



RECOVERY AND REFINING OF GOLD JEWELLERY SCRAPS AND WASTES

Dr Christopher W. Corti
Director, International Technology
World Gold Council
London, U.K.

INTRODUCTION

The manufacture of gold jewellery will always generate scrap material, whether made by traditional techniques in a workshop or by mass manufacture in a factory. Investment casting sprues and “webbing” strip from stamping are two obvious examples of this, where the quality, i.e., alloy composition and cleanliness, are known. Thus, we are reasonably happy to directly recycle this material back into production after cleaning, with a low risk of producing poor quality jewellery of uncertain gold content.

Not infrequently, scrap defective jewellery from production—or damaged and worn items returned from customers or bought in the market—is also available, but the quality of this is more uncertain, and there is a higher risk, if recycled, of poor quality. Certainly, in production, other forms of scrap materials and wastes are generated where we know contamination results in unclean materials. Polishing dusts and bench filings (lemel) are good examples here. We cannot recycle these types of materials without appreciable risk. Their direct use in production will lead to quality problems, and we need to consider refining such materials back to pure gold.

These remarks are made purely from a technical perspective. However, there is also an economic aspect. The efficient recovery of scraps and wastes in gold jewellery manufacture is a vital component of a profitable jewellery manufacturing business, irrespective of whether it is a large factory or small, traditional workshop. Gold and other precious metals “lost” in the manufacturing process can be a significant cost factor that impacts product cost and business competitiveness.

Much of the scrap generated in production can be cleaned and recycled, but contaminated scrap and other wastes need to be collected and refined back to pure gold to recover the value of the precious metal. Such scraps and wastes need to be pre-treated before refining to reduce costs and maximise recovery of precious metals. We should note that one should not continuously recycle “clean” scrap. Periodic refining of scrap is important to remove deleterious, embrittling impurities that tend to build up over time and lead to quality problems.

Thus, in any jewellery production situation, scraps and other wastes are created that need to be collected and refined for technical and economic reasons. One question to be faced is whether to send them to a toll refiner or to refine in-house. Which is preferable will depend on several factors, including economics and, not least, the availability of the technical skills needed to ensure full recovery of the gold if done in-house. Refining in-house will also require access to analytical facilities. In some countries, sending materials to a toll refiner is not always a realistic option and so an in-house refining capability becomes a necessity.

The jeweller wishing to refine his scrap materials in-house is faced with the dilemma of which process technology to choose. Some are best suited for primary refining of ores on the larger scale and others more suited for secondary refining scraps and wastes, particularly on the small scale, typical of jewellers' needs. Process efficiency is clearly important if all the gold and other precious metals are to be recovered economically.

It is now 13 years since Roland Loewen reviewed precious metal refining techniques at this Symposium¹ and seven years since the publication of his classic book², which is based on Roland's considerable practical experience. It is also five years since I reviewed the recovery, recycling and refining of gold^{3,4} so, perhaps, it is time to review this topic again. In this presentation I will focus on gold and consider:

- Sources of scraps and wastes and their precious metal contents
- Treatment of scraps and wastes prior to refining
- Refining techniques for gold and their suitability for small scale refining by jewellers.

SOURCES OF SCRAPS AND WASTES IN JEWELLERY MANUFACTURE

As Raw⁵ has pointed out, the efficient recovery of scraps and wastes does depend on knowing how much precious metal enters the factory or workshop and how much leaves it in the form of finished jewellery. This, coupled with how much scrap and gold-containing wastes are knowingly recovered and either recycled or sent for refining, enables the jeweller to know how much is being lost in the system and to take appropriate action to recover it.

Scrap arises at all stages in the manufacture of jewellery—at the alloying and ingot stage, during stamping and blanking operations, in investment casting (feeders, defective castings, etc.), filing, drilling, sawing and soldering at the workbench, and finishing (diamond cutting, polishing, etc.). Scrap comprises redundant material discarded in manufacture and defective items of jewellery that are rejected. This can be high to medium grade in terms of precious metal content. The amount of scrap generated can be controlled through careful process design, material utilisation and implementation of best practice on the shop floor, but it cannot be eliminated.

Wastes can also arise at each stage of manufacture and are typically low grade in terms of precious metal content. Table 1 lists many of the common sources that occur in both traditional workshop and factory situations. Loewen^{1,6} has reported typical gold contents of scraps and wastes, as shown in Table 2, and Schneller^{7,8} has reported on precious metal contents of wastes in investment casting and their recovery. Clearly, the gold and other precious metal content will depend on the caratages of jewellery being made and the type of equipment in use. Platinum group metals may also be present if white golds, dental alloys and platinum jewellery are made on the same equipment. These have value, too, and may be worth recovering separately.

