Chapter 18

Laboratories and Pilot Plants

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18.1 Introduction

It is generally accepted in the gold mining industry in South Africa that efficient, ongoing metallurgical support should be provided for plant operations. At the same time, it is essential that research be undertaken to improve current process steps and to develop new techniques. The recent progress in the use of carbon-in-pulp (CIP) technology is a prime example of the latter.

The discussion in this chapter is concerned with metallurgical test work and evaluation, rather than with analytical chemistry and assaying. The latter subjects are dealt with comprehensively in a companion volume to this book, entitled Assay and Analytical Practice in the South African Mining Industry (Lenahan and Murray-Smith, 1986). Metallurgical laboratories may be conveniently divided into two types, the first of which are control or support laboratories which are situated on mines, and are largely concerned with day-to-day operations. These on-mine laboratories vary considerably in size and scope, as later discussion will show. The second are the laboratories operated by the mining houses or groups. Longer-term research and the investigation of new concepts are carried out in the group laboratories of most of the major mining houses in South Africa. Five of the six of these do in fact run group laboratories; Anglo American Research Laboratories (AARL) is the largest, and primarily dedicated to research on gold and uranium extraction. Eighty-four people are employed in the metallurgical section of this laboratory alone. The smallest of the group laboratories is that operated by Anglovaal with a total staff of about forty.

New work in research on local ores is carried out at Mintek, The Council for Mineral Technology, which although largely funded by the central government, carries out investigational programmes for the Chamber of Mines, groups and individual mines. Research at Mintek in the national interest is carried out free of charge, and the cost of other research is proportional to its confidentiality. It should be pointed out that Mintek, and most of the laboratories of the major groups, are not only concerned with the metallurgy of gold, but their interests cover a wide range of work on other precious metals such as platinum, as well as base metals and industrial minerals. For example, a considerable amount of research is carried out on the flotation and smelting of platinum group elements at J.C.I.’s group laboratory, as well as on subsequent processing steps. Gold Fields’ laboratory is directly concerned with operations at Zincor (Zinc Corporation of South Africa Ltd).
In addition to the facilities which have been mentioned, certain local equipment contractors and reagent suppliers run their own laboratories, and can provide information on diverse matters such as the effect of flocculants on pulp filtration, and CIP circuit design. Some work is also carried on at the universities; for example, one of them is at present carrying out, on a contract basis, a study on the use of bioleaching to enhance gold extraction from refractory ores in subsequent cyanidation. It is not the intention in this chapter to consider such laboratories, and the discussion will be restricted to the control or support laboratories on gold mines and the research at group laboratories and Mintek.

The second topic of interest is the operation of pilot plants. The main reasons for using a pilot plant to test a new process or unit operation are to evaluate the risks inherent in a new process and to operate in a continuous processing mode, which is usually not possible in bench-scale tests since these are normally done on a batch basis. Continuous operation in a pilot plant allows a study to be made of the effect of recycled streams on the overall process, and shows the build-up of impurities in the overall circuit. Differences in water qualities in bench-scale test work and in the pilot-scale operation are also important. It is usually essential to pilot a process to provide reliable design data for the full-scale plant and to produce the necessary information for a feasibility study. Another reason is to convince management that a novel process is feasible; a successful pilot plant is usually the best way of achieving this objective.

As would be expected, pilot plants, even when operated on gold mines, are usually the responsibility of the research, rather than the service, laboratories. Some overlapping in staffing can exist however, particularly if shift operation is necessary. The advantages that accrue when a pilot plant is operated at a mine relate particularly to the availability of typical feedstocks, taken as bleed streams in the full-scale plant. In certain cases, for example, when it is not necessary to have a continuous flow of typical feed into a pilot plant, pilot-scale research can be undertaken more conveniently at the group laboratory, where support facilities are usually more comprehensive. The siting of a pilot plant therefore depends on the nature of the research that is being undertaken.

It has been pointed out that the main gold-rich regions in South Africa are highly concentrated in the Witwatersrand area or its vicinity, which makes for a healthy interaction between research organizations and the mining industry. This close location assists research, in contrast to the situation in the United States, Canada, Australia and the Soviet Union, where gold-rich regions can be thousands of kilometres apart.

The ore of the Transvaal and Free State mines is generally very amenable to processing by cyanidation. It is nevertheless remarkable how much effort has been applied in recent years to research on the cyanidation process, which has been used since before the end of the nineteenth century, and which was not the subject of any significant efforts in research and development until about the mid 1970's. While the annual output from amenable gold sources comprises approximately 99% of the total South African production, never-
theless significant amounts of gold are obtained from refractory deposits in the eastern Transvaal. Obviously, the amount of research and development that is applied to these reserves is disproportionate to their economic importance but relates rather to the difficulties that are experienced in extracting gold from them. A very minor amount of gold is recovered from anode slimes in copper refining, as well as from the two platinum group metal refineries in South Africa. These sources are considered to be outside the scope of this discussion.

18.2 Characteristics of Metallurgical Laboratories of the Gold Mining Industry

In this section, the layouts of both on-mine and group laboratories are dealt with, together with their equipment and their staffing, followed by the functions which they perform.

18.2.1 On-mine laboratories

18.2.1.1 Layout

The scope of the laboratories situated at gold mines in South Africa ranges from the simplest grading room to extensive, well-equipped facilities. On some of the smaller mines, the metallurgical testing function is assumed by the assay offices.

In the Gencor group all routine analytical work for process control is undertaken by assay laboratories on each mine. Metallurgical process development work is undertaken by a Metallurgical Services Department with area offices in Springs serving group mines in the central and eastern Transvaal, and in Stilfontein serving the western Transvaal and the Orange Free State.

The Anglo American group has a very large operation at Vaal Reefs and at the Joint Metallurgical Scheme in the Orange Free State. The scale of the metallurgical test facilities that are available at these locations falls between those found in group and on-mine laboratories.

The advent of the East Rand Gold and Uranium Company Limited introduced new concepts into gold metallurgy on the Witwatersrand. Here the unit operations include flotation, roasting and CIP, all on a vast scale. They do not include crushing or grinding. The metallurgical laboratory that deals with plant operation is also more elaborate than that provided on the average mine. Rand Mines Milling and Mining have recently started treating tailings dumps, but at the time of writing the facilities for on-site metallurgical testwork were still quite limited.

Dump leaching in 1985 is the preserve of quite small operations, usually less than 50 000 t/month. It may be expected that this method of gold recovery will be practised on an increasing scale. In the present small operations, facilities for testwork are extremely few and far between, and all these operations obviously need better provision than they have at present.

The smaller the group that controls a mine the greater will be the objection to having specialized manpower and equipment spread in on-site laboratories, so that the central or group laboratory will tend to take over
more of the work of the on-mine laboratory.

