# Macraes Gold Project: Value creation through applied technology - Pressure oxidation

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## Abstract

The Macraes Gold Project, operated by GRD Macraes Limited, engaged GRD Minproc Limited to assist with the evaluation of a pressure oxidation circuit, this being the key component of a recovery enhancement project. The initial study gave sufficient confidence in the process to enter into project execution. GRD Macraes Limited was the first company to license Newmont Mining Corporation's pressure oxidation technology, which aims to improve gold recovery from the carbonaceous sulfidic flotation concentrate. This paper outlines the fundamental chemistry of the process followed by a description of the plant that was ultimately installed. A summary of the commissioning is given together with an overview of the production results to date. The project ramp-up was rapid, with design temperature and throughput being achieved within days of hot commissioning. Gold recoveries have exceeded expectations, improving from around 70% prior to the installation of pressure oxidation to above 84%. The project has increased the nominal gold output at Macraes from 120,000 oz/y to 170,000 oz/y. Ongoing plant optimisation for process parameters is discussed, giving rise to flexibility in gold production, with key controlling parameters exceeding design.

## Introduction

The Macraes Gold Project is located 90 km north of Dunedin in the South Island of New Zealand. The original treatment plant was commissioned in October 1990 and was designed to treat 1 Mt/y of oxide ore and 1.5 Mt/y of sulfide ore on a campaign basis. The plant was upgraded to a capacity of 3 Mt/y of sulfide ore in 1994, and was further optimised to achieve 3.4 Mt/y. The gold is associated with a carbonaceous refractory sulfide ore that is subjected to flotation. Prior to the installation of pressure oxidation, the concentrate was reground and leached in a CIL circuit. The carbonaceous ore is preg-robbing with overall gold recoveries historically ranging from 70 to 75%. The project has a 7 - 10 year mine life, which, together with the potential for improved gold recovery, provided the impetus for the Macraes Recovery Enhancement Project.

The enhancement project is taking place in two stages, with Stage 1 having increased throughput from 3.4 Mt/y to 3.8 Mt/y for sulfide and oxide ore, as well as introducing pressure oxidation. It is planned that Stage 2 will increase throughput to 4.5 Mt/y with the inclusion of a recycle crusher in the grinding circuit and up-grades to the water supply and plant services. Following the completion of Stage 1, gold production has increased from 120,000 oz/y to 170,000 oz/y. The pressure oxidation circuit is designed to process the concentrate produced from milling 4.5 Mt/y of ore. Prior to the expansion to 4.5 Mt/y, additional concentrate will be reclaimed from a CIL residue dam to supplement the feed to the autoclave. This paper focuses on the design and operation of the pressure oxidation circuit included in Stage 1 of the Macraes Recovery Enhancement Project.

The Macraes pressure oxidation circuit is the first licensed application of Newmont's high temperature pressure oxidation technology. It is also the first time the technology has been applied to a flotation concentrate. The technology was originally developed for Newmont's Twin Creeks project in Nevada, which is a whole-of-ore oxidation.

## Process chemistry and the development of high temperature pressure oxidation

The ores at Macraes are refractory and contain preg-robbing carbonaceous material. The metallurgical process has been optimised over the last eight years based upon the production of a flotation concentrate which is deslimed, sulfidised and oxygenated prior to a carbon in leach circuit. The CIL operated with very high carbon movements and low loadings to reduce the preg-robbing impacts. Each week, approximately 112 t of loaded carbon was stripped and reactivated prior to being returned to the last stage of the CIL train. The loss in gold recovery, coupled with the operability of the CIL plant, provided the impetus to examine alternative technologies, including Newmont's high temperature pressure oxidation process.

In the development work for Twin Creeks, Newmont (Simmons, 1998) identified that gold was being lost onto carbonaceous material. Further investigative work determined that chloride and free acid concentrations impacted greatly on the leach recoveries subsequent to pressure oxidation. These parameters were tested by the addition of limestone to adjust free acid levels and washing of the ore to control chloride levels. Avraamides (1985) describes the dissolution of gold by chloride as:

$$3O_2 + 4Au + 16Cl^- \Rightarrow 4AuCl_4 + 6H_2O$$

and the precipitation of gold by carbon as:

$$3C + 6H_2O + 4AuCl_4 \Rightarrow 4Au + 16Cl^- + 3CO_2 + 12H^+$$

Once the gold is deposited onto the carbonaceous material it cannot be recovered by a cyanide leach. Simmons determined in his work that batch tests behaved differently from pilot tests, with the former generally returning higher recoveries. To assist with the process development, semi-continuous test procedures were developed. Various leach conditions were tested for Twin Creeks, with the optimum determined as 225°C, an oxygen overpressure of 700 kPa and a grind size of 80% passing 20 micron.