Table 1 Typical sources of wastes in gold jewellery manufacture

Process Stage	Sources	Comments
Melting and casting	Crucibles, moulds, casting dies Slags, fluxes, splashes and "dirt" Cooling water from graining Residues from ingot dressing Investment casting	Metal trapped in cracks, etc. Can entrap gold particles Fine particles float Metal trapped in mould material after quenching and cleaning
Working operations	Sheet and strip: • edge cracks and alligating • blisters, laps Rod rolling—fins Wire drawing Lubricating oils Stamping and blanking Chain making Annealing and soldering in belt furnace Cleaning rags	Metal particles fall out Metal flakes off Metal flakes off Points break off Particles entrapped Flash on dies Slivers of wire trapped Items trapped in furnace, particles in quench tanks Pick up particles
Assembly, cleaning and finishing	Cutting, filing, sawing, soldering Grinding and polishing Diamond milling and faceting Cleaning fluids Spent electroplating solutions Rinse waters in electroplating, etc. Acid pickling baths, bombing solutions Cleaning rags, tissues, brushes, etc.	Filings and dusts " " Trapped particles Dissolved metal Dissolved metal, particles " Particles of metal
Workers and workplace	Clothes, skin, hair, feet Floors, walls, ledges, lights, benches Sinks and drains Equipment, extraction systems, fans	Particles carried out; theft Dusts accumulate Particulates lost (fit traps) Particles lost (clean, fit filters)
Test samples	Test specimens for analysis, etc.	Contain precious metal (recover)

Table 2 Typical gold contents for scraps and wastes

Material	Gold content, wt %
Old jewellery	39–73 approx.
Bench scrap	19–52
Sink trap settlings	6–8 approx.
Carpets and wood floors	0.1–9
Old crucibles	0.8–5
Polishing dusts and sweeps	0.5–5
Watchbands and miscellaneous gold-filled scrap	0.25–5
Emery papers, floor and other shop dirt, brushes	0.1–4

Raw⁵ has discussed the control of gold losses in a production situation; thus it is not appropriate to discuss it further here. We are just concerned that all scraps and wastes are identified and recovered.

TREATMENT OF SCRAPS AND WASTES

In any strategy to recover precious metals such as gold, it is important to consider the cost of recovery. There is no sense in spending more in processing costs than the value of metal recovered. In particular, the processing of wastes to reduce bulk and concentrate the precious metal is essential to economic recovery. Refining costs are usually based on gross weight shipped in, if for example, waste is sent to a toll refiner.

Whether directly recycling high grade scrap or sending materials for refining, there are some broad guidelines that should be followed if efficient, cost-effective recovery is to be achieved:

Recycling of scrap directly in new melts

- Segregate scrap by colour and by caratage
- Use only clean, high-grade scrap of known composition. Ensure contaminants such as entrained investment, abrasives and inclusions, surface oxides and grease are removed by suitable cleaning procedures such as sand- or water-blasting, acid pickling or alkali treatment, and ultrasonic degreasing.
- It is preferable to remelt scrap under a flux cover and grain it before re-use. The use of grain assists melting and alloy homogeneity.

- Always check gold content and alloy composition before adding scrap to new metal to ensure the new melt will meet fineness specification and does not contain deleterious impurities. Scrap from external sources may contain embrittling levels of metals such as silicon and lead or even cadmium-containing solders.
- Do not use more than 50% scrap in a new melt and preferably less, especially in investment casting. The yield of good castings reduces as scrap content of the new melt increases. However, it is important to keep scrap used in balance with scrap generated so it does not accumulate.

Recycling of contaminated scraps and wastes

High-grade (>20% gold) scraps and wastes such as bench sweepings (or lemel), casting spills and sprues, pot sludge from electrostripping, etc., should be remelted (smelted) in a graphite crucible with a suitable flux to take up any dirt, oxides, refractory abrasives and inclusions and other impurities. Gibbon⁹ has given practical advice on smelting and fluxes. Typically, a soda-ash flux is used^{1,9,10}, such as shown in Table 3. This has a low viscosity, i.e., is very fluid. The melt should be kept hot and fluid for 30 minutes and stirred occasionally with a graphite rod before being cast into an oiled iron mould and allowed to cool. The slag can be knocked off the cast bar when cold, leaving a clean bar. This can be sampled and assayed prior to re-use, preferably as grain. If there is any doubt about cleanliness of the alloy or if it contains platinum metals, it should be sent for refining.

Table 3 Typical flux composition for smelting scrap

Component	Amount (parts by weight)
Soda ash (sodium carbonate)	4
Borax (pentahydrate)*	5*
Barium nitrate	4
Fluorspar (calcium fluoride)	1

*Reduce to 3.5 parts by weight if anhydrous borax used, or increase to 6.5 parts by weight if decahydrate used.

Low-grade wastes

These include floor sweepings, polishing dusts, spent plating solutions, rags and tissues and plated base metals. Treatment of these is tailored to the type of waste.

Fines, floor sweepings, rags and tissues contain low gold contents and need to be incinerated slowly for long times, say 24 hours, under controlled conditions so that fine particles are not blown up the flue. Such "air-tight" furnaces are commercially available and Loewen^{2,10} has described a suitable construction in detail. The resulting ashes should be milled, screened, sampled and assayed prior to mixing (with flux in a 5:7 ratio of ash), and fluxed and smelted for 2–3 hours before pouring and casting, as described previously for high-grade material. This material should be refined to pure gold.