A typical, well-appointed metallurgical laboratory on the mine will consist of a grading room, a small laboratory where shift titrations and other determinations such as pH measurements can be carried out, and a separate room for an atomic absorption analyser, used mainly for the rapid determination of gold in solution. Adequate facilities for sample preparation will be provided, and entirely separate locations for high and low grade materials will be essential, in order to prevent contamination. Provision will be made not only for preparing samples for the assay office, but also for moisture determinations necessary for evaluation purposes. The floors in both the high and low grade sample preparation rooms should be carefully cambered to drainage systems, so that high standards of housekeeping can be maintained.

Adequate provision in the form of racks for the storage of samples should be provided. The importance of the provision of adequate storage facilities in an on-mine service laboratory cannot be overemphasized, and generally at least three separate storerooms should be available. One of these will be used to store laboratory glassware and reagents, as well as diverse items such as assorted filter papers and retort stands. An adequate stock of spare sieves used for grading analyses should be on hand, stored separately with calibrated sub-master screens. Specialized equipment of a non-routine nature can well be stored in this area, glass electrodes for pH meters and spare hollow cathode lamps for the atomic absorption analyser being examples. In a third storage area, equipment of a more robust type as used in sample preparation would be found. This store will contain enamel buckets,
aluminium pans and the like. It will of course be necessary to provide an office for the use of the person in charge of the metallurgical laboratory where managerial functions can be carried out. Provision for basic toilet facilities will also be necessary for the laboratory staff.

Facilities at on-mine metallurgical laboratories therefore depend on a number of factors, not least being the philosophy that exists among senior management in each of the six major mining houses. Obviously, it is to be expected that greater emphasis will be placed on on-mine facilities if group laboratory facilities are either non-existent or limited, and vice versa. Drawings of what is considered to be a well-appointed on-mine metallurgical laboratory appear in Figures 18.1 and 18.2.

18.2.1.2 Equipment
It is impractical to provide an equipment list that will suit the needs of every on-mine laboratory, for as has already been stressed, such laboratories vary widely in scope. However, the following is an inventory for what is considered to be a well-equipped facility:

- Controlled temperature baths.
- Jaw crusher.
- Rolls for grinding tests.
- Rod mills.
- Full range of sieves including spares.
- Sub-master set of sieves.
- Sample splitters.
- Rotap-type machine for screening tests.
- Laboratory flotation machine.
- Range of balances.
- Bulk scale.
- Drying oven.
- Microwave oven.
- Thermometers.
- Equipment for the preparation of all types of samples, both high and low grade.
- Dust extraction facilities.
- Pressure filters.
- Rolling bottle assembly.
- Oxygen measurement equipment.
- Facilities for CIP efficiency determination and carbon elution efficiency determination.
- Vacuum filters.
- Hot plates.
- A range of glassware: beakers, filter funnels, measuring cylinders, Buchner funnels and flasks, burettes, pipettes, desiccators, etc.
- Buckets.
- Pressure pumps.
- Vacuum pumps.
Figure 18.2. Layout of a metallurgical research laboratory.

Room 1 Wet laboratory
Room 2 Dry laboratory
Room 3 Balance room
Room 4 Research officer's office
Room 5 Assistants' office

A Wet floor area
B Small James table
BC Bench with cupboard below
C Heated rolls
CTB Concrete-topped bench
D Filter presses
E Sink
F Wet grading spray
G Flotation cell
H Drying oven
I Vented sample preparation cupboard
J Sieve shaker
K Storage shelves
L Work bench
M Variable-speed rolls
N Pulp density balance
O Cupboard
P Balance
Q Safe
R Desk
S Scale
T Drawing desk
V Vacuum manifold
W Water distiller
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Chemical reagents.
PH and redox buffer solution and meters.
Cleaning equipment.
Miscellaneous items: filter papers, filter stands, retort stands, stationery, protective clothing, etc.
First aid equipment, including the provision of a cyanide antidote.
A desk-top computer for the evaluation of results would be desirable.

18.2.1.3 Functions
The list that follows indicates typical examples of testwork that is carried out in mine laboratories:

- Laboratory milling and gold leaching using a batch rod mill followed by cyanidation in bottles on rolls.
- Cyanidation tests for gold to determine the effects of leaching time and reagent concentration.
- Filtration tests to determine filtration rates and to compare different types of filter cloth and the effect of different flocculants.
- Grading tests and the determination of gold in the different size fractions.
- Settling tests to measure thickener efficiencies and the effect of feed pulp densities, fineness of grind and flocculant additions.
- Optimization of sample preparation procedures.
- The determination of the percentage of moisture in various samples.
- The determination of the specific gravities of various pulp samples.
- Preparation of all routine samples for chemical analysis and assaying.
- Preparation of composite samples.
- The calibration of mass flowmeters.
- The development of procedures for plant control.
- Trouble-shooting investigations.
- Flotation testwork.
- The determination of carbon loading and elution parameters.
- Pollution control.
- Tracer tests to identify short-circuiting in leaching operations.

18.2.1.4 Staffing
On-mine laboratories are staffed by plant metallurgists as well as laboratory assistants and labourers. The person in charge is usually appointed on a permanent basis, but employment of other staff is much more flexible, depending on needs as they occur. If operational problems were to arise, other plant metallurgists and assistants could be allocated to help in the laboratory to find solutions. The commissioning of new equipment can place a greater load on a laboratory; an evaluation or sampling exercise can make similar demands.
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When possible, personnel participating in training schemes can be usefully employed in the laboratories. Last but not least, representatives of companies who are engaged in testwork to promote their products can provide very valuable information at little or no cost.

It would be expected that the supervisors of such laboratories would be qualified, being either diplomates or graduates. The plant metallurgists who make use of the facilities would be similarly qualified. Recent graduates and diplomates in training schemes would gain valuable experience at such on-mine facilities.

18.2.1.5 Comment
Some of the advantages in carrying out on-mine metallurgical research are:

(a) Fresh ore pulp is readily available, and this is particularly important where flotation is involved, since ageing alters flotation response.
(b) A quick response to operational demands and better communication are possible.
(c) Testwork is conducted under actual conditions relative to water purity.

Disadvantages are:

(a) The central laboratory is sometimes seen as a competitor, and on-plant metallurgists may sometimes be diverted to the on-mine laboratory to perform long-term research. This may lead to deteriorating plant operation and a lack of attention to urgent plant problems.
(b) The effectiveness of group resources in technical manpower and equipment may be diluted.

