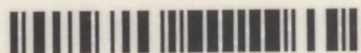


FLOTATION AS A SEPARATION
TECHNIQUE IN THE COAL GOLD
AGGLOMERATION PROCESS

LUCIAN BENEDICT MOSES

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FLOTATION AS A SEPARATION TECHNIQUE IN THE COAL GOLD AGGLOMERATION PROCESS

BY

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A DISSERTATION SUBMITTED IN FULFILMENT OF THE MASTER'S
DEGREE IN CHEMICAL ENGINEERING TECHNOLOGY AT THE CAPE
TECHNIKON

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ABSTRACT

Internationally, there is an increase in the need for safer environmental processes that can be applied to mining operations, especially on a small scale, where mercury amalgamation is the main process used for the recovery of free gold. An alternative, more environmentally acceptable, process called the Coal Gold Agglomeration (CGA) process has been investigated at the Cape Technikon. This paper explains the application of flotation as a means of separation for the CGA process.

The CGA process is based on the recovery of hydrophobic gold particles from ore slurries into agglomerates formed from coal and oil. The agglomerates are separated from the slurry through scraping, screening, flotation or a combination of the aforementioned. They are then ashed to release the gold particles, after which it is smelted to form gold bullion.

All components were contacted for fifty minutes after which a frother was added and after three minutes of conditioning, air, at a rate of one l/min per cell volume was introduced into the system. The addition of a collector (Potassium Amyl Xanthate) at the start of each run significantly improved gold recoveries. Preliminary experiments indicated that the use of baffles decreased the gold recoveries, which was concluded to be due to agglomerate breakage. The system was also found to be frother-selective and hence only DOW-200 was used in subsequent experiments. A significant increase or decrease in the air addition rate both had a negative effect on the recoveries; therefore, the air addition rate was not altered during further tests. The use of tap water as opposed to distilled water decreased the attainable recoveries by less than five per cent. This was a very encouraging result, in terms of the practical implementation of the CGA process.

Initial flotation experiments were performed in a one-litre cell constructed at the Cape Technikon, which revealed the most important flotation parameter (that would be important in scale-up) to be the contact speed. It was discovered that as the contact speed was increased, so did the mass of the flotation product and hence also the gold recoveries. Recoveries of up to 84 per cent were achieved on this scale. Investigation undertaken into the possibility of agglomerate recycle revealed that slightly less gold could be recovered in the second run, indicating that the agglomerates became more saturated after each run.

Further flotation experiments were performed in a 3.4 litre Wemco flotation cell, using a contact volume of 2.4 litres. Here, gold recoveries also increased with an increase in contact speed. Excellent results were achieved when the coal particle size was increased to between 500 and 650 microns. It was discovered that the larger coal particles were more floatable due to their porous structure. They also have a larger surface area per particle than the smaller particles and this, in addition to their porous structure, leads to improved gold particle penetration as well as adding stability to the agglomerates that were formed. When activated carbon was used in stead of coal, better floatability was observed. However, the activated carbon and oil did not agglomerate very well and hence gold was lost to the slurry, reducing the recoveries.

Against the background of the Small Scale Mining Initiative that was formed by the Department of Mineral and Energy Affairs, the proposed method of using coal-oil agglomerates can be an environmentally friendly alternative to mercury amalgamation.

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CHAPTER ONE

Introduction

1.1 Background

1.1.1 Gold extraction

The extraction of gold from its ores can be accomplished through various techniques such as cyanidation (incorporating the carbon-in-pulp, leaching and cementation processes) and amalgamation, in which copper plates, barrels, pocket amalgamators, amalgam presses or distillation retorts are used.

1.1.2 Small-scale gold mining

Existing gold recovery processes available to the small-scale gold mining sector pose a considerable hazard to the environment. It is however not only the environment that suffers under these processes, but also the communities that are resident in the underlying areas where small-scale gold mining is practiced. Currently, gold extraction is mainly done through mercury amalgamation and to a lesser extent cyanidation, using zinc precipitation.

1.1.3 An alternative process: Coal Gold Agglomeration

The small-scale gold mining processes mentioned above, unfortunately make use of very hazardous chemicals, as their names indicate. It was

therefore decided to develop a process that would be environmentally friendly, economical and relatively easy to implement.

Such a process was found in the Coal Gold Agglomeration (CGA) process, which was developed by the British oil and Minerals Company in the late eighties. Hydrophobic gold particles are recovered from ore slurries into agglomerates formed from coal and oil (See Figure 1). The agglomerates are usually recycled, separated from the slurry, burned and treated to recover the gold. However, it should be emphasised that this process can only be used to recover free gold.

1.1.4 Previous work

Laboratory procedures have been devised for rapidly testing the suitability of ore samples for treatment by CGA. Many ores of differing types have been examined and high gold recoveries have been achieved, provided that the gold is or can be liberated. Gold grains ranging from 1 to 500 microns can be recovered with equal ease. The process is most suitable for treating alluvial or free milling ores, gravity concentrates and current or old gravity plant tailings [Bellamy, *et al.*, 1989].

The ore samples tested by Bellamy, *et al.* (1989) originated from a beach sand deposit in New Zealand and had a varying mineralogical characterisation. The effect of wet and dry grinding, attrition scrubbing and screening below 150 microns as well as screening below 1.7 millimeters with no scrubbing was investigated as ore pre-treatment stages. All their tests were performed by agitating a slurry of ore and water in 0.6 dm³ Pyrex beakers fitted with four vertical baffles. When required, potassium amyl xanthate collector was added and the slurry conditioned for five minutes. The agglomeration time was 30 minutes and the agglomerates were separated from the tailings by screening. They also

compared the CGA process to conventional gold recovery techniques such as gravity concentration, cyanidation and flotation by using samples from the same deposit.

House, *et al.* [1988] tested local tailings deposits obtained from the 19th century mining of deep lead and quartz reef ore in Ballarat, Victoria which had an average head grade of 0.56 grams of gold per ton. A standard laboratory procedure was developed; whereby 2 kg of ore was contacted in a 5 liter baffled agitated container for various contact times. The agglomerates were then separated from the tailings by screening or flotation, and both were assayed for gold. The work was scaled up successfully to a bench scale 20 kg/h continuous rig, but it was soon discovered that a pilot plant was necessary to effectively test the CGA process. They therefore designed and constructed a one ton per hour pilot plant to test a range of agitation intensities, feed particle sizes, collector additions and throughputs, with very successful results.

Marciano, *et al.* [1994] investigated the effect of the type of coal, the type of oil, the oil : coal ratio (w/w) and the agglomerate : ore ratio (w/w) on the performance of the CGA process. Other operating parameters were also investigated, which included the contact time and the recycling of the agglomerates, up to six times. Their tests were conducted in non-aerated Denver sub-A flotation cells, with rotation speed control, using a three blade axial impeller in a contact volume of 2.0 to 3.0 liters. In addition to the CGA experiments, these researchers did a comparative study with mercury amalgamation, employing a horizontal cylinder rotating at 20 rpm, using sodium hydroxide as a conditioning agent. They found that the CGA process yielded better recoveries than the mercury amalgamation process.

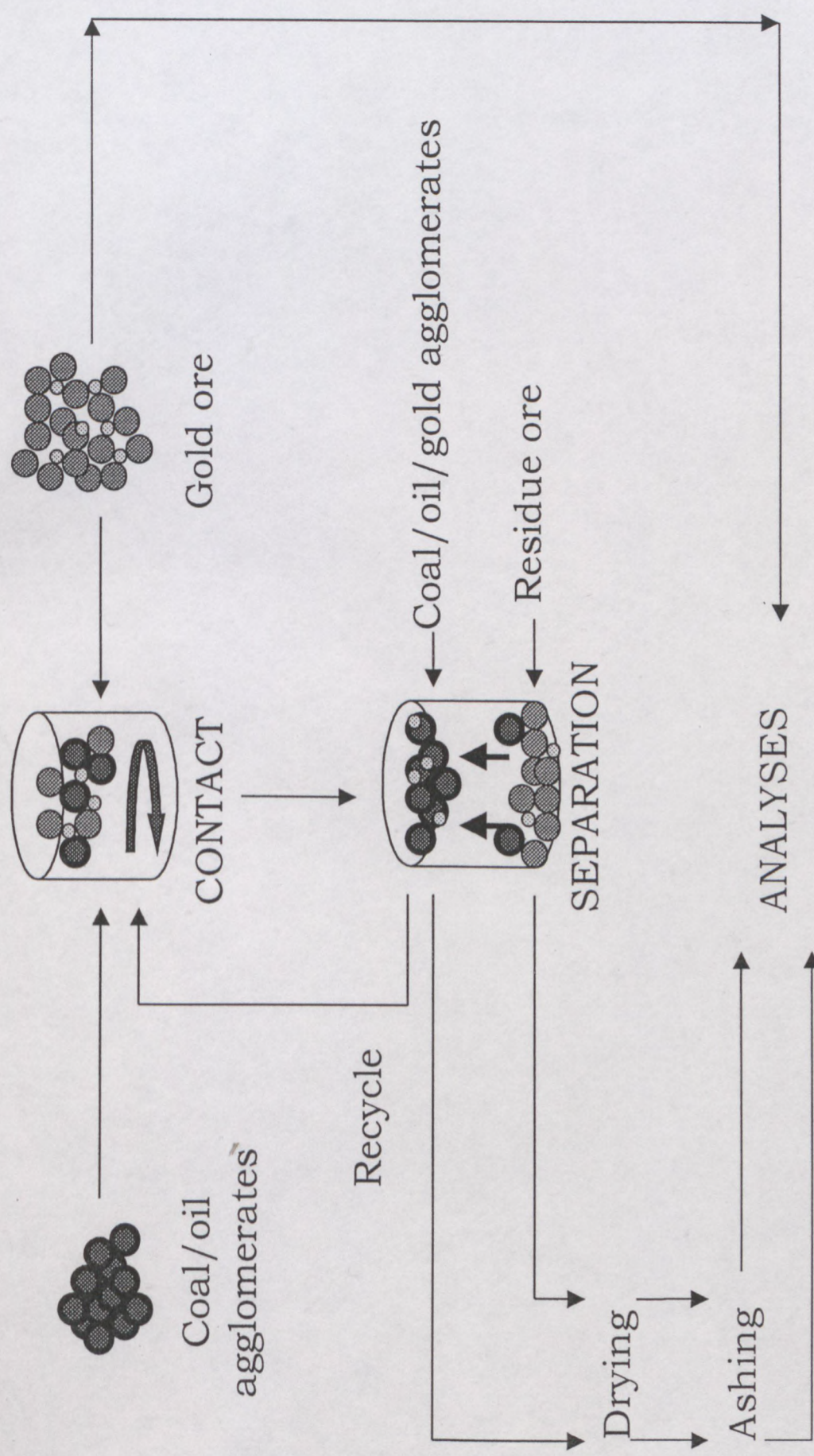


Figure 1: Layout of the CGA process

Calvez, *et al.* [1998], took a closer insight into the CGA process and the variables that affect both agglomeration and gold recovery. In addition to the oil : coal ratio (w/w), the agglomerate : ore ratio (w/w) and contact time, they also investigated the effect of pH, coal particle size and sulphides on the CGA process. The loaded agglomerates were separated from the tails by screening. They also studied the mechanism through which gold is captured by the agglomerates and determined the depth of gold penetration into the agglomerates by making use of fully loaded agglomerates.

Kotze and Petersen (1998) performed work on a South African coal, with ethyl oleate as an agglomerant on a small scale. Experiments were conducted in 150 ml sealed glass bottles and a magnetic stirrer was used as a means of agitation. They succeeded in optimising the operating parameters for this, specific combination of coal and oil. It was however evident that the separation efficiency could still be improved, which in turn would result in much better gold recoveries. The scale on which the experiments were done was impractical in that it would be impossible to use in a small-scale mining environment.

1.2 Objectives of this study

The operating parameters of the CGA process were optimised during a previous study by Kotze and Petersen [1998]. With the operating parameters set for maximum recovery under specific conditions, it was necessary to develop a satisfactory separation technique that would be capable of performing not only on a small batch scale, but also on a large batch scale, as well as under continuous operation. It was thus the focus of this project to optimise the separation phase of the CGA process and eventually evaluate the performance of the process under scaled-up conditions.

The specific objectives were:

- ◆ To become familiar with the operating parameters, experimental procedure and results of the CGA process by performing experiments on the same scale as Kotze and Petersen (1998). During this stage of the study, it was necessary to get an understanding of what effect the size of the agglomerates had on the separation, by using different oils. The effect of recycling the agglomerate and ore phases was also investigated.
- ◆ To understand the mercury amalgamation process and the accompanying safety precautions, as well as finding a suitable experimental procedure and set-up, and hence compare the results obtainable with this process to those of the CGA process.
- ◆ To investigate the effectiveness of other means of separation such as sieving and flotation. Separation by sieving was performed on the small scale, whereas a one-litre flotation cell was constructed at the Cape Technikon for the preliminary flotation experiments.
- ◆ To optimise the flotation parameters on a small scale, group the important parameters together and transfer these to a larger flotation cell, where the final optimisation was completed.
- ◆ To propose a design for a continuous, two-stage separation rig that will be robust enough for use in small-scale mining.

CHAPTER TWO

Literature review

2.1 Gold extraction processes

(Internet reference no. 1)

2.1.1 Cyanidation

The original process involved dissolution of the gold from the milled conglomerate by a weak cyanide solution in the presence of oxygen and its subsequent precipitation from the solution by using zinc shavings.

In modern plants, gold is precipitated out of the pregnant solution using zinc powder or absorbed onto activated charcoal. The precipitate is then filtered out of the solution, the filtrate (which looks like black mud at that point) is then melted with fluxes at the mine to recover the gold bullion as doré bars, containing typically 84 per cent gold, 10 per cent silver and 6 per cent light metals. These bars are then refined to 99.5 per cent or 99.99 per cent purity at a refinery. Gold absorbed onto charcoal is recovered by elution and submitted to the same pyrometallurgical process.

Counter-current decantation cyanidation remains important for ore that is not amenable to heap leaching. The operating cost is much higher than heap leaching since the ore is crushed and then ground to perhaps 80% minus 200 mesh (or even finer), prior to gold recovery.

2.1.1.1 Heap leaching

This process involves placing the ore in a stationary heap and a solvent (cyanide) percolates through the solid. The primary benefit of heap leaching is that it can be done with little reduction and hence significant cost savings.

Generally, ore of selected rock size is placed on a leach pad, which is saturated with a weak cyanide solution. The pads are constructed by laying impermeable plastic sheeting over a gently inclined and compacted graded soil. Before stacking the ore onto the leaching pads, a thin protective layer of sand is placed on the plastic insulator. The gold (and other metals) is then leached from the stack where it is gathered in a recovery pond for subsequent processing. For single stage leaching, two steps are involved:

1. Contact of solid and solvent for transfer of solute to solvent; and
2. Separation of the resulting solution from the residual solid.

The extract is the solvent phase and the raffinate is the solid material and its adhering solution. The solute in the raffinate is in both dissolved and undissolved forms. A derived process for refractory ores involves bacterial leaching to oxidise sulphide minerals.

2.1.1.2 Cementation (Zinc precipitation)

Leaching gold ores and concentrates with cyanide results in a solution containing anionic metal cyanide complexes from which gold must be recovered. The traditional method used was the separation of solution prior to gold recovery. The newer method is the carbon-in-pulp technology.

The most important method of gold recovery from dilute solutions arising from liquid-solid separation is zinc precipitation. The early use of zinc shavings was superseded by zinc dust from 1911 (the Merrill process) which offered a greater surface area per unit mass and required less handling than shavings. The precipitated gold and excess dust remained in the filter frames while the barren solution passed through the canvas filter cloth into a storage tank for re-use in the cyanide plant. Aluminium and charcoal were also applied as precipitants but never achieved the efficiency of zinc dust.

Further improvement took place in the form of the Crowe-Merrill zinc dust precipitation process involving the replacement of pressure-filter presses by suction-operated canvas frame filters comprising 36 or 48 leaves set radially in a circular tank. The main feature was the vacuum de-aeration tank invented by TB Crowe. This allowed dissolved oxygen in the pregnant solution to be removed just before the addition of zinc dust. In order to overcome the labour intensity of the Merrill process for cleaning the filters, enclosed pressure filters (mainly Stellar candle filters) were introduced in 1960 that allowed a measure of automation using back-washing. These filters were based on water clarification techniques developed during World War II.

2.1.1.3 Activated Carbon (Carbon-in-Pulp)

The application of activated carbon to gold recovery has its origins in the patented use of wood charcoal for the recovery of gold from chlorinating leach liquors in 1880. However, its use in precious metal recovery is a small element of activated carbon's potential and existing applications in any number of fields.

The carbon-in-pulp (CIP) process, which was developed to its present form in South Africa during the 1970s, is considered the most significant advance in gold recovery technology in recent years. The CIP method, is increasingly widely used (by 1995, there were 42 CIP circuits installed in South Africa). CIP technology makes use of the tremendous physical affinity 'activated' carbon has for gold (it can attract 7% of its weight in gold), which it readily attracts to its surface in cyanide solution.

The finely ground ore (typically about 75 μm particle size), and the slurry of fine ore and water (the 'pulp') are treated with cyanide in large tanks that are stirred mechanically or by air-agitation. Activated carbon is used to adsorb the gold directly from the cyanided pulp that flows continually from the first vessel to the last in the series, and the carbon is transferred intermittently by pumping in the opposite (counter-current) direction. The gold value of the pulp decreases downstream and the gold loading on the carbon increases upstream, with the highest value in the first tank.

The CIP process consists of three essential stages: adsorption in which the dissolved gold in the pulp is loaded onto aerated carbon, elution, in which the gold is removed from the carbon into an alkaline cyanide solution, and electro-winning, in which the gold is removed by an electrical process from the alkaline cyanide solution and deposited on steel wool electrodes. The carbon is then treated with acid to remove contaminants, after which the acid itself is treated. Both are then recirculated into the adsorption-elution circuit. When the leach and absorption circuits are combined, the process is described as carbon-in leach.

2.1.2 Gravity Concentration

Gravity concentration has been practiced for at least 4 000 years, allowing fine gold grains to be recovered from sand or river gravel. Washing the material in a stream of water across flat, sloping rocks, along inclined troughs, or over animal hides pegged to the bottom of a ditch (the Golden Fleece) effected this. Using these techniques, the heavier grains of gold were retained as a concentrate whilst the lighter sand was carried away by the flowing water. The difference between the specific gravity of gold (19,3) and that of the gangue (2,6 - 2,75) resulted in a satisfactorily high degree of concentration and of extraction.

Note that gravity concentration does not use buoyancy differences but inertia differences related to relative density. Where gold is found in particle sizes between 600 and 30 microns, gravity concentration remains effective. Therefore, it can be applied to crushed conglomerates such as South Africa's.

2.1.3 Amalgamation

Amalgamation was the principal gold recovery method used in South African gold mines last century. Crude amalgamation is still practiced by some artisanal gold miners in South Africa, mainly in the Mpumalanga province. Unfortunately, the method is in widespread use in other African countries and the Amazon region in Brazil, with devastating consequences for human health and the environment as mercury is released into rivers and the atmosphere during processing.

In large-scale commercial applications of amalgamation, ore was crushed and ground in stamp mills, and later in tube mills, which represented a

significant technological improvement. The crushed ore, as fine as talcum powder, was hydrated to form a viscous pulp that was passed over copper plates (4,57 metres long by 1,52 metres wide, 18% slope) coated on their upper surface with mercury. Because of its high relative density, the gold sank through the pulp into contact with the mercury, by which it was caught, and converted into amalgam. This amalgam (a solution of gold in mercury that took the form of a thick paste) was scraped off the plates, and retorted to yield gold sponge. Despite regular scraping, hard layers of gold amalgam accumulated on the plates. This was removed by softening the amalgam with steam, which allowed it to be scraped off without exposing the copper. By 1922, amalgam plates were replaced by corduroy strakes that were positioned in the discharge streams of tube mills. Using this process, pulp was passed over a flat, inclined surface covered with strips of corduroy fabric laid across the surface at right angles to the pulp flow. The gold and other heavy constituents were trapped in the corduroy riffles. The cloths were then removed and washed off into receptacles for amalgamation followed by retorting.

Amalgamation was still retained after the introduction of cyanidation in 1890 because it allowed the recovery of as much gold as possible at an early stage in processing. However, the introduction of the tube mill forced a move away from amalgamation since the slurry was coarser and less suitable to such treatment.

2.1.4 Flotation

Flotation was initially ignored in South Africa because of the efficiency and effectiveness of cyanidation. In flotation, reagents are added to flotation cells through which the finely ground ore is passed. Certain reagents will cause certain minerals to float to the top in a foam, and this

can be collected as a concentrate for subsequent processing. By the early 1900's, flotation was an important recovery process in the South African gold mining industry, although it was mainly confined to refractory ores such as those of the Barberton area.

However, the recovery of uranium oxide from gold ores from 1952 had a significant impact on its application in South Africa. This resulted in a trend toward using flotation as a complementary process to cyanidation. On South African gold mines, gold and the gold bearing minerals are floated, as they constitute the smallest component of the ore. Common practice favours high pyrite recovery.

2.2 Small-scale gold mining

In small-scale gold mining, the raw ore containing only about 1 to 100 grams of gold per ton has to be concentrated into marketable products containing at least 90 per cent gold. The requisite processes are diverse, complicated, and often involve the use of toxic reagents (cyanides, mercury, long-chain hydrocarbons, etc.). In the interest of safety and better techno-economic results, the global small-scale gold mining community is seeking advice and assistance. Additionally, the issue of environmental pollution by mercury contamination is preparing the way for alternative processing techniques with which to solve, or at least mitigate, the problem. (Priester and Hentschel, 1992)

2.2.1 Global distribution of small-scale gold mining

Most of the world's small-scale gold mining operations are situated in:

Latin America

Honduras, Nicaragua, Colombia, Ecuador, Peru, Bolivia, Chile, Brazil, Suriname, Venezuela and the Dominican Republic.

Africa

Ghana, Kenya, Tanzania, Zambia, Zimbabwe, Ethiopia, Guinea, Liberia, Nigeria, Gabon, the Central African Republic, Burundi and Madagascar.

Asia

India, China, the Philippines, Papua New Guinea, Indonesia and Malaysia.

In Brazil alone, more than a million people are directly involved in gold mining. Hence, the gold mining sector often constitutes a major source of employment in rural areas.

2.2.2 Generic problems of small-scale mining

Small-scale mining is an essentially artisanal or small-industrial form of raw material extraction. It is characterised by the following phenomena:

- little or no mechanisation in the form of machines and engines, resulting in a large proportion of heavy manual labour,
- low safety standards,
- generally low level of training,
- lack of technicians, resulting in deficient planning and organisation of extraction and processing activities,
- relatively poor exploitation of available resources due to selective extractions of rich ores in combination with low re-recovery rates, i.e., specific yields,
- low wages,
- low labour productivity,

- in part only seasonal employment in mines, or only as long as the world market prices are appropriately high,
- little awareness of environmental hazards,
- chronic shortage of capital,
- widespread illegal activities as a result of unfavourable mining laws and due to a lack of mineral rights/licensing.

Such problems frequently lead to a situation in which small-scale miners find themselves caught up in a vicious circle of economic bottlenecks, e.g. lack of working capital, with external assistance as the only possible path of escape.

A frequent and crucial technical and economic problem complex is the dressing of gold ore into marketable products. As a rule, the ores are of very low grade and require concentration by a factor of as much as 1 : 1 000 000. [Priester and Hentschel, 1992]

2.2.3 Mercury amalgamation

Out of all the processes mentioned in section 2.1, the most popular one for the recovery of gold on a small scale is mercury amalgamation. This is primarily due to low operating and capital costs associated with the process. Amalgamation is a process applied to precious-metal ores. Gold, silver and several of their compounds are capable of alloying with mercury. Such alloys are known as amalgams. First the raw ore is processed together with mercury; then the amalgam is separated and distilled (retorted) to separately recover the precious metal and the mercury.

The only raw material needed for the process is the mercury, whilst amalgamation can be accomplished in gold pans, sluices, drums, tubs,

amalgamating barrels, edge mills, stamp mills and amalgamating tables. The simplicity of the mercury amalgamation process makes it an ideal process for small-scale gold mining, which is mostly practiced by untrained, uneducated and very poor miners.

2.2.3.1 Environmental and health implications

There is however a growing concern for the effect of mercury on the environment. Mercury enters the environment during each of the two steps involved in acquiring the gold. Firstly, the sediments are taken from river bottoms and land mining sites and forced through a number of sieves. The sieves are coated with mercury, which bonds with the gold in the sediment, separating it from the rest of the material. Obviously, considerable amounts of mercury are left in the gold-depleted soil and enter the environment when this material is discarded. Secondly, the gold-mercury amalgam is heated to purify the gold by vaporising the mercury. If the heating is done in an unsealed container (which mostly happens), it enters the environment in gaseous form. This is particularly dangerous to the miner or smelter purifying the gold, as the person invariably inhales the mercury through breathing.

Vapor inhalation is the main route of entry into the body. Mercury vapor diffuses across the alveolar membranes of the lungs and it is estimated that between 74 and 80 percent of the inhaled mercury is retained in the body. After absorption, the elemental mercury continues to exist for a short time in the metallic form, thereby enabling it to cross the blood-brain barrier or placenta. Metallic mercury is oxidised by hydrogen peroxide-catalase to divalent ionic mercury (Hg^{2+}) which fixes to proteins. Oxidation of mercury to the ionic form, which is less likely to cross barriers, can trap it in the brain and the placenta. Mercury vapor is also absorbed through the human skin. The dermal uptake at whole-body

exposure is estimated to be 2.2 percent of the pulmonary uptake. Dermal contact with liquid mercury could therefore significantly increase biological levels. [Internet reference no. 2]

The effects of chronic exposure to mercury poisoning are readily apparent as it usually occurs through inhalation and causes violent coughing, chest pains, and leads to serious lung infections and disease along with causing serious damage to the central nervous system. It is more difficult to detect exposure in less than acute levels. Exposure to elemental mercury is largely restricted to those who work directly with the metal or to those who live in the area of a place where gold is being purified through the vaporisation of mercury, but the exposure to methylmercury is much more pervasive. Methylmercury is created when mercury is metabolised by animals into an organic compound, in Brazil this primarily occurs in the fish of the Amazon.

Exposure to methylmercury is much more dangerous than exposure to elemental mercury, because the human body can absorb it readily, increasing the chances for severe poisoning. High levels of methylmercury have been detected in fish caught over 300 kilometres away from primary mercury exposure sites, which is particularly distressing in light of the fact that fish is the primary staple of the poor in the Amazon.

The Amazon region is but one example where the lethal effects of mercury exposure has been highlighted, simply because Brazil is currently the world's fourth largest producer of gold. The use of mercury amalgamation is also very prominent in African countries such as Tanzania, where the ore is generally free milling and thus easily liberated.

It is therefore imperative that a new, environmentally friendly and economical process for free gold recovery becomes available to the small-scale gold mining sector or wherever mercury is used to recover free gold. Such a process was found in the Coal Gold Agglomeration (CGA) process, which was developed by the British oil and Minerals Company in the late eighties.

2.3 The Coal Gold Agglomeration process

Coal gold agglomeration (CGA) is a new concept in gold processing. It involves the recovery of hydrophobic, oleophilic gold grains by incorporation into agglomerates consisting of coal and oil. A collector is normally added to the system to increase the floatability of the floatable components. Under optimum conditions, very high gold recoveries can be achieved. The agglomerates are usually recycled to build up their gold loading. Burning the gold-loaded agglomerates with subsequent recovery of gold from the highly loaded ash by either dissolution/electrowinning or smelting produces gold bullion.

2.3.1 Previous work

A wide-ranging program of laboratory test work has been performed by Bellamy, *et al.* (1989) to investigate the response of different ore types to the process. The tests performed indicated that CGA is most applicable to ores in which the gold is liberated or can be liberated without difficulty, relatively coarse ($\pm 500 \mu\text{m}$) and fine ($< 5\mu\text{m}$) gold grains being recoverable with equal ease. Experimental results indicated the best opportunities for CGA to be:

- ♦ placers containing fine gold not recoverable by gravity concentration;

- ♦ low grade gravity concentrates to avoid multiple magnetic/gravity separation stages and amalgamation;
- ♦ free milling ores where the gold can be liberated at a reasonable particle size;
- ♦ tailings past or present from gravity concentration plants;

2.3.1.1 Component ratios

Marciano, *et al.* (1994) discovered that increasing the oil : coal, the agglomerate : ore ratios and the contact time, all increased the percentage gold recovered.

Calvez, *et al.* (1998) discovered that the rate of gold recovery was relatively faster at higher agglomerate : ore ratios (AOR). Increasing AOR correspondingly increases agglomerate surface area and number available for gold capture. Their results indicated that at lower AOR, more time is needed (or increased impeller speed as the case may be) for successful inter-particle collisions between the agglomerates and gold particles. They explain that in the agglomeration of coal by oil, the amount of oil and the degree of agitation control the size and strength of agglomerates.

At constant stirring speed, the size is mainly dependent on the amount of oil, where below the saturation point (over-critical oil addition), the diameter of the agglomerate increases with oil addition. It is therefore possible to vary the number and the surface area of agglomerates without changing the amount of coal used thereby having constant agglomerate to ore ratio. They discovered that increasing the amount of oil at constant weight of coal increases agglomerate size therefore decreasing the surface area of agglomerates formed.

They also found that the gold recovery is controlled not by the total amount of oil in the system, but rather the amount of oil available at the surface of the agglomerates as dictated by the size and number of agglomerates. With smaller agglomerates, the available surface areas of agglomerates formed at lower oil : coal ratios were greater resulting in higher gold uptake.

Kotze and Petersen (1998) discovered that doubling the amount of oil produces a very low percentage gold recovery. They construed this to be due to the larger agglomerates that was formed by the use of a large amount of oil and that the larger agglomerates in turn provided the gold particles with a much smaller contact area to attach themselves to. In addition, an increase in the amount of coal had a negative effect on the process.

2.3.1.2 Agglomerate recycle

Marciano, *et al.* (1994) also conducted experiments to test gold particles uptake by agglomerates in a recycling operation. In these tests, the agglomerates, after being screened, were contacted with a new pulp of the synthetic ore. This pulp made use of water of the previous cycle. They recycled the agglomerates six times and noted that uptake decreased with an increasing number of cycles while there was no increase at all in gold content of the agglomerates after the fifth cycle. They attributed this to the fact that the agglomerates became more compact after each cycle, therefore rendering gold penetration more difficult, since gold particles in these tests were relatively large in size (0.3 to 0.4 mm).

