipe

The Retort Testing detailed in this report has revealed that mercury mass retardation occurs within the discharge pipe. This is a result of mercury accumulation along the rough internal surface (corroded) of the discharge pipe (inevitable with aging of the pipe). The rough surface hinders the free flow of mercury and serves as a mercury trap. This mass should not be considered lost, since it is recoverable by sufficient tapping and/or continuous usage of the retort.

Retardation is a function of the material from which the discharge pipe is constructed, and the best material (high corrosion resistance) seems to be stainless steel or mild steel (ED Model 3 retort). While stainless steel is possibly the best material, it is relatively expensive. Since it is possible that this accumulation of mercury could increase over time and cleaning of the discharge pipe can be difficult (as was experienced during the course of testing), it is recommended that the following sequence of cleaning activities be executed on the vapor discharge pipes after retorting:

1. Flush with water, collecting water at the discharge end of the pipe. The water should be drained from the receptacle and the mercury recovered for further use.

2. Clean with a bottlebrush to remove flakes from the corroded internal surface.

3. Use dry rag on a flexible metal rod or stick to wipe the internal surface of the pipe.

It is recommended that the end of the discharge pipe be submerged in a vessel containing water during retorting, in order to prevent mercury vapor losses from the condenser pipe. During operation, the end of the vapor discharge pipe should be submerged no further than the bend at the end of the pipe. This will eliminate the possibility of water entering the crucible.

The crucible should be air-cooled after retorting while the condenser pipe is submerged in a receptacle with water. The use of water for rapid cooling results in the exfoliation of the internal and external surfaces of the crucible (non-uniform thermal expansion and contraction) and can result in instantaneous production of large amounts of steam within a confined space, which can result in an explosion. It is therefore recommended that air-cooling be employed to increase the longevity of the retort and to ensure the safety of personnel present during the retorting process.

For miners who wish to use charcoal as their heat source, it is recommended that the crucible be placed at a distance of 2-3 inches (5-8 cm) above the heat source. This would reduce exfoliation and damage to the vapour seal and increase the longevity of the retort.

### 5.2.4 Crucible Construction Considerations

The thermal properties of the material from which the crucible is constructed, as well as the thickness, significantly impacts on the Thermodynamic Efficiency of the retort, since the thicker the metal is, the longer the delay in heat transfer, and therefore a significantly higher temperature gradient (difference between external temperature and internal temperature) would be observed. The size of the retort also impacts on its' Thermodynamic Efficiency, i.e. smaller retorts are expected to have lower temperature gradients (all other conditions being equal), since multidirectional heat conduction is expected to prevail (retort engulfed in flame) in a wood fire. The size of the tested and recommended ED Model 3 Retort allows for it to be completely engulfed in the average size wood fire used during the testing. Consequently, this design is a more thermodynamically efficient design than the designs that only allow for uniaxial heat transfer.

## 5.3 Heat Source Considerations

ED Model 3 Retort is compatible for use on a wood fire as well as charcoal (diffused heat sources). This automatically makes it compatible for use on a gas flame (concentrated heat source), where higher temperatures are achievable and may be regulated to reduce damage to the crucible. Caution should be exercised when operating on a gas flame since continuous application of heat to a particular area of the surface may inflict severe damage to the crucible.

Charcoal was observed to produce higher temperatures than wood, during these experiments. This was a consistent observation during the testing done. It was also observed that the development of an external temperature greater than 600 $^{0}$C is necessary for effective performance of the retorts. Additionally, it was discovered that a contained flame (wood or charcoal in a containment structure) is more effective than an uncontained (kerosene stove) flame (because of the concentration of the heat upwards towards the crucible), and it is recommended that the wood fire be contained within a structure similar to a local 'fireside', in order to minimize the time required for complete distillation. To accommodate the significant bulk of a wood fire, ED Model 3 retort is equipped with three detachable legs to provide sufficient ground clearance for the retort. However, the use of these legs is optional.