Autoclave batch testwork for the Macraes Gold Project commenced in June 1997 at Hazen. The results were sufficiently encouraging to proceed to semi-continuous testwork aimed at optimising the conditions for oxidation and ultimately more than 70 semi-continuous tests were completed. In March 1998, 11 continuous pilot runs were completed and the data obtained confirmed the gold recoveries obtained in the semi-continuous tests and established the oxidation kinetics for design purposes. A residence time of 45 minutes was derived from kinetic modelling giving a total autoclave volume of 57 $m^3$. The system was designed to achieve 98% sulfide sulfur oxidation and this is being achieved in practice.

The main reactions involve the oxidation of pyrite and arsenopyrite to produce various iron precipitates and sulfates. All of the carbonates in the concentrate are reacted to form gypsum. It is postulated that a portion of the organic carbon is oxidised to carbon monoxide and carbon dioxide. It is also postulated that passivation of the carbonaceous material occurs under the pressure oxidation conditions. The autoclave is designed for a concentrate sulfur grade of 12.0% and will operate autothermally down to a sulfur grade of 8.0%. Compared with many other gold pressure oxidation circuits, Macraes has a high concentrate grade, high temperature and a short residence time.

The oxidised slurry remains slightly preg-robbing and relatively high carbon concentrations are maintained in the CIL circuit. The gold leach kinetics is rapid, with approximately 93% of the cyanide soluble gold recovered in the first three hours within the CIL circuit. Conventional kinetic modelling of the CIL circuit was not employed in design, as most models do not take into account preg-robbing. The CIL design was therefore based on existing plant data and in-house experience. As the impact of the preg-robbing would not be known until commissioning, the design carbon movement was based on 16 t/day, which is the upper limit of the existing circuit. There are two 2 tonne AARL elution circuits, which are capable of stripping the 16 t/day of loaded carbon.

Stage 1 of the Macraes Recovery Enhancement Project has increased the nominal throughput of the concentrator to 3.8 Mt/y. The pressure oxidation circuit has however been designed for the equivalent of 4.5 Mt/y, this being the upper limit to which the existing concentrator may be expanded. Previously leached concentrate has been stored in a separate tailings dam and this material will be reclaimed using a dredge to supplement the feed to the autoclave. The mass recovery from the concentrator is 3.05 w/w%, producing 13.7 t/h from the mill feed rate of 450 t/h.

The autoclave generates sulfuric acid, which requires neutralisation prior to discharge into the tailings dam. It was established that the flotation tailings had an acid neutralisation capacity greater than three times the acid generating capacity making the tailings highly suitable for residue treatment. A counter-current decantation (CCD) wash circuit cools the oxidised slurry ahead of CIL, and separates acidic liquor for neutralisation with flotation tailings. The CCD overflow contains significant quantities of ferrous and ferric ions in an acid environment making it ideal for complexing cyanide species. This CCD overflow stream is therefore first contacted with CIL tailings in a pipe reactor to precipitate the cyanide as a ferrous complex. The pipe reactor discharges into the final tailings hopper, where the remaining acid is neutralised by the carbonate contained in the flotation tailings. Hydrated lime is also added to this hopper to maintain a pH of 7.0 to 7.5 ahead of discharging into the tailings dam.

The process flowsheet incorporating pressure oxidation into the existing plant is depicted in Figure 1.

## Plant description

Flotation concentrate is thickened, reground (80% passing 18 micron) and washed using the existing equipment; one 6 m thickener, a 900 kW regrind ball mill and one 15 m thickener. Limestone, for pH control in the pressure leach, is added to the regrind mill discharge hopper and intimately mixes with the concentrate. The thickened reground flotation concentrate is stored in existing tanks, which provide a total of 122 hours of autoclave feed surge, prior to pumping to the autoclave.