In the pilot plant used by House, *et al.* (1988), a single batch of agglomerates was retained for over 200 hours, during which gold loading was increased to 930 g Au/ton. After the addition of fine (-10 μm)

powdered gold, the agglomerate gold loading increased to 1300 g Au/ton, therefore giving excellent recovery of fine liberated gold at 1 tph, even after extensive agglomerate recycling.

2.3.1.3 Coal particle size

Test work evaluating the importance of coal particle size by Calvez, *et al.* (1998) revealed that using agglomerates formed with fine coal sizes gave higher gold recoveries. They ascribed this to the size and strength of the agglomerates, where smaller and stronger agglomerates were produced using finer coal particles, as described by Swanson, *et al.* (1977). It was discovered that weaker agglomerates produced from +75 -212 μm coal fractions gave poorer gold recovery due to the chipping-off of small agglomerate particles during agitation, possibly carrying with them attached gold particles.

2.3.1.4 Other parameters

As mentioned before, in section 1.1, Kotze and Petersen (1998) investigated the parameters that affect the CGA process through the use of a South African coal with ethyl oleate as the agglomerant. Besides the parameters mentioned previously, they also focussed on the effect of collector addition, percentage solids, means of contact and the mineralogy of the ore. It was concluded that the addition of a collector enhances the floatability of the agglomerates and hence also improves the separation of the gold-loaded agglomerates from the ore slurry.

They also found that increasing the collector concentration had the same positive effect on the separation. Furthermore, they discovered that a stirring action kept the size of the agglomerates to a minimum and hence the contact area for gold particles to attach themselves to at a maximum, therefore resulting in an increase in the percentage gold recovery. Finally,

reducing the amount of water in the system by fifty per cent and hence increasing the percentage solids enhanced the recovery of gold. The optimum contact period for this particular combination of reagents was found to be fifty minutes, after which no further increase in gold recovery was observed under the same conditions. Experiments conducted on a tailings sample from the Western Area Gold mine revealed that the mineralogy of the ore plays a very important part in the effectiveness of the CGA process.

2.3.2 Advantages of the CGA process

The greatest advantage of the CGA process is that it uses relatively non-toxic raw materials to perform gold extraction. The most dangerous component in the system is the collector, which is added in very small quantities and hence it dissipates into the air at very low toxic levels during the smelting stage. This problem is significantly reduced when a smelter with a fume scrubber is used.

Furthermore, experimental runs on a 1-tph pilot-scale plant by House, *et al.* [1988] revealed the following advantages of the process:

- The agglomerates can be recycled considerably, which reduces operating as well as downstream processing cost. In the pilot plant mentioned above, a single batch of agglomerates was retained for over 200 hours, during which gold loading was increased to 930 g Au/ton.
- During a typical operation at 1 ton per hour feed, the mean ore residence time was found to be 30 minutes. This confirmed that gold recovery by CGA is much more rapid than by most conventional gold

extraction processes, such as cyanidation, which can take up to 65 hours for the leaching stage.

- Experimental runs on various feedstocks indicated that despite considerable variations in feed characteristics, the pilot plant was capable of providing consistent meaningful results.
- The results from the effect of attrition scrubbing indicate no significant difference in the response of scrubbed and unscrubbed ore. Gold recoveries were therefore not being limited by the presence of an abradable surface coating on the gold particles.

2.3.3 Separation techniques for the CGA process

From the literature, it became clear that the best separation techniques for the process are screening and flotation, or a combination of the two. In the pilot plant mentioned in 2.3.2, the ore and agglomerates were first mixed in a series of contactor tanks each fitted with dual modified Lightnin impellers. The outflow from the final contactor was pumped to a four-cell Denver No 8 flotation unit where the agglomerates were separated from the spent ore. The agglomerate/flotation concentrate was recycled, being pumped back to the first contactor. The ore tailings were pumped over a vibro-energy screen to collect any coarse agglomerates, and then pumped to the tailings pond without further treatment. This then clearly illustrates the effectiveness of combining flotation and screening in a particular CGA set-up.

2.4 Flotation

The flotation process is regarded as the key to effective and economical mining practice in the enrichment of various types of minerals. [Dowfroth Frothers Bulletin, 1981]

Flotation is a physical-chemical process than can be used to enrich various mineral species. In the process, the ore slurry is chemically treated to create favourable conditions under which the mineral particles can attach to the air bubbles in the system. These air bubbles carry the particles to the surface of the slurry, where a stable froth is formed. The froth is scraped off to recover the valuable material from it. The other, unwanted, mineral residue remains in the slurry. [Fourie, 1988]

The flotation process is the most effective, complex and commonly applicable process that is used for ore enrichment in the mining industry. It can theoretically be applied to any mixture of fine particles that is fine enough to be carried by rising air bubbles. A limited knowledge of the flotation mechanism did however limit its use to a relatively small group of minerals. [Fourie, 1988]

2.4.1 The flotation process

Flotation is a complex process that has a wide range of application as a separation process in mineral technology. With flotation, the properties of the slurry and froth phases play an important role in the effectiveness of the process. Three important characteristics of the process, namely grade, recovery and time are used together to determine a complete specification of the expected performance [Hemmings, C.E., 1980].

In a general flotation run, the following basic steps are followed [Dowfroth Frothers Bulletin]:

- The ore is milled fine enough to release the valuable mineral particles from the useless gangue.
- A stream of rising air bubbles is formed in the slurry.
- The process conditions are then made suitable for the adsorption of valuable minerals onto the air bubbles by the addition of specific collectors.
- A mineral-loaded froth is formed on the surface by adding a frother to the system.
- The layer of froth is then finally removed.

2.4.1.1 Flotation mechanisms

Various mechanisms are at play during the flotation process. Firstly, there is the carry-over mechanism from the slurry to the froth. This mechanism entails the attachment of the hydrophobic particles onto the rising air bubbles, as well as dragging from the slurry phase into the froth. Secondly, there is a carry-over mechanism from the froth to the slurry. With this mechanism partial back-drainage of the dragged slurry phase occurs when the air bubbles break and release the particles. These particles can then attach to stable air bubbles or drain back to the slurry phase [Lynch, *et al.*, 1981].

2.4.1.2 Physical and chemical parameters

There are a variety of physical and chemical parameters that also influence the process. The collectors and frothers used form a very

important part of the process. Certain chemicals that are added can influence the slurry processes while others will affect the process in the froth phase. Separation in flotation is based on the differences in the surface properties of the solids in the slurry. Coal particles, for example is a heterogeneous mixture that is naturally hydrophobic and thus require only a slight coverage in collector to float. [Lynch, *et al.*, 1981]

2.4.1.3 The frother

Frothers can be characterised according to the stability, mobility, drainage, bubble size and lamella thickness of their froth. The frother must be capable of forming a reasonable froth that will allow the removal of the mineral-carrying froth bubbles from the flotation apparatus. The froth that is formed should have minimal collective properties, so that the valuable material can be selectively recovered while the unwanted residue drains back to the slurry. The stability of the froth must allow it to flatten easily after its recovery [Dowfroth Frothers Bulletin, 1981].

2.4.1.4 Selectivity of flotation

All flotation processes are selective in that one mineral or group of hydrophobic minerals is separated from the accompanying gangue. Separation is thus primarily based on the difference in surface properties between the various components. It is always difficult to make correct predictions on the precise flotation activity of a particular ore based on investigations and analyses. A number of correlations have been derived and forms the basis of certain common rules and methods that can be used as guidelines for flotation processes.

2.4.2 Important operating variables

The effectiveness of the flotation process can generally be expressed in terms of the grade and recovery of the valuable material. Specified variables in the feed that can affect this effectiveness are: the flow rates, the percentage solids in the slurry and froth phase, the particle size distribution as well as the oxidation grade.

If the initial slurry is very aqueous, it will have virtually no effect on the flotation rate, but with concentrated slurries this parameter does however start to play a role [Mehrotra and Kapur, 1974]. Mixing effects also have a great influence on the flotation behavior due to the change in residence time that is brought about through it. Most researchers however agree that the mixing space in flotation machines can be seen as a perfect mixing vat. Any deviation from perfect mixing has the greatest effect on the flotation of coarser particles. [Lynch, *et al.*, 1981]

2.4.2.1 Collector and frother concentrations

Kawatra and Waters [1982] investigated the effect of a variation in the collector concentration and frother concentration on a froth flotation system. Their research revealed that the reagent present in excess (high concentration) has the greatest effect on the ultimate particle and water recovery. Collectors, for instance will boost the hydrophobicity of the coal and has a complex effect on the grade-recovery curves due to the changing hydrophobicity, froth drainage and bubble breakage. It was found that the collector would actually reduce froth stability if it is present in abundance.

2.4.2.2 Aeration

The flotation rate and overall flotation kinetics is directly affected by the aeration rate and particle size. Aeration can therefore be regarded as an important control parameter in flotation circuits (Mehrotra and Kapur, 1974). The airflow rate is thus a necessary variable for the control and optimisation in flotation plants (Laplante, *et al.*, 1983).

Gorain, *et al.* (1999) performed extensive studies on the bubble surface area flux (S_b), finding it a good measurement of the gas dispersion in a flotation cell, which has major implications for flotation scale-up. In the same references, it is explained that S_b is a property of the gas-dispersed phase in a flotation cell, which combines the effect of bubble size and superficial gas velocity. Mathematically, S_b can be represented as:

$$S_b = 6J_g / d_b,$$

where: S_b = bubble surface area flux (m^2 / m^2sec)

J_g = superficial gas velocity (m / sec)

d_b = Sauter mean bubble size (m).

These researchers defined that physically, S_b is the total surface area of bubbles moving through the cell per unit cell cross-sectional area per unit time. The overall flotation rate constant k of valuable minerals was found to have a strong correlation with S_b indicating that the greater the available surface area of bubbles, the greater the chance of particle-bubble contact and therefore the higher the flotation rate constant.

2.4.2.3 Particle size

The particle size is also an important flotation parameter and has a distinctly noticeable effect on the process. A specific relation exists between the grade of hydrophobicity required to bring about flotation and the particle size itself. It has also been proven that high flotation rates only occur within a limited size range.

The effects caused by fine solids were thoroughly investigated by various researchers. Fine particles lead to a high consumption of reagents due to the availability of a larger surface area and hence coarser particles experience incomplete adsorption. The quick appearance of fine particles in the froth leads to a higher flotation rate which in turn results in an immobile and overloaded froth. These froth characteristics occurs to the trepidation of the coarser particles, which drains back to the slurry in the process. [Lynch, *et al.*, 1981]

The flotation rate of fine particles is generally stated to be low relative to the rate of other particle sizes. This phenomenon is mainly due to the decline in bubble-particle collisions as the particle size decreases. [Trahah, 1981] However, the fine particles are also dragged into the froth, which results in the flotation rate appearing to be even lower. Any variable that will influence water recovery will also affect the recovery of fine particles. The effectiveness of the separation is thus mainly dependent on the gangue dragging, and is lowered with a reduction in the feed size under otherwise identical operating conditions.

2.4.2.4 Froth characteristics

Froth is a relatively unstable composition of air bubbles with the water phase in between. It thus forms a dispersion, with air as the discrete phase and the water solution as the continuous phase. This continuous phase is in some cases reduced to virtual negligence due to dilution. [Hemmings, 1980]

A cellular, two-phased froth flattens quicker with an increase in viscosity, froth height and bubble size, but this flattening rate decreases with increasing liquid density, surface tension and critical water film

thickness. During froth flotation, the froth must however display a controlled lifetime. It must therefore be stable enough to float the valuable component, but it must be able to release the component at an acceptable rate [Barber and Hartland, 1975].

The stability of the froth is mainly dependent on the amount of frother that is added to the system. At low frother concentrations, the froth flattens quickly, so that the rate of solids carried over also becomes lower. An increase in frother concentration is however similar to a decrease in froth height so that more water can be recovered. The effect of this variable is greater on hydrophilic gangue particles than on the valuable hydrophobic particles [Lynch, *et al.*, 1981].

The frother can therefore be used as a variable to control froth stability. By thus varying the size and amount of bubbles in the slurry, the amount of water and particles that is carried over is increased. By controlling the froth stability, the drainage of particles out of the froth as well as the losses due to froth over-loading and this drainage are also controlled [Kawatra and Waters, 1982].

2.4.2.5 Water carry-over and drainage

In the modeling of the flotation process, it is important to allow for the dependence on water recovery. With a constant froth height and aeration rate, the water recovery depends on the stability and mobility of the froth. This dependence is difficult to predict, but can be determined empirically [Engelbrecht and Woodburn, 1975].

Water thus plays an important role in the structure and working of the froth. During flotation, there is a netto upward movement of the water in the froth that causes the top part of the slurry to be dragged upwards.

These dragged particles will either drain back due to their greater density, or be dragged with the water due to their ultrafine size. Everything is however a function of the distribution of bubbles, the size, shape and density of the particles and the netto upward movement of the water [Kawatra and Waters, 1982].

2.5 Significance of the literature review

From the literature review, it is clear that a need exists for an environmentally friendly process for small-scale gold recovery, mainly due to the hazardous nature of currently available processes. It also became clear that the CGA process is an environmentally friendly process that is both economical and easy to implement. A detailed investigation was launched into the flotation process, which revealed that it could be successfully used in conjunction with the CGA process, if the flotation operating parameters applicable to the CGA process can be optimised.

The operating parameters such as oil : coal ratio, slurry concentration, collector addition and contact time for the particular combination of ethyl oleate oil and an industrial coal obtained from the Athlone power station (Cape Town) were optimised by Kotze and Petersen (1998). This then laid the foundation for applying flotation methodology to the CGA process, which made it possible for the CGA process to be scaled up to an acceptable small-scale unit operation.

CHAPTER THREE

Experimental

3.1 Experimental materials

3.1.1 The ore

The ore used for all of the experiments was synthetically prepared by milling of clean silica sand and the subsequent screening of the milled material into a particular particle size distribution, as indicated in Table 3.1.

<i>Particle size range (μm)</i>	<i>Mass (grams)</i>
-300 + 212	150
-212 + 150	150
-150 + 106	400
-106 + 75	150
-75 + 25	150
Total	1000

Table 3.1 Particle size distribution of the synthetic ore

A 99 % pure, fine ($\pm 44 \mu\text{m}$) gold powder in the Au^0 form was then added to the sand to give a gold loading of approximately 7 grams per ton. This

gold particle size was found to be a relatively good average for coal gold agglomeration, amongst the gold particle sizes used by other researchers. The chemical analysis of the gold used is depicted in Table 3.2.

<i>Element</i>	<i>PPM</i>
Silver (Ag)	60
Iron (Fe)	15
Magnesium (Mg)	1
Gold (Au)	Remainder

Table 3.2 Trace analysis of the gold powder, ICP

3.1.2 The coal

The coal used was obtained from the Athlone Power Station, and after screening below 300 micron, it was found to have a particle size distribution as illustrated in Table 3.3.

<i>Particle size range (μm)</i>	<i>Mass (grams)</i>
-300 + 212	145
-212 + 150	202
-150 + 106	134
-106 + 90	68
-90	453
Total	1000

Table 3.3 Particle size distribution of the coal.

3.1.3 Chemicals

Potassium Amyl Xanthate was used as the collector for all experiments, with Sodium Ethyl Xanthate investigated as an alternative. Karbochem supplied both chemicals. Dow 200 was used as frother, with MIBC (Methyl Isobutyl Carbinol) as the alternative, both received from the University of Cape Town.

Ethyl oleate oil was used as the agglomerant, and three other base oils from the CALTEX range were tested. The physical properties of these oils are shown in Table 3.4.

Distilled water, produced in The Cape Technikon's Chemical Engineering laboratory using an Aquatron W4D distiller, was used in all the experiments, except where noted otherwise.

Physical/Chemical property	100 S/N	150 S/N	450 S/N
Density @ 20° C, kg/l	0.860	0.868	0.8803
Viscosity @ 40 °C, mm ² /s	20.28	32.2	86.78
Viscosity @ 100 °C, mm ² /s	4.093	5.408	10.23
Viscosity index	100	101	99
Flash point, °C	202	210	248
Pour point, °C	-18	-15	-6
Colour	L1.5	L1.5	L3.5
Calcium, ppm	<1.0	<1.0	<1.0
Zinc, ppm	<1.0	<1.0	<1.0
Magnesium, ppm	<1.0	<1.0	<1.0
Water by crackle	Negative	Negative	Negative

Table 3.4 Physical properties of oils supplied by CALTEX.

3.2 Experimental procedures

3.2.1 Coal Gold Agglomeration

3.2.1.1 CGA in a stirred tank reactor

Experiments were done initially to become familiar with the CGA process, its experimental procedures, results and interpretation of the results. These experiments were analogous to those of Kotze and Petersen (1998) and hence consisted of the parameters indicated in Table 3.5 below.

<i>Component</i>	<i>Identification</i>	<i>Quantity</i>	<i>Units</i>
Coal	45 % -90 μm	4.17	g
Oil	ethyl oleate	1	ml
Ore	Gold, 7 g/t	4.17	g
Collector	PAX	0.04	g
Water	Distilled	75	ml

Table 3.5: Experimental conditions for initial experiments

The above components were contacted for fifty minutes, which is the minimum time that allowed maximum gold recovery, according to Kotze and Petersen (1998). The experiments were done at an ambient temperature of approximately 22 degrees Celsius. Agglomerates were initially formed by manually stirring the mixture of coal and oil in a vial and then transferring the contents to the reaction vessel. Further literature study however showed that the most practical way to form agglomerates is to add the oil while the coal particles are suspended in the water. This method proved to be both practical and timesaving, and hence it was used for all further experiments. The interaction between the various components took place inside a 250-ml bottle on a magnetic stirrer set at full speed.

After contacting, the mixture was shaken and left standing for a few minutes, after which the floating agglomerates were scraped off. This procedure was repeated until all the agglomerates have been removed. The agglomerates were then dried over night at 80 degrees Celsius, and ashed for 7 hours at 800 degrees Celsius. The following day the gold in the sample was dissolved in *aqua regia*, filtered and analysed. At the same time, an untreated gold ore sample was also analysed in the same way. A set of three tests was performed at the same time and the average gold recovery taken.

3.2.1.2 CGA with flotation on a small scale

The flotation apparatus used for these experiments was built at the Cape Technikon, as a direct scale-down of the popular Barker flotation cell. The reason for the scale-down was to eliminate any serious loss of material and time that was bound to occur during the initial stages of the project.

<i>Component</i>	<i>Identification</i>	<i>Quantity</i>	<i>Units</i>
Coal	45 % -90 μm	41.7	g
Oil	ethyl oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4.0	g
Frother	DOW 200	0.01	ml
Water	Distilled	600	ml
Air	Atmospheric	2.2	l/min

Table 3.6: Experimental conditions for CGA with flotation on a small scale.

The total volume of the cell is one litre, but the contact step was performed in 600 ml, giving a higher per cent solids, which improved

contacting. The experiments were done at an ambient temperature of approximately 22 degrees Celsius. All the component ratios were kept the same, but individual component quantities were increased tenfold, as indicated in Table 3.6. Furthermore, 0.01 ml of frother was added to the mixture before air was passed through the slurry and flotation commenced.

The following flotation procedure was then developed for the CGA process:

1. Weigh ore and coal.
2. Make PAX solution (50 ml).
3. Add water (cover impeller).
4. Start impeller (low rpm).
5. Add coal (spray with water and turn up impeller speed until coal is distributed).
6. Add oil.
7. Agglomerate $\pm$ 3 min.
8. Add ore (spray with water).
9. Add PAX solution.
10. Stop adding water at mark ($\pm$ 600 ml).
11. Contact for 50 min.
12. Add frother (0.01 ml)
13. Condition for 2 min.
14. Open air inlet.
15. Open cell feed water.
16. Start scraping off froth ($\pm$ 2 min.).
17. Add more frother (0.01-ml) and scrape off froth until it is depleted.
18. Filter off froth, dry over night, ash, weigh, treat with *aqua regia* and analyse.

3.2.1.3 CGA with flotation on a larger scale

These tests were performed in a 3.4 litre Wemco flotation cell, using a contact volume of 2.4 litres. The experiments were done at an ambient temperature of approximately 22 degrees Celsius. The previous component quantities were increased fourfold, as the contact volume was also increased similarly, as indicated in Table 3.7. The aeration rate for the scale-up was increased per liter of cell volume, which relates closely to the bubble surface area flux method proposed by Gorain, et al. (1999).

<i>Component</i>	<i>Identification</i>	<i>Quantity</i>	<i>Units</i>
Coal	45 % -90 μm	166.8	g
Oil	ethyl oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Air	Atmospheric	6	l/min
Water	Distilled	2400	ml

Table 3.7: Experimental conditions for CGA with flotation on a larger scale.

3.2.2 Mercury amalgamation

After extensive research into the dangers associated with mercury amalgamation and the lethal effects of mercury exposure, it was desired to develop a suitable system for performing the experiments. For this purpose, Professor Ben Burger of Stellenbosch University greatly assisted in developing a system in which the mercury/gold amalgam can be dissolved in *aqua regia* under reflux condensing. This system ensured that no mercury vapours could escape into the atmosphere.

Furthermore, a contacting system as well as component ratios had to be established. Research revealed that comparative studies between mercury amalgamation and the CGA process were done before. It was thus decided to simulate the process used by the most successful of these researchers, Marciano *et al.* [1994]. The following parameters were used for these tests:

- ♦ 20 gram gold-containing ore (gold loading ± 7 g/ton);
- ♦ 1 gram mercury;
- ♦ 0.02 gram sodium hydroxide, as a conditioning agent;
- ♦ 50 ml distilled water;
- ♦ Contact for 2 hours at 200 rpm, using the rolling bottle technique.

The components were separated by means of a separation funnel, after which they were dissolved in *aqua regia* and sent away for analysis on an ICP. At the same time, a sample of original ore was also prepared and sent away for analysis. A set of three tests was performed at the same time and the average gold recovery was taken.

3.2.3 Normal gold flotation

Experiments were conducted whereby no coal/oil agglomerates were mixed with the gold-bearing ore. The ore was merely contacted with the same concentration of potassium amyl xanthate used previously, for thirty minutes only, simulating what was done by Bellamy, *et al.* [1989]. After the specified contact time, a collector (DOW 200) was added to the system and after about three minutes of conditioning the gold-bearing froth was scraped off and treated for analysis as all previous samples were.

3.3 Analytical methods

3.3.1 Sample preparation

The *aqua regia* used to leach the gold from the ashed samples consisted of 82 per cent hydrochloric acid and 18 per cent nitric acid. Samples were leached twice with constant stirring with aliquots of freshly prepared *aqua regia*. [Bratzel, *et al.* (1972)] The samples were boiled to dryness after adding each aliquot. A third aliquot was then added and the temperature of the mixture raised to near boiling, then cooled slowly to room temperature, filtered, and washed with 10 per cent (v/v) hydrochloric acid into 100 ml volumetric flasks.

3.3.2 Analytical instruments

3.3.2.1 Graphite tube atomiser

All sample analyses were firstly done on a graphite tube atomiser (GTA). This instrument determines the amount of gold in the sample by measuring the amount of 'gold' light (light of such a frequency that it will only be absorbed by gold atoms) that it absorbs. The GTA is calibrated by aspirating a number of standard gold solutions. The relationship between the concentration of the standards and the absorbance is normally linear. This straight line is then used to calculate the amount of gold in the sample, according to the absorbance that it gave. The results obtained with the mass balance tests revealed that the GTA analysis is not very reliable, because inconsistent results as well as poor recoveries were repeatedly observed.

3.3.2.2 Inductive coupled plasma

It was thus decided to prepare samples for analysis by an external company, who makes use of inductive coupled plasma (ICP) apparatus.

With these results it was possible to complete the mass balance, and at the same time higher recoveries were also observed (See section 4.1).

It can thus be concluded that the GTA is not an accurate enough apparatus for our analytical needs, and it was thus decided that all future samples would be analysed on the ICP.

CHAPTER FOUR

CGA in a Stirred Tank Reactor

4.1 Coal gold agglomeration

4.1.1 Process methodology

Coal-oil agglomerates were formed by agitating a mixture of coal and oil in an aqueous suspension inside 250-ml glass bottles. Coal and oil are both hydrophobic and hence these two components grouped together when brought in contact with water. A synthetic gold ore made up from fine gold powder and silica sand was added to the agglomerates and agitated for fifty minutes. Since the gold particles are also hydrophobic, they group together with the agglomerates and actually penetrate them, thus allowing their extraction from the ore.

The next step was to separate the gold-loaded agglomerates from the residue slurry. During the first stage of the study, this was achieved by shaking the mixture and allowing the agglomerates to float to the top and then scraping them from the top. The next phase of the study was dedicated to scaling up the process by making use of flotation as a separation technique. After separation, both phases were dried, ashed, treated with aqua regia and analysed. At the same time a few samples of original ore was also analysed.

4.1.2 Experiments performed

The effect of varying the viscosity of the oil in the experiment was investigated, using three oils with different viscosities as alternatives to ethyl oleate. Two types of recycling experiments were performed, i.e. recycling of the ore and recycling of the agglomerates. All recycling tests were performed with ethyl oleate as agglomerant. Experiments were performed to check the accuracy of the analytical procedures, sampling techniques and analytical equipment by performing mass balances over the system. Finally, a different separation technique was used to remove the floating agglomerates from the residue ore. A plastic household sieve was used to capture the agglomerates by decantation of the vessel.

4.1.3 Results and discussion

4.1.3.1 Oil type

The effect of varying the viscosity of the oil in the experiment was investigated, as indicated in Figure 4.1. For this purpose, three base oils from the Caltex range, each with a different viscosity but with similar densities, were used in the place of ethyl oleate. During these tests it was observed that decreasing the oil's viscosity leads to the formation of smaller agglomerates, which affected the gold recoveries significantly. Less viscous oils are thinner and thus the same volume covers more surface area hence coming into contact with more coal particles. The coal particles can therefore move more freely between the oil droplets until they are saturated, resulting in the formation of smaller agglomerates. As can be seen, the lower viscosity oils reduced the attainable gold recovery by ten to fifteen per cent. The lowest recovery was achieved with the Caltex 100 solvent neutral oil, which has the lowest viscosity.

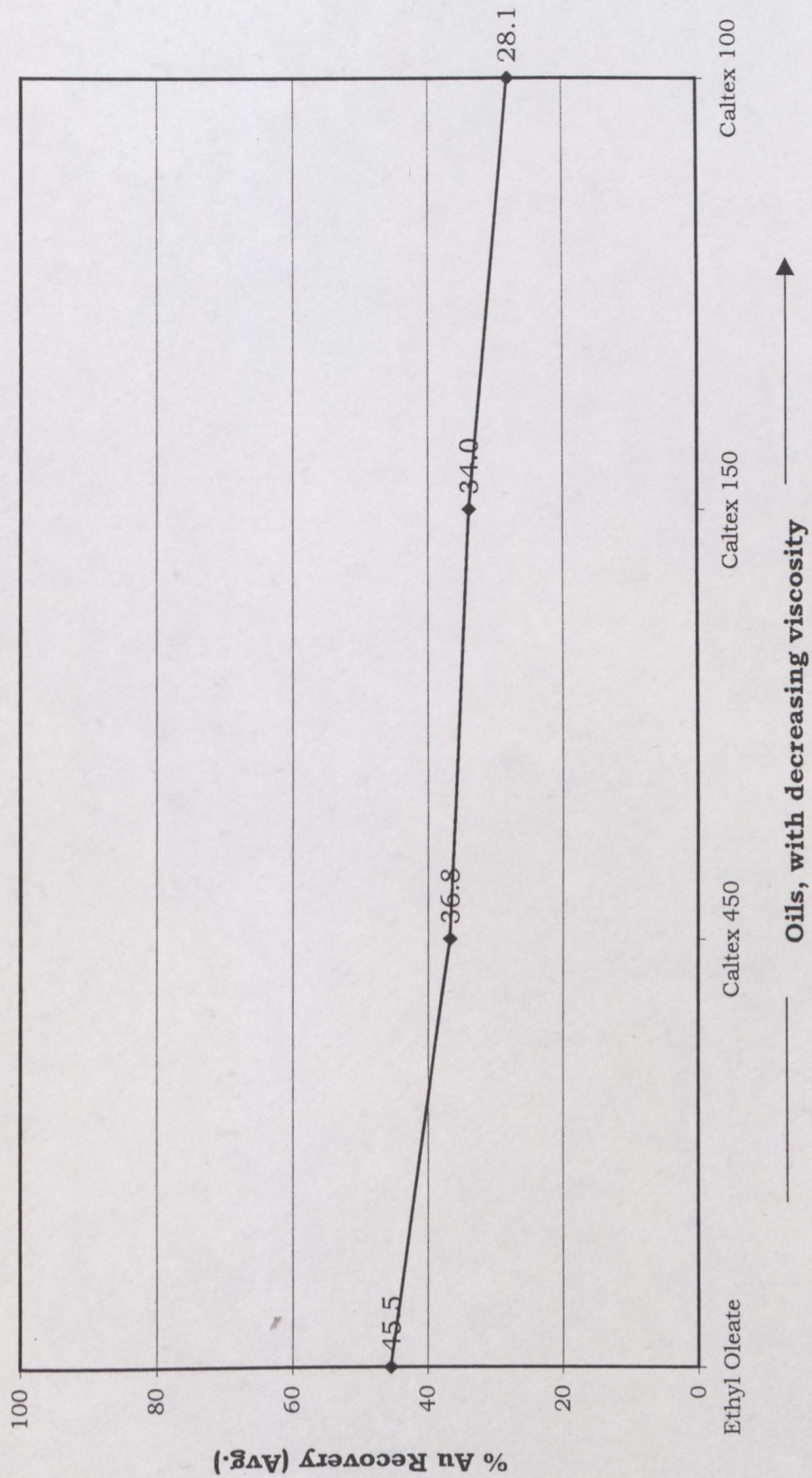


Figure 4.1: % Au Recovery vs. Oil Type

Although these samples were analysed on a GTA, and hence the recoveries were substantially lower, it still allowed a comparative study to be performed, since the same volume dosage was used for all the experiments. It can however be argued that adsorption and chemical reactions take place on a molar concentration basis rather than volume, but the difference in molecular weights of the oils are very small, so that this aspect could be neglected.