Spent cyanide solutions from plating or bombing can be treated with fine zinc or aluminium powder to precipitate the precious metal^{2,10}. An addition of 50g/l of caustic soda will stimulate the reaction. The precipitated metals are then filtered off, washed and dried, and added to the high-grade waste, whose treatment was described above. On a safety note, I will remind you of the danger of putting acids on cyanide solutions; they can generate lethal hydrogen cyanide gas.

Investment casting and "muds" resulting from quenching of flasks and cleaning the cast trees are also low grade wastes as Schneller has described^{7,8}. These can be screened and the bulk of the precious metals will be found in the coarse fraction, which can be sent for refining. Likewise, old crucibles can be crushed, milled and sent for refining.

REFINING TECHNIQUES FOR GOLD SCRAPS AND WASTES

When we consider refining of contaminated scraps and wastes from jewellery manufacture, there is a tendency to think of refining them back to pure gold (and recovering platinum metals, if present). This will be re-alloyed with silver and copper, etc., to produce a carat gold once again for new jewellery manufacture. However, often all that is really needed is to ensure the removal of non-metallic and other base metal impurities to leave a clean gold-copper-silver alloy for re-alloying to the desired composition. This approach is possible and can be considered if scrap is being recovered and refined in-house. A pyrometallurgical refining process for such "upgrading" of scrap has been developed and used successfully by a major European alloy producer, with economic benefit compared to refining back to pure gold⁹. This option will be included in the review below.

There are a number of refining techniques available for recovering gold, but not all are suitable for small-scale refining in a jewellery production environment. It is worth noting that:

- (1) The gold purity obtained can vary, depending on the technique used and the skills employed in operating it. As long as an assay is made to ascertain gold purity, this may not be important if the gold is being used for re-alloying in-house, although knowing what the impurities are is important if alloying to a tight colour or property requirement.
- (2) The impurities not removed by the technique may also be important in considering re-use of the gold for new alloy production. This may influence choice of technique.
- (3) Ensuring all the gold is recovered, i.e., a yield close to 100%, is economically important. An understanding of the underlying technology and good process control is vital.
- (4) There are health, safety and environmental pollution aspects to be considered, too. Local legislation on disposing of effluents and release of toxic fumes may restrict choice of technique. Many refining techniques require use of strong acids, and the safe storage and handling of these may also restrict choice.

Possible techniques for refining of gold are listed in Table 4, along with some important attributes. All will be discussed, but I will focus on those more suitable for in-house refining.

Table 4 Possible gold refining techniques

Refining Technique	Removes			Suitable for Large	Suitable for Small
	Base Metals	Removes Silver	Removes PGMs	Scale Refiners	Scale Refiners
Cupellation	3	8	8	3	3
Inquartation and Parting	3	3	8 ⁴	8	3
Miller Chlorination Process	3	3	8	3	8
Wohlwill Electrolytic Process ¹	3	3	3	3	8
Fizzer Cell	3	3	3	8	3
Solvent Extraction	3	3	3	3	8
Aqua Regia Process ²	3	3	3	3	3
Pyrometallurgical Process	3 ³	8	8	3	8

1 Can only be used when initial gold content is about 98%

2 Only suitable when initial silver content is less than 10%

3 Copper (and silver) remains in gold

4 Platinum and palladium removed

1. Cupellation

This is the technique that forms the first part of the fire assay process. It involves the addition of lead to the unrefined gold material. This is heated in air to around 1000–1100°C (1830–2010°F), when the gold-containing metal will dissolve in the lead. All base metals, including the lead, are oxidised to form a lead oxide slag, leaving behind a gold-silver bullion which will also contain any platinum group metals (PGMs) present. If pure gold is required, further refining steps are necessary to separate out the gold. If parting is used, then additional silver will need to be added to the original material (as in the fire assay procedure) to result in the bullion containing <25% gold. Figure 1 gives an outline of the process.

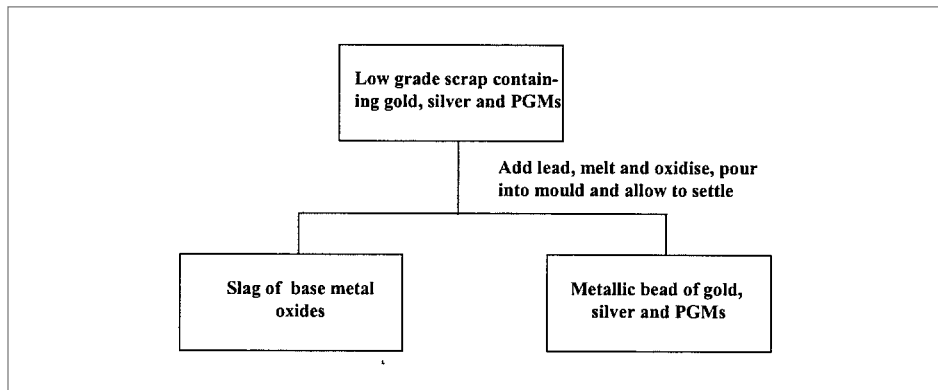


Figure 1 Outline of small-scale cupellation

Whilst this procedure can be used on a very small scale, as in fire assay, its use on a small-medium scale is not recommended, as it emits copious quantities of toxic lead oxide fumes, giving rise to environmental pollution unless expensive fume abatement systems (gas scrubbers) are installed.