18.2.2 Group Laboratories
It was pointed out in the introduction that five of the six large mining houses in South Africa find it worthwhile to finance their own group laboratories to carry out not only research investigations, but also testwork of a routine nature to back up metallurgical operations at their mines. The confidentiality that is possible in in-house projects is an attractive feature of this system. The group laboratory provides a pool of expertise, made up of graduate metallurgists, chemical engineers, chemists and mineralogists as well as diplomates in some or all of these fields. Mineralogists provide a service to mining and prospecting as well. The combined knowledge in group laboratories of the metallurgical operations in each group has been built up over many years, as the staff turnover is usually less in the stable conditions that exist in these organizations than in metallurgical plants where transfers are common. The staff at group laboratories are usually part of head office staffs, so that the advantages that are consequently enjoyed make for this stability.

In addition to graduates and diplomates who lead the project teams and who direct work in metallurgy, analytical chemistry and mineralogy, these laboratories employ matriculated laboratory assistants and technicians as well as tradesmen, administrative staff and labourers. A great emphasis is placed
on training, and matriculants are encouraged to study further to improve
their qualifications. The director or manager of a group laboratory usually
reports directly to the Chief Consulting Metallurgist, and ideally, regular
meetings are held with him together with those consultants and assistant con-
sultants interested in particular projects. Metallurgical managers and other
senior plant personnel would attend these meetings as well. Project research
and testwork is the subject of regular reporting, when the overall status of
the work that is being undertaken is featured at regular intervals in sum-
marized form. Technical aspects are not the only reported activity; it is ob-
viously necessary to maintain strict financial control, and the finance depart-
ments at the head offices are regularly advised of the state of annual budgets.

The way in which a group laboratory is financed is a vexed problem.
Costs are usually shared between the group mines and head office. In South
African tax law there is an incentive to carry out research and development,
so that the direct cost of operating a group laboratory is considerably less
than that indicated by its annual budget. A workable financing method is
to ensure that the operations in the group that make use of the facilities of
a group laboratory contribute in a reasonable way, perhaps on the basis of
before-tax profit. It would then be up to each mine to ensure that it gets
its proper share of the group laboratory’s output in proportion to its con-
tribution. Priorities would be decided by the Chief Consulting Metallurgist,
particularly if a number of metals or minerals were mined in the group. Alter-
natively, it could be the responsibility of the group laboratory to promote
its interests by demonstrating success in certain projects. However, by the
very nature of research, some projects will fail. For this reason, the good-
will of the sponsors must be maintained by service work which may be of
a routine nature, but best provided by a central facility.

The titles of the different sections that make up the laboratory vary from
group to group, but in most cases they accord with the disciplines of ore-
dressing, hydrometallurgy, analytical chemistry and mineralogy. Pyro-
metallurgy is important at some of the group laboratories but is not included
here since, in relation to gold, it is not the subject of any significant research
effort at the present time. Obviously, staff are involved in administration,
and workshops and maintenance are essential. Without exception, pilot-plant
facilities exist at each location, their extent depending mainly on current and
previous work. A further facility which is common is a library of text books
and journals. It is most useful to researchers and innovators to have selected
journals circulated on a regular basis so that they are able to maintain their
current awareness. Attendance at conferences and symposia is another ex-
cellent method of maintaining awareness, local meetings usually being well
attended by group laboratory personnel.

In addition to the group laboratories, Mintek provides a very impor-
tant input into research in the gold mining industry. Mintek will be discuss-
ed separately in Section 18.3.

In dealing with on-mine laboratories, layout, equipment, functions and
staffing have been discussed. The same categories are used for group
laboratories in the sub-sections which follow.
18.2.2.1 Layout
All of the group laboratories have been in existence for a considerable time, and several make use of defunct mine offices or adapted buildings. Without exception, additions have been carried out to the buildings over the years, and there is considerable variation in layout. All of them have separate metallurgical testing facilities which involve hydrometallurgy as well as ore-dressing. Support is provided by analytical and mineralogical sections. Classical fire assaying methods for gold and silver are still used by the assayers, but increasing use is made of instrumental methods such as atomic absorption. The mineralogical sections of several of the group laboratories have advanced microprobes which are useful in studying aspects of gold metallurgy.

Pilot-plant facilities are common to all of the group laboratories, and will be discussed in a later section. Provision for crushing and milling of samples exists, and certain of the larger laboratories have well-stocked libraries, while inter-library loans involving the Johannesburg Public Library, Mintek and the Council for Scientific and Industrial Research (CSIR) are common among all of them. At several of the group laboratories canteens supply meals, usually at subsidized rates.

18.2.2.2 Equipment
The equipment that a well-equipped group laboratory has is discussed in this section. Obviously, since this chapter deals specifically with metallurgical testwork, only the equipment used for ore dressing and in hydrometallurgy need be listed.

All of the equipment listed in Section 18.2.1.2 for a typical on-mine laboratory will be found at a group Metallurgical Laboratory. In addition, the following items are included, in view of the greater capability that is required:

Ore dressing
- Cone crusher or roll crusher.
- Pulverizer.
- Sieve shakers.
- Sample splitters including spinning rifflers.
- Cyclosizer.
- Infrasizer.
- Laser beam particle sizer.
- Flotation machines.
- Magnetic separators, wet and dry.
- Jig for gravity separations.
- Shaking table.
- Corduroy table.
- Superpanner.
- Heavy media cone.
- Rod mills on rolls.
- Bond Index mill.
- Flotation reagents and chemicals.
Dust extraction equipment.
Binocular microscope.
Centrifuge.
Pycnometer for density determination.
Desk-top computer terminal.

**Hydrometallurgy**
- Constant temperature baths with rolls.
- Waterbaths.
- Autoclaves.
- CIP test rig.
- Pumps, metering pumps, valves, solenoid valves.
- Rectifier.
- Electrowinning cells.
- Shaking tables for flasks.
- Columns for carbon/resin loading and elution.
- Sample drying facilities.
- A glassed-steel reactor (Pfaudler type).
- Columns for heap leaching simulation.
- Stirred tanks and storage vessels.
- Pachucas.
- Chart recorders.
- Combined magnetic stirrers/hot plates.
- An extended range of glassware including ground glass jointed apparatus.

**Mineralogy**
- The mineralogical section at a group laboratory provides a service for the group mines, geological exploration and the laboratory itself.
- The equipment required is listed below:
  - Diamond saw.
  - Sample splitting device.
  - Grinding equipment.
  - Diamond polishing equipment.
  - Small superpanner.
  - Heavy liquid separation apparatus.
  - Frantz isodynamic separator.
  - Binocular and ore microscopes.
  - Modern photographic equipment.
  - Carbon-coating equipment.
  - Electron microprobe.
  - X-ray diffraction apparatus.
  - X-ray fluorescence apparatus.

18.2.2.3 Functions

**Ore dressing**
The work of an ore dressing section at a group laboratory deals routinely with testwork to support operations at the group mines as well as work of
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a more investigative nature.

The list below indicates the sort of work that is performed:
Sample preparation, large and small, for further testwork and chemical analyses.