It is understandable that a decrease in the viscosity of the agglomerant will lead to the formation of weaker agglomerates, because of an increased rate of shear at a constant applied shear force. Since viscosity is defined as the ratio $\delta s / \delta \theta$, at a constant stirring rate (shear force, or δs), an increase in the viscosity will result in the reduction of the rate of shear ($\delta \theta$), causing stronger agglomerates to form. Stronger agglomerates are very much less prone to breakage that occurs as a result of the stirring action employed, especially in the presence of baffles.

4.1.3.2 Recycling tests

Two types of recycling experiments were performed, that is recycling of the ore and recycling of the agglomerates. The first type of recycling was done to observe whether there was any gold remaining in the ore slurry after the first separation and to quantify this gold. This was done by first completing a standard run and then removing the agglomerates from the vessel. A batch of fresh agglomerates was then added to the residue ore, after which contact proceeded for another fifty minutes.

It is evident from Table 4.1 (Experiments 5, 7 & 9) that there were very little gold recovered in the second run, indicating that the amount of gold remaining in the residue ore after the first run was sparse. It is obvious

that the second ore-recycling test yielded a higher recovery, but this can be discarded, as the other two tests gave similar recoveries.

The objective of the agglomerate recycling was to increase the loading on the agglomerates, and thus decreasing the amount of raw materials to be used per kilogram of ore in the process. This will obviously increase the economical viability of CGA. For these experiments, the gold-loaded agglomerates that were removed from a single run were introduced to fresh ore and a second contact and separation cycle was completed. It is clear from Table 4.1 (experiment 13) that a very high percentage of gold can be recovered in the second run (75.6 per cent), using the same agglomerates as for the first run (which yielded 83 per cent). Further recycling of the agglomerates could thus be possible, since it appears that the agglomerates are not fully loaded. This agrees with literature (Marciano, *et al* [1994]), that indicated that the agglomerates could be recycled up to six times.

4.1.3.3 Mass balancing

Besides the above tests, it was also necessary to complete the mass balance over an experiment (Table 4.1, Experiments 8, 9, 10, 11 & 12). For this purpose, both the agglomerates and the remaining ore were analysed, as well as a sample of the original ore. All these tests were performed with ethyl oleate as agglomerant. Since the system was operated as a closed-loop system, where the complete sample was analysed, a successful gold balance was expected.

Unfortunately, the mass balance could not be completed when the GTA was used. The mass balance could only be completed when the ICP was used for analysis and at the same time higher gold recoveries were again observed in comparison to GTA analysis. As explained in section 3.3.2.1,

this was the primary reason why the ICP was then preferred as the ideal analytical instrument over the GTA. The other reason was that the ICP delivers a much more accurate result at very low concentrations such as those used in these experiments.

4.1.3.4 Separation by sieving

Normal CGA experiments were conducted as mentioned in 3.2.1.1, but with sieving employed as a method of separation. For this purpose, a standard household sieve was used. After the required contact time of fifty minutes, the mixture was shaken and left standing a minute or two, to allow the heavier ore particles to settle to the bottom. The floating agglomerates were then decanted through the sieve, with special care being taken to avoid the residue ore to also pass through. The results were fairly satisfactory, with gold recoveries averaging 77.4 per cent and 22.1 per cent remaining in the ore phase. The results are however slightly poorer than those for which scraping was used as a means of separation, where 83 per cent was recovered on a single run.

Exp. No.	Parameter investigated	Mass of agglom. (g)	Au loading (g/ton)	Au loading (g/ton feed)	% Au Recovery (Avg.)		
					1 st Run	2 nd Run	Ore
1	Standard	4.25	2.19	4.90	45.5	-	-
2	Caltex 100	4.48	0.55	4.89	12.1	-	-
3	Caltex 150	3.31	1.84	4.05	34.0	-	-
4	Caltex 450	4.16	1.66	4.85	36.8	-	-
5	Recycling ore	3.99	1.16	4.78	30.8	4.3	-
		4.83	0.35				
6	Caltex 100	3.60	2.00	5.45	28.1	-	-
7	Recycling ore	4.32	2.46	4.08	51.4	3.9	-
		4.55	0.14				
8	Mass balance	4.36	1.58	4.34	37.9	-	6.4
		3.97	0.29				
9	Recycle ore & mass balance	4.13	1.55	4.82	31.8	4.7	2.3
		4.50	0.21				
		3.68	0.13				
10	Mass balance	4.28	1.36	4.83	28.9	-	11.8
		3.90	0.61				
11	Mass balance*	4.09	7.76	9.39	81.2	-	15.1
		4.04	1.43				
12	Mass balance*	3.97	6.52	8.67	71.0	-	16.6
		3.93	1.52				
	Mass balance	3.97	1.13	4.63	34.4	-	17.2
		3.93	0.57				
13	Recycle of agglomerates*	4.00	12.32	6.22	83.0	75.6	-
14	Separated by sieving*	4.31	6.24	8.35	77.4		22.1
		3.85	1.74				

Table 4.1: Summary of results for initial experiments.

(Samples marked with an asterisk were analysed on an ICP, others on a GTA.)

4.2 Comparison between CGA and mercury amalgamation

4.2.1 Results

The results (Table 4.2) indicate that a mass balance could not be performed over the experiment, even when the contact time was doubled (Exp. 17). Several possible reasons exist: Firstly, more *aqua regia* was used to dissolve the amalgam samples and thus a more acidic medium was present during analysis, and the influence of mercury on the analysis for gold is also not known. This is also evident in the large variability of the results (the shown recoveries are the average of three), with recoveries as low as 0.98 per cent achieved.

On the other hand, the ore that was analysed was free from any impurities and hence gave results that are more reliable. It is for these reasons that it was decided to calculate the recoveries in the amalgam, by making use of the true values for the recoveries in the ore. If this is done, then the average gold recovery for the mercury amalgamation process is 72 per cent, compared to the 83 per cent gold recovery attainable with the CGA process. It thus became clear that much less gold was recoverable by the mercury amalgamation process than through the CGA process, under similar operating conditions and feed gold loading.

4.2.2 Differences between CGA and mercury amalgamation

A direct comparison between the two processes is possible, since both can only be applied to the recovery of free gold. In the CGA process, the coal-oil agglomerates cover the gold particles, and in mercury amalgamation

the liquid mercury covers them. The major differences between the two processes lies in the separation of the gold-loaded phase from the residue ore and the subsequent recovery of the gold particles.

In both instances the CGA process exhibits negligible toxic effects towards the environment compared to mercury amalgamation, which enters the environment during both stages of the gold recovery process. There is therefore no doubt that the CGA process outperforms the mercury amalgamation process, not only where the attainable gold recovery is concerned, but also on an environmental scale.

<i>Exp. no.</i>	<i>Phase</i>	<i>Au loading</i> <i>(g/ton)</i>	<i>Mass of Au</i> <i>(mg)</i>	<i>% Au</i> <i>recovered</i>
15	Amalgam	7.37	0.0076	4.5
	Residue	1.30	0.0295	29.3
	Feed	5.03	0.1006	-
16	Amalgam	11.81	0.012	15.7
	Residue	1.49	0.0298	25.6
	Feed	5.09	0.1006	-
17	Amalgam	6.03	0.0031	8.5
	Residue	1.36	0.0136	29.3
	Feed	5.09	0.0509	-

Table 4.2: Summary of results for mercury amalgamation experiments.

CHAPTER FIVE

CGA with flotation on a small scale

5.1 Experiments performed

Experiments were performed to observe the effect of baffles as well as different frothers and collectors on the separation of the agglomerates. Furthermore, the effect of stirring rate, air addition rate, contact time and different oils was also investigated.

5.2 Results and discussion

5.2.1 Preliminary experiments

From the results of the first three tests, in Table 5.1, it was clear that baffles have a detrimental effect on the separation, and that MIBC performed poorer than DOW 200 did, as a frother for the CGA process. These tests were conducted at 1200 rpm, the contact speed that was found by Fourie (1988) to be ideal for the flotation coal particles. Obviously, this speed was not satisfactory for the CGA process, most probably due to the larger mass of the agglomerate particles. Therefore, all further tests were conducted without baffles and with DOW 200 as frother. Furthermore, when Sodium Ethyl Xanthate (SEX) was used as a collector (Table 5.1, Experiment 29), recoveries dropped to an average of 77.5 per cent, compared to the 84.2 per cent recovery obtained when

Potassium Amyl Xanthate (PAX) was used. It was thus decided to continue the study with PAX as collector.

5.2.2 Stirring rate

It is clear from Figure 5.1 that the gold recovery increased with an increase in the stirring rate. This is because more of the agglomerates are kept in suspension at a higher contact speed and they can thus be easier floated. A very high gold recovery (86.5 %) was obtained when a stirring rate of 1800 rpm was used (Table 5.1, Experiment 22). However, this is not a true result, since some ore was lifted with the agglomerates due to the high stirring rate. This caused the mass of agglomerates recovered to be much higher than what was expected (Table 5.1, column 4). Since we relied on representative sampling for the analysis and calculation of the total amount of gold recovered, it is obvious that a large mass recovery for the agglomerates will falsely increase the amount of gold recovered.

It thus became evident that there is a maximum, cut-off contact speed for any flotation apparatus and that if this speed was exceeded, substantial ore lifting will occur. This will then obviously lead to inaccurate results as well as increased exigency during the final gold recovery stages, on a practical scale. The best result was thus achieved when stirring at 1600 rpm, as indicated in bold in Table 5.1. This recovery of 84.2 % is on par with recoveries achieved on smaller scale during the first phase of the project (83 %).

At this stage of the study it was encouraging to note that similar recoveries could be obtained on a larger scale, using flotation techniques. This opened the door to further scale-up of the CGA process.

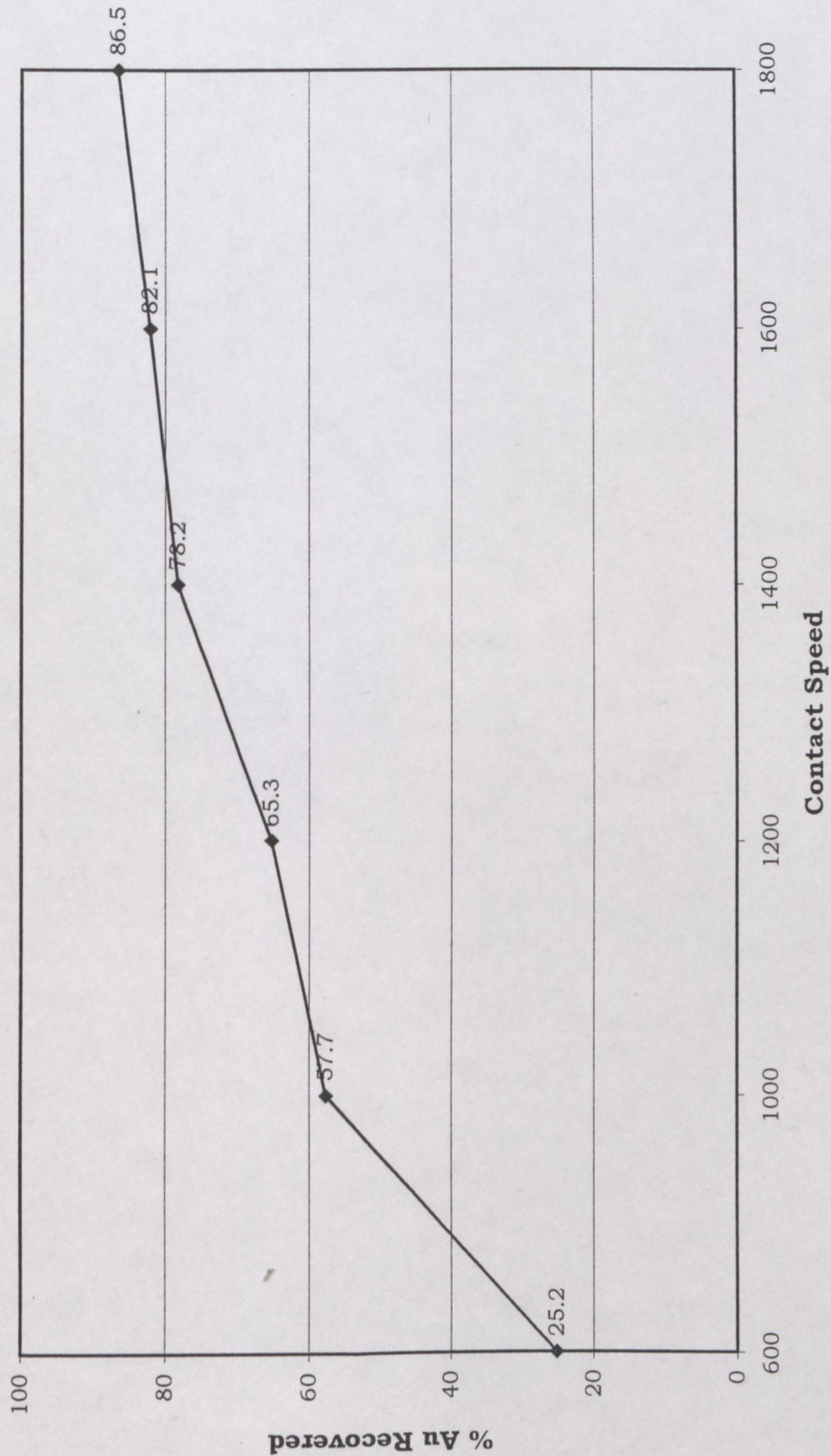


Figure 5.1: % Au recovered vs. Contact speed using Small Scale Flotation

5.2.3 Contact time

Investigation revealed that gold recovery dropped when contact time was reduced from 50 minutes to 30 minutes (Table 5.1, Experiments 26 & 28), which was expected. This is self-explanatory, because a substantial amount of time is required for the free gold to actually penetrate the coal/oil agglomerates. Contact time was already investigated by Kotze and Petersen (1998), but it was given a second thought because of the much higher stirring rates being used now, as this will obviously improve the penetration of the gold particles into the agglomerates. The stirring intensity on this scale was however found to be similar to that of the smaller scale, and hence the same minimum contact time was required to achieve a satisfactory gold loading onto the agglomerates.

5.2.4 Aeration rate

As indicated on Figure 5.2, reducing or increasing the air rate too much both had a negative effect on the separation. These tests were all performed at a contact speed of 1600 rpm. The optimum air addition rate for this apparatus was found to be 2.2 litres per minute, which amounts to 2.2 l/min. per litre cell volume. This is very comparable to the 2.0 l/min. per litre cell volume that was used by Fourie (1988).

It is obvious that a lower air addition rate will cause less of the agglomerates to float to the top, because the ratio of air bubbles to agglomerates is reduced. The low recoveries for the higher air addition rates can be explained in terms of bubble attachment and detachment, whereby a bubble will not be given enough time to attach itself onto an agglomerate particle and hence it will merely pass through the slurry into the atmosphere. At the higher aeration rates, it could be seen that the air bubbles bursts through the layer of floating agglomerates without attaching themselves to agglomerates in suspension.

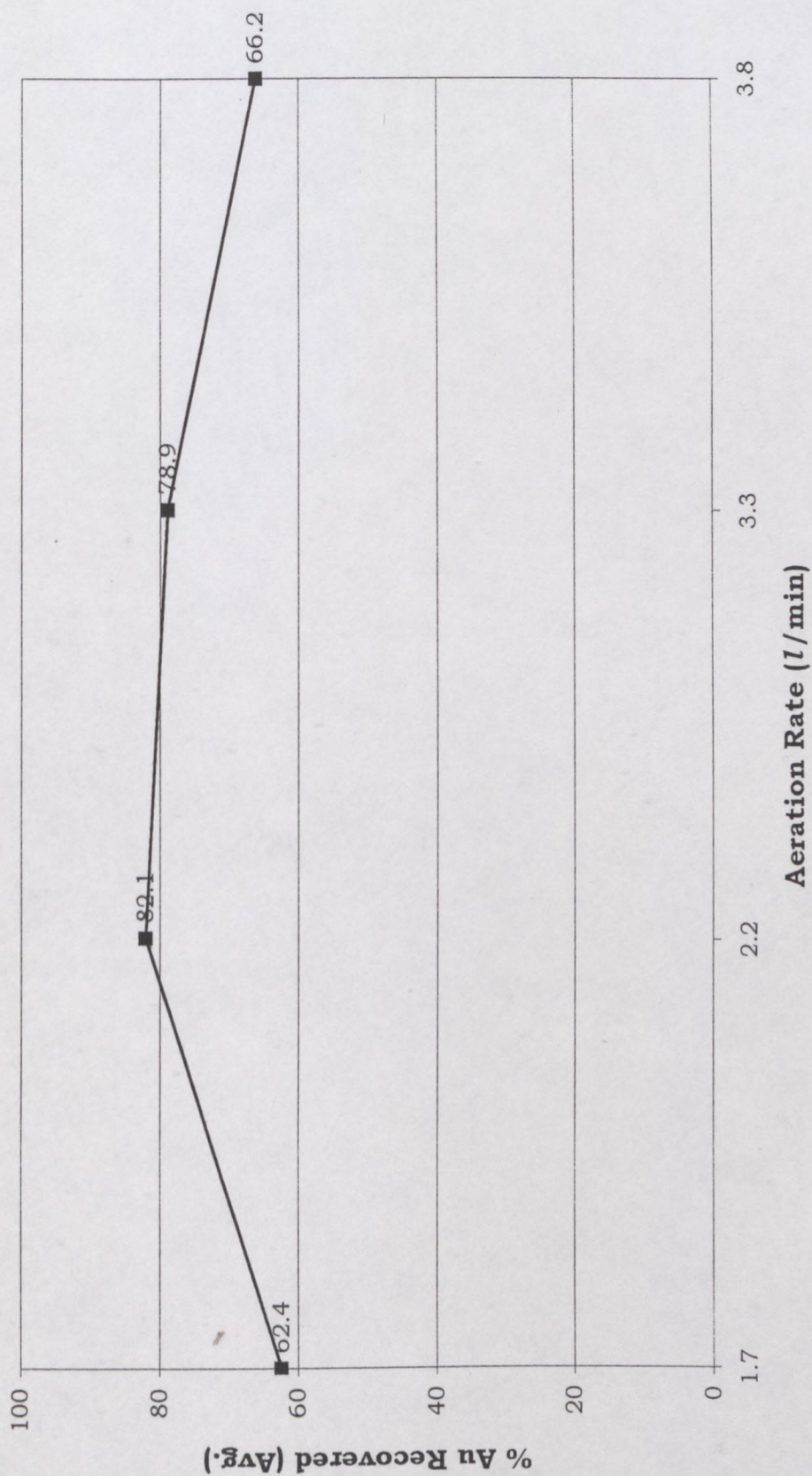


Figure 5.2: % Au recovered vs. Aeration Rate using Small Scale Flotation

5.2.5 Other agglomerants

Concerning the use of different oils for the process, Figure 5.3 displays that lower viscosity oils impaired the separation of the agglomerates from the slurry, as did the experiments on a smaller scale. What is more important however, is these results showed that other oils can be successfully used in the process, provided that they are of similar viscosity and density, due to the nature of the apparatus. It is also important to mention that the oils used showed a spread in density of not more than 100 kg/m^3 .

5.2.6 Undistilled water

Another encouraging result obtained from the experiments was that the use of normal tap water did not have a seriously adverse effect on the separation. There was a mere five per cent drop in the recovery observed, compared to the best result (Table 5.1, Experiment 33). This result is particularly important when one considers that this process is aimed at small-scale gold mining in developing countries, where pure water is largely unavailable.

5.3 Sensitivity of parameters

The experiments discussed in this chapter revealed that the contact speed would be the most important parameter for scale-up. There were other parameters that also influenced the gold recovery significantly, but it would be fair to assume that their influence would have been much less prevalent if higher contact speeds were used. The effect of using oils with lower viscosities reduced the gold recoveries, as they did with the experiments on a smaller scale. This indicated that the oil type would not present an obstacle when a larger scale flotation cell was used.

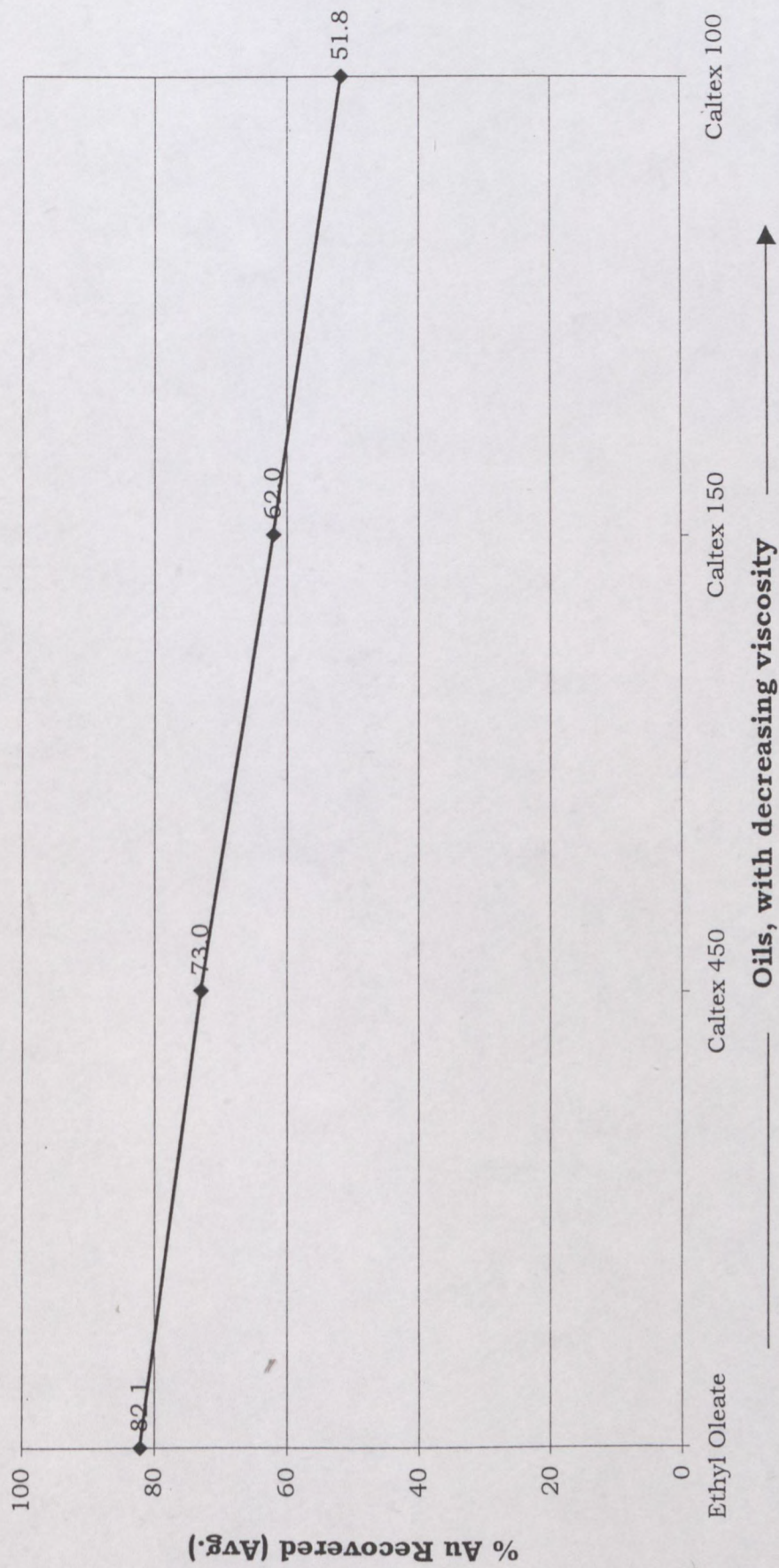


Figure 5.3: % Au recovered vs. Oil Type
using Small Scale Flotation

<i>Exp. no.</i>	<i>Parameter investigated</i>	<i>Mix speed (rpm)</i>	<i>Mass of aggl. (g)</i>	<i>Au loading (g/ton aggl.)</i>	<i>Au loading (g/ton feed)</i>	<i>% Au recovered</i>
18	Baffles	1200	43.79	4.41	8.15	56.9
19	Mix speed	1200	50.14	4.29	8.15	65.3
20	Baffles/MIBC	1200	42.90	4.15	8.15	52.4
21	Mix speed	600	14.42	5.26	7.23	25.2
22	Mix speed	1800	53.87	4.58	7.60	86.5
23	Mix speed	1000	45.23	3.79	7.17	57.7
24	Mix speed	1400	45.98	4.50	6.34	78.2
25	Mix speed	1600	47.04	4.62	6.34	82.1
26	30 min.	1400	46.63	4.25	6.34	74.8
27	Caltex 100	1600	38.50	3.22	6.35	51.8
28	30 min.	1600	44.35	3.60	6.35	60.3
29	SEX used	1600	45.72	4.49	6.35	72.1
30	3.8 l/min. air	1600	46.94	3.73	6.35	66.2
31	3.3 l/min. air	1600	31.16	2.69	3.40	78.9
32	1.7 l/min. air	1600	46.83	3.68	6.35	62.4
33	Tap water	1600	47.43	3.64	4.88	80.9
34	Caltex 150	1600	32.94	3.43	4.75	62.0
35	Caltex 450	1600	48.45	3.70	4.88	73.0

Table 5.1: Summary of results for CGA with flotation on a small scale.

CHAPTER SIX

CGA with flotation on a larger scale

6.1 Experiments performed

Due to the different nature of the two flotation devices used, a direct scale-up was not possible and hence further test work was required to optimise the Wemco flotation cell. The only operating variable that was influenced by the scale-up was the stirring speed because this is thought to be a function of the particular configuration. It is for this reason that the stirring rate still had to be optimised for the Wemco cell.

Some other experiments were also performed on the Wemco cell, to determine the adaptability of the CGA process to flotation. Therefore, the following concepts were given some attention:

- ♦ Three base oils, each with a different viscosity were tested;
- ♦ The particle size of the coal was increased, first to +300 μ m - 500 μ m and then to +500 μ m - 650 μ m;
- ♦ The effect of tap water on the process was investigated;
- ♦ The effect of recycling the agglomerates was investigated.

6.2 Results and discussion

6.2.1 Contact speed

It is evident from the results (depicted in figure 6.1) that the trend in terms of contact speed is similar to that observed on a smaller scale, whereby an increase in the contact speed (up to 1200 rpm) leads to an increase in the gold recovery. It is, however interesting to note that increasing the contact speed to 1300 rpm resulted in a drop in gold recovery. Since the gold recovery is directly related to the mass of agglomerates that is floated, it was concluded that the high contact speed led to a breakage of the agglomerates and most probably also a decrease in the particle-bubble attachments formed.

Since it was described in the previous section that an exorbitant increase in the contact speed leads to an increase in gold recoveries, but also a large carry-over of solids, it seems to be in contrast with the current findings. This phenomenon however substantiates that the optimal stirring rate for any process is dependent on the configuration of the apparatus used for that process.

It is the distinct differences between the configuration of the Wemco cell and that of the self-constructed cell that causes the optimum contact speed to be 1200 rpm on the first cell compared to 1600 rpm on the latter.

6.2.2 Contact time

With the contact time reduced to thirty minutes (Table 6.1, Experiment 40), it was noted that the gold recovery also decreased. This is exactly what was observed for the other configuration and was already explained in the previous chapter. The effect of a reduced contact time was once

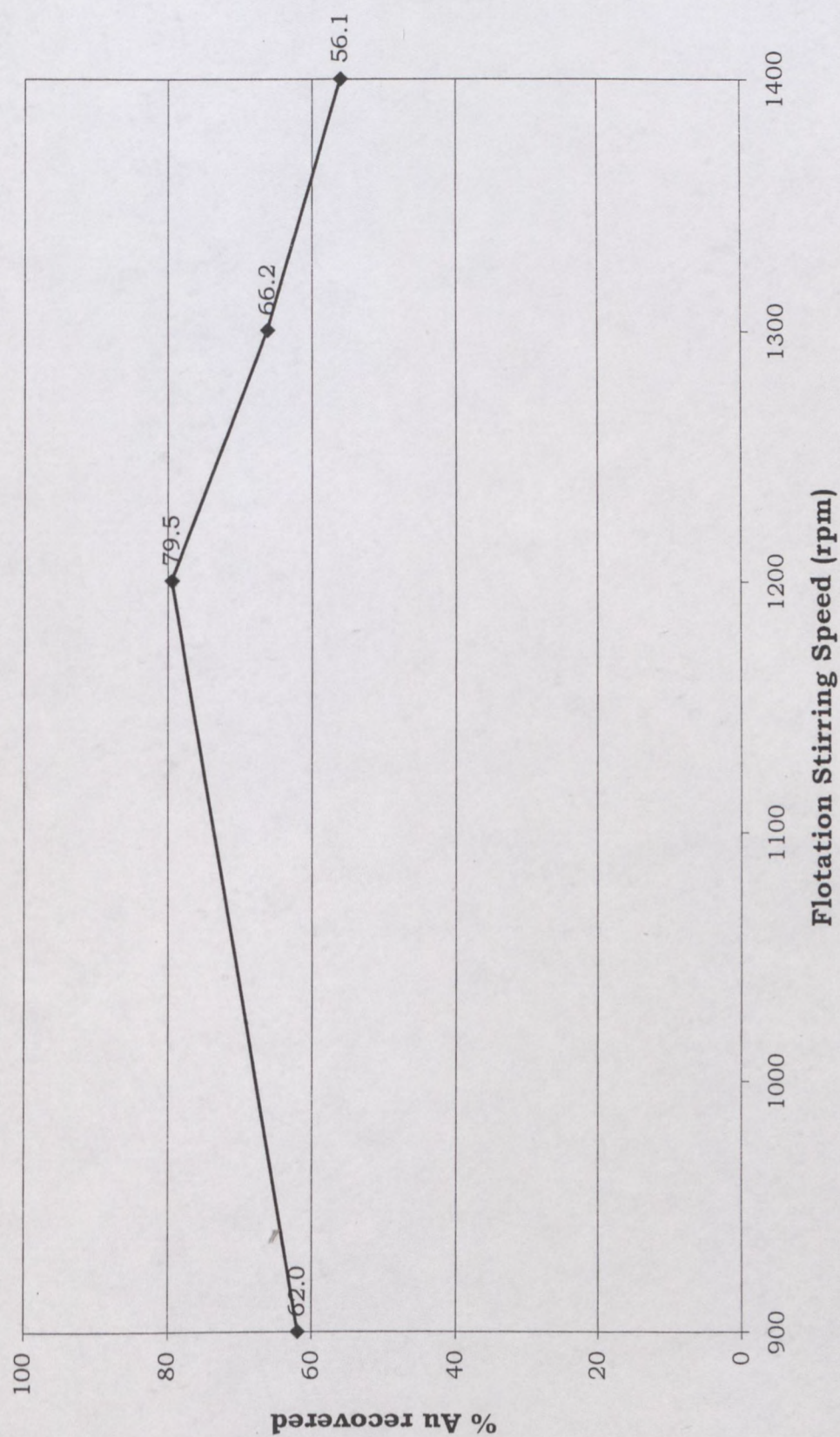


Figure 6.1: % Au recovered vs
Stirring Speed on a Wemco flotation cell

again investigated to entertain the possibility that the new set-up might have a better separation efficiency and hence require less contact time for an effective operation.

