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DRY GRINDING AT BARRICK GOLDSTRIKE'S ROASTER FACILITY

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ABSTRACT

The new roasting facility at Barrick's Goldstrike Mine in Nevada, U.S.A. was developed to process 12,000 tons per day of refractory gold ore. The process consists of crushing, dry grinding, roasting, extensive gas purification, calcine quenching, leaching in the presence of activated carbon and cyanide destruction. The new plant is integrated into the existing Goldstrike property treating ore from both open pit and underground sources.

The process design, procurement, construction and commissioning of the roaster facility was performed successfully over a 3½ year period with peaks of 400 engineering personnel and 950 construction personnel supporting the project. The US$330 million project was completed

ahead of schedule and under budget. The commissioning was well planned and proceeded smoothly through a rapid start-up to achieve all primary goals within three months of the start of processing of ore.

The oxygenated roasters are fed by two Krupp Polysius, double rotator, dry grinding mills. This paper describes the engineering, construction and operation of these double rotator circuits.

ROASTER PROJECT (1997 – 2000)

Background

As early as 1992, Barrick's Goldstrike Mine, located north of Carlin, Nevada had indications of the ore becoming increasingly carbonaceous in nature. As the open pit and underground exploration programs proceeded to step out over the years that followed, the accumulated amount of carbonaceous refractory ore had become significant. By 1997, 29 million tons of double refractory carbonaceous ore containing an estimated 11.6 million ounces of gold had been identified. By 2000 the resource had increased to 14.3 million ounces.

To maintain annual gold production from the property at about 2 million ounces, a processing alternative to treat the double refractory carbonaceous ore had to be operational by 2000. Following an extensive investigation to determine cost effective methods to process and recover the carbonaceous gold reserves, the decision was made in favor of whole ore roasting. The process plant selected was a 12,000 tons/day whole ore roasting plant in an oxygen enriched environment and would be in addition to the existing 17,500 tons/day Goldstrike autoclave facility. Carbonaceous matter decreases gold recovery, by preg robbing in the down stream cyanidation process, if it is not destroyed or passivated.

The stand alone roaster facility, located on the North Block area of the Goldstrike property, comprises crushing, dry grinding, roasting, neutralization, gas handling, carbon-in-leach circuits, cyanide destruction and a tailings pumping system to the existing tailings disposal pond. The oxygen for the roasting process is provided from a 1,100 ton per day low pressure air separation plant. The completed project was engineered by Hatch Associates and had a budget of $330 million dollars.

Various processing alternatives were considered and studied by Barrick to effectively recover this gold resource. The ammonium thiosulphate

(ATS) process was seriously considered a likely option. However, the fact that a limited amount of testwork had been done on the process, combined with time constraints, disqualified this option for the application.

Roasting of carbonaceous ores is a recognized process and is technically sound and proven. This is exemplified by the Independence mining operation at Jerritt Canyon north of Elko, Nevada where the oxygen enriched Freeport McMoRan (FMC) process for the fluid-bed roasting of whole ores is used. Test work was performed on the Goldstrike ores by Hazen Research in Denver, Colorado under the direction of Barrick and in conjunction with Crescent Technologies Inc., New Orleans, Louisiana. This group is an engineering firm associated with FMC and knowledgeable in the oxygen enriched roasting technology. To minimize operating and capital costs, Krupp Polysius double rotator dry grinding was chosen to feed the roasters.

The metallurgical test results were reviewed and a conceptual design was developed in May of 1997. Following a more detailed review of the process design, a risk analysis and a financial and business evaluation, a recommendation was made to Barrick's Board of Directors to proceed using double rotator grinding and oxygenated roaster technologies. The project was approved in September 1997.

Project definition began in early 1996 and proceeded through basic and detailed engineering with construction beginning in October 1998. The first ore was processed in March 2000, with full nameplate throughput of 12,000 tpd achieved in July 2000. Table 1 page I-177 presents a summary of the design criteria. Table 2 page I-177 and Table 3 page I-178 refer to various engineering and construction highlights.