Wood is a preferable fuel for the small-scale miners, since it is abundant and free, and therefore guarantees wider use of the ED Model 3 retort, which is designed for use with such a heat source. The minimum sustained fire size is shown in **Pictures 2 and 6.**

## 5.4 Durability

Criteria such as durability, user-friendliness, operating and maintenance costs would require evaluation over a longer time frame and multiple applications in order to obtain a representative assessment. This is outside the scope of this testing exercise.

It is suggested that, in order to assess the retorts on the latter criteria, the retorts collected be distributed to selected miners for use in the various regions, for a trial period of two months. These miners would be provided with a standardized form outlining the criteria to be assessed and the relative assessment scales. It is intended that the miners would evaluate the retorts as they use them. After this period, the retorts would be returned to the GGMC and be permanently displayed in the library (along with relevant cost and acquisition information).

The objectives of this methodology would be twofold:

- To provide a representative assessment of the durability etc. of the retorts, and
- To promote the use of retorts and provide a permanent display for miners to obtain the information necessary to acquire retorts.

## 5.5 General

- The 1:1 gold/mercury amalgam used in this study may not be the true representation of the ratio used in the field. It is therefore recommended, that computations of Vapour Recovery Efficiency be conducted in the fields (under field conditions and by miners) to verify the results of this study and to identify any deficiencies in the test procedures employed.

- The decision to discontinue testing on Models 1,2 and 4 were based on the worse case scenario, i.e. the assumption that retorting without a supporting mud seal is a frequent occurrence on small and medium scale mining sites.

- When a mud seal is used to complement the permanent seal of the retort, the following conclusions can be made:

    - Higher recoveries are obtained only in some cases,

    - There is no statistically significant change in the Time for Stable Recovery and

    - There is no significant impact on the thermodynamic efficiency of the retorts, except for Model 2, where a lower thermal gradient (difference between the stable external and internal temperatures) was observed, reflecting an increase in thermodynamic efficiency.

  It is nevertheless recommended that mud seals should always be used to complement the permanent seal of the retort during operation.

- The Time for Stable Recovery varies directly with the intensity of heat supplied to the crucible. This was especially obvious when the time for stable recovery on a wood fire was compared with that on a charcoal heat source for ED Model 3 retort. It can be seen **(Table 2)** that with a higher heat intensity (charcoal), a stable recovery is achieved much faster than with a low temperature heat source (wood). Hence, it could be concluded that, with a high temperature heat source, almost immediate vapourization of mercury occurs and the higher internal pressure of the system quickly forces the vapour out of the crucible and into the discharge pipe (lower temperature and pressure) where condensation takes place. Generally, the longer it takes to achieve a stable recovery, the lower the recovery efficiency of the retort.

This observation may differ with varying weather conditions (high or low velocity winds), since the intensity of a heat source depends on the amount of oxygen available for combustion.

- The thermodynamic efficiency is an indication of the thermal gradient (difference of external and internal temperatures) of the retorting process, as well as, the rate at which heat is transferred from the heat source to the interior of the crucible. Hence, on a wood or charcoal heat source, greater thermodynamic efficiencies effect faster rates of recovery (reduces the time for stable recovery), but will not necessarily increase the achievable recoveries. Vapour recovery efficiency depends on the internal temperature achieved and maintained (greater than $357^0$C) and the rate at which this temperature develops.

- Wrapping a wet rag around the condensate discharge pipe of the retort and keeping it damp throughout the retorting process had no significant impact on the time for stable recovery no the vapour recovery efficiency.

- When Model 3 was operated continuously (at least 4 consecutive times) without cleaning (crucible and discharge pipe) and carefully handled to avoid escape of mercury from the discharge pipe, 100% Vapour Recovery Efficiency was achieved. This suggests that the unrecovered mercury after a single run does not escape to the environment, but rather, remains in the system and is recoverable by constantly using the retort.

- When a kerosene stove was used as the heat source for testing of ED Model 2, the following observations were made:

  - The internal temperature did not achieve the 357 $^0$C reference temperature level (boiling point of mercury).

  - No condensate was collected in the condensate collection unit.

- Vapourization and recondensation of mercury into the crucible: 100% of the mercury used in the test was recovered in the crucible.