6.2.3 Baffle set-up

It was observed that without the Wemco cell's baffles in place, the recoveries dropped to below sixty per cent (Table 6.1, Experiment 39). Here it must however be noted that these baffles are not attached to the container, but actually surrounds the impeller itself. In addition to this, the baffle set-up also contains holes and all of this leads to the formation of a near-perfect, circular, axial mixing pattern. Without the baffle set-up in place, it was noted that the contents of the contacting vessel merely went around in a swirling motion, without any axial mixing taking place. It can thus be concluded that the separation efficiency of the CGA process is not only dependent on the contact speed, but also on the mixing pattern that is observed.

6.2.4 Recycling of agglomerates

Four runs were completed whereby the agglomerate phase was reintroduced to fresh ore (Table 6.1, Experiments 44 to 47). Disappointingly, these tests yielded very poor recoveries. This was later discovered to be because the agglomerates were dried over night in order to calculate proper mass balances. Drying of the agglomerates obviously led to the evaporation of some of the oil and hence the agglomerates became brittle and lost their gold when reintroduced into the system.

Furthermore, no oil was added to the system again and hence the ability of the agglomerates to capture and hold the gold particles was severely reduced. Regardless of this, when the experiments were repeated at 1200 rpm (when the agglomerates were directly transferred to the next stage, without drying), there was still no improvement in the results. It was

therefore decided that analysis of the whole sample would be necessary to complete the mass balance. However, this proved to be very difficult due to the large volume of sample that had to be filtered and analysed. It was therefore relied upon the gold loading achieved onto the agglomerates to give an indication of the successfulness of the recycling operation. This revealed that the gold loading on the agglomerates did in fact increase to an average of 6.2 g gold per ton of agglomerates.

6.2.5 Undistilled water

Undistilled water was used in one of the experiments, to check the stability of the process under non-ideal conditions. It was unfortunate to note that the gold recovery was repressed by the use of tap water, since this indicates that the process will not be very stable for practical mining operations, where distilled water is largely unavailable. The percentage gold recovered was just under five per cent lower than when this experiment was performed on a smaller scale. It must however be noted that this test was not performed with a larger coal particle size. Under these conditions, recoveries with undistilled water might well be above eighty per cent.

6.2.6 Coal particle size

Excellent results were achieved when the coal particle size was increased to between 500 and 650 microns, as indicated in Figure 6.2. In fact, three results of exactly 0.19 mg Au per liter was obtained, which gave a recovery of 90.70 per cent. It was discovered that the larger coal particles were more floatable due to their porous structure. They also have a larger surface area per particle than the smaller particles and this, in addition to their porous structure, leads to improved gold particle penetration as well as adding stability to the agglomerates that are formed. This result proves, without a doubt, that the CGA process is a most desirable

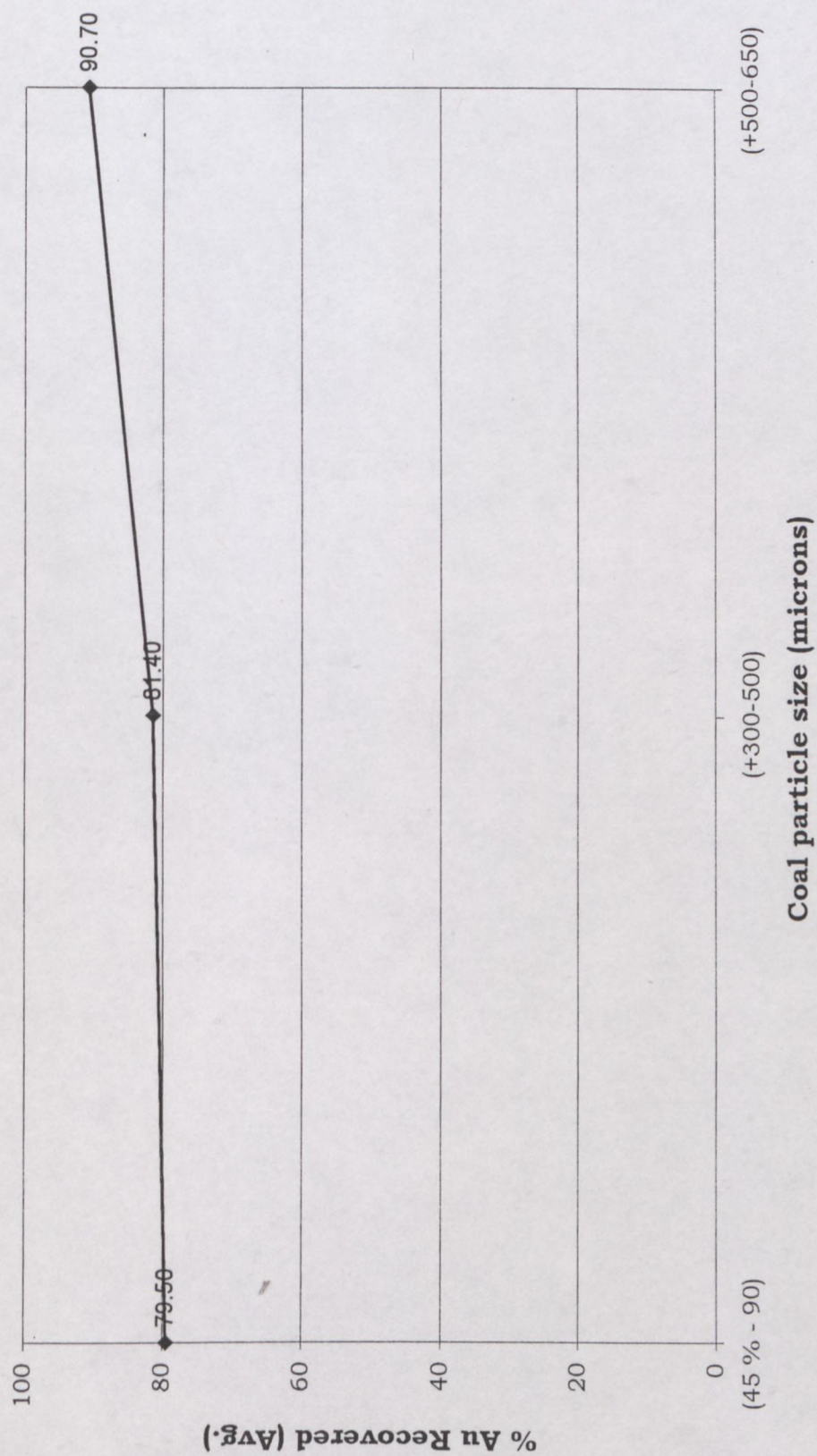


Figure 6.2: % Au recovery vs. Coal Particle Size on a Wemco flotation cell

alternative to any other small-scale gold extraction process.

6.2.7 Activated carbon

Although a large mass recovery was obtained with the activated carbon, the gold recovery was very poor at on 40.8 per cent (Table 6.1, Experiment 53). This is because the activated carbon agglomerates floated to the top of the vessel after only about eight minutes, without the addition of air.

Since most of the carbon- oil agglomerates was not kept in suspension for the full 55 minutes, interaction with the gold ore was limited and hence also the capturing of gold particles by the agglomerates. Furthermore, the carbon-oil agglomerates seemed to be completely dry when all the water was evaporated from them. This indicated that there was very little oil covering the carbon to begin with, and hence very weak agglomerates were formed.

6.3 Normal gold flotation

Very poor recoveries were achieved (between 5 and 15 per cent) with the normal flotation experiments, as indicated in Table 6.1, Experiments 51 & 52. The major downfall of this process is the vast amount of fine ore that is carried over to the froth phase. In practice, this will result in the need for substantial further treatment of the froth phase before smelting can be done. Typically, a gravity or centrifugal separation stage would be needed to separate the remaining ore from the free gold particles, with an obvious increase in both capital and operating costs.

<i>Exp. No.</i>	<i>Parameter investigated</i>	<i>Contact speed (rpm)</i>	<i>Mass of aggl. (g)</i>	<i>Au loading (g/t aggl.)</i>	<i>Au loading (g/t feed)</i>	<i>% Au recovered</i>
36	-	900	209	4.72	4.88	111.7
37	-	900	187.44	2.77	4.67	62.0
38	coal: +300-500	900	188.8	2.81	4.67	62.7
39	no baffles	900	164.21	4.75	6.62	60.4
40	contact 30 min	900	182.36	4.15	6.62	70.3
41	contact speed	1200	180.71	4.86	6.62	79.5
42	contact speed	1300	172.72	4.06	5.67	66.2
43	contact speed	1400	185.86	2.89	5.73	56.1
44	recycle agglom.	1400	176.87	7.45	5.73	56.8
45	recycle agglom.	1400	159.6	6.25	5.73	52.2
46	recycle agglom.	1200	154.79	5.08	5.67	45.7
47	recycle agglom.	1200	183.04	5.15	5.53	53.7
48	tap water	1200	184.45	3.88	5.73	74.7
49	coal: +500-650	1200	180.58	4.62	5.67	90.7
50	coal: +300-500	1200	181.13	3.87	5.67	70.2
51	no oil & coal	1200	6.03	9.45	3.75	5.0
52	no oil & coal	1200	3.53	54.79	7.49	15.5
53	Activated carbon	1200	190.57	1.98	5.53	40.8

Table 6.1: Summary of results for CGA with flotation on a Wemco flotation cell.

6.4 Flotation rig

During the latter part of the study, a design for a continuous, two-stage flotation rig was proposed. The basic design is laid out in figure 6.3, which shows the flow diagram for the proposed set-up.

It was decided to pre-mix the agglomerates and PAX (tank no. 1), to reduce operator handling and keep a constant concentration of reagents at the start of each run. Ore will be introduced manually into the system at reactors 2 and 4, which both have stirrers. After the desired contact time, air and water will be introduced these reactors, which will allow the agglomerates to float to the surface. The agglomerates gradually overflow via a sprout into the agglomerate capturing vessels 3 and 5. These vessels are fitted with screens of the correct aperture to allow the agglomerates to be captured while allowing any fine ore that is floated to pass through. At the bottom of each vessel, valves and pipes are fitted, which lead to the return-water holding tank. This tank is fitted with a screen of very small aperture, which allows virtually no ore to pass through. Water from this tank is recycled to the first reactor via a centrifugal pump.

The system obviously allows for only a single recycle of the agglomerate phase, as it was proved in this study that the combination of coal and oil used did not show any deterioration after one cycle. It is however possible to perform more than one recycle, but this has to be done manually. Optimisation of the flotation rig was not performed, since this was not the thrust of this study. The aim was merely to propose a design that would be capable of handling the CGA process on a larger scale.

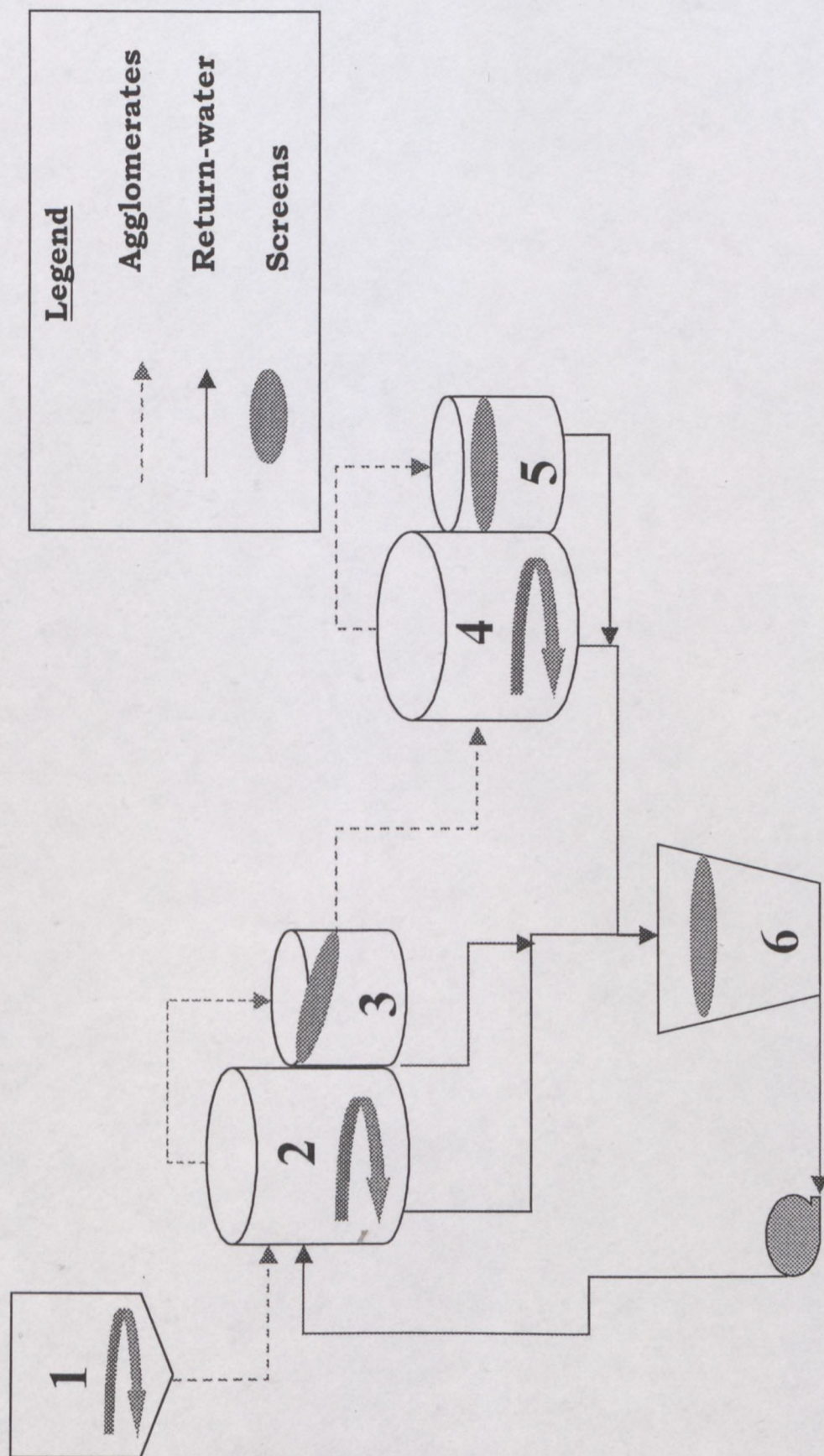


Figure 6.3 Diagrammatic layout of the flotation rig set-up.

CHAPTER SEVEN

Conclusion and Recommendations

7.1 Conclusion

It can be concluded that the CGA process responded positively when flotation was used as a means of separation, on a small scale as well as on a larger scale. This indicates that the process can be scaled up even further, without compromising the attainable gold recoveries. Due to the different configurations of the Barker and Wemco flotation cells, it was discovered that the optimum stirring rate varies from cell to cell and that each must be investigated on its own merit. The lower operating cost associated with the Wemco cell's configuration however makes it more attractive for the CGA process.

There was a positive indication that the agglomerates can be successfully recycled, without deterioration, but with a slight drop in the attainable gold recovery. The excellent results achieved with the larger particle size coal verify that gold particle penetration is of utmost importance in the efficiency of the CGA process.

Finally, it can be said that agglomerate stability, stirring rate and gold particle penetration are the most important factors that influence gold recovery through coal gold agglomeration.

7.2 Recommendations

- The recycling of the agglomerate phase is a critical step in the Coal Gold Agglomeration process, since it is the thrust of the economic viability of the process. It would thus be of great value if this could be investigated on a larger scale and for numerous cycles. The size of the product and tailings fractions obtained on the larger flotation cell made it difficult to further assess the viability of recycle on this scale, but with a continuous operation those problems can be overcome.
- It was shown that using oil with a lower viscosity reduced the attainable gold recoveries. The possibility thus exists that using oil with a higher viscosity, in combination with the same coal will improve gold recoveries due to the formation of stronger agglomerates. This will then also benefit the recycling operation, since stronger agglomerates will be recyclable more times. Thus, the overall operating cost of the process will be much reduced.
- Another, external, variable that could also have an effect on the stability of the agglomerates is the ambient temperature. This can in fact be used to the advantage of the process, since the use of a lower temperature might well lead to the formation of stronger agglomerates due to an increase in the oil's viscosity.
- The ultimate goal is obviously to apply coal gold agglomeration to the recovery of gold from an industrial ore. A proper investigation of this nature can however only be done once the above-mentioned factors have been completely investigated and the CGA process is fully optimised. There will however be many complications, due to the

complex nature of the various mineral species that will be present in natural ore and therefore it deserves a study of its own.

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APPENDIX A1

CGA in Stirred Tank

Reactor

Experiment 1

CGA in a Stirred Tank Reactor

Oil type: Ethyl Oleate

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
 75 ml Water, 20 ml PAX (5.004g/250 ml). Stirred for 50 minutes on magnetic stirrer
 Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

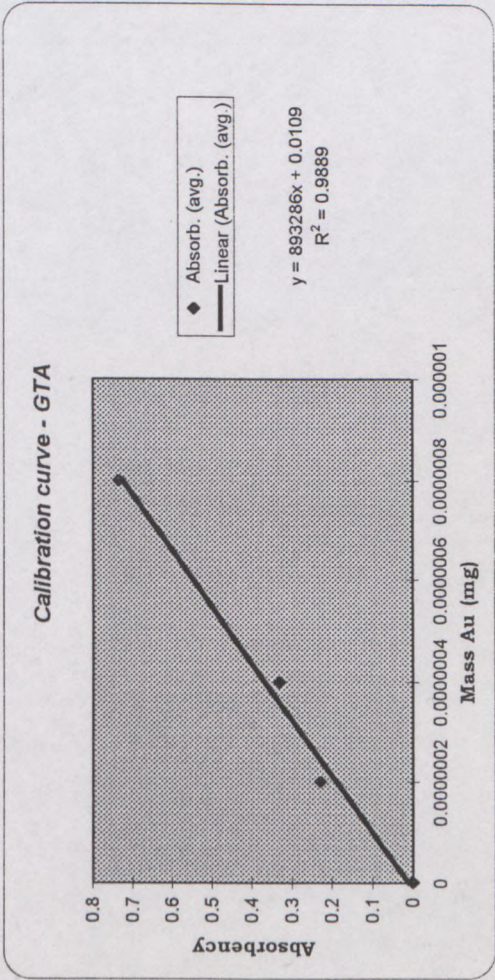
Calibration curve for GTA

Mass Au (mg)	Absorb.	Volume (micro l)	Conc. (ppm)
0	0.000	20	0
0.0000002	0.229	20	0.01
0.0000004	0.331	20	0.02
0.0000008	0.734	20	0.04

Intercept = 0.0109
 Slope = 893286

Abs. = S*mass Au + Int.

	Absorbance readings					
Stand. 1	0.21	0.218	0.243	0.249	0.225	
Stand. 2	0.323	0.321	0.349			
Stand. 3	0.75	0.72	0.733			



MASSSES

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+cr+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1 (agglom.)	31.5874	35.968	36.6075	32.321	4.17	4.3806	0.7336
2 (agglom.)	32.8583	36.9646	37.5821	33.556	4.17	4.1063	0.6977
3 (agglom.)	33.1842	37.4615	38.0903	33.8771	4.17	4.2773	0.6929
4 (ore)	-	-	-	-	0.70	-	-
5 (ore)	-	-	-	-	0.70	-	-
6 (ore)	-	-	-	-	0.70	-	-

RESULTS

Sample	Mass c/o (g)	Absorb. (avg.)	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings			% Au recovered
1 (agglom.)	4.3806	0.660	7.26E-07	0.036	0.00908	2.07	0.643	0.671	0.665	45.8
2 (agglom.)	4.1063	0.642	7.06E-07	0.035	0.00883	2.15	0.64	0.625	0.66	43.2
3 (agglom.)	4.2773	0.726	8.01E-07	0.040	0.01001	2.34	0.738	0.716	0.724	49.0
4 (ore)	0.7	0.618	6.79E-07	0.034	0.00340	4.85	0.611	0.615	0.627	-
5 (ore)	0.7	0.864	9.55E-07	0.048	0.00477	6.82	0.896	0.831	0.864	-
6 (ore)	0.7	0.630	6.93E-07	0.035	0.00347	4.95	0.635	0.652	0.616	-
Aggl. Avg.	4.25	0.676	7.44E-07	0.037	0.00930	2.19	-	-	-	46.0
Feed Avg.	0.700	0.704	6.86E-07	0.039	0.02044	4.90	-	-	-	-
Std. Deviation =										2.89
Variance =										8.35

Experiment 2

CGA in a Stirred Tank Reactor

Oil type: Caltex 100 Solvent Neutral

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.004g/250 ml). Stirred for 50 minutes on magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

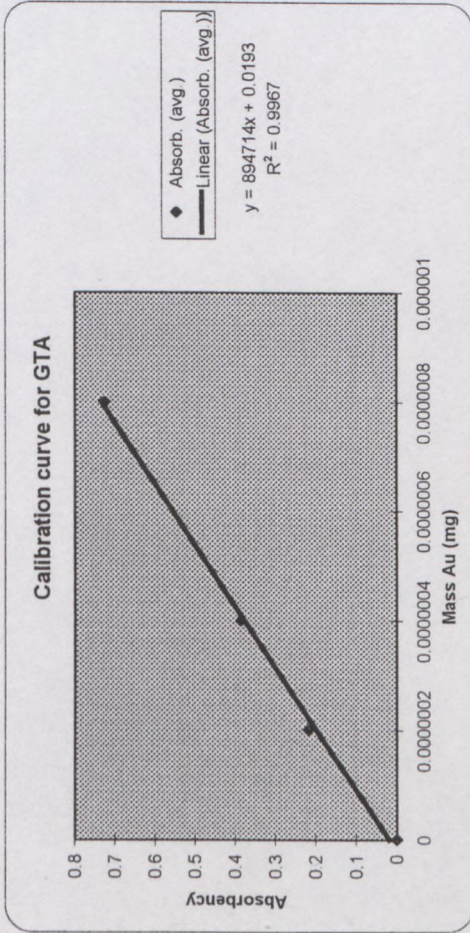
Calibration curve for GTA

Mass Au (mg)	Absorb. (avg.)	Volume (micro l)	Conc. (ppm)
0	0.000	20	0
0.0000002	0.218	20	0.01
0.0000004	0.386	20	0.02
0.0000008	0.726	20	0.04

Intercept = 0.0193
Slope = 894714

Abs. = S*mass Au + Int.

Absorbance readings	
Stand. 1	0.231 0.209 0.214
Stand. 2	0.398 0.373 0.387
Stand. 3	0.787 0.753 0.700 0.779 0.562



MASSSES

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+c+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1 (agglom.)	34.0203	38.5072	39.2668	34.5453	4.17	4.4869	0.525
2 (agglom.)	33.6322	37.9596	38.7635	34.1844	4.17	4.3274	0.5522
3 (agglom.)	34.1726	38.7879	39.6435	34.7463	4.17	4.6153	0.5737
4 (ore)	-	-	-	-	0.70	-	-
5 (ore)	-	-	-	-	0.70	-	-
6 (ore)	-	-	-	-	0.70	-	-

RESULTS

Sample	Mass c/o (g)	Absorb. (avg.)	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings			% Au recovered
1 (agglom.)	4.4869	0.216	2.20E-07	0.011	0.0027	0.612	0.213	0.223	0.212	13.5
2 (agglom.)	4.3274	0.196	1.97E-07	0.010	0.0025	0.569	0.194	0.194	0.199	12.1
3 (agglom.)	4.6153	0.176	1.75E-07	0.009	0.0022	0.474	0.171	0.179	0.178	10.7
4 (ore)	0.70	0.621	6.72E-07	0.034	0.0034	4.801	0.592	0.627	0.591	-
5 (ore)	0.70	0.662	7.18E-07	0.036	0.0036	5.129	0.626	0.688	0.615	-
6 (ore)	0.70	0.613	6.64E-07	0.033	0.0033	4.740	0.597	0.614	0.628	-
Aggl. Avg.	4.4765	0.196	1.97E-07	0.010	0.00247	0.55	-	-	-	12.1
Feed Avg.	0.70	0.632	6.85E-07	0.034	0.02039	4.89	-	-	-	-
Std. Deviation =										1.37
Variance =										1.88

Experiment 3 CGA in a Stirred Tank Reactor Oil type: Caltex 150 Solvent Neutral

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes - magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

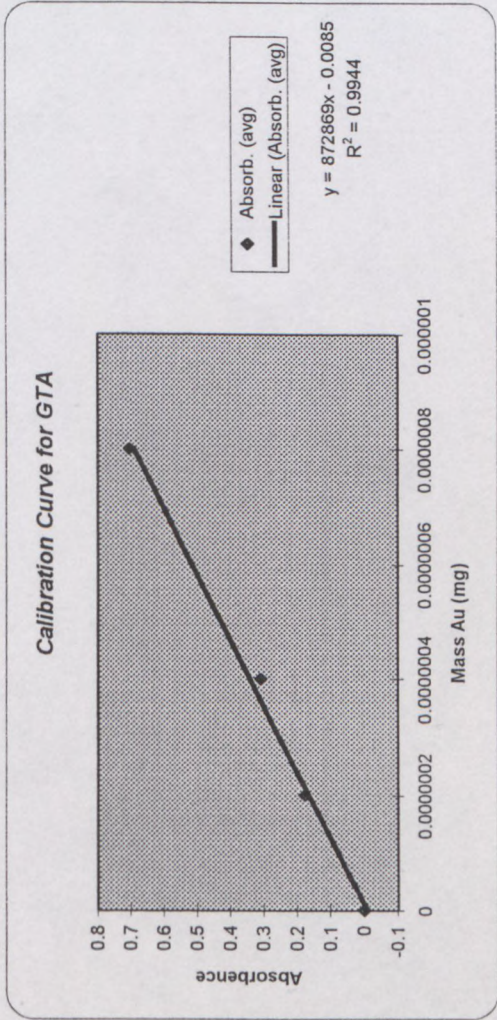
Calibration curve for GTA

Mass Au (mg)	Absorb.	Volume	Conc.
(mg)	(avg)	(micro l)	(ppm)
0	0.000	20	0
0.0000002	0.177	20	0.01
0.0000004	0.307	20	0.02
0.0000008	0.704	20	0.04

Intercept = -0.0085
Slope = 872869

Abs. = S*mass Au + Int.

	Absorbance readings		
Stand. 1	0.168	0.175	0.188
Stand. 2	0.319	0.296	0.307
Stand. 3	0.703	0.687	0.717
			0.708



MASSES

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc+c+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1 (agglom.)	33.4433	36.7228	37.4203	33.8584	4.17	3.2795	0.4151
2 (agglom.)	36.2975	39.3602	40.0279	36.7009	4.17	3.0627	0.4034
3 (agglom.)	33.5396	37.1365	37.8201	33.9676	4.17	3.5969	0.428
4 (ore)	-	-	-	-	0.702	-	-
5 (ore)	-	-	-	-	0.703	-	-
6 (ore)	-	-	-	-	0.702	-	-

RESULTS

Sample	Mass c/o (g)	Absorb. (avg.)	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings			% Au recovered
1 (agglom.)	3.2795	0.447	5.21E-07	0.0261	0.0065	1.99	0.427	0.452	0.461	34.8
2 (agglom.)	3.0627	0.426	4.98E-07	0.0249	0.0062	2.03	0.438	0.411	0.43	33.2
3 (agglom.)	3.5969	0.367	4.30E-07	0.0215	0.0054	1.49	0.358	0.357	0.385	28.7
4 (ore)	0.702	0.545	6.34E-07	0.0317	0.0032	4.52	0.527	0.553	0.556	-
5 (ore)	0.703	0.536	6.23E-07	0.0312	0.0031	4.43	0.541	0.522	0.544	-
6 (ore)	0.702	0.431	5.03E-07	0.0252	0.0025	3.58	0.443	0.431	0.418	-
Aggl. Avg.	3.3130	0.413	4.83E-07	0.024	0.00604	1.84	-	-	-	34.0
Feed Avg.	0.702	0.504	5.87E-07	0.029	0.01873	4.05	-	-	-	-
Std. Deviation =										1.10
Variance =										1.21

Experiment 4

CGA in a Stirred Tank Reactor

Oil type: Caltex 450 Solvent Neutral

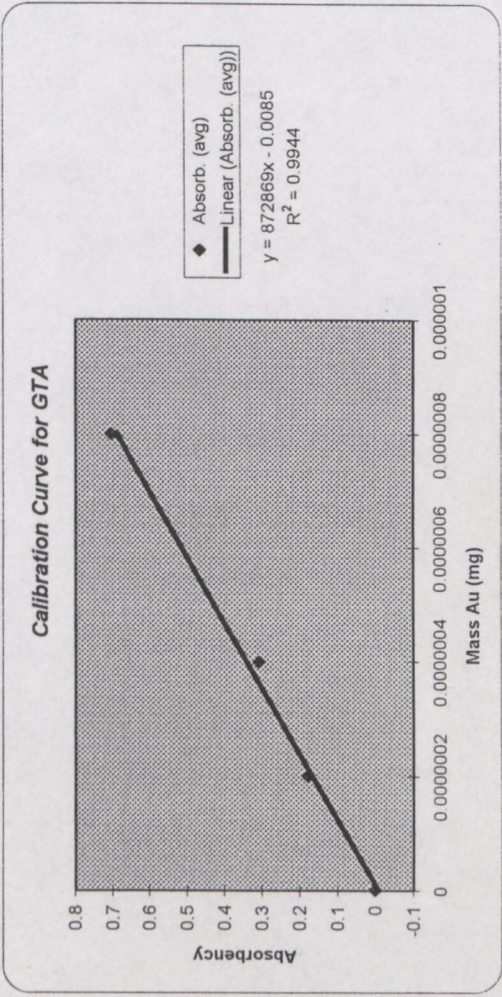
4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
 75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes on magnetic stirrer
 Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

Calibration curve for GTA

Mass Au (mg)	Absorb.	Volume (micro l)	Conc. (ppm)
0	0.000	20	0
0.0000002	0.177	20	0.01
0.0000004	0.307	20	0.02
0.0000008	0.704	20	0.04

Intercept = -0.0085
 Slope = 872869
 Abs. = S*mass Au + Int.