Communion testwork, Bond Work - Index determinations, relative grindability tests, liberation tests using rod and ball mills and drop tests for autogenous and semi-autogenous milling.

Gravity separation testwork using shaking tables, jigs, spiral concentrators, duplex table, Haultain superpanner.

Sizing and classification using screens, sieves, the cyclosizer, water and air elutriation, laser sizing devices, hydrocyclones.

Flotation testwork, rougher flotation, cleaner flotation and reclaimer flotation using a variety of laboratory-scale flotation machines.

Evaluation of flotation reagents such as activators, collectors, depressants and frothers.

Development of new flotation processes, making use of pH effects, and study of zeta potential.

Magnetic separation testwork using wet and dry magnetic separators, permanent magnets, electromagnets, WHIMS, Jones magnetic separators, Carpco separators, magnetic filters, Franz separators.

Sink-float test using the Eriksen cone.

Pilot-plant operations on a continuous and semi-continuous basis, with grinding mills, classifiers, flotation, magnetic separation, gravity separation, etc.

Thickening and filtration studies for sizing and design of equipment, and testing of flocculants.

Improvements to existing ore-dressing flowsheets, and the design of new flowsheets.

Testing of new ores and ore-dressing techniques.

Hydrometallurgy

Typical investigations in a department dealing with hydrometallurgy at a group laboratory will be as follows:

The cyanidation response of ore from new mines and prospects. This would include borehole cores prepared by the ore-dressing section.

The solving of problems at group mines as and when they arise, and general trouble-shooting.

The effect of such parameters as fineness of grind, agitation times, and varied reagent additions for operating plants.

The use of new reagents.

Intensive cyanidation of gravity concentrates.

Heap leaching tests in columns.

Methods for the control of water and air pollution.

Filtration testing and the evaluation of new flocculants.

Optimization of thickener performance.

Testwork on carbon-in-pulp to obtain design parameters.

Evaluation of carbon samples.
Loading and elution tests on carbon.
In-stope leaching of gold.
Acidic pressure leaching of refractory gold ores to liberate locked gold.
Bioleaching with species such as *Thiobacillus ferrooxidans* to liberate locked gold from sulphides.
Roasting to liberate locked gold from sulphides.
Gold extraction from solution using activated carbon in columns.

**Mineralogy**
The following are typical of the activities in the mineralogy section of a group laboratory:
- Rock identification and the ore minerals present from samples provided by exploration geologists.
- Establishing modes of occurrence of valuable constituents.
- Determining likely liberation characteristics.
- Performing microprobe analysis of gold and uranium minerals.
- Examination of plant products, for example, leach residues and carbon from CIP circuits.
- Establishing the reasons for losses in gold plants.
- Monitoring various beneficiation processes.
- Assisting mine geologists.
- Monitoring borehole intersections.
- Studying reef channel samples.
- Identification of likely cyanicides.

In most group laboratories, the mineralogical section is not only concerned with the occurrence of gold, but with many other elements as well.

**18.2.2.4 Staffing**
The group laboratory represents the store of metallurgical expertise within that group, so that the senior staff are of necessity carefully chosen. The laboratory director has probably graduated in one of the disciplines that have been discussed, while those in charge of the different sections have degrees in those particular fields.

The laboratory staff are almost invariably attached to the group head office, and the advantages that result from this association mean that turnover is minimal. This is a very important requirement if continuity is to exist. To build detailed technical knowledge of all of the operations in a group requires the passage of several years, and it is therefore an expensive procedure. Minimal staff turnover, however, can mean that fresh ideas are not introduced with new people. The staff in the different sections are made up of graduates, diplomates and matriculants, supported by less well-educated labourers and assistants in the lower grades. Administrative facilities are essential, and must include a team operating word processors to produce the technical reports which, after all, are the tangible evidence of the research that has been done. The availability of workshop and maintenance services is also very necessary.

The ever-increasing role that desk-top computers are playing in laboratory research has revolutionized experimental design and the process-
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ing of data in metallurgical research. Since large masses of data can now be rapidly processed, the interaction of parameters involved in extractive metallurgical processes can be determined with increased accuracy. Personnel at the group laboratories in the future will probably include staff skilled in mathematics, statisticians and an increasing proportion of computer programmers. The biggest section at a group laboratory is usually the analytical chemistry section but its activities are outside the present discussion.

18.3 Mintek
In the sections that follow, the early history and the present capability of the Council for Mineral Technology to contribute specifically to gold metallurgy in South Africa will be discussed. Much of this information has been provided by Mintek’s Information and Liaison section (S.A. Allison, personal communication).

18.3.1 Introduction
The identification of mineral resources in South Africa had advanced sufficiently in 1934 for the state to establish the Minerals Research Laboratory with the object of making exploitation possible. Even at that time, several metallurgical laboratories were operated by the mining houses and devoted to those projects likely to yield profits in the medium to short term. The results of the testwork, however, remained confidential, and the thought was that work in the national interest should be undertaken by a state-financed research organization. A state-financed institution is also able to undertake work of a long-term nature aimed at the fundamental understanding of economically beneficial new processes or modifications to existing processes.

In 1934 the research complement of the Minerals Research Laboratory was two, and it was located in the Department of Metallurgy at the University of the Witwatersrand. Ten years later the organization had its own premises and had its name changed to the Government Metallurgical Laboratory. By an Act of Parliament, it developed into the National Institute for Metallurgy, which earned a world-wide reputation for its practical approach to extractive metallurgy. The current site was established in 1974, and in 1981 a further Act of Parliament reshaped the body into the Council for Mineral Technology, which has at the present time an annual budget of some 25 million rands, and employs about 350 engineers, scientists and technicians, and 450 people in supportive roles, largely concerned with administration.

The phenomenon of the occurrence of South Africa’s mineral wealth within a relatively small geographical area allowed a very large complex to be built on a single site, in contrast to the tendency overseas to decentralization. The U.S. Bureau of Mines’ scattered locations are a good example of this. The location of the group laboratories all within easy reach of Mintek is particularly useful, since the Mintek library is very comprehensive and probably one of the best in the world. In addition, the comprehensive facilities and the expertise available are also very beneficial.
LABORATORIES AND PILOT PLANTS

The relationship between the gold mining industry and Mintek is excellent, and many cooperative efforts have enabled Mintek to avoid duplication of the research efforts of the various group laboratories, and vice versa.