2. Inquartation and Parting

In this process, the refinable material is melted, if necessary, with silver or copper to result in an alloy containing 25% or less gold, i.e., to "quarter" it, hence the term inquartation. This dilution ensures that all the base metals and silver can be dissolved out in nitric acid. The molten alloy should be grained to maximise surface area and the grained alloy can be attacked with nitric acid to dissolve out all the base metals and silver, leaving behind a gold sludge. This can be washed, filtered and dried. A process outline is given in Figure 2.

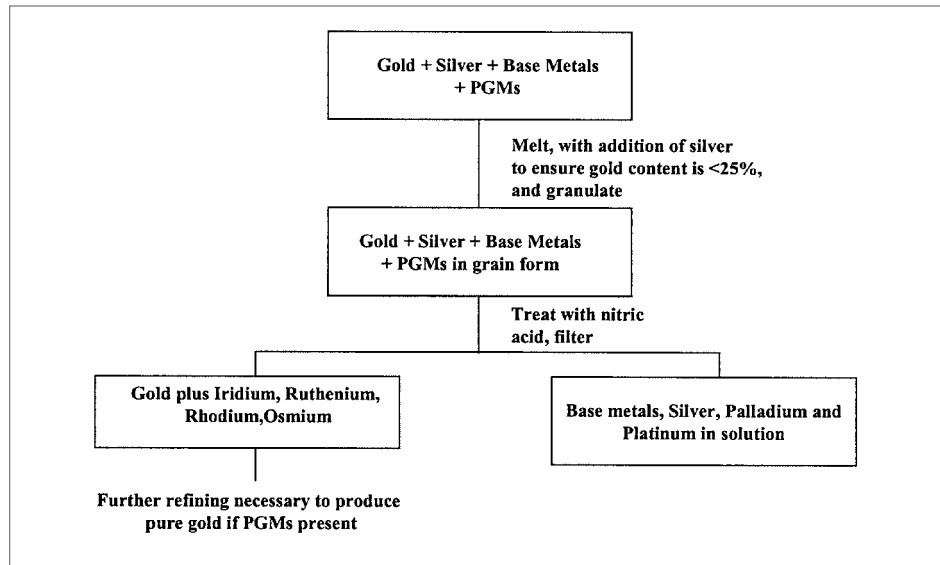


Figure 2 Outline of inquartation and parting

Any platinum and palladium present will also be dissolved out, although a repeat of the process may be required to ensure their complete removal. However, insoluble PGMs such as iridium will remain. The process is used by jewellers for refining and it is capable of producing gold of up to 99.99% purity in the absence of PGMs. Small scale equipment is available commercially, designed specifically for the jeweller¹². It is a process particularly suited for treatment of low-carat gold scrap, since large additions of copper or silver are unnecessary to achieve the desired <25% gold content. The process also finds application as a preliminary step to reduce the silver content of silver-rich refinable materials from 40–50% to below 10% prior to refining by the aqua regia process.

Raw¹² has described the trial processing of a 1.1kg batch of mixed 9-carat yellow gold scrap that had been diluted with copper to give an average gold content of 26.1% and then grained. This was refined in a commercial Italian-made machine capable of treating 3–4kg grain. The grain was larger than the optimum size but despite this, a recovery of 99.9% of the gold was achieved with a purity of 99.875%. On melting and casting, a bar of 99.97% gold purity was obtained.

3. Miller chlorination process

A pyrometallurgical chlorination process and one of the oldest and most widely used processes in large-scale gold refining, the Miller process involves bubbling chlorine gas through the molten bullion. The base metals and silver are removed as chlorides, which either volatilise or form a molten slag on the surface of the melt. The end of the process is recognisable when purple fumes of gold chloride

start to form, usually when the gold content reaches a purity of 99.6–99.7%. Any PGMs present are not removed. Typical gold purity achieved by this process is 99.5% with silver as the main impurity. The process has the attraction of being quick and is widely used for primary refining of gold doré from the mines. An outline of the process is given in Figure 3.