The autoclave (Figure 2) is 12.6 m overall length by 3.5 m internal diameter and fabricated from 40 mm plate. The autoclave is lined with Koch Pyroflex membrane and two courses of acid resistant bricks. Brick walls divide the autoclave into three compartments, with two agitators in the

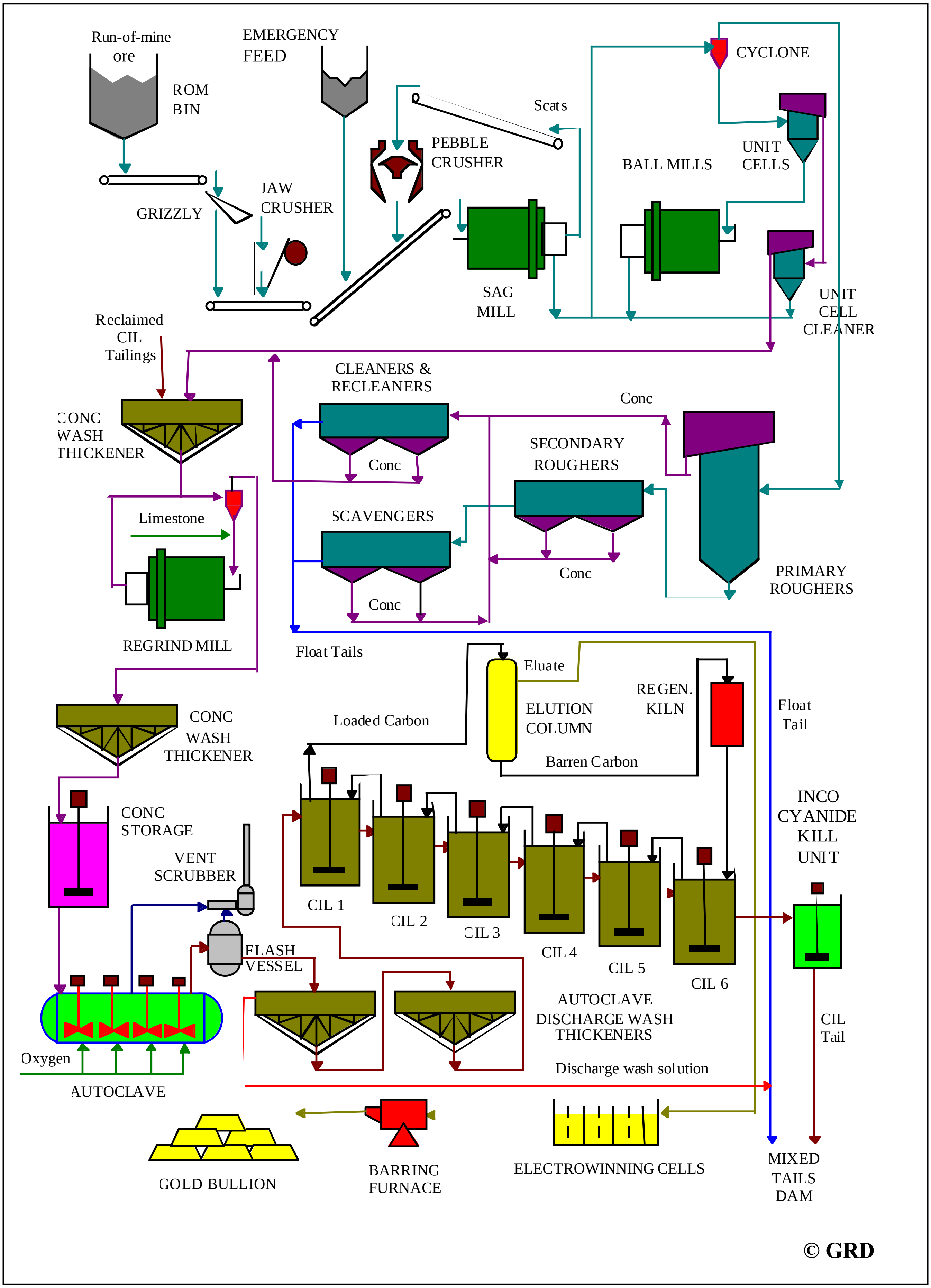


Figure 1. Process flowsheet.

first compartment and a single agitator in each of the other two compartments.

A single sparge line routed centrally to the underside of each agitator injects the necessary services for the autoclave, namely oxygen, steam and quench water. As the first compartment is fitted with two agitators, it is necessary to add quench water and steam to only one of these two agitators. Steam is used for start-up only and in normal operation, oxygen and quench water are added simultaneously to each sparge. Oxygen is not added when steam is being added.