PROCESSING

Process Selection

Tests conducted on the carbonaceous material indicated the ore is strongly preg-robbing as defined by the standard preg-rob test and Barrick Goldstrike Mines Inc. (BGMI) bleach leach procedures. The BGMI bleach leach test is considered a reasonable indicator of the preg-robbing nature of the ore.

Table 1: Basis for Design

Description	Design Criteria
Plant Capacity	12,000 TPD average
Grinding Availability	90%
Gyratory Crusher	1– 500 hp
Vibrating Screen	1 – 8' X 24'
Cone Crusher	1 – 800 hp
Grinding Mills – Double Rotator	2 in parallel – 10,000 hp each
Roasters and Hot Gas Train	2 in parallel
Roaster Gas Train – Cold Section	1
Neutralization Tanks	2 in series
Thickener	1 – 110 foot
CIL Tanks	6 in series
Leach Retention	16 hrs.
Cyanide Destruction	SO_2/Air - 1 tank
Capital Cost – budget	$330,000,000

Table 2: Engineering and Milestones

Date	Activity	Comments
January – June '97	Feasibility study	Preliminary plant design, preliminary capital and operating cost estimates, reserve definition and throughput selection, financial evaluation.
June '97	Presentation to Barrick management	Approval given for selection of 12,000 t/d, double rotator grinding and two stage oxygenated roasting technologies.
July – December '97	Project definition at Hatch (Basic Engineering)	Number of trains, type of gas handling equipment and size of oxygen plant optimized.
August '97	Air Quality permit submitted	Critical path activity.
January '98	Detailed engineering at Hatch	Definitive estimate prepared and production of detailed drawings.
October 1, 1998	Air Quality Permit received	Commence construction

Table 3
Project Statistics

Item	Units	Quantities
Excavation	Cu. Yds.	1,038,000
Backfill	Cu. Yds.	228,000
Concrete	Cu. Yds.	48,300
Steel	Tons	12,245
Piping	Miles	24
Electrical cable	Ft	1,000,000
Connected HP	HP	77,363
Total motors	Number	623
Construction manpower	Hours	1,250,000
Engineering manpower	Hours	590,000
Commence construction	Oct. 01, 1998	
Start first mill	Mar. 03, 2000	17 months
Essentially complete	May 31, 2000	20 months

Further mineralogical evaluations found the strongly carbonaceous matter to have a small crystalline structure. All the carbonaceous material types analyzed from Goldstrike have oxygen to carbon ratios of less than 0.6, which indicates an anthracite grade material or higher.

Because the gold encapsulating sulfides are extremely fine grained there was no economic opportunity for flotation upgrade and accordingly, dry grinding and whole ore oxygenated-roasting was determined to be the appropriate method. The overall process flowsheet is shown in Figure 1.

The ore contains about 1.9% sulfide sulfur and about 1.5% total carbonaceous matter (TCM) with calculated blended heat values between 200 and 300 BTUs per pound. This is insufficient to evaporate any moisture in the roaster feed and dry grinding was chosen accordingly (refer to Figure 2, page I-180).

Process Description

The choice of Krupp Polysius double rotator mills was deemed to have the least risk and the decision then became whether the plant should utilize two 10,000 hp mills in parallel configuration or a single 18,750 hp machine. The largest in operation at that time was 15,000 hp and it was considered too large a scale-up. Accordingly, two 10,000 hp mills (refer to Figure 3 page I-181) were chosen to enhance roaster availability and assure more flexibility for ore hardness variations. Each grinding circuit incorporates a bucket elevator, static classifier and dynamic classifier with product recovery baghouses dedicated to each classifier.