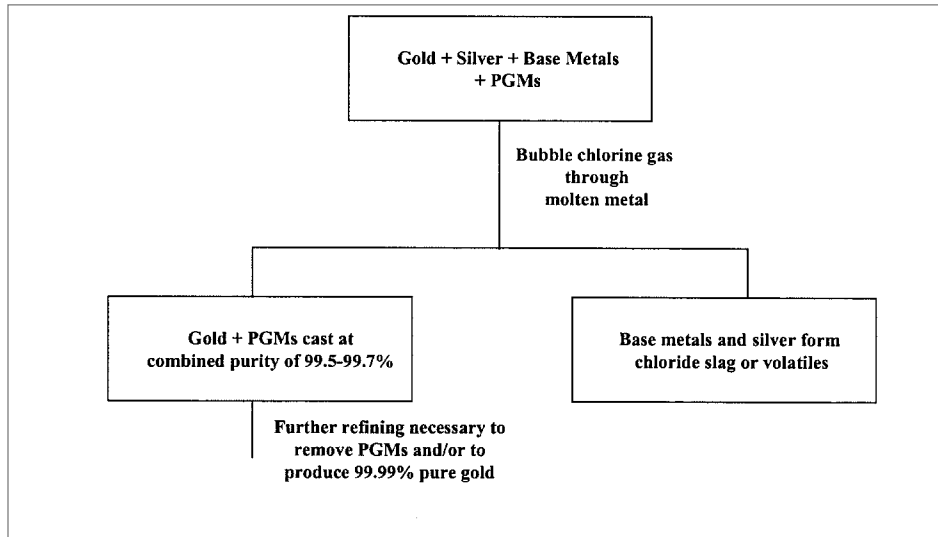


Figure 3 Outline of the Miller chlorination process

Considerable technical skills are required to operate this process, and there are considerable health and safety implications in the use of chlorine gas. Expensive fume extraction and treatment facilities are required. Consequently, this is a process not suited to small-scale refining.

4. Wohlwill electrolytic process

Another old and well established process, the Wohlwill process is widely used in the major gold refineries, often in conjunction with the Miller process. An electrolytic refining technique, it entails the electrolytic dissolution of an impure gold anode in a hydrochloric acid electrolyte and the consequent deposition of 99.99% purity gold at the cathode. The silver and PGMs fall out as anode slimes, silver precipitates out as silver chloride and all are recovered later whilst the base metals remain in solution. The process outline is given in Figure 4.

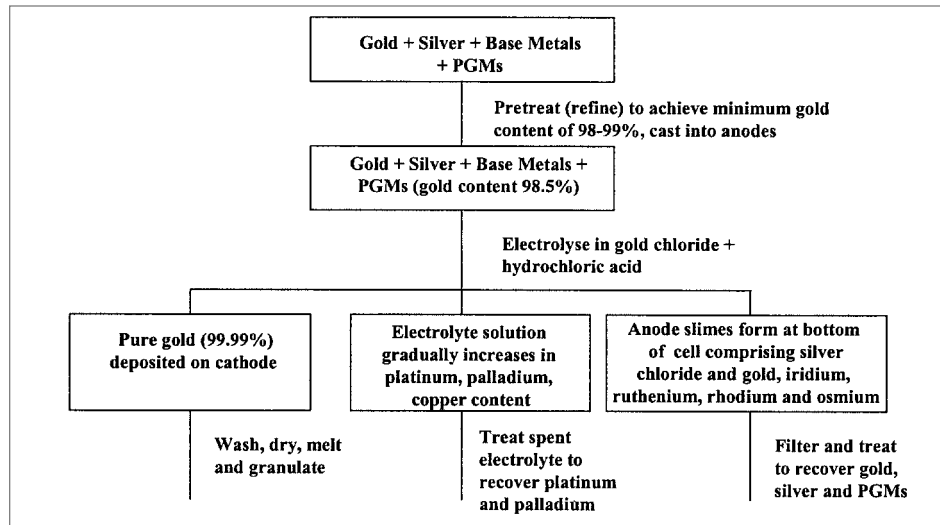


Figure 4 Outline of the Wohlwill electrolytic process

Gold with a purity of at least 98.5% is normally required for the anode, as too much silver will result in silver chloride building up on the anode surface, preventing dissolution of the gold. Typically, the input material for the anode is the gold from the Miller process. The process is time consuming and suffers from the lock-up of gold inventory in the electrodes and electrolyte. Consequently, it is not suitable for small-scale refiners. For normal jewellers' scraps and wastes, a preliminary refining step such as the Miller or inquartation process is required.

5. Fizzer cell process

This is a variant of the Wohlwill electrolytic process and more suited for small-scale refining by jewellers. In the electrolytic cell, the cathode is contained within a porous ceramic pot, which acts as a semi-permeable membrane, preventing gold dissolved in the electrolyte on the anode side of the wall from passing through and depositing on the cathode. Thus, gold and other soluble metal chlorides build up and insoluble chlorides such as those of silver and the insoluble PGMs drop to the bottom of the cell.