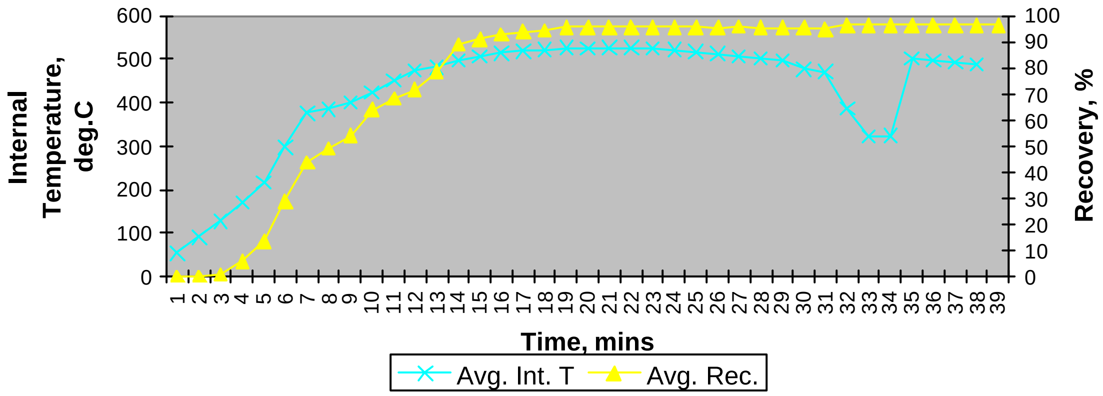
- Very low thermodynamic efficiency (<50%) of the operation and hence a very high thermal gradient.

- For the same retort, a general increase in recovery is observed from test to test – resulting from the accumulative effect of residual mercury in the system.

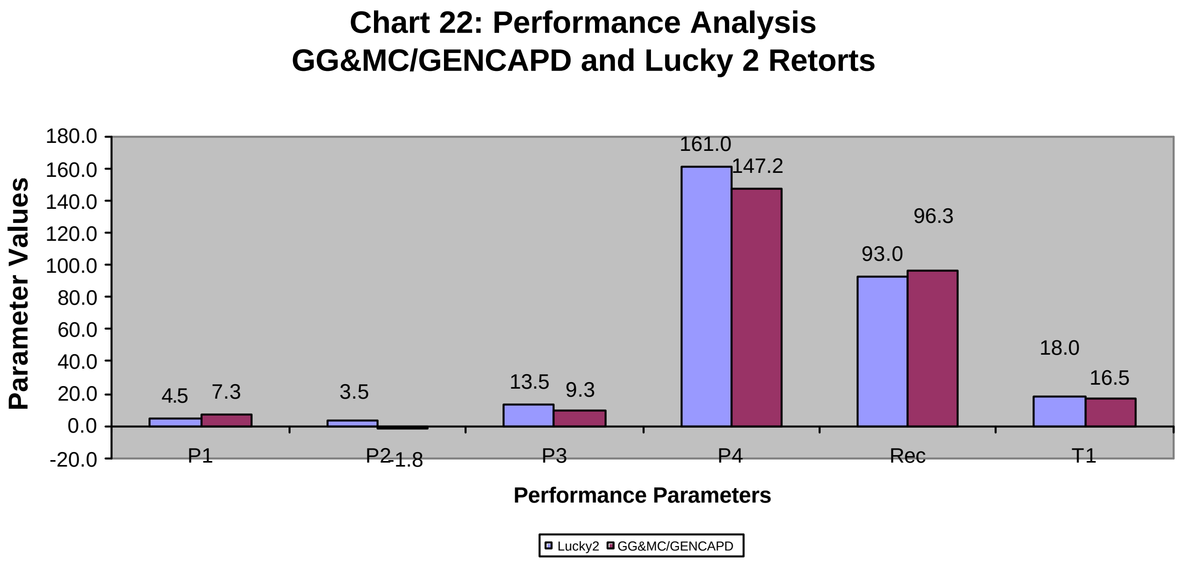
- Exfoliation of the internal surface of the crucible coupled with a high temperature (above 1063$^0$C – melting point of gold) heat source causes liquid gold to stick to the bottom surface of the crucible (forms a thin layer/coat on the bottom surface of the crucible), resulting in reduced recovery of gold (< 2% lost).