	Absorbance readings			
Stand. 1	0.168	0.175	0.188	
Stand. 2	0.319	0.296	0.307	
Stand. 3	0.703	0.687	0.717	0.708



MASSSES

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc+c+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1 (agglom.)	34.0211	38.5639	39.264	34.6098	4.17	4.5428	0.5887
2 (agglom.)	33.6327	37.8595	38.5985	34.2892	4.17	4.2268	0.6565
3 (agglom.)	34.1732	37.8695	38.6881	34.5578	4.17	3.6963	0.3846
4 (ore)	-	-	-	-	0.702	-	-
5 (ore)	-	-	-	-	0.703	-	-
6 (ore)	-	-	-	-	0.701	-	-

RESULTS

Sample	Mass c/o (g)	Absorb. (avg.)	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings			% Au recovered
1 (agglom.)	4.5428	0.541	6.30E-07	0.031	0.0079	1.73	0.535	0.550	0.539	39.6
2 (agglom.)	4.2268	0.464	5.41E-07	0.027	0.0068	1.60	0.439	0.487	0.465	34.0
3 (agglom.)	3.6963	0.414	4.84E-07	0.024	0.0061	1.64	0.432	0.405	0.405	30.5
4 (ore)	0.702	0.576	6.70E-07	0.033	0.0033	4.77	0.558	0.581	0.591	-
5 (ore)	0.703	0.571	6.64E-07	0.033	0.0033	4.72	0.571	0.577	0.565	-
6 (ore)	0.701	0.611	7.10E-07	0.035	0.0035	5.06	0.604	0.624	0.605	-
Aggl. Avg.	4.1553	0.473	5.52E-07	0.028	0.0069	1.66	-	-	-	36.8
Feed Avg.	0.702	0.586	6.81E-07	0.034	0.0199	4.85	-	-	-	-
Std. Deviation =										3.96
Variance =										15.68

Experiment 5

CGA in a Stirred Tank Reactor

Recycling of ore

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes - magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

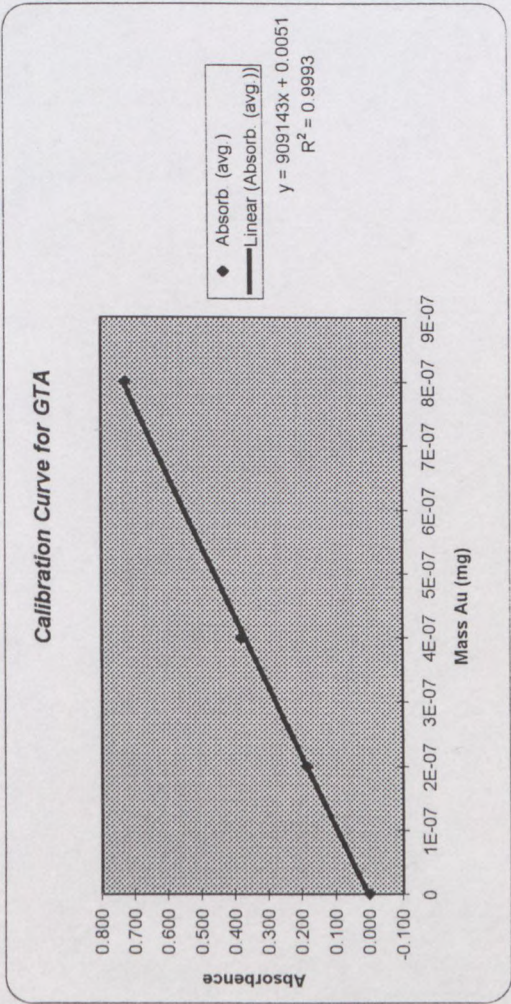
Calibration curve for GTA

Mass Au (mg)	Absorb. (avg.)	Volume (micro l)	Conc. (ppm)
0	0.000	20	0
0.0000002	0.186	20	0.01
0.0000004	0.381	20	0.02
0.0000008	0.727	20	0.04

Intercept = 0.0051
Slope = 909143

Abs. = S*mass Au + Int.

	Absorbance readings		
Stand. 1	0.176	0.195	0.186
Stand. 2	0.416	0.371	0.356
Stand. 3	0.746	0.708	0.726



MASSSES

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+c+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1 (aggl, stage 1)	33.6344	37.8666	38.5265	34.3568	4.170	4.2322	0.7224
2 (aggl, stage 1)	36.2981	40.5431	41.1914	37.0051	4.170	4.245	0.707
3 (aggl, stage 1)	33.5409	37.0435	37.7528	34.6143	4.170	3.5026	1.0734
4 (aggl, stage 2)	32.9469	37.5420	38.291	34.0817	4.170	4.5951	1.1348
5 (aggl, stage 2)	33.1844	37.8191	38.573	33.8651	4.170	4.6347	0.6807
6 (aggl, stage 2)	36.4741	41.7404	42.524	37.2353	4.170	5.2663	0.7612
7 (ore)	-	-	-	-	0.702	-	-
8 (ore)	-	-	-	-	0.705	-	-
9 (ore)	-	-	-	-	0.703	-	-

RESULTS

Sample	Mass c/o (g)	Absorb.	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbence readings		% Au recovered
1 (aggl, stage 1)	4.2322	0.446	4.85E-07	0.02423	0.0061	1.43	0.445	0.481	30.40
2 (aggl, stage 1)	4.2450	0.457	4.97E-07	0.02487	0.0062	1.46	0.427	0.473	31.20
3 (aggl, stage 1)	3.5026	0.154	1.64E-07	0.00819	0.0020	0.58	0.153	0.127	10.27
4 (aggl, stage 2)	4.5951	0.597	6.51E-07	0.03255	0.0033	0.71	0.572	0.598	16.34
5 (aggl, stage 2)	4.6347	0.099	1.03E-07	0.00516	0.0005	0.11	0.097	0.111	2.59
6 (aggl, stage 2)	5.2663	0.221	2.37E-07	0.01186	0.0012	0.23	0.231	0.206	5.95
7 (ore)	0.702	0.595	6.49E-07	0.03244	0.0032	4.62	0.57	0.604	-
8 (ore)	0.705	0.632	6.90E-07	0.03450	0.0034	4.89	0.635	0.625	-
9 (ore)	0.703	0.621	6.78E-07	0.03389	0.0034	4.82	0.624	0.64	-
Aggl. (1) Avg.	3.9933	0.352	3.82E-07	0.02	0.0048	1.16			30.8
Aggl. (2) Avg.	4.8320	0.306	3.30E-07	0.02	0.0017	0.35			4.3
Feed Avg.	0.703	0.616	6.72E-07	0.034	0.0199	4.78			-
							Std. Deviation =		0.569
							Variance =		0.324

Experiment 6

CGA in a Stirred Tank Reactor

Repeat of Oil type: Caltex 100 Solvent Neutral

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.003g/250 ml). Stirred for 50 minutes - magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

Calibration curve for GTA

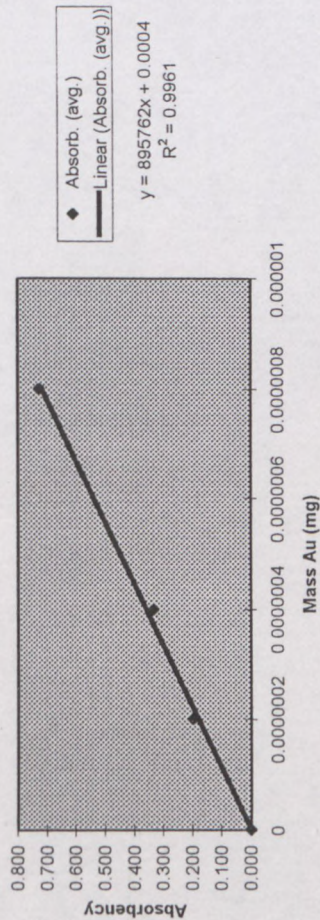
Mass Au (mg)	Absorb.	Volume (micro l)	Conc. (ppm)
0	0.000	20	0
2E-07	0.198	20	0.01
4E-07	0.332	20	0.02
8E-07	0.726	20	0.04

Intercept = 0.0004
Slope = 895762

Abs. = S*mass Au + Int.

	Absorbance readings		
Stand. 1	0.191	0.203	0.199
Stand. 2	0.332	0.337	0.328
Stand. 3	0.721	0.748	0.708

Calibration curve for GTA



MASSSES

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc+c+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1 (agglom.)	33.6344	37.4669	38.1701	34.0898	4.17	3.8325	0.4554
2 (agglom.)	34.1741	37.897	38.5752	34.6392	4.17	3.7229	0.4651
3 (agglom.)	32.9476	36.1952	36.9293	33.3436	4.17	3.2476	0.396
4 (ore)	-	-	-	-	0.703	-	-
5 (ore)	-	-	-	-	0.703	-	-
6 (ore)	-	-	-	-	0.704	-	-

RESULTS

Sample	Mass c/o (g)	Absorb. (avg.)	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings			% Au recovered
1 (agglom.)	3.8325	0.457	5.09E-07	0.025	0.0064	1.66	0.439	0.454	0.477	28.0
2 (agglom.)	3.7229	0.459	5.12E-07	0.026	0.0064	1.72	0.486	0.453	0.439	28.2
3 (agglom.)	3.2476	0.609	6.79E-07	0.034	0.0085	2.61	0.608	0.599	0.619	37.4
4 (ore)	0.703	0.640	7.14E-07	0.036	0.0036	5.08	0.629	0.657	0.633	-
5 (ore)	0.703	0.733	8.18E-07	0.041	0.0041	5.82	0.724	0.745	0.73	-
6 (ore)	0.704	0.560	6.25E-07	0.031	0.0031	4.44	0.545	0.569	0.566	-
Aggl. Avg.	3.6010	0.508	5.67E-07	0.028	0.0071	2.00				28.1
Feed Avg.	0.703	0.644	7.19E-07	0.036	0.0227	5.45				-
							Std. Deviation =			0.116
							Variance =			0.0134

Experiment 7 CGA in a Stirred Tank Reactor Repeat Recycling of ore

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.003g/250 ml). Stirred for 50 minutes - magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

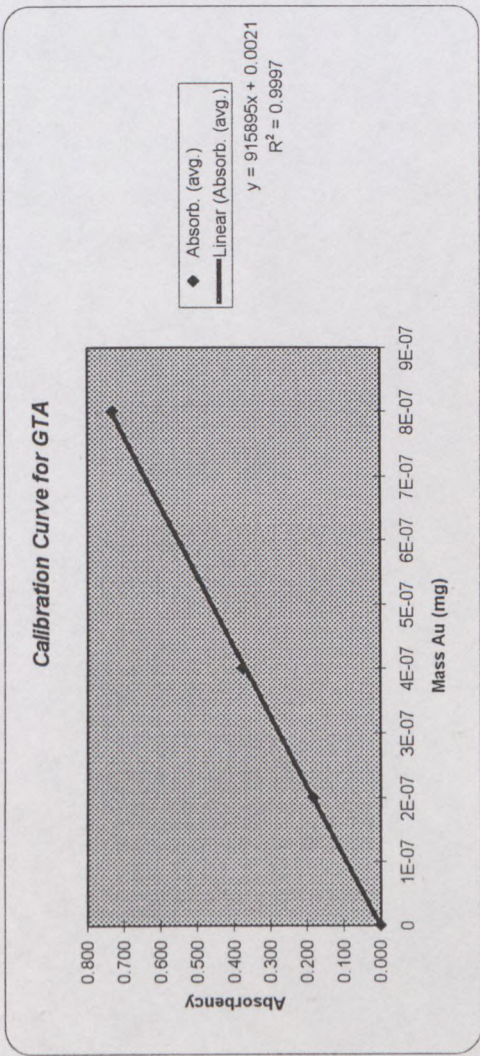
Calibration curve for GTA

Mass Au (mg)	Absorb.	Volume	Conc.
	(avg.)	(micro l)	(ppm)
0	0.000	20	0
0.0000002	0.183	20	0.01
0.0000004	0.377	20	0.02
0.0000008	0.731	20	0.04

Intercept = 0.0021
Slope = 915895

Abs. = S*mass Au + Int.

Absorbance readings			
Stand. 1	0.171	0.189	0.188
Stand. 2	0.397	0.361	0.372
Stand. 3	0.785	0.74	0.695
		0.743	0.694



Masses

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ct+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1 (aggl, stage 1)	34.0225	38.3624	39.0605	34.7438	4.170	4.3399	0.7213
2 (aggl, stage 1)	36.4748	40.8429	41.4981	37.1917	4.170	4.3681	0.7169
3 (aggl, stage 1)	33.4445	37.6876	38.3247	34.1466	4.170	4.2431	0.7021
4 (aggl, stage 2)	32.8598	37.4259	38.1951	33.5065	4.170	4.5661	0.6467
5 (aggl, stage 2)	33.5417	38.1732	38.9185	34.179	4.170	4.6315	0.6373
6 (aggl, stage 2)	35.6512	40.1024	40.7916	36.2462	4.170	4.4512	0.595
7 (ore)	-	-	-	-	0.705	-	-
8 (ore)	-	-	-	-	0.703	-	-
9 (ore)	-	-	-	-	0.705	-	-

RESULTS

Sample	Mass c/o (g)	Absorb.	Mass Au (mg)	Conc. (ppm)	mtotal (Au) (mg)	Au loading (g/ton)	Absorbance readings	% Au recovered
1 (aggl, stage 1)	4.3399	0.656	7.14E-07	0.0357	0.0089	2.06	0.665 0.659 0.645	52.51
2 (aggl, stage 1)	4.3681	0.628	6.83E-07	0.0342	0.0085	1.96	0.626 0.632 0.626	50.23
3 (aggl, stage 1)	4.2431	1.049	1.14E-06	0.0572	0.0143	3.37	1.048 1.05 1.05	84.05
4 (aggl, stage 2)	4.5661	0.111	1.19E-07	0.0060	0.0006	0.13	0.117 0.113 0.104	3.51
5 (aggl, stage 2)	4.6315	0.149	1.61E-07	0.0080	0.0008	0.17	0.148 0.158 0.142	4.73
6 (aggl, stage 2)	4.4512	0.100	1.07E-07	0.0053	0.0005	0.12	0.096 0.105 0.099	3.14
7 (ore)	0.705	0.547	5.95E-07	0.0298	0.0030	4.22	0.538 0.544 0.56	-
8 (ore)	0.703	0.510	5.55E-07	0.0277	0.0028	3.95	0.507 0.508 0.516	-
9 (ore)	0.705	0.527	5.73E-07	0.0287	0.0029	4.06	0.537 0.52 0.524	-
Aggl. (1) Avg.	4.3170	0.78	8.47E-07	0.042	0.0106	2.46	- - -	51.4
Aggl. (2) Avg.	4.5496	0.12	1.29E-07	0.006	0.0006	0.14	- - -	3.8
Feed Avg.	0.704	0.528	5.74E-07	0.029	0.0170	4.08	- - -	-
Std. Deviation =								1.61
Variance =								2.59

Experiment 8

CGA in a Stirred Tank Reactor

Repeat of Oil type: Ethyl Oleate

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
 75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes - magnetic stirrer
 Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

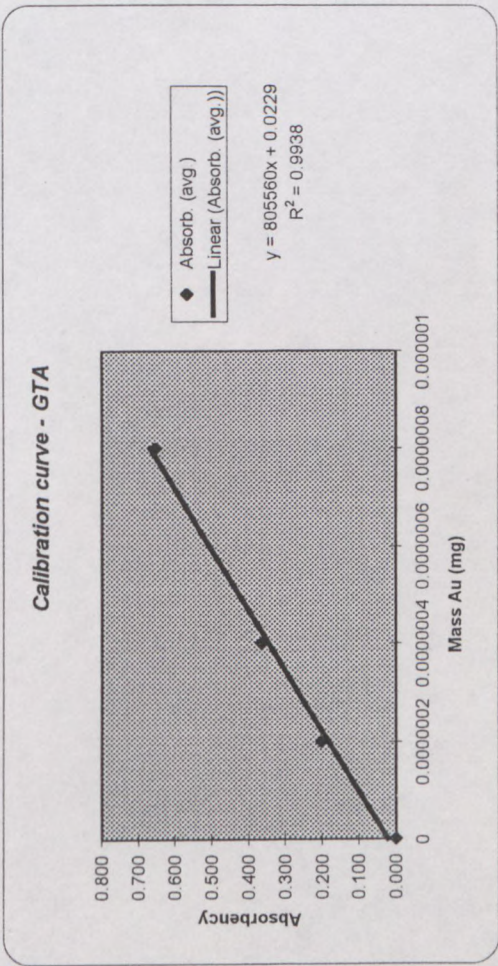
Calibration curve for GTA

Mass Au (mg)	Absorb.	Volume	Conc.
(mg)	(avg.)	(micro l)	(ppm)
0	0.000	20	0
0.0000002	0.202	20	0.01
0.0000004	0.365	20	0.02
0.0000008	0.653	20	0.04

Intercept = 0.0229
 Slope = 805560

Abs. = S*mass Au + Int.

	Absorbance readings		
Stand. 1	0.192	0.202	0.211
Stand. 2	0.366	0.371	0.357
Stand. 3	0.655	0.683	0.632
			0.643



Masses

Sample	m_{crucible} (g)	$m_{\text{cruc.+coal}}$ (g)	$m_{\text{cruc.+c+paper}}$ (g)	$m_{\text{cruc.+ash}}$ (g)	m_{ore} (g)	m_{coal} (g)	m_{ash} (g)
1	33.6349	38.0642	38.7718	34.3612	4.170	4.4293	0.7263
2	34.1746	38.6772	39.3709	34.9388	4.170	4.5026	0.7642
3	36.2987	40.7351	41.4023	37.0414	4.170	4.4364	0.7427
4	32.9480	36.9852	37.6840	33.6015	4.170	4.0372	0.6535
5	35.6521	40.0651	40.7312	36.4046	4.170	4.413	0.7525
6	33.1857	37.2532	38.4152	36.9752	4.0675	-	3.7895
7	34.0229	37.9803	38.9023	37.7025	3.9574	-	3.6796
8	36.4754	40.0909	44.7009	40.2021	3.6155	-	3.7267
9	33.4457	37.6917	40.4577	37.3232	4.246	-	3.8775
10	-	-	-	-	0.703	-	-
11	-	-	-	-	0.702	-	-
12	-	-	-	-	0.704	-	-
13	-	-	-	-	0.704	-	-
14	-	-	-	-	0.701	-	-

RESULTS

Sample	Mass c/o (g)	Absorb. (avg.)	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings			% Au recovered
1	4.4293	0.455	5.36E-07	0.0268	0.00670	1.51	0.435	0.465	0.465	37.0
2	4.5026	0.499	5.91E-07	0.0296	0.00739	1.64	0.509	0.484	0.504	40.8
3	4.4364	0.423	4.96E-07	0.0248	0.00620	1.40	0.438	0.415	0.415	34.3
4	4.0372	0.556	6.62E-07	0.0331	0.00828	2.05	0.569	0.56	0.54	45.7
5	4.413	0.394	4.60E-07	0.0230	0.00575	1.30	0.405	0.382	0.394	31.8
6	4.0675	0.085	7.75E-08	0.0039	0.000969	0.24	0.082	0.081	0.093	5.4
7	3.9574	0.073	6.22E-08	0.0031	0.000777	0.20	0.075	0.071		4.3
8	3.6155	0.123	1.24E-07	0.0062	0.001548	0.43	0.118	0.128	0.122	8.6
9	4.246	0.109	1.07E-07	0.0053	0.001336	0.31	0.11	0.108		7.4
10	0.703	0.606	7.24E-07	0.0362	0.00362	5.15	0.61	0.597	0.612	-
11	0.702	0.494	5.85E-07	0.0293	0.00293	4.17	0.493	0.486	0.504	-
12	0.704	0.463	5.46E-07	0.0273	0.00273	3.88	0.489	0.449	0.451	-
13	0.704	0.521	6.19E-07	0.0309	0.00309	4.39	0.562	0.499	0.503	-
14	0.701	0.4865	5.76E-07	0.0288	0.00288	4.10	0.489	0.484	0.489	-
Aggl. Avg.	4.36	0.47	5.49E-07	0.03	0.00687	1.58				37.9
Resid. Avg.	3.97	0.10	9.26E-08	0.00	0.00116	0.29				6.4
Feed Avg.	0.703	0.514	6.10E-07	0.031	0.0181	4.34				-
							Std. Deviation =			5.50
							Variance =			30.29

Experiment 9

CGA in a Stirred Tank Reactor

Repeat: Recycling of ore

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes - magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

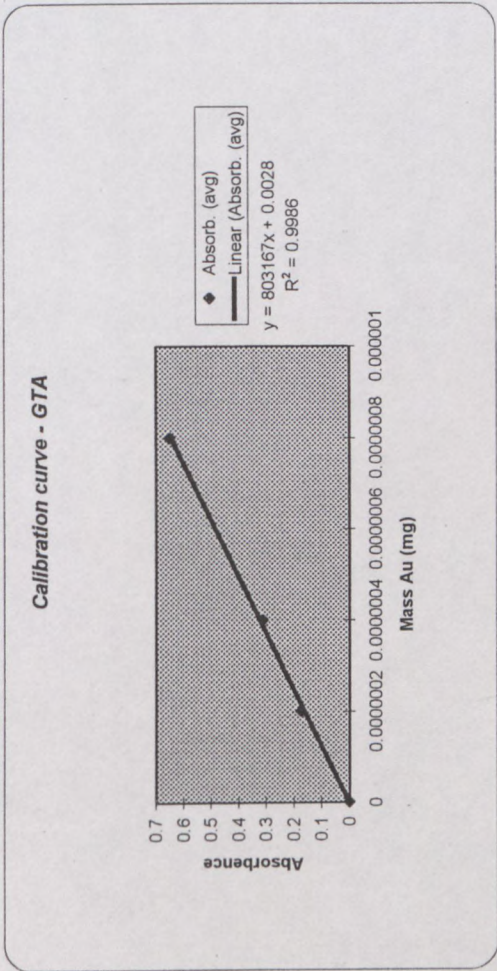
Calibration curve for GTA

Mass Au (mg)	Absorb. (avg)	Volume (micro l)	Conc. (ppm)
0	0	20	0
0.0000002	0.175	20	0.01
0.0000004	0.312	20	0.02
0.0000008	0.649	20	0.04

Intercept = 0.0028
Slope = 803167

Abs. = S*mass Au + Int.

	Absorbance readings		
Stand. 1	0.164	0.178	0.184
Stand. 2	0.293	0.329	0.313
Stand. 3	0.65	0.647	



Masses

Sample		$m_{crucible}$ (g)	$m_{cruc.+coal}$ (g)	$m_{cruc.+c+paper}$ (g)	$m_{cruc.+ash}$ (g)	m_{ore} (g)	m_{coal} (g)	m_{ash} (g)
1	agglom (1)	33.6349	37.6884	38.2907	34.3294	4.170	4.0535	0.6945
2		34.1739	38.4825	39.1052	34.9825	4.170	4.3086	0.8086
3		36.2985	40.3362	40.9301	37.0274	4.170	4.0377	0.7289
4	agglom (2)	32.9480	37.5076	38.2021	33.6090	4.170	4.5596	0.6610
5		35.6517	40.1855	40.8532	36.3373	4.170	4.5338	0.6856
6		33.1851	37.5835	38.2068	33.8159	4.170	4.3984	0.6308
7	residue ore	34.0226	37.8239	41.7447	37.7274	3.8013	-	3.7048
8		36.4748	40.1500	43.0345	40.0412	3.6752	-	3.5664
9		31.5882	35.1537	38.6544	35.0627	3.5655	-	3.4745
10	original ore	-	-	-	-	0.702	-	-
11		-	-	-	-	0.704	-	-
12		-	-	-	-	0.704	-	-

Results

Sample	Mass c/o (g)	Absorb. (avg.)	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings			% Au recovered
1	4.0535	0.460	5.70E-07	0.0285	0.0071	1.76	0.473	0.435	0.473	35.4
2	4.3086	0.410	5.07E-07	0.0253	0.0063	1.47	0.375	0.444	0.41	31.5
3	4.0377	0.372	4.59E-07	0.0230	0.0057	1.42	0.393	0.366	0.356	28.5
4	4.5596	0.075	8.99E-08	0.0045	0.0011	0.25	0.074	0.076	-	5.6
5	4.5338	0.061	7.25E-08	0.0036	0.0009	0.20	0.063	0.059	-	4.5
6	4.3984	0.055	6.50E-08	0.0032	0.0008	0.18	0.052	0.058	-	4.0
7	3.8013	0.028	3.08E-08	0.0015	0.00038	0.10	0.026	0.029	-	1.9
8	3.6752	0.033	3.76E-08	0.0019	0.00047	0.13	0.031	0.035	-	2.3
9	3.5655	0.038	4.38E-08	0.0022	0.00055	0.15	0.037	0.039	-	2.7
10	0.702	0.568	7.04E-07	0.0352	0.0035	5.02	0.592	0.577	0.536	-
11	0.704	0.519	6.43E-07	0.0321	0.0032	4.56	0.501	0.543	0.513	-
12	0.704	0.556	6.89E-07	0.0344	0.0034	4.89	0.566	0.55	0.552	-
Aggl. (1) Avg.	4.13	0.41	5.12E-07	0.03	0.0064	1.55	-	-	-	31.8
Aggl. (2) Avg.	4.50	0.06	7.58E-08	0.00	0.0009	0.21	-	-	-	4.7
Residue Avg.	3.68	0.03	3.74E-08	0.00	0.0005	0.13	-	-	-	2.3
Feed Avg.	0.703	0.548	6.79E-07	0.034	0.0201	4.82	-	-	-	-
							Std. Deviation =			3.44
							Variance =			11.85

Experiment 10

CGA in a Stirred Tank Reactor

Repeat of Oil type: Ethyl Oleate + mass balance

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
 75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes - magnetic stirrer
 Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

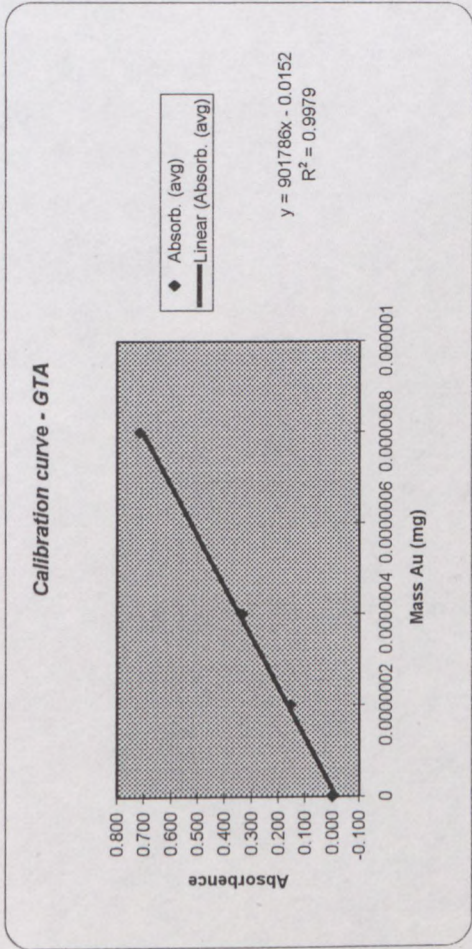
Calibration curve for GTA

Mass Au (mg)	Absorb.	Volume (micro l)	Conc. (ppm)
0	0.000	20	0
0.0000002	0.153	20	0.01
0.0000004	0.334	20	0.02
0.0000008	0.715	20	0.04

Intercept = -0.0152
 Slope = 901786

Abs. = S*mass Au + Int.