Periodically, the cell is drained and filtered, and the gold in the electrolyte is precipitated with a selective reducing agent, as in the Aqua Regia process to be described shortly. In this way, the dissolved PGMs are separated from the gold, which can reach a purity of 99.99%. Unlike the Wohlwill process, the Fizzer cell can treat anodes containing up to 10% silver, and up to 20% silver if an imposed alternating current is added. Silver chloride may need to be scraped from the surface of the anode at regular intervals. A process outline is given in Figure 5.

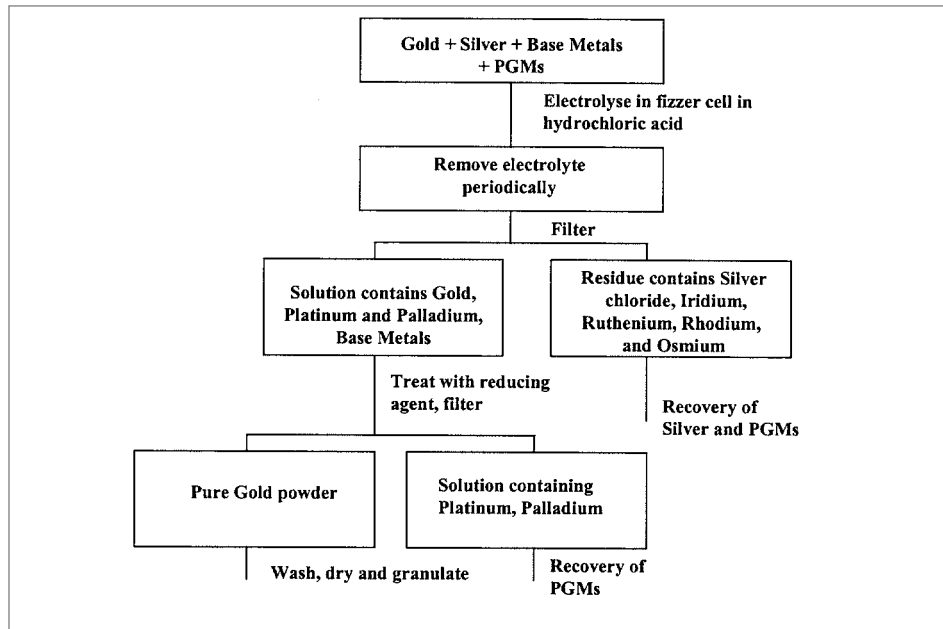


Figure 5 Outline of the Fizzer cell process

A variation of this process, patented by Shore in 1986, uses sodium chloride as the electrolyte and is marketed for use by small jewellers.

6. Solvent extraction process

This process involves the use of organic complexes such as diethylene glycol dibutyl¹³ to render gold soluble in organic solvents that are not miscible in water, thus allowing their selective separation. More recently, Mintek in South Africa has developed a small-scale process for primary refining of gold¹⁴ and this is in operation in at least one major gold mining company. It is not suitable for jewellery requirements, and will not be discussed further here.

7. Aqua regia process

This process is probably the most widely used at the small-medium scale by jewellers and refineries alike and can produce gold of up to 99.99% purity. It is based on the fact that aqua regia (a mixture of hydrochloric and nitric acids in a 4.5:1 ratio) can dissolve gold. Thus, the scrap gold is dissolved in the acid mixture to form soluble gold chloride. Silver chloride is precipitated and filtered off. The gold is selectively precipitated from solution by a reducing agent and filtered off, washed, dried and the resultant powder melted to a solid button or ingot.

In practice, the scrap is grained to increase surface area and treated with a series of aqua regia acid additions, aimed at using only a small excess of acid without leaving any undissolved gold. Gentle heating will speed up dissolution. Copious

brown fumes of nitrogen oxide are emitted during this stage, and fume abatement systems must be utilised to stop emission of these toxic fumes and to comply with pollution laws. It is also worth noting that suitable storage and safety procedures are required with the use of these strong acids.

Filtering of the yellow-green solution removes insoluble silver chloride, the insoluble PGMs and any non-metallics such as abrasives and inclusions. Gold can be selectively precipitated using a number of reducing agents such as ferrous sulphate (known as Copperas), sodium bisulphite and sulphur dioxide gas. Others include hydrazine, formaldehyde, oxalic acid, hydroquinone and some sugars. Some emit copious quantities of gas and some are carcinogenic. Loewen favours an aqueous solution of sodium bisulphite over ferrous sulphate^{1,2,15}. This is added slowly until the yellow colour of the solution disappears. He notes that a smell of sulphur dioxide may be noted at this point.

Loewen² also reports that hydroquinone is less aggressive than bisulphite and avoids some problems that can occur with copper, since it does not reduce cupric chloride. However, if platinum is present in worthwhile quantities, he suggests the use of ferrous sulphate. Completion of the reaction can be ascertained with the stannous chloride test.

After precipitation is complete, the solution should be allowed to stand overnight to allow the fine gold particles to settle as a sludge on the bottom, otherwise there is a danger of washing some of it away. The major part of the liquor can be decanted off and the remaining part with the gold can be filtered. This filtrate is washed with acid and then water, dried, and placed in a crucible for melting and graining.