- Generally, a direct relationship between the internal temperature (amalgam temperature) and the Vapour Recovery Efficiency of the GG&MC/GENCAPD (ED Model 3) retort was observed **(Chart 21)** i.e. mass accumulation closely mirrors the changes in the internal temperature of the retort.

**Chart 21: Comparison of Internal Temperature and Vapour Recovery Efficiency GG&MC/GENCAPD Retort**




- When compared with the retort with the best performance parameters from the Retort Evaluation Program, 2000 (Lucky 2 Retort), the GG&MC/GENCAPD Retort demonstrated an overall better performance **(Chart 22),** except that the internal temperature of the Lucky 2 retort achieved the $357^0C$ reference temperature faster than the GG&MC/GENCAPD retort.




The following instructions should be adhered to when the GG&MC/GENCAPD retort is employed in the fields:

1. REMOVE COVER FROM CRUCIBLE OF RETORT
2. PLACE THE GOLD/MERCURY AMALGAM INTO THE CRUCIBLE
3. IMMEDIATELY PLACE COVER OVER CRUCIBLE AND TIGHTEN (USING WING NUTS – AVAILABLE)
4. PLACE MUD ON THE CONTA CT BETWEEN THE COVER AND CRUCIBLE
5. PLACE RETORT ON THE FIRE (WOOD OR CHARCOAL)
6. ENSURE THAT CRUCIBLE IS IN AN HORIZONTAL OR NEAR-HORIZONTAL POSITION
7. POINT THE CONDENSATE DISCHARGE PIPE AWAY FROM ANYONE PRESENT AND IN SUCH A MANNER THAT THE SMOKE FROM THE FIRE DOES NOT TRAVEL TOWARDS THOSE PRESENT
8. PLACE THE END OF THE PIPE INTO A CONTAINER WITH WATER (AT LEAST ONE (1) INCH OF THE PIPE MUST BE UNDER WATER)
9. **OPTIONAL:** WET RAGS MAY BE DRAPED OVER THE PIPE TO MAKE THE MERCURY VAPOUR CHANGE BACK TO LIQUID MET AL BEFORE COMING OUT OF THE END OF THE PIPE. RE-WETTING THE RAGS OCCASIONALLY MAY BE NECESSARY WHILE YOU ARE BURNING THE AMALGAM.
10. NEVER USE EATING UTENSILS TO COLLECT LIQUID MERCURY AT THE END OF THE PIPE.

11. HEAT (ABOVE 600$^0$C) FOR AT LEAST 25-30 MINUTES, DEPENDING ON THE SIZE OF THE AMALGAM
12. REMOVE THE RETORT FROM THE FIRE AND ALLOW TO COOL FOR APPROXIMATELY 30 MINUTES (AIR COOL, DO NOT USE WATER)
13. REMOVE (UNSCREW) THE COVER AND REMOVE THE GOLD
14. DECANT WATER FROM THE CONTAINER AND POUR MERCURY INTO A PLASTIC CONTAINER
15. ADD WATER TO THE CONTAINER TO COVER THE SURFACE OF THE MERCURY (TO PREVENT VAPOURISATION OF MERCURY AT ROOM TEMPERATURE)
16. TIGHTLY COVER THE CONTAINER WITH MERCURY AND STORE FOR FURTHER USE
17. THEN WASH THE HANDS WHEN THE TASK IS COMPLETED
18. KEEP MERCURY OUT OF THE REACH OF SMALL CHILDREN.

- People can be contaminated by mercury in a number of ways:
  - When mercury is bought in large containers from wholesalers and decanted for retail sale into smaller sized bottles.

    Shopkeepers must be careful when handling mercury (mercury vapourizes at room temperature) and make sure they wash their hands immediately after pouring the mercury.

  - Handling mercury when mixing with black sand to amalgamate gold. Rubber gloves should be worn but if you have none, then a stick or a spoon should be used to mix the mercury with the black sand to form the amalgam.