The slurry discharges through a dip pipe drilled to provide a coarse screen. The slurry discharge line has double block valves, a modulating Survivor valve, choke tube and fixed choke. The level is measured via a nucleonic source inserted into a titanium well in the third compartment. The vent gas discharges via a modulating Survivor valve into a blast spool.

The oxidised slurry is let down in a single stage flash vessel having a cylindrical height of 6 m and a diameter of 4.5 m with semi-elliptical ends. The vessel is lined with a Pyroflex membrane and a single course of bricks, except for the bottom end of the vessel, which is lined with silicon-carbide bricks. The flash vessel operates with a shallow slurry pool, with the majority of the impact from the slurry being directed onto a refractory impingement block. Slurry exits the flash vessel from a side discharge nozzle and gravitates to a two stage counter-current wash circuit. Figure 3 shows the letdown equipment, CCD thickeners and vent gas system.

The blast spool is located directly on top of the flash vessel, with the letdown steam combining with the vent gases in the blast spool. This blast spool directs this gaseous stream to a cyclonic wet scrubber, which removes any particulates that may carry over with the vent gas or from the flash vessel. The drain from the scrubber gravitates to the CCD circuit. An oxygen analyser installed on the blast tube measures the oxygen content of the vent gas.

The oxidised slurry is washed in a two stage CCD circuit using process water. The underflow from the second stage is pumped to the first CIL tank. The CCD overflow is neutralised by the flotation tailings and the pH trimmed with lime prior to pumping to the tailings impoundment.

Oxygen is supplied by BOC under a build-own-operate contract. BOC installed a 180 t/day cryogenic plant incorporating an oxygen compressor to provide the necessary gaseous oxygen supply pressure. The oxygen plant includes 170 t of liquid oxygen storage in one 20 t high-pressure tank and two 75 tonne low pressure tanks.

The neutralisation circuit consists of two pipe reactors in series. The CCD overflow and CIL tailings react first to complex the cyanide ahead of the final tailings pipeline, in which the flotation tailings neutralise the remainder of the acid to produce gypsum. The residence time in the pipe reactor is 45 seconds and 5 minutes in the final tailings line. Hydrated lime is added to the final tailings hopper.

The pressure oxidation plant is designed for completely remote operation. Three closed circuit TVs enable operators to monitor equipment remotely. The addition of steam and subsequent flushing of the sparge lines are the only manual tasks required of operators. All other operations are via the DCS in the control room. Hard-wired emergency stops are installed in two locations within the autoclave building and also in the main control room.

The capital cost of the plant was US$10.3 million (NZ$19.8 million) which includes all plant between the battery limits from the autoclave feed pumps to the pressure oxidation CCD circuit and all associated reagents and services. This capital cost includes NZ$1.4 million in spares purchased prior to commissioning and all EPCM costs. The oxygen plant is a "build-own-operate" unit supplied by BOC, with the earthworks and civils being included in the project capital. The cost of other modifications and additions to the Macraes plant as a part of Stage 1 of the Macraes Recovery Enhancement Project are not included in the capital cost stated. Specifically, modifications to the CIL circuit for both leaching and concentrate storage are excluded.

Figure 2. Internal picture of autoclave.

Figure 3. Discharge system and autoclave building.

## Plant commissioning

Safety was of paramount importance and operation of the plant did not commence until all construction, pre-commissioning and commissioning activities had been completed. The operations personnel at Macraes had implemented comprehensive operating and safety procedures for the pressure oxidation plant well ahead of start-up

For hot commissioning, the autoclave was filled with a mixture of sulfuric acid and feed concentrate to provide a "fuel" source to initiate the reaction. The autoclave was heated to 235°C, the maximum design temperature for the vessel, and held at this temperature for 4 hours. This enabled the vessel and associated pipework to be checked at conditions close to design without the introduction of oxygen. All high-pressure flanges were taped and leak checks made using a gas analyser and a detergent spray bottle. The vessel was then allowed to cool to 225°C by reducing the pressure. Feed was introduced at the minimum feed rate and oxygen was introduced into the autoclave. During this first start-up, the first compartment of the autoclave cooled down to 199°C prior to the reaction starting, after, which the autoclave temperature increased to 218°C. From subsequent operating experience, the reaction has started at temperatures as low as 180°C. The design feed rate, albeit at a lower than design sulfur grade, was established within the first 4 hours of operations, with oxidised slurry being pumped to CIL thereafter.