Today, Mintek defines as its primary aim the promotion of mineral technology, including research into the properties, composition, recovery, extraction, processing, refining and utilization of minerals and mineral products. Each of the divisions at Mintek specializes in a particular branch of mineral science and technology. Most of the research on the metallurgy of gold is conducted within the Hydrometallurgy and the Mineral and Process Chemistry divisions, and where appropriate, in the Ore Dressing division. The objectives in research on gold metallurgy as stated in the most recent Mintek report (1984) are as follows:

1. To increase the recovery of gold (and associated elements), and to reduce the operating costs of existing gold plants.
2. To determine the occurrence of gold (and associated elements) in ores and processing products so that their behaviour during processing can be characterized.
3. To investigate the development of less conventional flowsheets, with special consideration of such techniques as carbon-in-pulp, resin-in-pulp, the use of carbon and resin in continuous adsorption columns, run-of-mine milling, gravity concentration, flotation, and wet high-intensity magnetic separation.
4. To investigate the economic recovery of gold (and associated elements) from sand dumps and slimes dams.
5. To develop instrumentation, on-line analytical techniques, and control strategies for ore-dressing and hydrometallurgical processes.
6. To develop improved extraction processes for the recovery of gold from refractory gold ores, with special emphasis on improved gold recoveries and pollution considerations.
7. To investigate improvements to existing processes and the development of alternative processes for the refining of gold and silver.
8. To study the techno-economics of gold production, both primary (from mines) and secondary (from dumps), with the object of developing computer models to assist in the comparison of processes and the selection of optimal flowsheet configurations.

The Council of Mintek is advised by two specially established committees. One is the Technical Advisory Committee and the other the Gold and Uranium Research Advisory Committee; both are made up of senior members of the mining industry as well as members of university staff.

18.3.2 Categories of sponsorship and the conditions pertaining to them

The categories in which projects can be undertaken are as follows:

Category A – Projects of national importance fully paid for by the State.
Category B – Partially sponsored projects.
Category C – Fully sponsored projects.
Table 18.1. Conditions of the various Mintek project categories.

<table>
<thead>
<tr>
<th>Category</th>
<th>Period of confidentiality</th>
<th>Costs recoverable</th>
<th>Rights to inventions</th>
<th>Licence conditions</th>
<th>Sponsors’ rights to use expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>At Mintek’s discretion</td>
<td>Nil</td>
<td>Belong to Mintek</td>
<td>At Mintek’s discretion</td>
<td>Belong to Mintek</td>
</tr>
<tr>
<td>B</td>
<td>12 months</td>
<td>By arrangement</td>
<td>Mintek’s but negotiable (in advance)</td>
<td>Free to sponsors within RSA; elsewhere may be negotiated</td>
<td>Free: unrestricted</td>
</tr>
<tr>
<td>C</td>
<td>Five years but may be extended</td>
<td>Full</td>
<td>As for B</td>
<td>As for B</td>
<td>As for B</td>
</tr>
<tr>
<td>D</td>
<td>At Mintek’s discretion</td>
<td>Nil</td>
<td>Belong to Mintek</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Category D – Exchange of services with other institutions.
Although all information is confidential to Mintek, work in any of the above categories can be classified as secret or confidential to ensure a greater degree of confidentiality.

The conditions for the various Mintek project categories are shown in Table 18.1.

18.3.3 The facilities at Mintek
Mintek is much larger than any of the laboratories operated by the mining houses, and it has extremely comprehensive facilities, not only in the form of laboratories and pilot-plant equipment, but also support facilities. Investigations in gold metallurgy are only a part of the overall picture in which studies of many other metals and minerals are concurrently undertaken. The technical expertise, space and equipment that are available nevertheless mean that any conceivable project connected with gold can readily be undertaken. The space provided for pilot plants is vast, and even the most elaborate pilot plant would occupy only a part of one of the six enormous bays, using whatever equipment necessary. The equipment available for sample preparation can also deal with any possibility. In perspective, however, the Anglo American Research Laboratory (AARL) probably has more research personnel working on gold metallurgy at any one time.

Mintek’s greatest contribution to progress in gold metallurgy in South Africa has been in the development of the carbon-in-pulp (CIP) and carbon-in-leach (CIL) processes, which have revolutionized the flowsheets of many of South Africa’s gold plants. This has led to more recent work on resin-in-pulp methods, which have application where base metal cyanide contamination in solution is low. A great deal of development work continues at Mintek on further refinements.
Table 18.2 Typical research programme steps.

<table>
<thead>
<tr>
<th>Step</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin of concept.</td>
<td>Initiate ideas and concepts to be investigated.</td>
</tr>
<tr>
<td>Basic research.</td>
<td>Determine basic feasibility of the project.</td>
</tr>
<tr>
<td>Preliminary economic evaluation.</td>
<td>Determine if economic incentive is sufficient to proceed with the project.</td>
</tr>
<tr>
<td>Laboratory research.</td>
<td>Develop basic data.</td>
</tr>
<tr>
<td>Product evaluation.</td>
<td>Evaluate the suitability of product.</td>
</tr>
<tr>
<td>Process development and preliminary engineering.</td>
<td>Produce preliminary design of a full-scale plant.</td>
</tr>
<tr>
<td>Pilot-plant study.</td>
<td>Prove basic reliability of the proposed process and demonstrate feasibility.</td>
</tr>
<tr>
<td>Demonstration unit.</td>
<td></td>
</tr>
<tr>
<td>Full-scale plant.</td>
<td>Full-scale production.</td>
</tr>
</tbody>
</table>

The equipment that is available at Mintek is probably greater in extent and variety than that in any group laboratory, particularly in the case of the smaller ones, so that joint pilot-scale investigations are sometimes undertaken at Mintek. The general scope of the research undertaken is covered by the list relating to group laboratories in Section 18.2.2.3 above, and Mintek’s staffing arrangements are covered by the requirements in Section 18.3.1.

18.4 Pilot Plants

18.4.1 Reasons for piloting

It was observed in Section 18.1 that the main reasons for using a pilot plant to test a new process or unit operation are to limit the risks that are inherent, and also to be able to operate continuously and in closed circuit, rather than batchwise as in most bench-scale testwork. These observations are considered worthy of repetition since they are the basic reasons for building a pilot plant.

In a novel process, as in carbon-in-pulp in the South African context, the design and construction of a full-scale plant would represent a very large investment in both time and money. While the rewards can be high in the pioneering of a novel process route, the risk is a factor to be considered very carefully. The operation of a pilot plant definitely reduces such risk.

The sequence of steps that should be followed in a research programme was listed by Van Sweringen (1982). The list in Table 18.2 shows an adaptation of that sequence.

It must be stressed that the basic concept must have been proved before a pilot plant is built. The tendency to make adaptations to the concept during the erection of the plant should be avoided, unless any suggested improvement can be justified by laboratory testwork. The aims of pilot-scale testwork, other than to reduce risk and provide the opportunity to operate continuously in closed circuit, include:
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Testing materials of construction.
Estimation of maintenance requirements.
Assessing hazards that may exist, e.g. in the use of chlorine as a solvent for gold.
The solution of problems relating to waste disposal.
Training operating staff.
Testing different control routines.
Obtaining data for the design of the full-scale plant.
Feasibility and cost studies.
Demonstrating to senior management that a concept is viable.
The production of by-products other than gold.