Figure 1: Overall Process

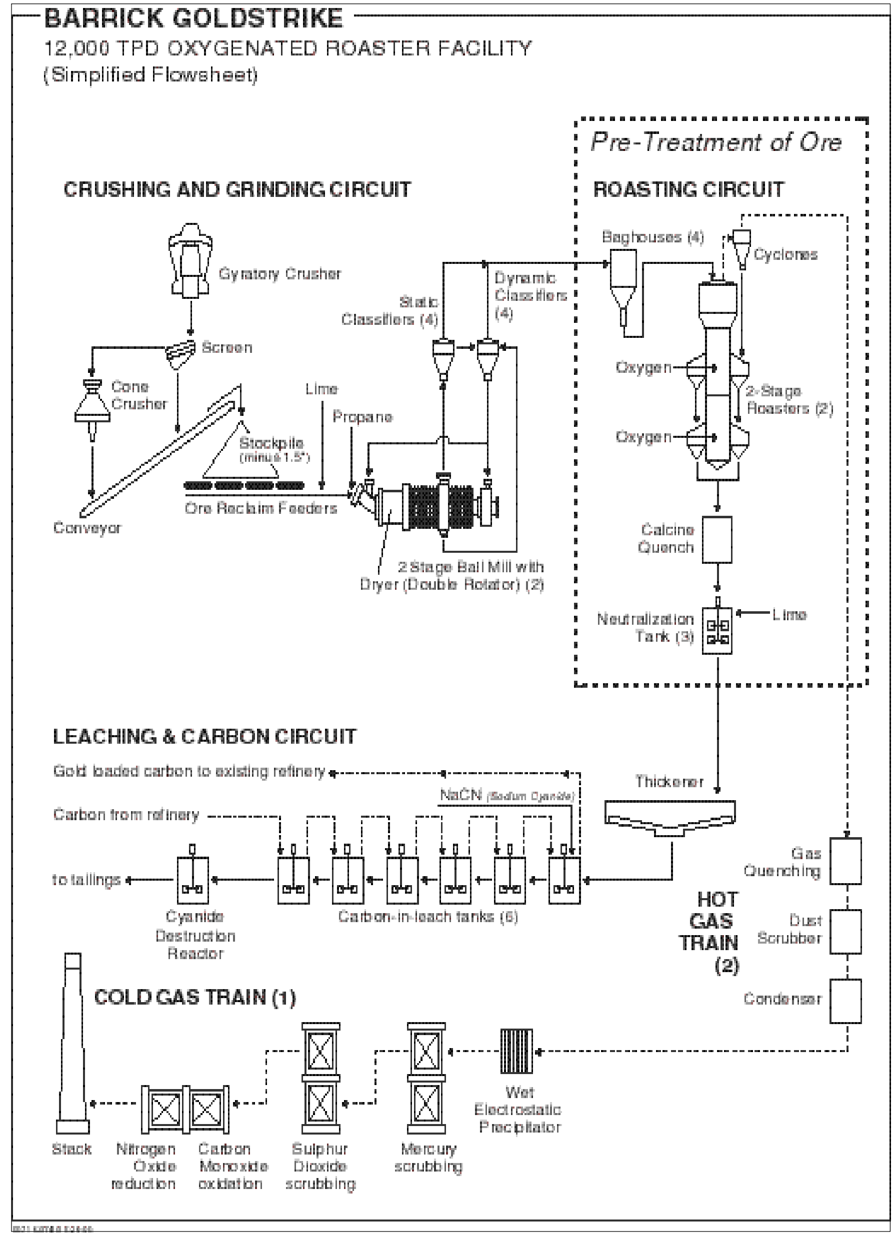
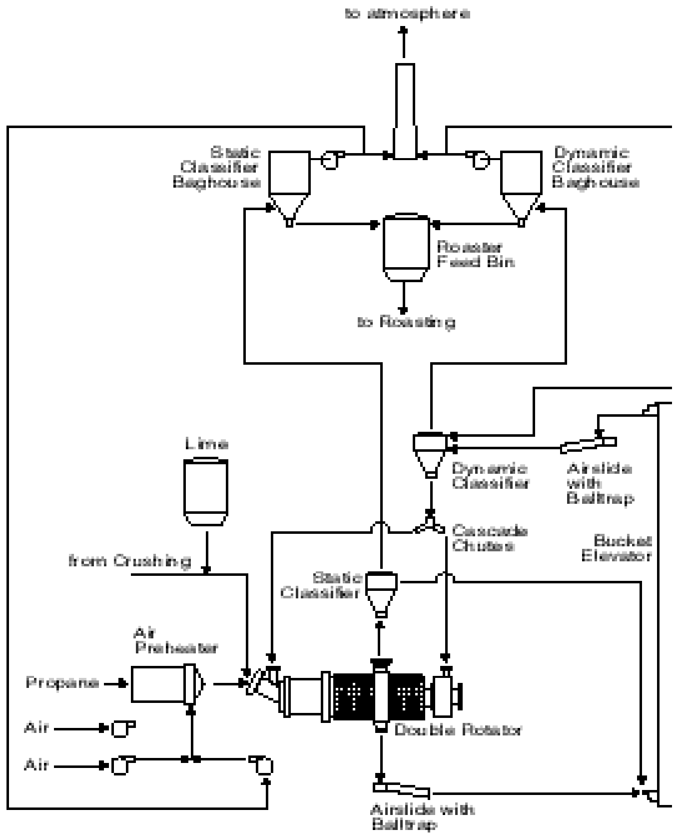