The autoclave was commissioned with low preg-robbing concentrate. This material was fed for the first two weeks and then high preg-robbing concentrate was fed for the next two weeks. For the low preg concentrate, CIL residues down to 1.93 g Au/t, equivalent to a CIL recovery of 94.3%, were achieved. With the changeover to high preg concentrate, recoveries in the low nineties were maintained until a gradual increase in throughput and changes in oxygen addition resulted in a decrease in recovery, with CIL residue grades approaching 4.0 g Au/t. From a review of the operating data, it was determined that the step drop in recovery was associated with the increase in oxygen addition to the first half of the autoclave. Having identified this, the operation was modified and, with further optimisation, CIL recoveries now average above 95.0%, with CIL residue grades in the range of 1.0 to 1.5 g Au/t for both low preg and high preg-robbing concentrates. With little or no difference in the CIL recoveries from the low and high preg-robbing concentrates, trials on blending of the two ore types to flotation commenced in an attempt to obtain more consistent operation of the flotation circuit, by way of constant head grade and ore hardness.

The limestone addition to the feed was restricted initially to ensure autothermal operation. With the limestone being reground with the concentrate, it was anticipated that the amount of limestone required would be less than that estimated from the pilot plant. The autoclave has continued to operate autothermally with sulfide sulfur grades as low as 6.0%. With the lower sulfur grades, the oxidation is noticeably "sluggish" in response to both feed rate and oxygen addition changes.

The first compartment operates at a temperature in the range of 205°C to 220°C, with the other two compartments at 225°C. No quench water is added to the first compartment, with the majority of quench water added to the second compartment. This differs from the design modelling, which estimated the water addition splits as 40/33/27 for the three compartments. The relatively short design residence time, combined with a moderate concentrate grade, ensures that the autoclave is quite responsive to changes in feed rate and oxygen addition. A change in temperature in the first compartment is detected, typically, within 10 to 15 minutes of making an alteration to feed rate or oxygen addition.

The oxygen plant was commissioned by BOC, with oxygen being available one week prior to the start-up of the autoclave. There is no surge capacity between the oxygen compressor and the autoclave, which led to several trips of the compressor and the autoclave until control logic and instrumentation changes were implemented. The pressure control for the liquid oxygen back up used mechanical valves, which could not operate within the pressure tolerances available to ensure uninterrupted oxygen supply. BOC subsequently installed electrically actuated control valves. The oxygen plant is manned five days per week and controlled from Auckland, some 1500 kilometres away, for the remainder of the time. The plant may be run completely remotely, including start-ups.

The design oxygen utilisation was 75% and operating data to date indicates that oxygen utilisation is in the range of 85 to 90%, albeit at lower than design sulfur feed grades. The design sulfur feed rate is 2.20 t S/h. Current operation is approximately 2.00 t S/h.

## Production results

Gold production has steadily improved, as the operating parameters of the autoclave have been refined over the past months. Below is a graph (Figure 4) of the gold recovery in the first three quarters of operation. Prior to the introduction of pressure oxidation gold recovery was around 70%, with the initial start-up the recovery improved to 80% and after 7 months of operation above-design recoveries of plus 84% were achieved.

The autoclave design was based on a nominal milling capacity at the Macraes Gold Project of 4.5 MTPA, but subsequent to

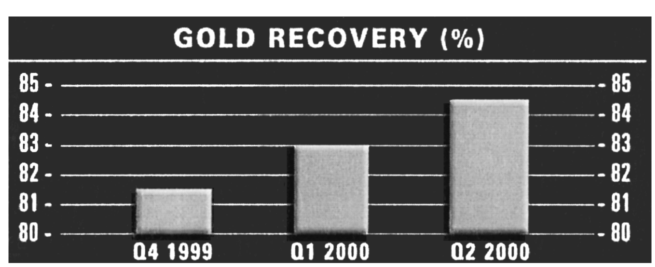


Figure 4. Gold recovery over three quarters since commencement of pressure oxidation.

| Process Parameter | Design | Current Operation | Maximum Operation |
|---|---|---|---|
| Autoclave Capacity | 50 $m^3$ | 57 $m^3$ | 57 $m^3$ |
| Feed Rate | 18.5 t/hr | 23.3 t/hr | 29.2 t/hr |
| Oxygen Plant | 157 t/day | 146 t/day | 180 t/day |
| Concentrate Sulphur Grade | 12% | 8% - 9% | 12% |
| Mechanical Availability | 85% | 90% | 95% |

Table 1. Pressure oxidation circuit process parameters.

finalisation of the autoclave design, key design parameters were changed and with operating experience, operating parameters optimised. A summary of the key parameters is given in Table 1 with current, design and maximum achievable values. The maximum achievable values are the result of the late design changes and operating experience and are the limit of our current understanding of the process to-date, but it is believe these values will be bettered with more operating experience.