18.4.2 Types of pilot plants
The most obvious variable in pilot-plant classification is its size, which can vary from a bench top to a prototype unit. Obviously, the costs and the time that are involved are proportional to the size of the unit. The complexity of the process usually defines the size that is required to test its feasibility. Since metallurgical operations within the gold mining industry are comparatively simple when compared to, say, the production of synfuels, it is to be expected that pilot plants will generally fall within the smaller size range. However, the fact that there is a lower limit to the size of metallurgical equipment such as, for example, mills or flotation machines, imposes a limit on how small a pilot plant can be.

The amount of instrumentation installed in a pilot plant also has a bearing on costs. In the simplest type of pilot plant, data gathering is usually by manual means and the operators are required to optimize the operating conditions and to set them manually by means of control valves and the like. Some form of automatic data capture in the form of recording instruments is normally also used. Capital costs increase with increasing complexity in control philosophy. Since sophisticated computer control of plants is as yet relatively undeveloped in the gold mining industry, proportionately less money is required for a hydrometallurgical leach plant. The situation could, however, rapidly change with the availability of such systems as Proscon and Centum.

18.4.3 Scale-up factors
Pilot-plant design with the eventual goal of building a full-scale plant should use commercially available equipment and not place reliance on makeshift apparatus. The use of commercial equipment ensures that in the pilot-scale operation the same effects, such as short-circuiting in reactors, will be found as in the commercial plant. The transfer of a novel project from pilot-scale to full-scale conditions is the period of greatest risk, as large sums of money are then required. The risk lies in unknown factors, chemical or physical, which are different in the two situations. Typical of this situation was the development of the carbon-in-leach process.

In the case of conventional gold plants, however, experience gained over many years allows of design after only basic laboratory testing has been performed.
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Good design at the pilot scale ensures that the scale-up factor can be high, much higher than the generally accepted statement in previous years that a scale-up factor should not be higher than 10. Pilot-scale carbon-in-pulp rigs at Grootvlei have recently been translated to full-scale operations where the scale-up factor was about 1000 (P.A. Laxen, personal communication).

18.4.4 Design of pilot plants
The specific purpose for which the pilot plant is intended must first be defined. If this is not done, considerable modification during its operation is likely. The development of a mathematical model when unit operations at reduced scale are used allows high scale-up factors and reproduces process variables. It also reduces the time required for the engineering design. Sometimes, however, equipment must be designed to overcome a particular problem when novel concepts are being investigated. Mintek’s screens for use in CIP circuits are an example of this, as are the electrowinning cells used on eluates derived from loaded carbon.

When a pilot plant is to be constructed, those items with long delivery times should be ordered as soon as the decision to go ahead has been taken. CAD (computer-aided design) systems will greatly speed up pilot-plant design and allow metallurgical flowsheets to be constructed rapidly and accurately.

18.4.5 Operation of pilot plants
The operating cost of a pilot plant is directly related to the time period over which the plant is operated, so that it is very necessary to decide on a programme to meet the objectives as part of the design of the plant. The results obtained in the laboratory during the earlier part of the investigation are used to define operating conditions. If operating problems develop at the pilot stage, it is usually less costly to return to the laboratory to overcome them, rather than persevere with pilot-scale work.

Statistical planning of pilot-plant operation as a function of the effects of variable parameters by using previous laboratory data can save much time and provide more meaningful results.

It is usually necessary to operate a pilot plant over a wider range of conditions than would be the case at full scale in order to define the effect of variables on the process.

Apart from establishing the viability of the process that is under study, the operation of a pilot plant is used to provide information on operating costs, which can be used in a feasibility study. Other benefits relate to the training of operators for full-scale operation, and those concerned with plant maintenance, as well as the establishment of safety procedures. It is to be expected that much more detailed information will be gathered in pilot-plant operation than on an operating plant, so that the sampling and monitoring procedures would be more intensive.

18.4.6 Pilot plant location
The operation of a pilot plant very often requires a continuous supply of
feed material which can best be supplied at an operating plant. Carbon-in-pulp or carbon-in-leach processes are examples of these, and pilot facilities are most appropriately established where a continuous source of milled pulp is available. Pilot plants using batch processing procedures, or where the technology is more complicated, are preferably carried out at a research laboratory. Pressure or bacterial leaching comes to mind in this instance, as does investigational work on new ore bodies where no continuous supply of feed material is possible.

In continuous operation, the disposal of wastes is a problem more easily dealt with at a mine, where slimes dams are available. In a ‘greenfields’ operation this facility would not be present. Operating a pilot plant at a mine also means that the transport of feed material is avoided, as are the legal aspects, including the necessity for obtaining police permission for transport of gold-bearing material, particularly when significant values are present, as in gold-rich flotation concentrates. The problem of oxidation of pyritic concentrates while transporting them over long distances is also overcome by immediate processing at an on-mine pilot plant.

A concept which is receiving attention at the present time is that of mobile pilot plants, mainly for ore-dressing operations. A budget estimate in 1985 for a 10 ton/hour mobile pilot plant consisting of a crushing and screening unit, a milling and classification unit, as well as a flotation unit, was R1,4 million (J. Dear, personal communication).

### 18.4.7 Type of investigation carried out in pilot plants
Some of the aspects of gold metallurgy that have been studied in recent years at pilot scale are listed below:

- CIP and CIL processing.
- Elution of gold-loaded carbon.
- Elution of gold using methanol (the Micron system).
- Development of electrowinning cells (the AARL, Mintek and Micron systems).
- Regeneration of carbon in kilns or in the ‘Rintoul’ furnace.
- Loading of gold onto carbon from “regen-aqueous” solutions from uranium solvent extraction.
- Pinned bed carbon adsorption.
- Continuous gold elution.
- Pressure cyanidation in a pipe reactor.
- Acidic pressure preleaching to liberate locked gold in refractory ores.
- Bacterial leaching with *Thiobacillus ferrooxidans* to liberate locked gold in refractory ores.
- Sulphation roasting of pyrite concentrates to liberate locked gold.
- Flotation of pyritic concentrates.
- Run-of-mine milling.
- Dump cyanidation.
- Intensive cyanidation.
- Chlorination to dissolve gold in refractory slags.
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Reverse osmosis for the treatment of tailings dam water.
In-stope leaching with thiourea and thiocyanate.

18.5 References
APPENDICES

In most laboratories in the gold mining industry standard procedures for routine metallurgical testing are in use. An edited selection of these follows. The permission of the Joy Manufacturing Company to use a publication entitled 'Determining Thickener Capacities', by H.J. Gisler, is gratefully acknowledged.