Full details of this process are given in the excellent book by Roland Loewen², and I commend it to anyone wishing to use this process. A process outline is given in Figure 6. I do occasionally come across jewellers trying this process who complain that they have lost a considerable amount of the gold. This suggests that either they are not fully dissolving all the gold in the first stage or, more probably, not precipitating all the gold in the reducing step. Never throw the liquor away before analysing it for gold content!

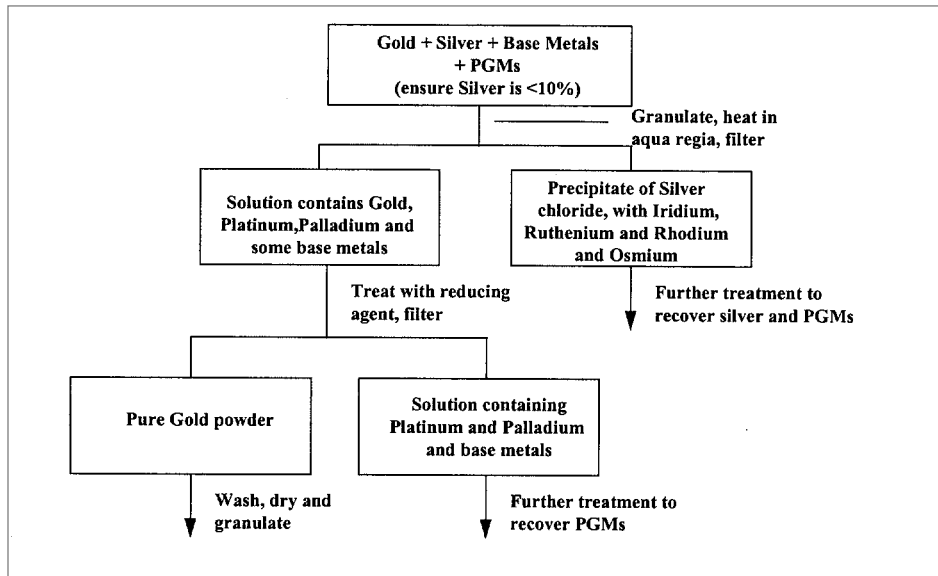


Figure 6 Outline of the aqua regia process

Besides aqua regia, it is possible to dissolve gold in other aggressive acids such as a mixture of hydrochloric acid and 50% hydrogen chloride or chlorine gas in hydrochloric acid. Both are somewhat hazardous and the latter is slower than aqua regia.

I have already mentioned the dangers of handling strong acids. The jeweller using this process must be aware of the risks and ensure he has trained chemists and proper safe facilities. In my experience this is not too often the case.

8. Pyrometallurgical gold refining process

The principle of this pyrometallurgical oxidation process is the selective oxidation of base metal impurities. This is achieved by bubbling air or oxygen through the molten scrap gold under a flux cover of a special formulation. This removes all base metals other than copper first, and then some copper. The oxides formed, plus any non-metallic inclusions, float to the metal surface and are dissolved in the flux to form a slag. An outline of the process is given in Figure 7.

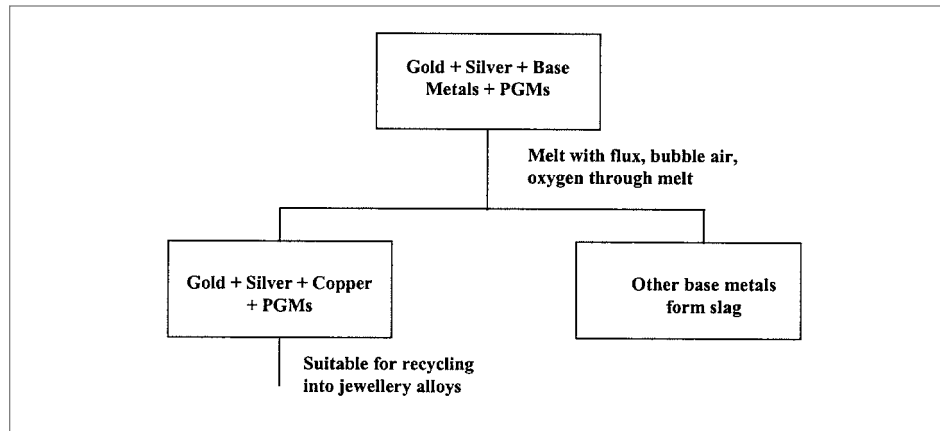


Figure 7 Outline of the pyrometallurgical gold refining process

Gibbon has described the process in some detail⁹. After first smelting the scrap using a normal soda-ash flux, the resulting slag, i.e., flux with dissolved oxides, is poured off. Then fresh, specially formulated flux is added to the melt and air is blown through the melt via an immersed refractory tube. Impurities such as zinc, tin, lead and cadmium are quickly and cheaply removed and collected in the slag. Some gas scrubbing and collection are required, as copious zinc oxide fume can be evolved during “blowing.” Again, this slag is removed, further fresh flux added, and the process repeated. After about one hour the reaction is essentially complete. The flux can be poured off and the gold-silver-copper alloy poured into an iron mould and cast. Its composition must be determined before it is used for re-alloying into a carat gold.