The autoclave capacity was increased from 50 $m^3$ to 57 $m^3$, as the initial design had three courses of acid resistant bricks in the internal structure, but after definite analysis of the autoclave two courses was sufficient which resulted in a 14% increase in the autoclave volume. This volume can either be utilised to achieve greater retention time at design feed rate or greater feed rate at design retention time.

The maximum capacity of the feed pumps in their current configuration is 29 t/hr at the operating density of 40% solids. Higher feed rates could be achieved by operating both feed pumps at once, which would provide further potential throughput benefits. The feed rate is also limited by the discharge system, but the design is such that for little expenditure the valve and choke system could be modified to handle up to 40 t/hr.

The oxygen utilisation is in the range of 85 to 90% significantly better than the design of 75%; hence there is more available oxygen for sulphur conversion. The oxygen plant should be the limiting factor in optimising the operation of the pressure oxidation circuit at Macraes. The oxygen plant has a finite oxygen production of 180 t/day and all other parameters should be optimised to fully utilise this capacity. Sulphur oxidation is essentially complete with, typically, 98% of the suflide sulfur oxidised.

Experience has shown the autoclave able to autothermally operate at sulphur grades as low as 6% to 7%. The current operating strategy is to operate at lower than design sulphur grade to slightly improve flotation recovery, as the capacity in other parameters can take up the additional throughput required to operate in this mode.

As operating issues are identified and final solutions put in place availabilities as high as 95% are very achievable, as demonstrated by operations such as Placer's Red Lake operation.

## Conclusions

The Macraes pressure oxidation plant has successfully adopted Newmont's technology to improve recovery from a sulphidic, preg-robbing concentrate. The autoclave operates at the high end of the temperature range for gold autoclaves ie 225$^{o}$C and 3,140 kPa. The capital cost for the pressure oxidation plant was remarkably low at US$10.3 million and the execution phase was completed in a period of 62 weeks. The project was under budget and ahead of schedule.

Gold recovery improved from the traditional 70% to 84%, a 20% increase in gold production.

An integrated client-engineer team approach combined with detailed planning and a proactive attitude resulted in the successful commissioning of this project. Design parameters were quickly achieved and exceeded. Table 2 highlights the significant capacity still inherent and available for further value add.

Mineral processing at Macraes was previously that of a typical gold plant with ore type and grade the key input parameters. However, the introduction of autothermal pressure oxidation has transformed the operation to that of a sulphur plant with sulphur and sulphur/gold ratios now of key importance to process optimisation.

No longer do ore sources get described by ore grade and tonnes but by ultimate flotation concentrate sulphur and gold grade

| Parameter | Proportion of capacity currently utilised |
|---|---|
| Throughput Rate | 80% |
| Oxygen Plant | 81% |
| Sulphur Grade | 71% |
| Mechanical Availability | 95% |

Table 2. Autoclave capacity.

to enable optimising of the mining and processing schedules. The focus on concentrates also unlocks the potential of satellite orebodies requiring greatly reduced capital investment and the transport of acceptable volumes of material to Macraes for further processing. This potential could be realised at projects such as Reefton with the production of a flotation concentrate on site, followed by transport of the concentrate to the autoclave for ultimate gold recovery.

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## References

Simmons, G.L., Baughman, D.R., Gathje, J.C., Oberg, K.C. "Pressure oxidation problems and solutions: Treating carbonaceous gold ores containing trace amounts of chlorine (halogens)." Mining Engineering, January 1998, pp 69-73.

Simmons, G.L. "Pressure oxidation process development for treating refractory carbonaceous ores at Twin Creeks." Randol Gold Forum, 1996.

Avraamides, J., Hefter, G., Budiselic, C. "The uptake of chloride solutions by activated carbon." Bulletin Processing Australasia, November 1995, pp 59-62.

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