APPENDIX 18.1

Determination of Relative Grindability using a Laboratory Batch Rod Mill

1. Introduction
(1) Given a mill feed charge of acceptable size, the amount of milled product passing a stated fine size increases linearly with time up to about 90% passing.
(2) If \( x \) = milling time,
    \( y \) = mass of product passing stated size expressed as percent of feed mass,
    \( c \) = original mass percent of feed passing stated size,
    \( r \) = milling rate = mass ground through stated size per unit time,
    \( f \) = feed mass,
then \( y = \frac{100rx}{f} + c \)
(3) The Milling Curve, which is a plot of \( y \) against \( x \), is a useful tool in comparing grindabilities of different ore bodies and therefore the power requirements and costs of milling.
(4) Laboratory batch milling rates are commonly expressed in units of g/min of \(-75 \mu m\).

2. Procedure
(1) Reduce representative 10 kg sample of ore to \(-3 \text{ mm}\) using jaw crusher and roll crusher.
(2) Using a stationary or rotary splitting technique, obtain at least five representative samples each weighing 1 kg (plus/minus 1 g). Determine per cent \(-75 \mu m\) according to the standard dry-screening method.
(3) Charge a stainless steel batch rod mill as follows:
   1. To the clean, dry 200 mm d \( \times \) 200 mm mill, add 1 kg sample of \(-3 \text{ mm material}\).
   2. Add 540 ml of domestic tap water (equivalent to 35 percent moisture since \( \frac{540}{1000 + 540} \times 100 = 35 \))
   3. Add suitable grinding rods to half fill the mill. It is essential that
the same mass and number of rods are always used.

4. Close and secure the mill.

(4) Place the mill on rollers and roll at 75 r.p.m. for 5 minutes.
(5) Remove the mill from rollers. Open the mill carefully and wash all solids adhering to the lid down into the mill.
(6) Remove rods singly, carefully washing all solids from each rod down into the mill. Use the minimum amount of wash water.
(7) Using a wooden frame, support a clean 75 μm deep-frame screen in a clean, empty bucket. Slowly and carefully wet screen the total contents of the mill on this screen, ensuring that no solids are left and retaining oversize and undersize separately. Undersize may be discarded if no subsequent mineralogical investigations or ore treatment steps are necessary and the sample is plentiful.
(8) Filter oversize carefully to avoid loss and (a) oven dry if no mineralogical examination is required or (b) dry in the open-air in a sheltered position. Weigh oversize (plus/minus 1 g).
(9) Repeat steps 3 to 8 for milling times of 10, 15, 20 and 30 minutes. Convert masses of oversize to percent of original feed by dividing by 10.
(10) Draw a milling curve as shown:

\[ y = \text{Percentage passing } 75 \, \mu m \]

\[ y = rx + c \]

\[ x = \text{milling time (min)} \]

Figure 18.3. Graph of milling time versus percentage passing 75 μm.

3. Notes
(1) The milling rate or relative grindability remains constant according to the equation \( y = rx + c \). If different samples are roll crushed under slightly different conditions to produce different amounts of \(-75 \, \mu m\) in the \(-3 \, mm\) feed, then \( c \) varies in the above equation. So whilst \( r \) remains constant, different values of \( y \) (percent \(-75 \, \mu m\) in product) will be obtained for a fixed time \( x \).
(2) If sample size is limited to say 1 kg, both oversize and undersize from first milling may be recombined (dry) after weighing oversize and remilling four more times. However, errors may be introduced through repeated filtration and recombining operations.
APPENDIX 18.2
Standard Procedure for Routine Size Analysis of Finish-ground Products

1. Introduction
Total grading analysis error is an accumulation of errors from various independent sources such as sampling, sample preparation, screen mesh accuracy and repeatability of screening technique.
To reduce this error the following conditions must be observed:

(i) Sample preparation must be done meticulously.
(ii) Good quality screens must be used and be maintained in good condition.
(iii) Every operation in the standard grading analysis procedure must be carried out, and the taking of shortcuts must be avoided.

2. Equipment required
1. Balance of at least 200 g capacity and resolution to 0.1 g (an electronic balance with auto-zero facility will reduce weighing time considerably).
2. Spatula with 200 mm to 250 mm blade.
3. Deep aluminium, enamelled or stainless steel dishes, 200 mm diameter.
4. Paint brush, 50 mm. Bristles must not be cut short.
5. Water spray with steady head arrangement.
6. Water hose connection with 6 mm tube.
7. A 63 μm aperture full height test sieve of 200 mm diameter for wet screening. This sieve should be in good condition and be regularly inspected for holes, tears, etc.
8. Sets comprising one standardized 75 μm and one 150 μm diameter test sieves for dry screening. (The number of sets required will be dictated by the needs of the mine.) These sieves should be kept in immaculate condition and used for monthly composite, residue, cyclone O/F and thickener U/F samples only. (See screen calibration diagram.) Each set should be clearly marked with an identification number.
9. A laboratory sieve shaker.

3. Grading procedures
1. Sample preparation
1.1 Each shift must submit dry samples of residue, cyclone overflow and thickener underflow of at least 1 kg each from each plant unit to the grading room for sieve analysis. Figure 18.4 shows the residue sample preparation procedure; other samples need only be dried before submission to the grader.
1.2 Each entire sample must be deagglomerated by gently breaking it through a 1.0 mm aperture screen onto a 1 m × 1 m rubber mat to break up lumps formed during drying.
1.3 Coarse material remaining on the sieve after all the lumps have been disintegrated must be combined with the −1.0 mm portion.
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Residue samples (3 Shifts)

Cuprous chloride added and stirred
(if T.G. values are being determined)

Filtered by shift concerned on filters at the sampling point
(if U.G. values are being determined, repulp with water and filter six cycles)

Total sample dried in stainless steel pans in ovens heated with infrared elements

Deagglomerated through 1.7 mm screen

Rolled at least 10 times and 2 x 1 kg samples taken by dip sampling

One sample to assay office for T.G. analysis (or U.G. where applicable)

One sample for grading analysis (1 000 g)

Deagglomerate (1 mm)

Grade according to standard procedures

Report

T.G. = Total gold
U.G. = Undissolved gold

Figure 18.4. Schematic diagram of residue sample preparation procedure.

1.4 Roll the sample on the rubber mat from alternate corners at least ten times.

1.5 With the spatula, spread the heap to an even depth of about 15 mm over the mat.

1.6 Sample 100,0 g from the material on the mat with a small spatula or teaspoon by taking small dips over the entire area of the flattened material. (If more 100 g lots are required, the sample should be re-rolled, again spread out and sampled as before.)

2. Wet screening

2.1 Place the sample prepared as above in an aluminium or enamelled dish and add approximately 150 ml of water.

2.2 Play a gentle spray of water onto the pulp until the dish is about half full. Slowly decant the slime through the 63 μm aperture sieve reserved for wet screening. The passage of slime through the screen can be assisted by gently tapping the side of the screen.