  - Using mercury in sluice boxes or gold dishes to capture the fine gold when mining.

    When the mercury is spread on the collection plate, use a flat knife or a similar object and the same when scraping off the amalgam after the gold has attached itself to the plate. Try not to use bare hands, and if you do, wash your hands afterwards.

- When squeezing the amalgam to have it ready for heating in a retort.

  Always wear gloves if possible and always make sure that you wash your hands well before starting the next activity or going to eat.

- When burning the amalgam.

  Always burn the amalgam outside of the camps or buildings, so that the mercury vapour does not get into your lungs.

  No smoking of cigarettes near the burning of the amalgam, since this can increase the risk of inhaling the mercury vapour.

  Don't breathe the smoke given off by the burning of amalgam. Do not eat near the site where the amalgam is being burnt.

  Small children and pregnant women should be kept away from the site where the amalgam is being burnt, since they are the ones most at risk.

- Eating the fish caught from mercury contaminated rivers, creeks, lakes, ponds, etc.
  Avoid eating fish caught from lakes, rivers or old dredging ponds that have resulted from alluvial mining activity.

* Safety Rules for Using Mercury
  - Always wear the appropriate safety gear before handling mercury if they are available.
  - Always wear hand gloves if available.
  - Do not let mercury touch your skin
  - Do not handle mercury directly. Always use a spoon or a stick, when no hand gloves are available.
  - Do not eat or smoke when using mercury.
  - Keep children and pregnant women away from where mercury is being used.
  - Do not use mercury containers for storing food or drink.

- If you are in possession of mercury, always mark or label the containers so it is easy to identify.

- Keep your mercury covered with water, since it gives off mercury vapor (smoke), which you can breathe into your lungs when mercury is exposed.

- Never use mercury inside or near a house or any enclosed area.

- When burning or retorting mercury and gold always observe the wind direction. Place yourself where the wind blows the smoke away from you. Never inhale the smoke given off during burning or retorting mercury and gold.

- Burn your mercury and gold in a proper retort so that most of the mercury is recovered for further use.

- Dispose of waste from burning mercury by burying it at least 45 centimeters below the surface. Make sure it is well away from where pigs could dig it out or where it won't be accidentally dug up in gardens.

- Advantages of Recycling Mercury

Recycle mercury as much as possible by capturing it through the use of a retort. You can repeatedly recycle mercury, but each time you use it, you may lose approximately 5% (± 5%) of your initial mass i.e. when retorting is conducted using the GG&MC/GENCAPD retort.

By capturing and recycling used mercury, you are:

- Saving Money,
- Protecting the Environment and
- Saving yourself and others from mercury poisoning.

For further testing, the following observations should be taken into consideration:

1. Tapping of condensate pipe during testing to facilitate the flow of mercury within the pipe results in fluctuation and false interpretation of the recorded condensate mass (accumulative mass) – accumulative condensate mass appears to be greater than expected (tapping during testing is not recommended).

2. Bridging of the thermocouples during testing results in false internal and external temperature readings (thermocouples should not be in contact during testing).

3. Variation of the internal pressure (vapour pressure) of the retort system causes fluctuations in the recorded mass of condensate. Condensate pipes of smaller diameter causes less fluctuation.

4. In general, the time lag between the external temperature attaining $357^0$C and the internal temperature attaining that threshold is greater when the crucible is sealed with mud compared to testing without a mud seal (mud reduces the rate at which heat is transferred to the interior of the crucible).

5. There was an insignificant loss of water from the condensate collection unit. This loss does not affect the actual mass of the condensate collected, since, at the end of each test, the water is decanted and the condensate is dried and weighed. Hence, the use of an open condensate collection unit does not affect the mass of condensate collected.