As Gibbon remarks⁹, the process efficiency and economics are greatly influenced by the choice of crucible material and flux formulation. The key to the success of the process is an understanding of the thermodynamics of the take-up of the oxides into the flux, and so flux formulation is critical. Copper is used to indicate the oxidation state of the slag, and the levels of the other base metals in the bullion and slag can be calculated from a knowledge of the copper content of the slag. Table 5 shows the effectiveness of base metal removal by this process and is typical of those achieved in commercial practice.

Table 5 Removal of base metals in the pyrometallurgical gold refining process⁹

Metal	Removal %
Zinc	99
Lead	92
Tin	96
Iron	>99
Cadmium	91
Antimony	90
Bismuth	77
Arsenic	94
Nickel	>90

The advantages of the process to the small-medium jeweller are:

- Combination of smelting and refining in one operation
- Simple and effective method for production of a gold-silver-copper alloy suitable for re-alloying
- Significant cost and time savings over other pure gold refining processes
- Minimal gold and silver losses
- Reduced health and safety problems
- Proven suitability for use by jewellery manufacturers

This process has been used advantageously by a major European jewellery alloy producer.

CHOICE OF REFINING PROCESS

As indicated in Table 4, of the eight gold refining techniques discussed, only five are suitable for the in-house refining of scrap on the small-medium scale typical of jewellery production. Two of these, cupellation and pyrometallurgical gold refining, do not produce pure gold but a gold-silver (including any PGMs) or a gold-silver-copper alloy (including any PGMs), respectively. Where PGMs are absent, then these gold alloys can be used for re-alloying into a new carat gold.

Cupellation, is not recommended on health and safety grounds. Where significant quantities of scraps are refined, pyrometallurgical gold refining is a good choice in terms of speed, cost-effectiveness and compatibility with normal metallurgical operations involved in jewellery production. No special chemical skills are required.

Of the processes that result in pure gold, the inquartation process is also straightforward to perform, but it requires a feedstock containing 25% or less of gold if pure gold is to result. This process may not be so desirable for an operation making predominantly medium-high carat gold jewellery, as scraps from production may need to be substantially diluted with copper or silver. It is more suited to a low-medium carat gold operation¹², although it is of use as a pretreatment to reduce silver content prior to refining by the aqua regia process.

Of the electrolytic methods, the Fizzer cell process is the only one suited to a jeweller's needs, but the scale makes it more suited to very small operations such as traditional workshops. Its end product is not pure gold but a gold-rich chloride solution from which the gold is selectively precipitated, as in the aqua regia process.

The aqua regia acid dissolution and precipitation process is most suited to the medium-large scale jewellery producers and is widely used by them for in-house refining as well as by the toll refiners. Typical batch size would be up to 4kg scrap, and equipment in a range of capacities is commercially available from several companies. The reaction vessels are in glass in order to withstand the strong acid environment. The process has a limitation in that the feed material should have a silver content of 10% or less to avoid blocking the dissolution of the scrap. Because of this, pretreatment by the inquartation process to reduce the silver content may be necessary. Alternatively, the low silver content may be achieved by a judicious blending of batches of scrap. Thus, the process is more suited to medium-high carat gold scrap refining.

Which process is selected depends on a number of factors:

- Amount and nature (caratage) of scrap to be processed,
- Capital cost of equipment and safety/pollution control installations,
- Technical skills available,
- Speed and yield of process, which impact overall economics.

The overall cost of in-house refining must be set against the recovery efficiency achieved (amount of gold and other precious metals) and compared to that obtained by use of a toll refiner. It may well be that it is not economical to recover low grade scraps and wastes in-house and that they are best treated by a toll refiner, for example. Silver and platinum metal (PGM) recovery will also play a part in determining the economic viability of in-house processing.

CONCLUDING REMARKS

In conclusion, the recovery and refining of gold jewellery scraps and wastes has been reviewed. The sources of such materials in a production facility have been identified and procedures for their pre-treatment, to reduce bulk and concentrate the precious metals prior to recycling or refining, summarised.

The refining processes for recovery of gold from scrap gold materials have been reviewed with the emphasis on those techniques suitable for use in-house in a jewellery production facility. One technique that upgrades scrap to a clean gold-silver-copper alloy, suitable for re-alloying back to carat gold, has been highlighted. This can be cost-effective in the larger jewellery production facilities.

There are other refining techniques suitable for use in-house that produce pure gold, and the factors affecting choice of process have been identified. Other techniques are only suitable for large-scale refiners processing primary gold materials from the mines. The benefit of refining in-house must be weighed against the cost and yield of gold obtained from use of toll refiners. In some cases, use of toll refiners may be more cost-effective.

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