Figure 2: Dry Grinding Flowsheet



Operating Cost Comparison – Dry Versus Wet

The Goldstrike property operates both a wet mill and a dry mill grinding circuit on similar ore. The latter part of the year 2000 provided an opportunity to compare the cost of operation of the two circuits on a per ton basis. Table 4 page I-181 and Table 5 page I-182 show this comparison. Note that the electrical power costs and ball consumptions have been adjusted in the wet mill to compensate for finer finished products. Costs are very similar. The higher power consumption in the dry mills is related mainly to the requirement for large fans, consuming about 10kWh per ton.

Figure 3: Double Rotator Grinding Mill

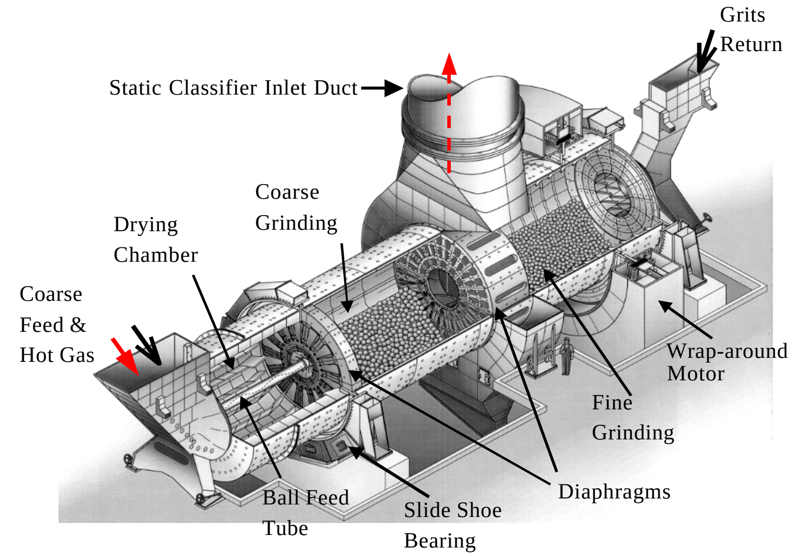


Table 4: Last Half, Year 2000

	Wet Grinding	Adjusted Wet	Dry Grinding
Tons Treated	2,765,869	2,765,869	227,491
F80µ	55,900	55,900	19,050
P80µ	135	74	74
Wi (avg.) kWh/t	17.2	17.2	16.9
Work Required kWh/t	16.1	22.6	39.7

Downstream Systems

The two roasters are each two stage vertical units that operate in an enriched oxygen atmosphere at a temperature of 1025 degrees F in the primary stage and up to 1050 degrees F in the second stage. The ores are oxidized by the exothermic reaction. The sulphides and carbonaceous materials are oxidized to gaseous SO_2 and CO. The gold bearing solids are then quenched and the slurry pumped to the neutralization circuit, mixed with lime to raise the pH of the slurry to 9.5 and thickened.