# Appendix A: Results of Replicate Runs

| Model: | 3 | Heat Source: | Wood | Seal: | No | Test: | 1 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery (mins) | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | 6 | -2 | 10 | 73.4 | 16 | 94.1 |
| 2 | 6 | 0 | 8 | 79.2 | 14 | 93.8 |
| 3 | 6 | -2 | 6 | 78.42 | 12 | 96.3 |
| 4 | 5 | -1 | 11 | 83.53 | 16 | 99.1 |
| **Mean Value** | 5.75 | -1 | 8.75 | 78.64 | 14.5 | 95.8 |
| **Standard Deviation** | 0.5 | 1 | 2.22 | 4.15 | 1.91 | 2.45 |

| Model: | 2 | Heat Source: | Wood | Seal: | No | Test: | 1 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery (mins) | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | 12 | 1 | 11 | 67.3 | 23 | 84.6 |
| 2 | 10 | 1 | 12 | 74.1 | 22 | 93.4 |
| 3 | 10 | 2 | 13 | 66.8 | 23 | 90.3 |
| 4 | 3 | 0 | 8 | 74.4 | 11 | 87.6 |
| **Mean Value** | 8.15 | 1 | 11 | 70.65 | 19.8 | 89 |
| **Standard Deviation** | 3.95 | 0.82 | 2.16 | 4.16 | 5.85 | 3.76 |

| Model: | 2 | Heat Source: | Wood | Seal: | Yes | Test: | 2 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery (mins) | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | 7 | 2 | 10 | 71.1 | 17 | 86.8 |
| 2 | 7 | 0 | 9 | 82.8 | 16 | 91.5 |
| 3 | 3 | 2 | 18 | 88.4 | 21 | 89.1 |
| 4 | 2 | 2 | 8 | 99.9 | 10 | 94.3 |
| **Mean Value** | 5 | 1.5 | 11.25 | 85.55 | 16.0 | 90.4 |
| **Standard Deviation** | 2.31 | 1 | 4.57 | 11.98 | 4.55 | 3.2 |

| Model: | 3 | Heat Source: | Wood | Seal: | Yes | Test: | 2 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery (mins) | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | 8 | -1 | 5 | 72.6 | 13 | 96.5 |
| 2 | 7 | -4 | 8 | 73.1 | 15 | 96.6 |
| 3 | 9 | -3 | 9 | 84.4 | 18 | 95.1 |
| 4 | 5 | 1 | 15 | 81.1 | 20 | 97.1 |
| **Mean Value** | 7.25 | -1.75 | 9.25 | 77.80 | 16.50 | 96.3 |
| **Standard Deviation** | 1.71 | 2.22 | 4.19 | 5.88 | 3.11 | 0.86 |

| Model: | 3 | Heat Source: | Wood | Seal: | Yes + Wet Rag | Test: | 3 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery [min] | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | | 9 | 9 | | 18 | 96.1 |
| 2 | | 6 | 7 | | 13 | 94.2 |
| 3 | | 5 | 10 | | 15 | 98.7 |
| 4 | | | | | | |
| **Mean Value** | | 6.7 | 8.7 | | 15.3 | 96.3 |
| **Standard Deviation** | | 2.08 | 1.53 | | 2.52 | 2.26 |

| Model: | 3 | Heat Source: | Coals | Seal: | No | Test: | 6 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery 3 [min] | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | | 2 | 4 | | 6 | 98 |
| 2 | | 1 | 6 | | 7 | 92.5 |
| 3 | | 3 | 5 | | 8 | 92.5 |
| 4 | | 5 | 7 | | 12 | 94.6 |
| **Mean Value** | | 2.8 | 5.5 | | 8.25 | 94.4 |
| **Standard Deviation** | | 1.71 | 1.29 | | 2.63 | 2.6 |

| Model: | 3 | Heat Source: | Coals | Seal: | Yes | Test: | 7 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery 3 [min] | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | | 4 | 5 | | 9 | 97.4 |
| 2 | | 3 | 3 | | 6 | 96.1 |
| 3 | | 3 | 9 | | 12 | 99.2 |
| 4 | | 3 | 6 | | 9 | 96.5 |
| **Mean Value** | | 3.3 | 5.8 | | 9 | 97.3 |
| **Standard Deviation** | | 0.50 | 2.50 | | 2.45 | 1.38 |