	Absorbance readings			
Stand. 1	0.152	0.155	0.152	
Stand. 2	0.336	0.331		
Stand. 3	0.693	0.728	0.725	



Masses

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1	33.6351	37.9271	38.5799	34.3444	4.170	4.2920	0.7093
2	34.1739	38.4904	39.1634	34.9109	4.170	4.3165	0.7370
3	36.2994	40.5186	41.1561	37.0136	4.170	4.2192	0.7142
4	32.9482	36.7834	37.7903	36.6642	3.8352	-	3.7160
5	35.6517	39.6101	40.7067	39.4156	3.9584	-	3.7639
6	33.1852	37.1005	38.1192	36.9897	3.9153	-	3.8045
7	-	-	-	-	0.703	-	-
8	-	-	-	-	0.705	-	-
9	-	-	-	-	0.701	-	-

RESULTS

Sample	Mass c/o (g)	Absorb. (avg.)	Mass Au (mg)	Conc. (ppm)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings		% Au recovered
1	4.2920	0.371	4.29E-07	0.021	0.00536	1.25	0.351	0.408	26.5
2	4.3165	0.441	5.05E-07	0.025	0.00632	1.46	0.372	0.379	31.2
3	4.2192	0.404	4.65E-07	0.023	0.00581	1.38	0.383	0.403	28.7
4	3.8352	0.200	2.39E-07	0.012	0.00298	0.78	0.194	0.205	14.7
5	3.9584	0.176	2.12E-07	0.011	0.00265	0.67	0.17	0.198	13.1
6	3.9153	0.096	1.23E-07	0.006	0.00154	0.39	0.089	0.103	7.6
7	0.703	0.593	6.74E-07	0.034	0.00337	4.80	0.632	0.597	-
8	0.705	0.601	6.84E-07	0.034	0.00342	4.85	0.61	0.606	-
9	0.701	0.607	6.90E-07	0.035	0.00345	4.92	0.628	0.588	-
Aggl. Avg.	4.28	0.405	4.66E-07	0.023	0.00583	1.36	-	-	28.8
Resid. Avg.	3.90	0.157	1.91E-07	0.010	0.00239	0.61	-	-	11.8
Feed Avg.	0.703	0.601	6.83E-07	0.034	0.02025	4.86	-	-	-
Std. Deviation =									2.37
Variance =									5.61

Experiment 11

CGA in a Stirred Tank Reactor

Repeat Exp. 10, analyses on ICP

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes - magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

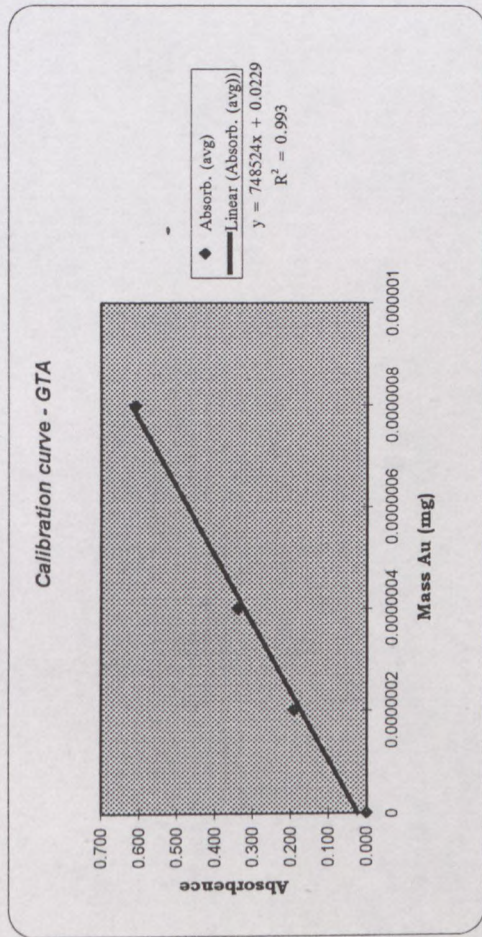
Calibration curve for GTA

Mass Au (mg)	Absorb. (avg)	Volume (micro l)	Conc. (ppm)
0	0.000	20	0
0.0000002	0.191	20	0.01
0.0000004	0.341	20	0.02
0.0000008	0.608	20	0.04

Intercept = 0.0229
Slope = 748524

Abs. = S*mass Au + Int.

	Absorbance readings		
Stand. 1	0.209	0.169	0.195
Stand. 2	0.374	0.31	0.338
Stand. 3	0.58	0.618	0.626



Masses

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1	33.6345	37.7125	38.4117	34.3053	4.170	4.0780	0.6708
2	34.1737	38.2447	38.8888	34.8433	4.170	4.0710	0.6696
3	36.2989	40.4263	41.1325	36.9854	4.170	4.1274	0.6865
4	32.9476	36.8483	38.9652	36.7077	3.9007	-	3.7601
5	35.6511	39.6247	41.8993	39.5563	3.9736	-	3.9052
6	33.1844	37.4416	39.3528	37.0904	4.2572	-	3.906
7	-	-	-	-	0.703	-	-
8	-	-	-	-	0.705	-	-
9	-	-	-	-	0.701	-	-

RESULTS

Sample	Mass c/o (g)	Absorb.	Mass Au (mg)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings	% Au recovered
1	4.0780	0.325	4.03E-07	0.0202	0.0050	1.24	0.304	12.9
2	4.0710	-	-	0.3500	0.0350	8.60	-	89.4
3	4.1274	-	-	0.2850	0.0286	6.93	-	73.1
4	3.9007	0.328	4.07E-07	0.0204	0.0020	0.52	0.352	5.2
5	3.9736	-	-	0.0580	0.0058	1.46	-	14.8
6	4.2372	-	-	0.0600	0.0060	1.41	-	15.3
7	0.703	0.513	6.55E-07	0.0328	0.0033	4.66	0.465	-
8	0.705	-	-	0.0680	0.0068	9.65	-	-
9	0.701	-	-	0.0640	0.0064	9.13	-	-
Aggl. Avg.	4.09			0.219	0.02288	7.76		81.2
Resid. Avg.	4.04			0.046	0.00461	1.43		15.1
Feed Avg.	0.703			0.055	0.03915	9.39		-
Samples coloured in were analysed by Infrutech on an ICP.								Std. Deviation = 11.56
								Variance = 133.62

Experiment 12
CGA in a Stirred Tank Reactor
Repeat Exp. 11, some samples analysed on ICP
Agglomerates formed in water

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes - magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C

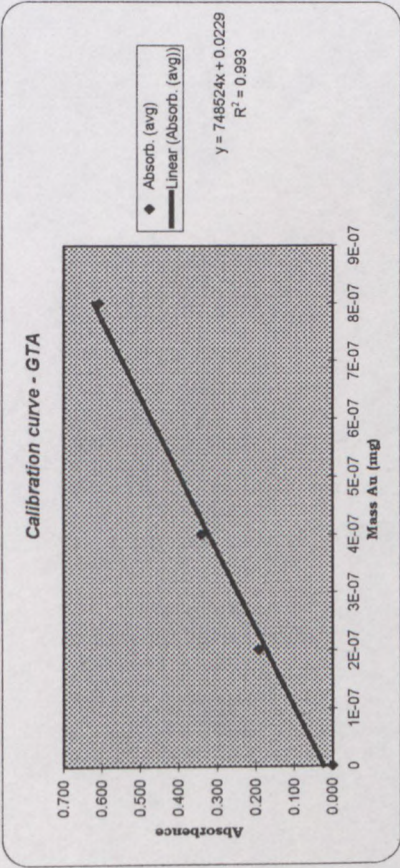
Calibration curve for GTA

Mass Au (mg)	Absorb. (avg)	Volume (micro l)	Conc. (ppm)
0	0.000	20	0
0.0000002	0.191	20	0.01
0.0000004	0.341	20	0.02
0.0000008	0.608	20	0.04

Intercept = 0.0229
Slope = 748524

Abs. = S*mass Au + Int.

	Absorbance readings		
Stand. 1	0.209	0.169	0.195
Stand. 2	0.374	0.31	0.338
Stand. 3	0.58	0.618	0.626



Masses

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+paper} (g)	m _{cruc.+ash} (g)	m _{ore} (g)	m _{coal} (g)	m _{ash} (g)
1	18.7480	22.8767	23.5476	19.4045	4.170	4.1287	0.6565
2	17.1549	20.9311	21.6083	17.7484	4.170	3.7762	0.5935
3	17.6867	21.5036	22.2020	18.2859	4.170	3.8169	0.5992
4	18.4075	22.583	23.2321	19.1111	4.170	4.1755	0.7036
5	32.8606	36.8159	39.1448	36.7504	3.9553	-	3.8898
6	31.5879	35.8533	38.0902	35.5254	4.2654	-	3.9375
7	36.4751	40.0355	42.0926	40.006	3.5604	-	3.5309
8	-	-	-	-	0.703	-	-
9	-	-	-	-	0.704	-	-
10	-	-	-	-	0.701	-	-
11	-	-	-	-	0.703	-	-

RESULTS

Sample	Mass c/o (g)	Absorb.	Mass Au (mg)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	Absorbance readings	% Au recovered
1	4.1287	-	-	0.25700	0.0257	6.22	-	71.0
2	3.7762	-	-	0.25700	0.0257	6.81	-	71.0
3	3.8169	0.355	4.44E-07	0.02218	0.0055	1.45	0.346	42.7
4	4.1755	0.226	2.71E-07	0.01357	0.0034	0.81	0.249	26.1
5	3.9553	-	-	0.06000	0.0060	1.52	-	16.6
6	4.2654	0.399	5.02E-07	0.02510	0.0025	0.59	0.406	19.3
7	3.5604	0.316	3.92E-07	0.01958	0.0020	0.55	0.315	15.1
8	0.703	-	-	0.05700	0.0057	8.11	-	-
9	0.704	-	-	0.06500	0.0065	9.23	-	-
10	0.701	0.453	5.75E-07	0.02873	0.0029	4.10	0.452	-
11	0.703	0.566	7.25E-07	0.03626	0.0036	5.16	0.571	-
Aggl. Avg.	3.9743	-	-	0.257	0.0257	6.52	0.555	71.0
	3.9962	0.29	3.58E-07	0.018	0.0045	1.13	-	34.4
Presel. Avg.	3.9553	-	-	0.06	0.01	1.52	-	16.6
	3.9129	0.36	4.47E-07	0.02	0.00	0.57	-	17.2
Feed Avg.	0.703	0.509	6.50E-07	0.047	0.0362	8.67	-	-
Samples coloured in were analysed by Infrutech on an ICP.								Std. Deviation = 11.72 Variance = 137.36

Experiment 13

CGA in a Stirred Tank Reactor

Recycle of agglomerates

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
 75 ml Water, 20 ml PAX (5.001g/250 ml). Stirred for 50 minutes - magnetic stirrer
 Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C.

RESULTS - Analyses on ICP

Sample	m _{coal/ore} (g)	m _{ash} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered	% Au recovered (average)	% Au recovered to agglom.	Standard deviation	Variance
1 (ore, 1 st sep.)	4.0012	3.8730	0.044	0.0044	1.061	17.0	-	-		
2 (ore, 1 st sep.)	4.0491	3.9004	0.047	0.0047	1.161	18.1	-	-		
3 (ore, 1 st sep.)	4.2612	3.9346	0.041	0.0041	0.962	15.8	17.0	83.0	1.16	1.34
4 (agglomerates)	4.2232	0.7984	0.521	0.0521	12.337	100.4	-	-		
5 (agglomerates)	4.0159	0.7647	0.494	0.0494	12.301	95.2	-	-		
6 (agglomerates)	3.7478	0.7028	0.548	0.0548	14.622	105.6	97.8	-		
7 (ore, 2 nd sep.)	3.7303	3.7843	0.072	0.0072	1.930	27.7	-	-		
8 (ore, 2 nd sep.)	4.0679	3.9633	0.066	0.0066	1.622	25.4	-	-		
9 (ore, 2 nd sep.)	3.9421	3.8600	0.052	0.0052	1.319	20.0	24.4	75.6	3.96	15.64
10 (orig. ore)	0.700	-	0.049	0.0049	7.000	-	-	-	-	-
11 (orig. ore)	0.701	-	0.042	0.0042	5.991	-	-	-	-	-
12 (orig. ore)	0.701	-	0.047	0.0047	6.705	-	-	-	-	-
13 (orig. ore)	0.703	-	0.039	0.0039	5.548	-	-	-	-	-
14 (orig. ore)	0.703	-	0.046	0.0046	6.543	-	-	-	-	-
15 (orig. ore)	0.703	-	0.039	0.0039	5.548	-	-	-	-	-
Residue (1) Avg.	4.10	-	0.04	0.0044	1.06	-	-	-	-	-
Agglomerate Avg.	4.00	-	0.52	0.0521	12.32	-	-	-	-	-
Residue (2) Avg.	3.91	-	0.06	0.0063	1.62	-	-	-	-	-
Feed Avg.	0.702	-	0.044	0.0259	6.22	-	-	-	-	-

Experiment 14 CGA in a Stirred Tank Reactor Separation by SIEVING

4.17g coal (Athlone Powerstation, 1997), 1 ml Ethyl Oleate, 4.17 g synthetic ore
75 ml Water, 20 ml PAX (5.002g/250 ml). Stirred for 50 minutes - magnetic stirrer
Dried coal/oil agglomerates overnight at 80 °C. Ashed for 7 hours at 800 °C.

RESULTS - Analyses on ICP

Sample	m _{mash} (g)	m _{coal/ore} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered	Standard deviation	Variance
1 (agglomerates)	1.0135	4.1350	0.329	0.0329	7.956	94.5		
2 (agglomerates)	0.9852	4.4300	0.362	0.0362	8.172	104.0		
3 (agglomerates)	0.7272	3.9612	0.255	0.0255	6.437	73.3		
4 (agglomerates)	0.9947	4.2156	0.275	0.0275	6.523	79.0		
5 (agglomerates)	0.9809	4.5742	0.278	0.0278	6.078	79.9		
6 (agglomerates)	0.9176	4.5550	0.270	0.0270	5.928	77.6	2.94	8.62
7 (used ore)	3.3341	3.9214	0.085	0.0085	2.168	24.4		
8 (used ore)	3.3855	3.7821	0.068	0.0068	1.798	19.5		
9 (used ore)	3.6729	4.3095	0.089	0.0089	2.065	25.6		
10 (used ore)	3.3771	3.7726	0.065	0.0065	1.723	18.7		
11 (used ore)	3.4087	3.4981	0.049	0.0049	1.401	14.1		
12 (used ore)	3.5835	3.8011	0.049	0.0049	1.289	14.1	3.45	11.91
13 (original ore)	-	0.700	0.059	0.0059	8.429	-	-	-
14 (original ore)	-	0.702	0.058	0.0058	8.262	-	-	-
15 (original ore)	-	0.702	0.054	0.0054	7.692	-	-	-
Agglomerate Avg.	-	4.31	0.29	0.0270	6.24	77.4	-	-
Residue Avg.	-	3.85	0.07	0.0068	1.74	22.1	-	-
Feed Avg.	-	0.701	0.059	0.0348	8.35	99.5	-	-

Experiment 15

Mercury Amalgamation, Test 1

20 g ore; 1g Hg; 50 ml NaOH aq. (0.1010 g/ 250 ml)
 Contacted for 2 hrs at 200 rpm
 Separated with separation funnel

RESULTS - Analyses on ICP

Sample	Mass (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered	% Au recov. (average)	Standard deviation	Variance
1 (amalgam)	1.0342	0.139	0.0139	13.44	13.8	4.5	0.141	0.020
2 (amalgam)	1.0234	0.044	0.0044	4.30	4.4			
3 (amalgam)	1.0512	0.046	0.0046	4.38	4.6			
4 (used ore)	20.0001	0.275	0.0275	1.37	27.3	29.3	1.94	3.76
5 (used ore)	20.0008	0.190	0.0190	0.95	29.3			
6 (used ore)	20.0004	0.314	0.0314	1.57	31.2			
7 (original ore)	1.0008	0.057	0.0057	5.70	-	-	-	-
8 (original ore)	1.0007	0.046	0.0046	4.60	-	-	-	-
9 (original ore)	1.0002	0.048	0.0048	4.80	-	-	-	-
Amalgam Avg.	1.0363	0.0763	0.0076	7.37	-	-	-	-
Residue Avg.	20.0004	0.2597	0.0295	1.30	-	-	-	-
Feed Avg.	1.0006	0.0503	0.1006	5.03	-	-	-	-

Experiment 16 **Mercury Amalgamation, Test 2**

20 g ore; 1g Hg; 50 ml NaOH aq. (0.1010 g/ 250 ml)
 Contacted for 2 hrs at 200 rpm
 Separated with separation funnel

RESULTS - Analyses on ICP

Sample	Mass (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered	% Au recov. (average)	Standard deviation	Variance
1 (amalgam)	1.0098	0.169	0.0169	16.74	16.6	15.7	1.32	1.74
2 (amalgam)	1.0168	0.150	0.0150	14.75	14.7			
3 (amalgam)	1.0114	0.040	0.0040	3.95	3.9			
4 (used ore)	20.00	0.284	0.0284	1.42	27.9	25.6	3.19	10.20
5 (used ore)	20.00	0.372	0.0372	1.86	36.5			
6 (used ore)	20.00	0.238	0.0238	1.19	23.4			
7 (original ore)	1.0020	0.053	0.0053	5.29	-		-	-
8 (original ore)	1.0010	0.047	0.0047	4.70	-			
9 (original ore)	1.0010	0.053	0.0053	5.29	-			
Amalgam Avg.	1.0127	0.1197	0.0120	11.81	-	-	-	-
Residue Avg.	20.0000	0.2980	0.0298	1.49	-			
Feed Avg.	1.0013	0.0510	0.102	5.09	-			

Experiment 17

Mercury Amalgamation, Test 3

10 g ore; 0.5g Hg; 50 ml NaOH aq. (0.1010 g/ 250 ml)
 Contacted for 2 hrs at 200 rpm
 Separated with separation funnel

RESULTS - Analyses on ICP

Sample	Mass (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered	% Au recov. (average)	Standard deviation	Variance
1 (amalgam)	0.5086	0.061	0.0061	11.99	12.0	8.5	2.92	8.50
2 (amalgam)	0.5095	0.026	0.0026	5.10	5.1			
3 (amalgam)	0.5048	0.005	0.0005	0.99	1.0			
4 (used ore)	10.00	0.109	0.0109	1.09	21.4	29.3	1.11	1.23
5 (used ore)	10.00	0.153	0.0153	1.53	30.0			
6 (used ore)	10.00	0.145	0.0145	1.45	28.5			
7 (original ore)	1.0020	0.053	0.0053	5.29	-	-	-	-
8 (original ore)	1.0010	0.047	0.0047	4.70	-	-	-	-
9 (original ore)	1.0010	0.053	0.0053	5.29	-	-	-	-
Amalgam Avg.	0.5076	0.0307	0.0031	6.03	-	-	-	-
Residue Avg.	10.0000	0.1357	0.0136	1.36	-	-	-	-
Feed Avg.	1.0013	0.0510	0.0509	5.09	-	-	-	-

APPENDIX A2

CGA with flotation on a small scale

Experiment 18 **Small-scale Flotation cell** **Effect of baffles @ 1200 rpm**

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1200	rpm
Baffles	8 Plates	1	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+aggl.} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{aggl./ore} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	50.88	94.67			43.79				
1 (agglomerates)	34.0234	38.0242	34.5881	0.5647	4.0008	0.179	0.196	4.47	57.7
2 (agglomerates)	35.6502	39.6515	36.2184	0.5682	4.0013	0.174	0.190	4.35	56.1
3 (agglomerates)	32.8563	36.8598	33.4201	0.5638	4.0035	0.09	0.098	2.25	29.0
4 (orig. ore)	-	-	-	-	1.000	0.076	0.3169	7.60	-
5 (orig. ore)	-	-	-	-	1.001	0.087	0.3624	8.71	-
6 (orig. ore)	-	-	-	-	1.001	0.103	0.4291	10.31	-
Agglomerate Avg. Feed Avg.					4.002	0.148	0.162	3.690	56.9
					1.001	0.089	0.340	8.154	
								Std. Deviation =	1.14
								Variance =	1.31

Experiment 19

Small-scale Flotation cell

Contacted @ 1200 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1200	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	180.53	230.67	-		50.14				
1 (agglomerates)	35.1267	39.1414	35.8278	0.7011	4.0147	0.179	0.224	4.46	65.8
2 (agglomerates)	34.1737	38.1772	34.8742	0.7005	4.0035	0.161	0.202	4.02	59.4
3 (agglomerates)	32.9481	36.9548	33.6416	0.6935	4.0067	0.176	0.220	4.39	64.8
4 (orig. ore)	-	-	-	-	1.000	0.076	0.3169	7.60	-
5 (orig. ore)	-	-	-	-	1.001	0.087	0.3624	8.71	-
6 (orig. ore)	-	-	-	-	1.001	0.103	0.4291	10.31	-
Agglomerate Avg. Feed Avg.					4.008	0.172	0.215	4.291	65.3
					1.001	0.089	0.340	8.154	
Std. Deviation =									0.689
Variance =									0.474

Experiment 20

Small-scale Flotation cell

Effect of MIBC with baffles @ 1200 rpm

Parameters:

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	MIBC	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1200	rpm
Baffles	8 Plates	1	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	186.06	228.96	-	-	42.90	-	-	-	-
1 (agglomerates)	36.4756	40.4765	36.9836	0.5080	4.0009	0.168	0.180	4.20	53.0
2 (agglomerates)	33.1865	37.1889	33.6886	0.5021	4.0024	0.169	0.181	4.22	53.3
3 (agglomerates)	31.5877	36.5887	32.2737	0.6860	5.0010	0.201	0.172	4.02	50.8
4 (orig. ore)	-	-	-	-	1.000	0.076	0.3169	7.60	-
5 (orig. ore)	-	-	-	-	1.001	0.087	0.3624	8.71	-
6 (orig. ore)	-	-	-	-	1.001	0.103	0.4291	10.31	-
Agglomerate Avg. Feed Avg.					4.335 1.001	0.179 0.089	0.178 0.340	4.147 8.154	52.4
Std. Deviation Variance =									1.40 1.97

Experiment 21 **Small-scale Flotation cell** **Contacted @ 600 rpm**

Parameters

Component	Identification	Quantity	Units
Coal	Ethyl Oleate	41.7	g
Oil	Gold, 7 g/t	10	ml
Ore	PAX	41.7	g
Collector	DOW 200	4	g
Frother	Distilled	0.01	ml
Water	Atmospheric	1000	ml
Air		2.2	l/min
Mix speed		600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	51.05	65.47	-	-	14.42	-	-	-	-
1 (agglomerates)	35.772	39.79	36.291	0.519	4.018	0.217	0.078	5.40	25.8
2 (agglomerates)	33.73	37.746	34.277	0.547	4.016	0.212	0.076	5.28	25.2
3 (agglomerates)	34.141	38.18	34.697	0.556	4.039	0.206	0.074	5.10	24.4
4 (orig. ore)	-	-	-	-	1.001	0.077	0.3208	7.71	-
5 (orig. ore)	-	-	-	-	1.000	0.075	0.3128	7.50	-
6 (orig. ore)	-	-	-	-	1.000	0.065	0.2711	6.50	-
Agglomerate Avg. Feed Avg.					4.024	0.212	0.076	5.260	25.2
					1.000	0.072	0.302	7.236	
Std. Deviation =									0.723
Variance =									0.522

Experiment 22 **Small-scale Flotation cell** **Contacted @ 1800 rpm**

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1800	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	184.56	238.43	-	-	53.87	-	-	-	-
1 (agglomerates)	36.417	40.42	37.000	0.583	4.003	0.201	0.270	5.02	89.7
2 (agglomerates)	32.965	36.977	33.628	0.663	4.012	0.187	0.251	4.66	83.3
3 (agglomerates)	35.213	39.342	36.432	1.219	4.129	0.168	0.219	4.07	72.7
4 (orig. ore)	-	-	-	-	1.001	0.077	0.3208	7.71	-
5 (orig. ore)	-	-	-	-	1.000	0.075	0.3128	7.50	-
6 (orig. ore)	-	-	-	-	1.000	0.065	0.2711	6.50	-
Agglomerate Avg. Feed Avg.					4.048 1.000	0.185 0.072	0.247 0.302	4.584 7.236	86.5 4.55 20.71
Std. Deviation Variance =									

Experiment 23
Small-scale Flotation cell
Contacted @ 1000 rpm

Parameters

Component	Identification	Quantity	Units
Coal	Ethyl Oleate	41.7	g
Oil	Gold, 7 g/t	10	ml
Ore	PAX	41.7	g
Collector	DOW 200	4	g
Frother	Distilled	0.01	ml
Water	Atmospheric	1000	ml
Air		2.2	l/min
Mix speed		1000	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	111.04	156.27	-	-	45.23	-	-	-	-
1 (agglomerates)	35.115	39.132	35.712	0.597	4.017	0.195	0.2196	4.85	73.5
2 (agglomerates)	35.644	39.653	36.240	0.596	4.009	0.153	0.1726	3.82	57.8
3 (agglomerates)	34.015	38.026	34.578	0.563	4.011	0.151	0.1703	3.76	57.0
4 (agglomerates)	36.463	40.465	37.080	0.617	4.002	0.157	0.1774	3.92	59.4
5 (agglomerates)	35.643	39.644	36.247	0.604	4.001	0.158	0.1786	3.95	59.8
6 (agglomerates)	33.179	37.180	33.769	0.590	4.001	0.145	0.1639	3.62	54.8
7 (orig. ore)	-	-	-	-	1.001	0.0717	0.2988	7.17	-
8 (orig. ore)	-	-	-	-	1.000	0.0717	0.2991	7.17	-
9 (orig. ore)	-	-	-	-	1.000	0.0717	0.2991	7.17	-
10 (orig. ore)	-	-	-	-	1.001	0.0717	0.2988	7.17	-
11 (orig. ore)	-	-	-	-	1.001	0.0717	0.2988	7.17	-
12 (orig. ore)	-	-	-	-	1.001	0.0717	0.2988	7.17	-
Agglomerate Avg.					4.0068	0.160	0.1804	3.99	57.7
Feed Avg.					1.00	0.0717	0.2989	7.17	
Std. Deviation =									1.98
Variance =									3.93

Experiment 24 **Small-scale Flotation cell** **Contacted @ 1400 rpm**

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1400	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	183.54	229.52	-	-	45.98	-	-	-	-
1 (agglomerates)	32.94	36.956	33.488	0.548	4.016	0.184	0.211	4.58	79.6
2 (agglomerates)	31.58	35.587	32.14	0.56	4.007	0.219	0.251	5.47	95.0
3 (agglomerates)	33.178	37.185	33.731	0.553	4.007	0.177	0.203	4.42	76.8
4 (orig. ore)	-	-	-	-	1.001	0.061	0.2541	6.11	-
5 (orig. ore)	-	-	-	-	1.001	0.073	0.3041	7.31	-
6 (orig. ore)	-	-	-	-	1.001	0.066	0.2749	6.61	-
Agglomerate Avg. Feed Avg.					4.010	0.193	0.222	4.82	78.2
					1.001	0.067	0.265	6.36	
Std. Deviation =									2.02
Variance =									4.08

Experiment 25 **Small-scale Flotation cell** **Contacted @ 1600 rpm**

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	185.43	232.47	-	-	47.04	-	-	-	-
1 (agglomerates)	27.796	32.006	28.403	0.607	4.210	0.198	0.221	4.70	83.6
2 (agglomerates)	26.391	30.403	26.960	0.569	4.012	0.199	0.233	4.96	88.2
3 (agglomerates)	27.200	31.214	27.832	0.632	4.014	0.182	0.213	4.53	80.6
4 (orig. ore)	-	-	-	-	1.001	0.061	0.2541	6.11	-
5 (orig. ore)	-	-	-	-	1.001	0.073	0.3041	7.31	-
6 (orig. ore)	-	-	-	-	1.001	0.066	0.2749	6.61	-
Agglomerate Avg.					4.079	0.193	0.223	4.732	82.1
Feed Avg.					1.001	0.067	0.265	6.36	
Std. Deviation =									2.12
Variance =									4.51

Experiment 26

Small-scale Flotation cell

Contacted for 30 min. @ 1400 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1400	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	167.81	214.44	-	-	46.63	-	-	-	-
1 (agglomerates)	29.432	33.436	30.007	0.575	4.004	0.167	0.194	4.17	73.5
2 (agglomerates)	32.303	36.306	32.881	0.578	4.003	0.17	0.198	4.25	74.9
3 (agglomerates)	27.307	31.314	27.902	0.595	4.007	0.173	0.201	4.32	76.1
4 (orig. ore)	-	-	-	-	1.001	0.061	0.2541	6.11	-
5 (orig. ore)	-	-	-	-	1.001	0.073	0.3041	7.31	-
6 (orig. ore)	-	-	-	-	1.001	0.066	0.2749	6.61	-
Agglomerate Avg. Feed Avg.					4.005 1.001	0.170 0.067	0.198 0.265	4.245 6.36	74.8
Std. Deviation = Variance =									1.29 1.67

Experiment 27

Small-scale Flotation cell

Caltex 100 oil @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Caltex 100	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	122.4	160.9	-	-	38.5	-	-	-	-
1 (agglomerates)	27.441	31.444	27.877	0.436	4.003	0.206	0.198	5.15	74.9
2 (agglomerates)	27.908	31.909	28.351	0.443	4.001	0.136	0.131	3.40	49.4
3 (agglomerates)	26.506	30.507	26.966	0.460	4.001	0.149	0.143	3.72	54.2
4 (orig. ore)	-	-	-	-	1.001	0.061	0.2541	6.11	-
5 (orig. ore)	-	-	-	-	1.000	0.073	0.3044	7.30	-
6 (orig. ore)	-	-	-	-	1.000	0.066	0.2752	6.60	-
Agglomerate Avg. Feed Avg.					4.002 1.000	0.164 0.067	0.157 0.265	4.09 6.35	51.8 Std. Deviation = Variance =
									3.34 11.17

Experiment 28

Small-scale Flotation cell

Contacted for 30 min. @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	122.47	166.82	-	-	44.35	-	-	-	-
1 (agglomerates)	31.668	35.668	32.109	0.441	4.000	0.178	0.197	4.45	74.6
2 (agglomerates)	32.937	36.938	33.383	0.446	4.001	0.136	0.151	3.40	57.0
3 (agglomerates)	36.448	40.450	36.856	0.408	4.002	0.152	0.168	3.80	63.6
4 (orig. ore)	-	-	-	-	1.001	0.061	0.2541	6.11	-
5 (orig. ore)	-	-	-	-	1.000	0.073	0.3044	7.30	-
6 (orig. ore)	-	-	-	-	1.000	0.066	0.2752	6.60	-
Agglomerate Avg.					4.001	0.155	0.172	3.88	60.3
Feed Avg.					1.001	0.064	0.265	6.35	
Std. Deviation =									4.73
Variance =									22.35

Experiment 29

Small-scale Flotation cell

Using SEX as collector @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal	Ethyl Oleate	41.7	g
Oil	Gold, 7 g/t	10	ml
Ore	SEX	41.7	g
Collector	DOW 200	4	g
Frother	Distilled	0.01	ml
Water	Atmospheric	1000	ml
Air		2.2	l/min
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	128.17	173.89	-	-	45.72	-	-	-	-
1 (agglomerates)	26.389	30.392	26.893	0.504	4.003	0.205	0.234	5.12	88.5
2 (agglomerates)	27.792	31.795	28.299	0.507	4.003	0.154	0.176	3.85	66.5
3 (agglomerates)	27.759	31.763	28.261	0.502	4.004	0.18	0.206	4.50	77.7
4 (orig. ore)	-	-	-	-	1.000	0.065	0.2711	6.50	-
5 (orig. ore)	-	-	-	-	1.000	0.069	0.2877	6.90	-
6 (orig. ore)	-	-	-	-	1.001	0.062	0.2583	6.21	-
Agglomerate Avg. Feed Avg.					4.003 1.001	0.180 0.064	0.205 0.265	4.49 6.35	72.1 Std. Deviation = Variance =
									7.92 62.73