Table 5: Operating Cost US$/t

	Wet Grinding	Adjusted Wet	Dry Grinding
Grinding Media	0.81	1.14	0.37
Electrical Power	0.72	1.02	1.79
Grind Labor	0.79	0.79	0.71
Grind Consumables	0.02	0.02	0.08
Grind Overhead	0.01	0.01	0.01
Allocations	0.04	0.04	0.05
Grind Liners/Repair Parts, etc.	1.46	1.45	1.18
Fuel for Ore Drying	0	0	0.92
SBC Crushing	0.43	0.43	0
Total Grinding Costs	**4.28**	**4.90**	**5.11**
Crushing	0.46	0.46	0.46
Total Comminution Costs	**4.74**	**5.35**	**5.57**

The gases from the roaster circuit (refer to Figure 1) require extensive cleaning to remove contaminants. This is done in a single gas handling train that handles all the gases from the roaster circuits. The gases initially pass through a wet electrostatic precipitator to remove micron-sized elemental mercury and SO_3 particles. Then the gases are scrubbed to remove gaseous mercury using the Calomel process. Next, sulphur dioxide (SO_2) is removed using soda ash scrubbers. Carbon monoxide incineration and nitrogen oxide reduction are the last steps to ensure clean gases are released. Oxygen is required for the roasting process. A 1,100 tons/day Air Products low pressure oxygen plant supplies this to the roasters.

Cyanidation occurs in a counter-current carbon-in-leach configuration that has become a standard for Barrick's plants. It offers optimum recovery, reasonable operating cost and minimizes the probability of operator error relative to CIP technologies. A series of six tanks was chosen for the roaster facility. The loaded carbon is shipped to the existing autoclave facility for gold stripping and refining and reactivated carbon is returned. Rotary swept screens from Kemix of South Africa were chosen for interstage carbon retention and are operating very well.

Tails from the sixth tank are detoxified of residual cyanide using the INCO SO_2/Air process. The reactant of choice is ammonium bisulfite (ABS) due to its benign nature and ease of handling. Weak acid dissociable cyanide levels of less than 2 ppm are achieved with copper sulfate added at 5 ppm as a catalyst. The detoxified tails are pumped

through three stages of hard metal centrifugal pumps to the existing Goldstrike tailings pond approximately 350 feet above the roaster facility. Two tailings lines are in service with a standby spare. Tailings lines are steel clad HDPE leaving the roaster facility to handle the pump discharge pressure of 310 psi. At the point where pressure drops below 125 psi the line reverts to HDPE. The tailings pond relies on deposition, water management and evaporation to maintain a zero discharge status.

DESIGN CONSIDERATIONS

There is a range of grinding systems available for the comminution of carbonaceous gold ore. The double rotator system was selected since it provided optimum conditions related to the characteristics of the Goldstrike ore being:

- moisture content up to 9%
- limited hot gas temperature
- system compatibility with sticky ore feed components such as clays

For drying of the ore, mills need to be ventilated. The amount of air required is a function of the hot gases needed for drying and the additional air needed for the transport of ground ore within the system. When velocities and air volumes are too low, the mills show a tendency to overgrind the ore or overload the plant. High velocities and air volumes result in inefficient grinding and excessive wear. Additionally the grinding system selected has an influence on the air volumes and air speeds within the circuit.

The best compromise to cover these points is the center-discharge mill, the double rotator (refer to Figures 2, 3 & 4).

The moist feed material is fed to the drying chamber where the ore is dried to a moisture content of 1 to 2 %. Thus a detrimental effect of the feed moisture content on the grinding efficiency is avoided. An intermediate diaphragm discharges the material into the first or coarse grinding compartment. The removal of the residual water is effected in the grinding compartment. After the coarse grinding takes place, the material leaves the first grinding compartment through the central discharge of the mill, avoiding overgrinding to the greatest possible extent. The ore is then transported to the dynamic separator by means of a bucket elevator.

The gases for drying also leave the mill via the central discharge. Material which is airswept by the mill venting gases is separated in a static separator. The product is collected in a baghouse filter unit and reports to the roaster feed bin. The coarse part of the airborne product or grits being classified in the static separator reports to the dynamic separator through the bucket elevator.