| Model: | 3 [Hg + Au] | Heat Source: | Wood | Seal: | Yes | Test: | 5 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery [min] | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | 9 | 0 | 3 | 86.3 | 12 | 89.5 |
| 2 | 6 | 2 | 7 | 78.2 | 13 | 84.7 |
| 3 | 18 | -14 | -12 | 73.1 | 6 | 82.9 |
| 4 | | | | | | 98.3 |
| **Mean Value** | 11 | -4 | -0.67 | 79.20 | 10.3 | 88.9 |
| **Standard Deviation** | 6.24 | 8.72 | 10.02 | 6.66 | 3.79 | 6.89 |

| Model: | 3 [Hg + Au] | Heat Source: | Coals | Seal: | Yes | Test: | 8 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery 3 [min] | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | | 5 | 3 | | 8 | 99.6 |
| 2 | | 3 | 2 | | 5 | 97.5 |
| 3 | | | | | | |
| 4 | | | | | | |
| **Mean Value** | | 4 | 2.5 | | 6.5 | 98.5 |
| **Standard Deviation** | | | | | | |

| **Model:** | 4 | **Heat Source:** | Wood | **Seal:** | No | **Test:** | 1 |
|---|---|---|---|---|---|---|---|

| **Run** | **Parameter 1 [min]** | **Parameter 2 [min]** | **Parameter 3 [min]** | **Thermo. Eff.[%]** | **Time for Stable Recovery [min]** | **Vapor Recovery [%]** |
|---|---|---|---|---|---|---|
| 1 | | 6 | 3 | | 9 | 14.2 |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| **Mean Value** | | | | | | |
| **Standard Deviation** | | | | | | |

| **Model:** | 4 | **Heat Source:** | Wood | **Seal:** | Yes | **Test:** | 2 |
|---|---|---|---|---|---|---|---|

| **Run** | **Parameter 1 [min]** | **Parameter 2 [min]** | **Parameter 3 [min]** | **Thermo. Eff.[%]** | **Time for Stable Recovery 3 [min]** | **Vapor Recovery [%]** |
|---|---|---|---|---|---|---|
| 1 | | 3 | 7 | | 10 | 87.4 |
| 2 | | 8 | 3 | | 11 | 77.6 |
| 3 | | | | | | |
| 4 | | | | | | |
| **Mean Value** | | 5.5 | 5 | | 105 | 82.5 |
| **Standard Deviation** | | | | | | |

| **Model:** | 3 | **Heat Source:** | Wood | **Seal:** | Yes + Continuos | **Test:** | 4 |
|---|---|---|---|---|---|---|---|

| **Run** | **Parameter 1 [min]** | **Parameter 2 [min]** | **Parameter 3 [min]** | **Thermo. Eff.[%]** | **Time for Stable Recovery [min]** | **Vapor Recovery [%]** |
|---|---|---|---|---|---|---|
| 1 | | 3 | 7 | | 10 | 98.9 |
| 2 | | 5 | 10 | | 15 | 99.0 |
| 3 | | 4 | 7 | | 11 | 103.8 |
| 4 | | | | | | |
| **Mean Value** | | 4.0 | 8.0 | | 12.0 | 100.6 |
| **Standard Deviation** | | 1.00 | 1.73 | | 2.65 | 2.80 |

| **Model:** | 2 | **Heat Source:** | Wood | **Seal:** | Yes + Continuos | **Test:** | 3 |
|---|---|---|---|---|---|---|---|

| Run | Parameter 1 [min] | Parameter 2 [min] | Parameter 3 [min] | Thermo. Eff.[%] | Time for Stable Recovery (mins) | Vapor Recovery [%] |
|---|---|---|---|---|---|---|
| 1 | | 5 | 9 | | 14 | 86.4 |
| 2 | | 4 | 6 | | 10 | 90.1 |
| 3 | | 7 | 13 | | 20 | 97.7 |
| 4 | | | | | | |
| **Mean Value** | | 5.3 | 9.3 | | 14.7 | 91.4 |
| **Standard Deviation** | | 1.53 | 3.51 | | 5.03 | 5.76 |

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| | |
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