Experiment 30

Small-scale Flotation cell

Using a high air flowrate @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	3.8	l/min
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	116.8	163.74	-	-	46.94	-	-	-	-
1 (agglomerates)	27.202	31.202	27.742	0.540	4.000	0.147	0.173	3.68	65.2
2 (agglomerates)	31.579	35.581	32.128	0.549	4.002	0.148	0.174	3.70	65.6
3 (agglomerates)	34.166	38.167	34.724	0.558	4.001	0.153	0.180	3.82	67.8
4 (orig. ore)	-	-	-	-	1.000	0.065	0.2711	6.50	-
5 (orig. ore)	-	-	-	-	1.000	0.069	0.2877	6.90	-
6 (orig. ore)	-	-	-	-	1.001	0.062	0.2583	6.21	-
Agglomerate Avg. Feed Avg.					4.001 1.001	0.149 0.064	0.175 0.265	3.73 6.35	66.2 Std. Deviation = Variance =
									1.42 2.02

Experiment 31

Small-scale Flotation cell

Using a high air flowrate @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal	Ethyl Oleate	41.7	g
Oil	Gold, 7 g/t	10	ml
Ore	PAX	41.7	g
Collector	DOW 200	4	g
Frother	Distilled	0.01	ml
Water	Atmospheric	1000	ml
Air		3.3	l/min.
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	120.48	151.64	31.16	0.335 0.334 0.337	0.0838 0.0835 0.0843	2.69 2.68 2.70	78.8 78.6 79.3
4 (orig. ore)	-	-	1.000	0.040	0.1668	4.00	-
5 (orig. ore)	-	-	1.000	0.023	0.0959	2.30	-
6 (orig. ore)	-	-	1.001	0.028	0.1166	2.80	-
Agglomerate Avg. Feed Avg.			1.001	0.335 0.034	0.0838 0.106	2.69 3.40	78.9 -
Std. Deviation =							0.359
Variance =							0.129

Experiment 32

Small-scale Flotation cell

Using a low air flowrate @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	1.7	l/min.
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	137.76	184.59	-	-	46.83	-	-	-	-
1 (agglomerates)	27.309	31.309	27.846	0.537	4.000	0.135	0.158	3.38	59.7
2 (agglomerates)	32.301	36.303	32.846	0.545	4.002	0.147	0.172	3.67	65.0
3 (agglomerates)	29.428	33.429	29.971	0.543	4.001	0.16	0.187	4.00	70.8
4 (orig. ore)	-	-	-	-	1.000	0.065	0.2711	6.50	-
5 (orig. ore)	-	-	-	-	1.000	0.069	0.2877	6.90	-
6 (orig. ore)	-	-	-	-	1.001	0.062	0.2583	6.21	-
Agglomerate Avg. Feed Avg.					4.001	0.147	0.172	3.68	62.4
					1.001	0.06	0.265	6.35	
Std. Deviation =									3.73
Variance =									13.92

Experiment 33
Small-scale Flotation cell
Using undistilled water @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	From Tap	1000	ml
Air	Atmospheric	2.2	l/min.
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	121.44	168.87	-	-	47.43	-	-	-	-
1 (agglomerates)	34.164	38.167	34.675	0.511	4.003	0.158	0.1872	3.95	87.5
2 (agglomerates)	33.176	37.180	33.690	0.514	4.004	0.132	0.1564	3.30	73.1
3 (agglomerates)	33.868	37.869	34.375	0.507	4.001	0.116	0.1375	2.90	64.3
4 (agglomerates)	32.880	36.882	33.360	0.480	4.002	0.177	0.2098	4.42	98.0
5 (agglomerates)	32.938	36.938	33.457	0.519	4.000	0.148	0.1755	3.70	82.0
6 (agglomerates)	36.466	40.467	36.982	0.516	4.001	0.144	0.1707	3.60	79.8
7 (orig. ore)	-	-	-	-	1.001	0.0640	0.2666	6.39	-
8 (orig. ore)	-	-	-	-	1.000	0.0530	0.2210	5.30	-
9 (orig. ore)	-	-	-	-	1.000	0.0530	0.2210	5.30	-
10 (orig. ore)	-	-	-	-	1.001	0.0490	0.2041	4.90	-
11 (orig. ore)	-	-	-	-	1.000	0.0430	0.1793	4.30	-
12 (orig. ore)	-	-	-	-	1.001	0.0460	0.1916	4.60	-
Agglomerate Avg.					4.002	0.1458	0.1728	3.64	80.9
Feed Avg.					1.001	0.0513	0.2139	4.88	
Std. Deviation =									1.58
Variance =									2.50

Experiment 34
Small-scale Flotation cell
Using Caltex 150 oil @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Caltex 150	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min.
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	128.59	161.53	-	-	32.94	-	-	-	-
1 (agglomerates)	35.085	39.085	35.198	0.113	4.000	0.114	0.094	2.85	47.4
2 (agglomerates)	34.823	38.824	35.485	0.662	4.001	0.156	0.128	3.90	64.9
3 (agglomerates)	31.583	35.583	31.961	0.378	4.000	0.142	0.117	3.55	59.1
4 (orig. ore)	-	-	-	-	1.001	0.049	0.2041	4.90	-
5 (orig. ore)	-	-	-	-	1.000	0.043	0.1793	4.30	-
6 (orig. ore)	-	-	-	-	1.001	0.046	0.1916	4.60	-
Agglomerate Avg.					4.000	0.137	0.113	3.43	62.0
Feed Avg.					1.001	0.048	0.198	4.75	
Std. Deviation =									4.11
Variance =									16.88

Experiment 35
Small-scale Flotation cell
Using Caltex 450 oil @ 1600 rpm

Parameters

Component	Identification	Quantity	Units
Coal		41.7	g
Oil	Caltex 450	10	ml
Ore	Gold, 7 g/t	41.7	g
Collector	PAX	4	g
Frother	DOW 200	0.01	ml
Water	Distilled	1000	ml
Air	Atmospheric	2.2	l/min.
Mix speed		1600	rpm
Baffles	8 Plates	0	

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	119.01	167.46	-	-	48.45	-	-	-	-
1 (agglomerates)	36.291	40.297	36.787	0.496	4.006	0.126	0.1524	3.15	71.2
2 (agglomerates)	33.628	37.633	34.127	0.499	4.005	0.149	0.1803	3.72	84.2
3 (agglomerates)	36.466	40.467	36.965	0.499	4.001	0.132	0.1598	3.30	74.7
4 (agglomerates)	28.402	32.406	28.890	0.488	4.004	0.162	0.1960	4.05	91.6
5 (agglomerates)	27.309	31.312	27.810	0.501	4.003	0.153	0.1852	3.82	86.6
6 (agglomerates)	26.741	30.742	27.236	0.495	4.001	0.167	0.2022	4.17	94.5
7 (orig. ore)	-	-	-	-	1.001	0.0640	0.2666	6.39	-
8 (orig. ore)	-	-	-	-	1.000	0.0530	0.2210	5.30	-
9 (orig. ore)	-	-	-	-	1.000	0.0530	0.2210	5.30	-
10 (orig. ore)	-	-	-	-	1.001	0.0490	0.2041	4.90	-
11 (orig. ore)	-	-	-	-	1.000	0.0430	0.1793	4.30	-
12 (orig. ore)	-	-	-	-	1.001	0.0460	0.1916	4.60	-
Agglomerate Avg.					4.003	0.148	0.1793	3.70	73.0
Feed Avg.					1.001	0.051	0.2139	4.88	
Std. Deviation =									2.46
Variance =									6.07

APPENDIX A3

CGA with flotation on a large scale

Experiment 36
Wemco flotation cell
Trial run

Parameters

Component	Identification	Quantity	Units
Coal	Ethyl Oleate	166.8	g
Oil	Gold, 7 g/t	40	ml
Ore	PAX	166.8	g
Collector	DOW 200	16	g
Frother	Distilled	0.04	ml
Water	Atmospheric	2400	ml
Air		6	l/min.
Contact speed		900	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	397.0	606.0	-	-	209.0	-	-	-	-
1 (agglomerates)	32.304	36.303	33.015	0.711	3.999	0.168	0.8780	4.20	102.6
2 (agglomerates)	26.703	30.702	27.419	0.716	3.999	0.183	0.9564	4.58	111.8
3 (agglomerates)	26.737	30.739	27.450	0.713	4.002	0.158	0.8251	3.95	96.4
4 (agglomerates)	26.706	30.709	27.437	0.731	4.003	0.227	1.1852	5.67	138.5
5 (agglomerates)	32.306	36.306	33.034	0.728	4.000	0.215	1.1234	5.38	131.3
6 (agglomerates)	29.434	33.435	30.161	0.727	4.001	0.183	0.9559	4.57	111.7
7 (orig. ore)	-	-	-	-	1.001	0.0640	1.0665	6.39	-
8 (orig. ore)	-	-	-	-	1.000	0.0530	0.8840	5.30	-
9 (orig. ore)	-	-	-	-	1.000	0.0530	0.8840	5.30	-
10 (orig. ore)	-	-	-	-	1.001	0.0490	0.8165	4.90	-
11 (orig. ore)	-	-	-	-	1.000	0.0430	0.7172	4.30	-
12 (orig. ore)	-	-	-	-	1.001	0.0460	0.7665	4.60	-
Agglomerate Avg. Feed Avg.							0.9873 0.8558	4.72 4.88	111.7
Std. Deviation = Variance =									0.0395 0.00156

Experiment 37
Wemco flotation cell
Contact speed = 900 rpm

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		900	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	170.39	357.83	-	-	187.44	-	-	-	-
1 (agglomerates)	34.168	38.168	34.855	0.687	4.000	0.153	0.717	3.83	92.1
2 (agglomerates)	33.627	37.628	34.305	0.678	4.001	0.127	0.595	3.17	76.5
3 (agglomerates)	34.824	38.826	35.502	0.678	4.002	0.101	0.473	2.52	60.8
4 (agglomerates)	35.646	39.647	36.326	0.680	4.001	0.105	0.492	2.62	63.2
5 (orig. ore)	-	-	-	-	1.000	0.050	0.834	5.00	-
6 (orig. ore)	-	-	-	-	1.001	0.046	0.767	4.60	-
7 (orig. ore)	-	-	-	-	1.000	0.044	0.734	4.40	-
Agglomerate Avg. Feed Avg.					4.001 1.000	0.122 0.047	0.569 0.778	2.77 4.67	62.0 Std. Deviation = 1.71 Variance = 2.94

Experiment 38

Wemco flotation cell

Coal particle size = [+300-500] micron @ 900 rpm

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2700	ml
Air	Atmospheric	6	l/min.
Contact speed		900	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	192.7	381.5	-	-	188.8	-	-	-	-
1 (agglomerates)	27.308	31.308	28.119	0.811	4.000	0.116	0.548	2.90	70.4
2 (agglomerates)	29.433	33.436	30.238	0.805	4.003	0.101	0.476	2.52	61.2
3 (agglomerates)	28.403	32.407	29.205	0.802	4.004	0.127	0.599	3.17	77.0
4 (agglomerates)	26.741	30.743	27.544	0.803	4.002	0.106	0.500	2.65	64.3
5 (orig. ore)	-	-	-	-	1.000	0.050	0.834	5.00	-
6 (orig. ore)	-	-	-	-	1.001	0.046	0.767	4.60	-
7 (orig. ore)	-	-	-	-	1.000	0.044	0.734	4.40	-
Agglomerate Avg. Feed Avg.					4.002 1.000	0.113 0.047	0.531 0.778	2.81 4.67	62.7 Std. Deviation = Variance =
									2.15 4.64

Experiment 39 Wemco flotation cell No baffles

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		900	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	193.05	357.26	-	-	164.21	-	-	-	-
1 (agglomerates)	28.336	32.336	28.987	0.651	4.000	0.245	1.006	6.13	91.0
2 (agglomerates)	26.707	30.705	27.362	0.655	3.998	0.155	0.637	3.88	57.6
3 (agglomerates)	29.425	33.423	30.092	0.667	3.998	0.170	0.698	4.25	63.2
4 (orig. ore)	-	-	-	-	1.001	0.075	1.250	7.49	-
5 (orig. ore)	-	-	-	-	1.002	0.068	1.132	6.79	-
6 (orig. ore)	-	-	-	-	1.001	0.056	0.933	5.59	-
Agglomerate Avg. Feed Avg.					3.999 1.001	0.190 0.066	0.780 1.105	4.75 6.62	60.4 -
Std. Deviation = Variance =									3.94 15.54

Experiment 40 **Wemco flotation cell** **Contacted for 30 minutes**

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	170.39	352.75	-	-	182.36	-	-	-	-
1 (agglomerates)	26.741	30.741	27.350	0.609	4.000	0.157	0.716	3.93	64.8
2 (agglomerates)	27.311	31.312	27.948	0.637	4.001	0.171	0.779	4.27	70.5
3 (agglomerates)	32.305	36.307	32.942	0.637	4.002	0.170	0.775	4.25	70.1
4 (orig. ore)	-	-	-	-	1.001	0.075	1.250	7.49	-
5 (orig. ore)	-	-	-	-	1.002	0.068	1.132	6.79	-
6 (orig. ore)	-	-	-	-	1.001	0.056	0.933	5.59	-
Agglomerate Avg. Feed Avg.					4.001 1.002	0.166 0.072	0.748 1.105	4.15 6.62	70.3
Std. Deviation = Variance =									0.304 0.0925

Experiment 41 **Wemco flotation cell** **Contact speed = 1200 rpm**

Parameters:

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	193.05	373.76	-	-	180.71	-	-	-	-
1 (agglomerates)	34.827	38.828	35.442	0.615	4.001	0.199	0.899	4.97	81.3
2 (agglomerates)	35.094	39.093	35.698	0.604	3.999	0.190	0.859	4.75	77.7
3 (agglomerates)	28.774	32.774	29.379	0.605	4.000	0.247	1.116	6.18	101.0
4 (orig. ore)	-	-	-	-	1.001	0.075	1.250	7.49	-
5 (orig. ore)	-	-	-	-	1.002	0.068	1.132	6.79	-
6 (orig. ore)	-	-	-	-	1.001	0.056	0.933	5.59	-
Agglomerate Avg. Feed Avg.					4.000 1.001	0.195 0.066	0.879 1.105	4.86 6.62	79.5
Std. Deviation = Variance =									2.57 6.62

Experiment 42 **Wemco flotation cell** **Contacted @ 1300 rpm**

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1300	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates Ore	170.40 192.51	343.12 343.68	- -	- -	172.72 151.17	- -	- -	- -	- -
1 (agglomerates)	31.107		31.672	0.565	4.001	0.15	0.648	3.75	68.5
2 (agglomerates)	33.392		33.949	0.557	4.002	0.14	0.604	3.50	63.9
3 (agglomerates)	17.543		18.108	0.565	4.000	0.19	0.820	4.75	86.8
4 (agglomerates)	16.508		17.075	0.567	4.003	0.17	0.734	4.25	77.6
5 (original ore)	-		-	-	4.00	0.24	1.001	6.00	-
6 (original ore)	-		-	-	4.00	0.24	1.001	6.00	-
7 (original ore)	-		-	-	4.00	0.2	0.834	5.00	-
Agglomerate Avg. Feed average					4.002 4.000	0.163 0.227	0.701 0.945	4.06 5.67	66.2
Std. Deviation = Variance =									3.24 10.50

Experiment 43

Wemco flotation cell

Contacted @ 1400 rpm

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1400	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates	193.05	378.91	-	-	185.86	-	-	-	-
1 (agglomerates)	34.165	38.164	34.763	0.598	3.999	0.109	0.507	2.73	53.0
2 (agglomerates)	34.016	38.017	34.618	0.602	4.001	0.122	0.567	3.05	59.3
3 (agglomerates)	33.873	37.874	34.486	0.613	4.001	0.092	0.427	2.30	44.7
4 (orig. ore)	36.467	37.468	-	-	1.001	0.104	1.733	10.39	-
5 (orig. ore)	35.089	36.089	-	-	1.000	0.098	1.635	9.80	-
6 (orig. ore)	34.824	35.824	-	-	1.000	0.042	0.701	4.20	-
7 (orig. ore)	32.942	33.943	-	-	1.001	0.032	0.533	3.20	-
Agglomerate Avg. Feed Avg.					4.000 1.001	0.108 0.069	0.500 0.956	2.89 5.73	56.1
Std. Deviation = Variance =									4.45 19.78

Experiment 44
Wemco flotation cell
Recycle of agglomerates @ 1400 rpm

Parameters

Component	Identificatio	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1400	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates Ore	302.13 192.41	479 334.83	- -	- -	176.87 142.42	- -	- -	- -	- -
1 (agglomerates)	27.312	31.305	27.903	0.591	3.993	0.27	1.196	6.76	62.5
2 (agglomerates)	28.770	32.775	29.386	0.616	4.005	0.431	1.903	10.76	99.5
3 (agglomerates)	26.743	30.737	27.335	0.592	3.994	0.251	1.112	6.28	58.1
4 (agglomerates)	29.436	33.437	30.037	0.601	4.001	0.240	1.061	6.00	55.5
5 (ore, 1 st sep.)	33.643	37.646	-	-	4.003	0.033	0.117	0.82	12.3
6 (ore, 1 st sep.)	32.313	36.314	-	-	4.001	0.010	0.036	0.25	3.7
7 (ore, 1 st sep.)	28.331	32.333	-	-	4.002	0.050	0.178	1.25	18.6
8 (ore, 1 st sep.)	32.843	36.842	-	-	3.999	0.050	0.178	1.25	18.6
10 (orig. ore)	36.467	37.468	-	-	1.001	0.104	1.733	10.39	-
11 (orig. ore)	35.089	36.089	-	-	1.000	0.098	1.635	9.80	-
12 (orig. ore)	34.824	35.824	-	-	1.000	0.042	0.701	4.20	-
13 (orig. ore)	32.942	33.943	-	-	1.001	0.032	0.533	3.20	-
Agglomerate Avg.					3.998	0.298	1.318	7.45	56.8
Residue (1) Avg.					4.001	0.036	0.127	0.89	18.6
Feed Avg.					1.001	0.069	0.956	5.73	
Std. Deviation =									1.87
Variance =									3.50

Experiment 45 **Wemco flotation cell** ***Repeat the recycling of agglomerates @ 1400 rpm***

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1400	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates									
Ore - 1	195.34	354.94	-	-	159.60	-	-	-	-
Ore - 2	193.04	309.30	-	-	116.26	-	-	-	-
	192.40	357.37	-	-	164.97	-	-	-	-
1 (agglomerates)	34.200	31.305	34.852	0.652	4.000	0.230	0.918	5.75	48.0
2 (agglomerates)	34.050	32.775	34.745	0.695	4.000	0.230	0.918	5.75	48.0
3 (agglomerates)	33.910	30.737	34.588	0.678	4.000	0.250	0.998	6.25	52.2
4 (agglomerates)	27.340	33.437	28.044	0.704	4.000	0.290	1.157	7.25	60.5
5 (ore, 1 st sep.)	28.780	37.646	32.732	3.952	4.000	0.050	0.145	1.25	15.2
6 (ore, 1 st sep.)	26.750	36.314	30.697	3.947	4.000	0.030	0.087	0.75	9.1
7 (ore, 1 st sep.)	29.440	32.333	33.394	3.954	4.000	0.030	0.087	0.75	9.1
8 (ore, 1 st sep.)	33.640	36.842	37.581	3.941	4.000	0.050	0.145	1.25	15.2
9 (ore, 2 nd sep.)	32.310	-	36.211	3.901	4.000	0.010	0.041	0.25	4.3
10 (ore, 2 nd sep.)	28.330	-	32.257	3.927	4.000	0.010	0.041	0.25	4.3
11 (ore, 2 nd sep.)	38.791	-	42.689	3.898	4.000	0.020	0.082	0.50	8.6
12 (ore, 2 nd sep.)	36.254	-	40.171	3.917	4.000	0.010	0.041	0.25	4.3
13 (orig. ore)	36.467	37.468	-	-	1.001	0.104	1.733	10.39	-
14 (orig. ore)	35.089	36.089	-	-	1.000	0.098	1.635	9.80	-
15 (orig. ore)	34.824	35.824	-	-	1.000	0.042	0.701	4.20	-
16 (orig. ore)	32.942	33.943	-	-	1.001	0.032	0.533	3.20	-
Agglomerate Avg.	-	-	-	-	4.000	0.25	0.998	6.25	52.2
Residue (1) Avg.	-	-	-	-	4.000	0.04	0.116	1.00	12.2
Residue (2) Avg.	-	-	-	-	4.000	0.01	0.052	0.31	5.4
Feed Avg.	-	-	-	-	1.00	0.07	0.956	5.73	
Std. Deviation =									2.41
Variance =									5.80

Experiment 46

Wemco flotation cell

Recycling of agglomerates @ 1200 rpm

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglom. 1	193.23	368.31	-	-	175.08	-	-	-	-
Agglom. 2	192.94	347.73	-	-	154.79	-	-	-	-
Ore - 1	112.23	264.32	-	-	152.09	-	-	-	-
Ore - 2	90.72	247.55	-	-	156.83	-	-	-	-
1 (agglomerates)	36.295	31.305	36.836	0.541	4.000	0.23	0.890	5.08	47.1
2 (agglomerates)	31.585	32.775	32.125	0.540	4.002	0.25	0.967	5.52	51.2
3 (agglomerates)	33.871	30.737	34.416	0.545	4.004	0.22	0.850	4.86	45.0
4 (agglomerates)	27.313	33.437	27.850	0.537	4.001	0.22	0.851	4.86	45.0
5 (original ore)	-	-	-	-	4.00	0.24	1.001	6.00	-
6 (original ore)	-	-	-	-	4.00	0.24	1.001	6.00	-
7 (original ore)	-	-	-	-	4.00	0.20	0.834	5.00	-
Agglomerate avg.	-	-	-	-	4.002	0.230	0.890	5.08	45.7
Feed average	-	-	-	-	4.000	0.227	0.945	5.67	-
Std. Deviation =									1.20
Variance =									1.44

Experiment 47

Wemco flotation cell

Agglomerate recycle @ 1200 rpm

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+aggl/ore} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{a/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates									
Ore 1	209.38	392.42	-	-	183.04	-	-	-	-
Ore 2	112.19	264.63	-	-	152.44	-	-	-	-
	120.48	286.73	-	-	166.25	-	-	-	-
1 (agglomerates)	33.653	37.671	34.328	0.675	4.018	0.215	1.032	5.64	55.9
2 (agglomerates)	31.113	35.124	31.791	0.678	4.011	0.239	1.091	5.96	59.1
3 (agglomerates)	32.228	36.244	32.906	0.678	4.016	0.176	0.800	4.37	43.4
4 (agglomerates)	33.395	37.396	34.062	0.667	4.001	0.186	0.850	4.65	46.1
5 (residue ore 1)	34.695	38.697	38.683	3.988	4.002	0.050	0.190	1.24	20.6
6 (residue ore 1)	37.164	41.182	41.167	4.003	4.018	0.027	0.103	0.67	11.1
7 (residue ore 1)	33.707	37.768	37.758	4.051	4.061	0.029	0.110	0.72	11.9
8 (residue ore 2)	36.144	40.160	40.130	3.986	4.016	0.015	0.061	0.37	6.6
9 (residue ore 2)	36.158	40.162	40.123	3.965	4.004	0.008	0.035	0.21	3.8
10 (residue ore 2)	34.723	38.741	38.714	3.991	4.018	0.008	0.031	0.19	3.4
11 (original ore)	-	-	-	-	1.00	0.062	1.033	6.19	-
12 (original ore)	-	-	-	-	1.00	0.051	0.849	5.09	-
13 (original ore)	-	-	-	-	1.00	0.050	0.829	4.97	-
14 (original ore)	-	-	-	-	1.00	0.059	0.980	5.87	-
Agglomerate avg.	-	-	-	-	4.012	0.204	0.943	5.15	53.7
Feed average	-	-	-	-	1.002	0.055	0.923	5.53	
Std. Deviation =									6.78
Variance =									46.02

Experiment 48
Wemco flotation cell
Using undistilled water @ 1200 rpm

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	From tap	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates Ore	120.52 112.22	304.97 250.39	- -	- -	184.45 138.17	- -	- -	- -	- -
1 (agglomerates)	34.840	38.840	35.509	0.669	4.00	0.180	0.83	4.50	86.8
2 (agglomerates)	32.960	36.960	33.631	0.671	4.00	0.130	0.60	3.25	62.7
3 (agglomerates)	33.200	37.200	33.864	0.664	4.00	0.220	1.01	5.50	106.1
4 (used ore)	31.105	35.071	-	3.966	4.00	0.010	0.03	0.25	3.6
5 (used ore)	33.395	37.344	-	3.949	4.00	0.020	0.07	0.51	7.3
6 (used ore)	17.540	21.490	-	3.950	4.00	0.010	0.03	0.25	3.7
7 (used ore)	16.520	20.508	-	3.988	4.00	0.010	0.03	0.25	3.6
8 (original ore)	-	-	-	-	1.00	0.104	1.73	10.40	-
9 (original ore)	-	-	-	-	1.00	0.098	1.63	9.80	-
10 (original ore)	-	-	-	-	1.00	0.042	0.70	4.20	-
11 (original ore)	-	-	-	-	1.00	0.032	0.53	3.20	-
Agglomerate Avg. Residue Avg. Feed Avg.	- - -	- - -	- - -	- - -	4.00 4.00 1.00	0.155 0.01 0.07	0.715 0.044 0.956	3.88 0.32 5.73	74.7 4.6 -
Std. Deviation = Variance =									17.05 290.6

Experiment 49

Wemco flotation cell

Coal particle size = [+500-650] micron

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglom. Ore	192.51	373.09	-	-	180.58	-	-	-	-
	112.23	261.97	-	-	149.74	-	-	-	-
1 (agglomerates)	32.310	-	32.900	0.590	4.001	0.17	0.767	4.25	81.2
2 (agglomerates)	28.339	-	28.926	0.587	4.000	0.19	0.858	4.75	90.7
3 (agglomerates)	38.791	-	39.372	0.581	4.003	0.19	0.857	4.75	90.7
4 (agglomerates)	36.257	-	36.844	0.587	4.002	0.19	0.857	4.75	90.7
5 (original ore)	-	-	-	-	4.00	0.24	1.001	6.00	-
6 (original ore)	-	-	-	-	4.00	0.24	1.001	6.00	-
7 (original ore)	-	-	-	-	4.00	0.2	0.834	5.00	-
Agglomerate average	-	-	-	-	4.002	0.185	0.835	4.62	90.7
Feed average	-	-	-	-	4.000	0.227	0.945	5.67	

Experiment 50 **Wemco flotation cell** **Coal particle size = [+300-500] micron @ 1200 rpm**

Parameters

Component	Identification	Quantity	Units
Coal		166.8	g
Oil	Ethyl oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+coal} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{c/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglom. Ore	195.33 90.71	376.46 245.51	- -	- -	181.13 154.80	- -	- -	- -	- -
1 (agglomerates)	32.310	-	33.287	0.977	4.002	0.140	0.634	3.50	67.0
2 (agglomerates)	28.339	-	28.499	0.160	4.003	0.160	0.724	4.00	76.6
3 (agglomerates)	38.791	-	39.400	0.609	4.003	0.170	0.769	4.25	81.4
4 (agglomerates)	36.257	-	36.900	0.643	4.002	0.180	0.815	4.50	86.2
5 (original ore)	-	-	-	-	4.00	0.24	1.001	6.00	-
6 (original ore)	-	-	-	-	4.00	0.24	1.001	6.00	-
7 (original ore)	-	-	-	-	4.00	0.20	0.834	5.00	-
Agglomerate avg.	-	-	-	-	4.003	0.163	0.735	4.06	81.4
Feed average	-	-	-	-	4.000	0.227	0.945	5.67	
Std. Deviation = 4.80									4.80
Variance = 23.02									23.02

Experiment 51

Wemco flotation cell

"Normal" gold flotation @ 1200 rpm

Parameters

Component	Identification	Quantity	Units
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{total} (g)	m _{f/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Float	35.76	41.79	6.03	-	-	-	-
Ore	192.4	346.75	154.35	-	-	-	-
1 (float)	35.76	41.79	6.03	0.57	0.057	9.45	5.0
2 (used ore)	36.467	40.467	4.00	0.06	0.232	1.50	20.1
3 (used ore)	36.292	40.292	4.00	0.06	0.232	1.50	20.1
4 (used ore)	32.845	36.845	4.00	0.13	0.502	3.25	43.6
5 (original ore)	-	-	1.00	0.02	0.334	2.00	-
6 (original ore)	-	-	1.00	0.08	1.334	8.00	-
7 (original ore)	-	-	1.00	0.02	0.334	2.00	-
8 (original ore)	-	-	1.00	0.03	0.500	3.00	-
Residue average	-	-	4.00	0.083	0.322	2.08	28.0
Feed average	-	-	1.00	0.04	1.150	3.75	-

Experiment 52

Wemco flotation cell

Repeat "Normal" gold flotation @ 1200 rpm

Parameters

Component	Identification	Quantity	Units
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Mix speed		1200	rpm
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{total} (g)	m _{f/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
1 (float)	53.08	56.61	3.53	1.934	0.193	54.79	15.5
2 (used ore)	90.92	245.72	154.80	0.097	0.034	0.22	2.7
3 (original ore)	-	-	1.000	0.086	1.434	8.60	-
4 (original ore)	-	-	1.001	0.061	1.016	6.09	-
5 (original ore)	-	-	1.002	0.083	1.382	8.28	-
6 (original ore)	-	-	1.000	0.070	1.168	7.00	-
Feed average	-	-	1.00	0.08	1.25	7.49	-

Experiment 53
Wemco flotation cell
Activated Carbon @ 1200 rpm

Parameters

Component	Identification	Quantity	Units
Activated Carbon	>500<650 micr	166.8	g
Oil	Ethyl oleate	40	ml
Ore	Gold, 7 g/t	166.8	g
Collector	PAX	16	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min.
Contact speed		1200	rpm

RESULTS - Analyses on ICP

Sample	m _{crucible} (g)	m _{cruc.+aggl/ore} (g)	m _{cruc.+ash} (g)	m _{ash} (g)	m _{a/o} (g)	Conc. (mg/l)	m _{total} (Au) (mg)	Au loading (g/ton)	% Au recovered
Agglomerates Ore 1	94.02 139.29	284.59 298.83	- -	- -	190.57 159.54	- -	- -	- -	- -
1 (agglomerates)	28.406	32.414	28.695	0.289	4.008	0.088	0.418	2.20	45.3
2 (agglomerates)	26.743	30.752	26.965	0.222	4.009	0.204	0.968	5.08	104.9
3 (agglomerates)	32.008	36.013	32.155	0.147	4.005	0.070	0.333	1.75	36.0
4 (agglomerates)	27.922	31.922	28.110	0.188	4.000	0.079	0.378	1.99	41.0
5 (residue ore)	36.935	40.962	40.922	3.987	4.027	0.0083	0.033	0.21	3.6
6 (residue ore)	40.058	44.062	44.001	3.943	4.004	0.0079	0.031	0.20	3.4
7 (residue ore)	32.998	37.011	36.963	3.965	4.013	0.0093	0.037	0.23	4.0
8 (original ore)	-	-	-	-	1.00	0.062	1.033	6.19	-
9 (original ore)	-	-	-	-	1.00	0.051	0.849	5.09	-
10 (original ore)	-	-	-	-	1.00	0.050	0.829	4.97	-
11 (original ore)	-	-	-	-	1.00	0.059	0.980	5.87	-
Agglomerate average	-	-	-	-	4.006	0.110	0.524	2.75	40.8
Feed average	-	-	-	-	1.002	0.055	0.923	5.53	
Std. Deviation = Variance =									3.08 9.46

APPENDIX A4

**Publication in
international journal**



FLOTATION AS A SEPARATION TECHNIQUE IN THE COAL GOLD AGGLOMERATION PROCESS*

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ABSTRACT

Existing gold recovery processes available to the small-scale gold mining sector pose a considerable hazard to the environment, due to the use of lethal chemicals such as mercury and cyanide. A gold recovery method, called the coal gold agglomeration (CGA) process, whereby hydrophobic gold particles are recovered from ore slurries into coal-oil agglomerates, and the subsequent burning of these agglomerates to recover the gold, was developed some years ago.