The airflow can be adjusted to the drying requirements without having a detrimental effect on the grinding taking place in the first grinding compartment. In order to avoid excessive oxidation of the sulfides contained in the ore the hot gas temperature needs to be limited. This again requires high air flows for the drying. Here again the double rotator concept, especially in conjunction with the shell supported mill design, allows handling of high gas volumes required inside the mill. The second or fine grinding compartment receives the rejects from the dynamic separator. Since drying is not required in the second compartment, the airflow can be set so that the optimum grinding conditions for fine grinding are achieved.

This grinding system is the one that is the most appropriate for ores with high wear characteristics. The product of a double rotator plant itself shows a steep particle size distribution. It minimizes overgrinding since the material that has undergone the coarse grinding reports immediately to the separator and removes the finish ground product.

Since the grinding mill capacity has to match the roaster throughput and compensate for varying hardness of the ore, the power draw of the double rotator plant can be adjusted either by changing the mill speed between 60 and 80 % of critical or by changing the ball charge level within the two compartments. The double rotator is 5.8m in diameter by 12.75m effective grinding length, with a 10,000 HP wrap around ABB motor. When the softer ores are encountered a milling capacity of more than 320 stph has been achieved.

The double rotator technology was selected as dry grinding removes the requirement for filtration after wet grinding, thereby reducing costs.

The dry grinding plant (refer to Figure 4) was successfully started up in March 2000.

Figure 4: Double Rotator

RESULTS

The plant has come up to operating capacity very smoothly, with full production achieved within one hour of starting the second grinding mill. The average daily production exceeded the design in the third full month of production (refer to Table 6).

Table 6: Production Statistics

Month	Average tpd Processed	Average Grinding Mill Availability (%)	Average Roaster Availability (%)
March 2000	2,000	75.0	60.0
2^{nd} Quarter	8.973	74.3	84.6
3^{rd} Quarter	12,723	87.4	95.3
4^{th} Quarter*	11,470	81.0	82.4

* Downtime principally associated with Oxygen Plant availability. Mill and roaster availability would have been approximately 90%.

To date operating costs have been quite favorable when compared to the forecast developed during engineering. Operating costs for the roaster facility including crushing through carbon handling and overhead were projected at $16.00 per ton. Table 7 page I-186 reviews the operating costs through December 2000.

The major deviations between budget and actual operating costs have been in the areas of power, propane and maintenance costs.

Table 7: Operating Costs

Month	Costs $/ton
May	13.44
June	9.74
July	12.66
August	11.40
September	12.47
October	14.24
November	12.58
December	15.00

ASSURING SUCCESS

The relatively smooth commissioning and start up of the plant can be attributed to several factors.

- The operating superintendents and an electrical/instrumentation engineer were deeply involved in the design and detailing of the plant from the project start. They were given a clear mandate for a "clean plant design".
- The plant relies heavily on instrumentation and process control. Accordingly, the development of the process control strategy was well underway before the equipment orders were placed.
- The commissioning plan was developed well ahead of the completion of start up and provided guidance to the order of completion for the various circuits.
- The operating and maintenance crews were brought in several months in advance of start up and through their existing knowledge and additional specific training were familiar with the plant before it was completed.
- The maintenance crews monitored the installation of every piece of equipment. They consistently checked the alignment and vibration baselines of all rotating devices. This was very helpful in identifying misalignments and "soft foot" characteristics of some of the installations. This is particularly important when more than 1100 motors are to be started. These issues were largely resolved prior to start up.

CONCLUSIONS

The dry grinding circuit at the new Goldstrike roaster has been successfully designed, commissioned and operated. Design tonnage was reached within a few months of the official start date. The project was completed under budget and ahead of schedule. The advance efforts in defining the project, developing a clearly articulated process control strategy and implementing it far out-weighed any added costs.

Although several challenges were encountered during the commissioning and early months of operation, the project has been a true success. The plant runs consistently and is relatively easy to keep clean. Maintenance is keeping pace with the issues and improvements are noted on a daily basis.

ACKNOWLEDGMENTS

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