The objective of this study was to optimise the separation phase of the CGA process through a flotation technique. It was also necessary to compare the gold recovery of the CGA process to that of the mercury amalgamation process, to determine the feasibility of implementing the CGA process as an alternative to the mercury amalgamation process.

Batch tests were performed on a synthetic (7g/t) gold ore containing a fine ($\pm 44 \mu\text{m}$) gold powder. Agitating an industrial charcoal and oil in an aqueous suspension formed agglomerates. After a suitable agglomeration time the ore slurry and a collector such as potassium amyl xanthate (PAX) was added and stirring continued for fifty minutes before the separation was effected. The gold-loaded agglomerates and residue ore were then dried, ashed and treated with aqua regia and analysed. During the experimental program, the process was scaled up from 150 milliliters (using magnetic stirrers and scraping) to a one-liter flotation cell, and eventually to a three-liter flotation cell.

It was found that for both flotation configurations an increase in the stirring rate results in an increase in the gold and mass recoveries. Maximum gold recoveries were however obtained at a certain stirring rate above which the gold recovery dropped again. Increasing the viscosity of the oil caused the formation of stronger agglomerates and hence gold recovery was also increased. The use of larger coal particles gave rise to higher gold recoveries due to increased agglomerate flotation and superior gold particle penetration into the agglomerates. Recycling of the agglomerate phase showed that gold loading on the agglomerates could be increased to reduce operating cost. © 2000 Published by Elsevier Science Ltd. All rights reserved.

Keywords

Coal; gold ores; agglomeration; froth flotation; environmental

INTRODUCTION

Most small-scale gold mining operations make use of very hazardous chemicals such as mercury and cyanide during the ore enrichment stages. These chemicals are frequently released into the environment

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which then leads to serious implications for the organisms and animals that comes into contact with them. It is however not only the environment that suffers under these processes, but also the communities that are resident in the underlying areas where small-scale gold mining is practiced. Mercury, for instance, is metabolised into methylmercury after consumption by fish, which is unknowingly consumed by local residents, with devastating effects.

It is thus imperative that a new free gold recovery process becomes available to the small-scale gold mining community. This paper deals with the optimisation of such a process, called the coal gold agglomeration (CGA) process, which was developed some years ago by the British oils and Minerals Company. Although the process is strictly speaking not novel, scope existed for the optimisation of the process, particularly for the separation stage. The separation stage is an integral part of the process, as indicated in Figure 1, and is thus pivotal in obtaining maximum gold recoveries.

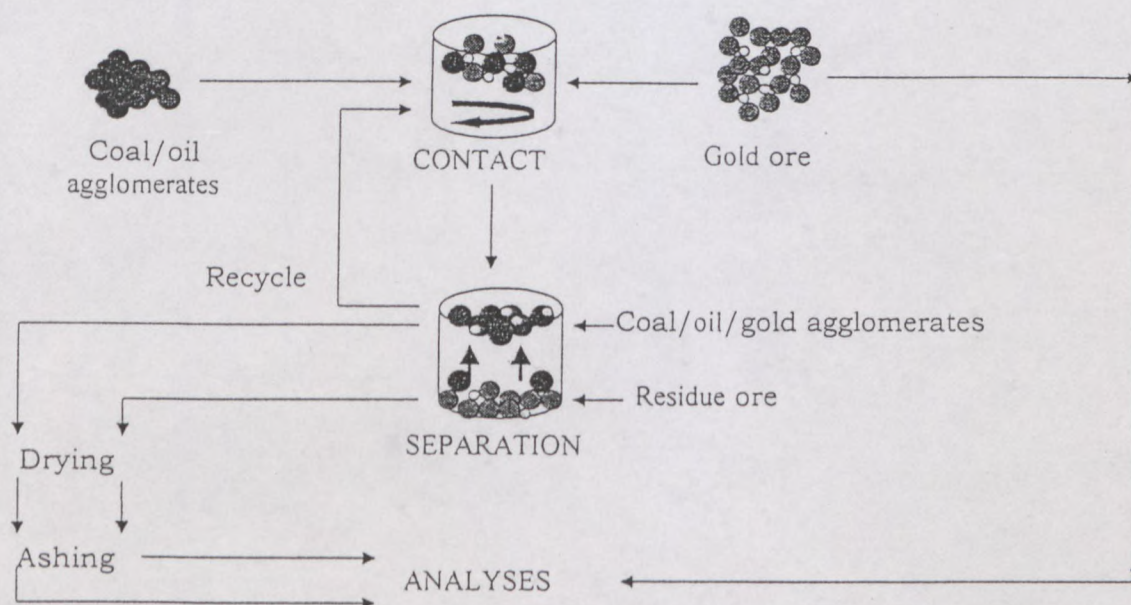


Fig.1 Layout of the CGA process.

Laboratory procedures have been devised for rapidly testing the suitability of ore samples for treatment by CGA. Many ores of differing types have been examined and high gold recoveries have been achieved, provided that the gold is or can be liberated. Gold grains ranging from 1 to 500 microns can be recovered with equal ease. The process is most suitable for treating alluvial or free milling ores, gravity concentrates and current or old gravity plant tailings [Bellamy *et al.*, 1989].

The ore samples tested by Bellamy *et al.* (1989) originated from a beach sand deposit in New Zealand and had a varying mineralogical characterisation. The effect of wet and dry grinding, attrition scrubbing and screening below 150 microns as well as screening below 1.7 millimeters with no scrubbing was investigated as ore pre-treatment stages. All their tests were performed by agitating a slurry of ore and water in 0.6 dm³ Pyrex beakers fitted with four vertical baffles. When required, potassium amyl xanthate collector was added and the slurry conditioned for five minutes. The agglomeration time was 30 minutes and the agglomerates were separated from the tailings by screening. These researchers thus focussed on optimising the pre-treatment of the ore and not on the final separation step. Due to the batch nature of their experimental set-up, screening could effectively separate the agglomerates, but this will be very tedious and time-consuming on a continuous basis. They also compared the CGA process to conventional gold recovery techniques such as gravity concentration, cyanidation and flotation by using samples from the same deposit, and found the CGA process to be quicker, cleaner and more effective.

Marciano *et al.* (1994) investigated the effect of the type of coal, the type of oil, the oil: coal ratio (w/w) and the agglomerate: ore ratio (w/w) on the performance of the CGA process. Other operating parameters that were also investigated includes the contact time and the recycling of the agglomerates, up to six times. Their tests were conducted in non-aerated Denver sub-A flotation cells, with rotation speed control, using a three blade axial impeller in a contact volume of 2.0 to 3.0 liters. It was again observed that the researchers focussed on the operating parameters, while neglecting to optimise the separation step. In addition to the CGA experiments, these researchers did a comparative study with mercury amalgamation, employing a horizontal cylinder rotating at 20 rpm, using sodium hydroxide as a conditioning agent. They found that the amalgamation and CGA experiments yielded similar results.

Bouwer (1999) performed work on a South African coal, with ethyl oleate as an agglomerant on a small scale. Experiments were conducted in 150 ml sealed glass bottles and a magnetic stirrer was used as a means of agitation. They succeeded in optimising the operating parameters for this, specific combination of coal and oil. It was however evident that the separation efficiency could still be improved, which in turn would result in much better gold recoveries. The scale on which the experiments were done was impractical in that it would be impossible to use in a small-scale mining environment.

It thus became clear that a need exists for an effective separation method for the CGA process that will be capable of operating on a fairly large scale. Flotation was considered as the best process route due to its wide range of application and ease of operation and implementation. The flotation process is the most effective, complex and commonly applicable process that is used for ore enrichment in the mining industry. It can theoretically be applied to any mixture of fine particles that is fine enough to be carried by rising air bubbles.

EXPERIMENTAL

Initial experiments

Initial CGA experiments were performed analogous to those of Bouwer (1999). The parameters for this set of tests are given in Table 1. Analyses were initially performed on a Graphite Tube Atomiser, which proved to be inadequate, as revealed by the mass balancing results and hence an Inductive Coupled Plasma (ICP) apparatus was used for further analyses.

TABLE 1 Parameters for initial experiments

<i>Component</i>	<i>Identification</i>	<i>Quantity</i>	<i>Units</i>
Coal	45 % -90 μ m	4.17	g
Oil	Ethyl Oleate	1	ml
Ore	Gold, 7 g/t	4.17	g
Collector	PAX	0.04	g
Water	Distilled	75	ml

The components were contacted for 50 minutes inside a 250-ml bottle on a magnetic stirrer set at full speed. After contacting, the mixture was shaken and left standing for a few minutes, after which the floating agglomerates were scraped off. This procedure was repeated until all the agglomerates have been removed. The agglomerates were then dried over night at 80 degrees Celsius, and ashed for 7 hours at 800 degrees Celsius. The gold in the sample was dissolved in *aqua regia*, filtered and analysed. At the same time, an untreated gold ore sample was also analysed in the same way. A set of three tests was performed at the same time and the average gold recovery was taken.

CGA with flotation on a small scale

The flotation apparatus used for these experiments was built at the Cape Technikon, as a direct scale-down of the popular Barker flotation cell. The reason for the scale-down was to eliminate any serious loss of material and time that was bound to occur during the initial stages of the project. The experimental

procedure was altered to accommodate general flotation principles (Table 2), but analytical procedures were the same as those used for the initial experiments.

TABLE 2 Parameters for small-scale CGA flotation

<i>Component</i>	<i>Identification</i>	<i>Quantity</i>	<i>Units</i>
Coal	45 % -90 μm	41.70	g
Oil	Ethyl Oleate	10	ml
Ore	Gold, 7 g/t	41.70	g
Collector	PAX	4.00	g
Frother	DOW 200	0.01	ml
Water	Distilled	600	ml
Air	Atmospheric	2.2	l/min

The total volume of the cell is one litre. The contact volume was 600 ml, giving a higher per cent solids, which improved contacting. All the component ratios were kept the same as for the initial experiments, but individual component quantities were increased tenfold. Furthermore, 0.01 ml of frother was added to the mixture before air was passed through it and flotation commenced. The gold-loaded agglomerate froth was then scraped from the liquid surface.

CGA with flotation on a larger scale

The experiments were performed in a 3.4 litre Wemco flotation cell, using a contact volume of 2.4 litres. The previous component quantities were increased fourfold, as the contact volume was also increased similarly. The experimental and analytical procedures were the same as those for the previous flotation cell. Due to the different nature of the two flotation devices used, a direct scale-up was not possible and hence further test work was required to optimise the Wemco flotation cell. The only operating variable that was influenced by the scale-up was the stirring speed because this is thought to be a function of the particular configuration (Table 3).

TABLE 3 Parameters for CGA flotation on Wemco cell

<i>Component</i>	<i>Identification</i>	<i>Quantity</i>	<i>Units</i>
Coal	45 % -90 μm	166.80	g
Oil	Ethyl Oleate	40	ml
Ore	Gold, 7 g/t	166.80	g
Collector	PAX	16.00	g
Frother	DOW 200	0.04	ml
Water	Distilled	2400	ml
Air	Atmospheric	6	l/min

RESULTS AND DISCUSSION

Initial experiments

Oil type

The effect of varying the viscosity of the oil in the experiment was investigated. For this purpose three oils, each with a different viscosity, were used as alternatives to ethyl oleate. These tests showed that decreasing the oil's viscosity leads to the formation of smaller agglomerates, which affected the gold recoveries significantly, as indicated in Figure 2. It is understandable that a decrease in the viscosity of the agglomerant will lead to the formation of weaker agglomerates, because of an increased rate of shear at a constant applied sheer force. Since viscosity is defined as the ratio $\delta s/\delta \theta$, at a constant stirring rate (sheer

force, or δs), an increase in the viscosity will result in the reduction of the rate of shear ($\delta\theta$), causing stronger agglomerates to form.

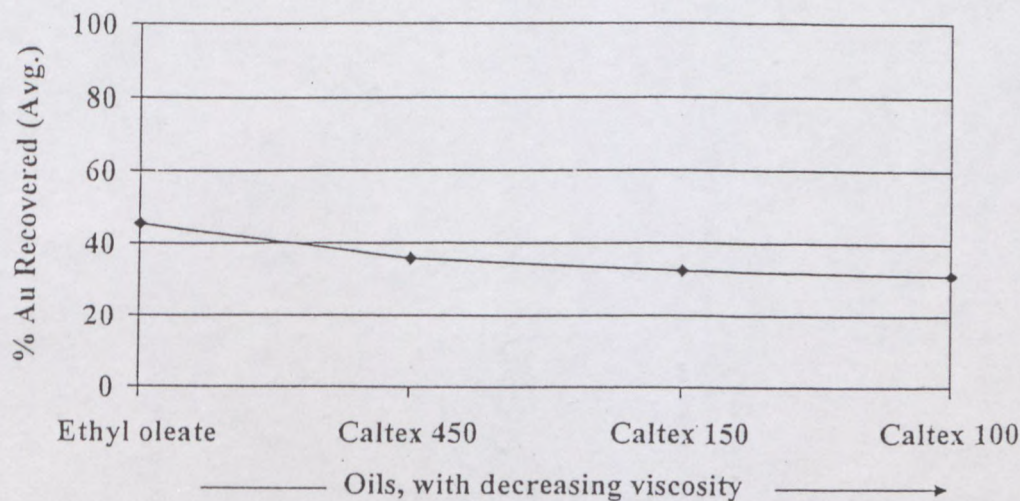


Fig.2 % Au recovered vs. oil type – initial experiments.

Recycling tests

Two types of recycling experiments were performed, i.e. recycling of the ore and recycling of the agglomerates, as indicated on Table 4. The first type of recycling was done to observe whether there was any gold remaining in the ore slurry after the first separation and to quantify this gold. The objective of the second type of recycling was to increase the loading on the agglomerates, and thus decrease the amount of raw materials to be used per kilogram of ore in the process. This will obviously increase the economical viability of the process. All recycling tests were performed with ethyl oleate as agglomerant.

TABLE 4 Results for recycling tests

Parameter	Recycling of ore		Recycling of Agglomerates❖
	Test 1	Test 2	
Aggl. Mass (g) #	3.99	4.13	
Aggl. Mass (g) *	4.83	4.50	4.00
Au loading (g/ton aggl.)#	1.16	1.55	
Au loading (g/ton aggl.)*	0.35	0.21	12.3
Au loading (g/ton feed)	4.78	4.82	6.22
% Au Recovered #	30.8	31.8	83.0
% Au Recovered *	4.30	4.70	75.6

First stage

* Second stage

❖ Analysed on ICP

Considering the recycling of the ore phase, there was very little gold recovered in the second run, indicating that most of the gold was recovered in the first run. It is also clear that a very high percentage of gold can be recovered in the second run, using the same agglomerates as for the first run. This agrees with literature, which indicates that the agglomerates can be recycled up to six times.

Separation by sieving

Normal CGA experiments were conducted, but with sieving employed as a method of separation. For this purpose, a standard household sieve was used. Results were satisfactory, with gold recoveries averaging 77.4 per cent and 22.1 per cent remaining in the ore phase. The results are however slightly poorer than

those for which scraping was used as a means of separation, when a gold recovery of 83 per cent was achieved.

CGA with flotation on a small scale

Preliminary experiments

From the results displayed in Table 5 it is clear that baffles have a detrimental effect on the separation and that MIBC performed poorer than DOW 200 did, as a frother for the CGA process. For this reason, all further tests were conducted without baffles and with DOW 200 as frother. Furthermore, when sodium ethyl xanthate (SEX) was used as a collector, recoveries dropped slightly and it was thus decided to continue the experiments with PAX as collector.

TABLE 5 Results for preliminary experiments

<i>Parameters Investigated</i>	<i>Mass of aggl. (g)</i>	<i>Au loading (g/ton aggl.)</i>	<i>Au loading (g/ton feed.)</i>	<i>% Au recovered</i>
Baffles/DOW 200	43.79	4.41	8.15	56.9
No baffles/DOW 200	50.14	4.29	8.15	63.3
Baffles/ MIBC	42.90	4.15	8.15	52.4
Standard (1600 rpm)	47.04	4.62	6.34	84.2
SEX used	45.72	4.49	6.35	77.5
Undistilled water	47.43	3.38	4.95	79.4

Stirring rate

It is clear from Figure 3 that the gold recovery increased with an increase in the stirring rate. This is conceivable, because more of the agglomerates are kept in suspension at a higher contact speed and hence can be easier floated. A very high gold recovery was obtained when a stirring rate of 1800 rpm was used, but this is not a true result, since some ore was lifted with the agglomerates due to the high stirring rate.

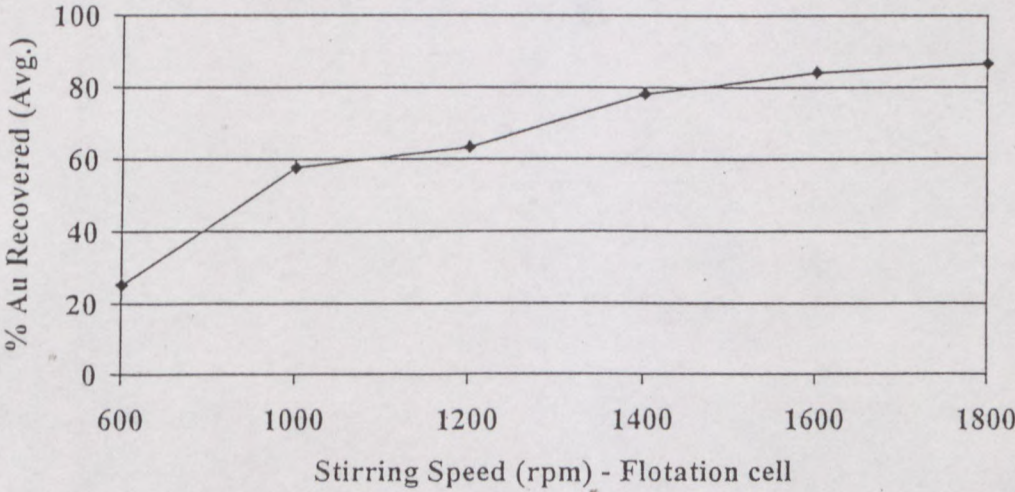


Fig.3 % Au recovered vs. stirring speed using small-scale flotation.

The best result was thus achieved when stirring at 1600 rpm, when 84.2 per cent gold was recovered. This is on par with recoveries achieved on smaller scale during the first phase of the project. It thus became evident that there is a maximum, cut-off contact speed for any flotation apparatus and that if this speed was exceeded, substantial ore lifting will result. This will then obviously lead to inaccurate results as well as increased exigency during the final gold recovery stages.

Aeration rate

As indicated in Figure 4, reducing or increasing the air rate both had a negative effect on the separation. It is obvious that a low air addition rate will cause less of the agglomerates to float to the top, because the ratio of air bubbles to agglomerates is reduced. The low recoveries for the high aeration rate can be explained in terms of bubble attachment and detachment, whereby a bubble will not be given enough time to attach itself onto an agglomerate particle and hence it will merely pass through the slurry into the atmosphere.

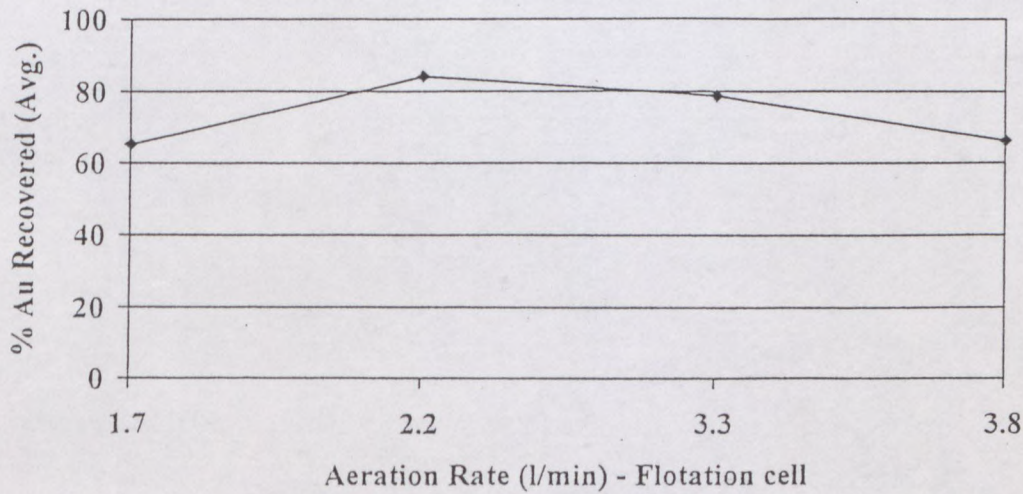


Fig.4 % Au recovered vs. aeration rate using small-scale flotation.

Other agglomerants

Concerning the use of different oils for the process, Figure 5 displays that lower viscosity oils impaired the separation of the agglomerates from the slurry, just as it did with the experiments on a smaller scale. What is more important however, is that these results showed that another oil could be successfully used in the process, provided that it is of similar viscosity and density, due to the nature of the apparatus. This was evident in the results achieved with the Caltex 450 oil, which yielded gold recoveries very close to that of Ethyl oleate.

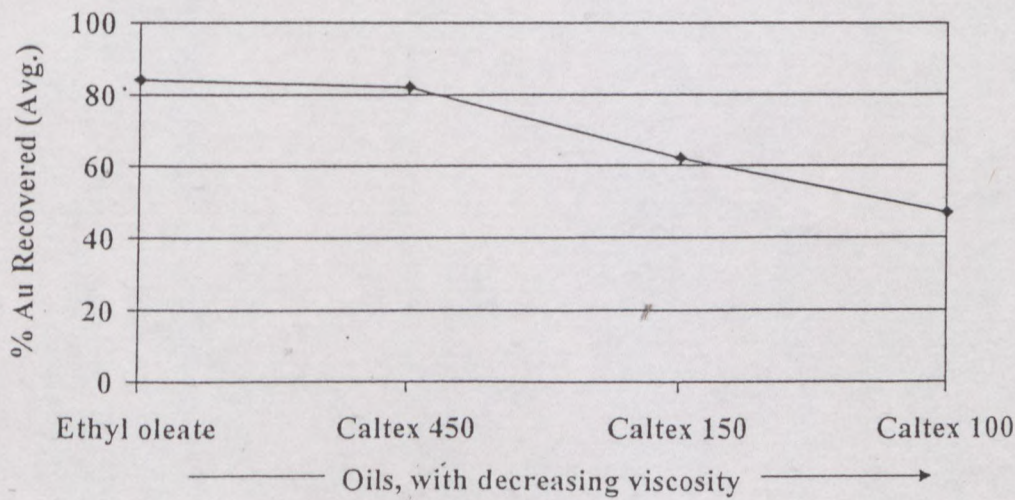


Fig.5 % Au recovered vs. oil type using small-scale flotation.

CGA with flotation on a larger scale

Flotation Stirring speed

It is evident from the results (depicted in Figure 6) that the trend in terms of contact speed is similar to that observed on a smaller scale, whereby an increase in the contact speed leads to an increase in the gold recovery. It is however interesting to note that increasing the contact speed above 1200 rpm resulted in a drop in gold recovery. Since the gold recovery is directly related to the mass of agglomerates that is floated, it was concluded that the high contact speed led to a breakage of the agglomerates and most probably also a decrease in the particle-bubble attachments formed.

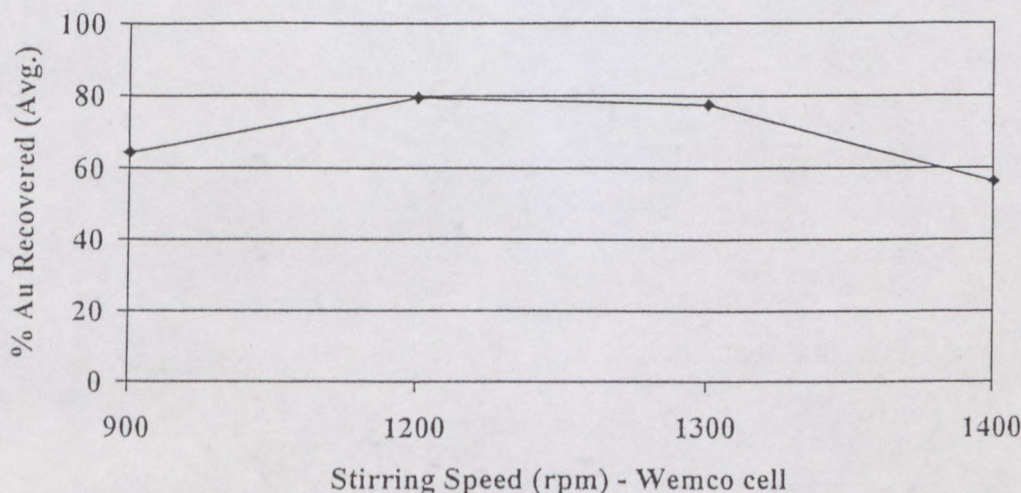


Fig.6 % Au recovered vs. stirring speed on a Wemco flotation cell.

Since it was explained in the previous section that an exorbitant increase in the contact speed leads to an increase in gold recoveries, but also a large carry-over of solids, it seems to be in contrast with these findings. These results however exemplify how the optimal stirring rate for any process is dependent on the configuration of the apparatus used for that process. It is the distinct differences between the configuration of the Wemco cell and that of the self-constructed cell that causes the optimum contact speed to be 1200 rpm on the first cell compared to 1600 rpm on the latter.

Baffle set-up

It was observed that without the Wemco cell's baffles in place, the recoveries dropped to below sixty per cent. Here it must however be noted that these baffles are not attached to the container, but actually surrounds the impeller itself. In addition to this, the baffle set-up also contains holes and all of this leads to the formation of a near-perfect, circular, axial mixing pattern. Without the baffle set-up in place it was noted that the contents of the contacting vessel merely went around in a swirling motion, without any axial mixing taking place. It can thus be concluded that the separation efficiency of the CGA process is not only dependent on the contact speed, but also on the mixing pattern that is observed.

Coal particle size

Excellent results were achieved when the coal particle size was increased to between 500 and 650 microns, as indicated in Figure 7. It was discovered that the larger coal particles were more floatable due to their porous structure. They also have a larger surface area per particle than the smaller particles and this, in addition to their porous structure, leads to improved gold particle penetration as well as adding stability to the agglomerates that are formed.

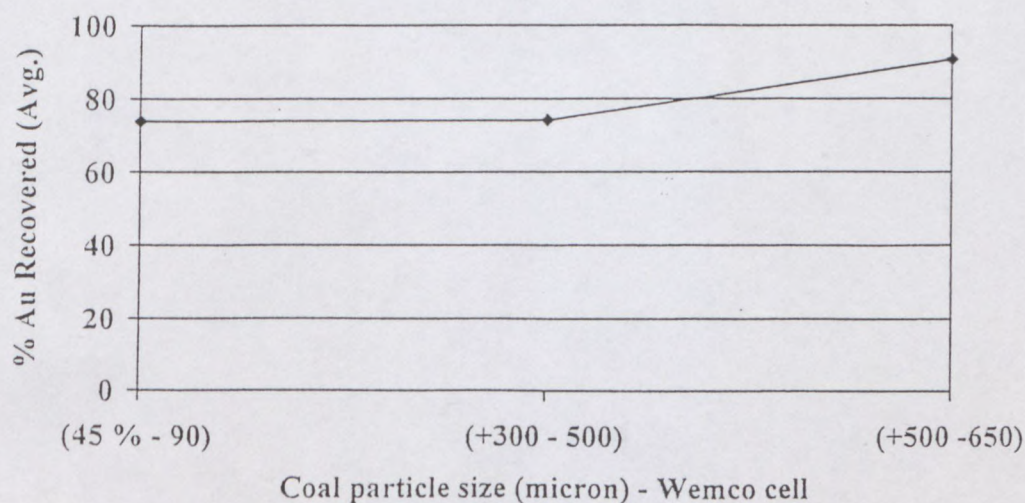


Fig.7 % Au recovered vs. coal particle size on a Wemco flotation cell.

CONCLUSIONS

It can be concluded that the CGA process responded positively when flotation was used as a means of separation, on a small scale as well as on a larger scale. This indicates that the process can be scaled up even further, without compromising the attainable gold recoveries. Due to the different configurations of the Barker and Wemco flotation cells, it was discovered that the optimum stirring rate varies from cell to cell and that each must be investigated on its own merit. The lower operating cost associated with the Wemco cell however makes it more attractive for the CGA process. The excellent results achieved with the larger particle size coal verify that gold particle penetration is of utmost importance in the efficiency of the CGA process. Finally, it can be said that agglomerate stability (dictated by the type of oil and the presence of baffles), stirring rate and gold particle penetration are the most important factors that influence gold recovery.

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