Repeat the procedure until most of the slime has been transferred
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to the screen. Finally, wash all the material from the dish onto the screen using the rubber hose.
2.3 By holding the screen under the spray in one hand, wash the material remaining on the screen in a rotary action whilst tapping gently on the side of the screen with the other hand.
2.4 Wash the solids on the screen back into the dish using the rubber hose. Allow the solids to settle and drain off the excess water. Dry slowly to avoid spitting.

3. Dry screening
3.1 When the sample is dry, remove it from the drier to cool.
3.2 Clean the appropriate standardized 75 \( \mu \text{m} \) and 150 \( \mu \text{m} \) screens using a soft paint brush. Brush the bottom of the screen cloth with the screen inverted on the table, then brush the top and finish by brushing off the bottom.
3.3 Arrange the nest of screens with the 150 \( \mu \text{m} \) screen on top and a pan at the bottom and transfer the sample from the dish to the screens. Fit the nest of screens tightly in the sieve shaker so that no lost motion occurs after the motor is started.
3.4 Shake for 10 minutes plus/minus 10 seconds. (Check the time switch on the shaker with a stopwatch and mark the clock face to give a run of exactly 10 minutes.)

4. Weighing
4.1 When the shaker stops, remove the nest of screens. Invert each screen on top of a large clean dish.
4.2 Brush the bottom of the screen gently using a soft paint brush covering the whole area of the screen.
4.3 Holding the inverted screen about 100 mm above the dish gently tap the side of the screen frame.
4.4 Transfer the material from the dish to the balance pan and weigh to the nearest 0.1 g.

5. Reporting
5.1 Each set of standardized screens has factors which must be added to the oversizes to obtain the corrected oversize mass on each screen. The screen sets must not be separated but always used together. For example:
   In set No. 1 the 150 \( \mu \text{m} \) sieve has a factor of +0.3 and the 75 \( \mu \text{m} \) sieve has a factor of −0.2.
   Results are calculated as shown in Table 18.3.
5.2 To standardize a set of screens the average of five replicates is compared with the average of five replicates obtained from the same sample using a set of sub-master screens. The sub-master screens are used only for standardizing and are checked at intervals against a sample of known size distribution to give the correction factors shown in column (2) of Table 18.4.
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Table 18.3. Application of screen correction factors.

<table>
<thead>
<tr>
<th>Screen no.</th>
<th>Aperture (µm)</th>
<th>Actual mass oversize (g)</th>
<th>Correction factor</th>
<th>Calc. mass oversize (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>150</td>
<td>4,1</td>
<td>+0,3</td>
<td>4,4*</td>
</tr>
<tr>
<td>1B</td>
<td>75</td>
<td>20,3</td>
<td>-0,2</td>
<td>20,1*</td>
</tr>
</tbody>
</table>

*Values to be reported.

5.3 The grader would report the corrected, not the actual, weights. Alternatively, to minimize the possibility of using wrong screen factors, the metallurgical clerk could have a list of the screen set numbers and their corresponding factors. The grader would then merely report the oversize weights and the screen set number and the clerk would make the required adjustments.

5.4 Calculation and screen calibration should be checked on a regular basis by senior personnel. Figure 18.5 shows a scheme used by one South African mining group in the standardization of its screens.

Table 18.4. Calculation of screen correction factors.

<table>
<thead>
<tr>
<th>Sub-master set</th>
<th>Working set</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Average oversize (g)</td>
<td>Corrected oversize (g)</td>
</tr>
<tr>
<td>Aperture (µm)</td>
<td>(1)</td>
</tr>
<tr>
<td>150</td>
<td>4,5</td>
</tr>
<tr>
<td>75</td>
<td>21,3</td>
</tr>
</tbody>
</table>

(1) and (4) are the averages of five replicates in each case.
(3) = (1) + (2)
(5) = required correction factor = (6) - (4).
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Group Laboratory Master Screen Set (M) (kept in safe at Laboratory)

Lab. Sub-Master Set (Mi) (kept by Head of Metallurgy Section at Laboratory)

Mi used to calibrate working master screen sets for the laboratories (SM1 to SM3)

Calibrates mine Assay Office Master Screen A01

Calibrates needed number of working sub-master sets A1 to Ax

Calibrates mine Master Screen kept by Asst. Plant Superintendent (MM1)

Calibrates monthly composite master set (MM2)

Calibrates working sub-master sets:
S1 — Residue samples
S2 — Cyclone O/T and Thickener UF/samples

Residue sample screens should be renewed monthly, the new set being used for residue samples and the old residue screen moved down one position. Residue screens should be clearly marked.

Figure 18.5. Screen calibration scheme.
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APPENDIX 18.3
Determination of Thickener Area

1. Introduction
The thickener capacity required to handle a predetermined tonnage of a certain pulp, by overflowing a clear solution and obtaining the desired pulp density of thickener discharge, depends upon the settling rate of the solids in that particular pulp. The settling rate may be determined by simple laboratory tests using measuring cylinders and can then be used in a simple formula for calculating the necessary thickener area.

2. Procedure
The procedure used by the Joy Manufacturing Company, as reported by H.J. Gisler, is as follows:
Place a measured quantity of pulp at a known density in a beaker or glass cylinder. Fix a narrow strip of paper on one side of the container. Mix pulp thoroughly. Draw a line on the paper at the top of the pulp and mark "0" minutes. For five minutes, at one-minute intervals, mark the point to which the solids have settled. Graph distance settled versus time. The settling rate R is the slope of the straight portion (i.e. the pre-compression portion) of the graph. This determines the free settling rate of the solids at the initial density.
Usually readings are taken at three different densities of the pulp corresponding approximately to densities which will exist in the various zones in the thickener.
Decant sufficient clear water or solution to establish a pulp with intermediate density. For instance, if initial pulp density was 4:1, water to solids, the removal of one-fourth of the water would establish a density of 3:1. Mix thoroughly. Repeat readings of settlement as above.
Then decant again to obtain a pulp at one-third density. The pulp just tested was at 3:1 dilution, so decanting one-third of the water will give 2:1 dilution, water to solids. Mix thoroughly. Repeat settling measurements at one-minute intervals for five minutes.
The settling rate per minute should be uniform during the testing at each dilution, until compression is reached, at which time the amount of settling will decrease during each succeeding minute. Measure the pre-compression settling marks in millimetres, thus determining the settling rate in millimetres per minute for each pulp density, and convert this to millimetres per hour. The distance settled versus time graphs for all dilutions tested should be included in the test report.

Determining final density
Final density is then determined. Thoroughly mix the pulp remaining after the test at 2:1 dilution and allow to settle for 19 hours. Mark the position of settled pulp and let stand for a few hours to see if final density was reached. If pulp continues to settle, mark its position at hourly intervals until settling stops. Decant off all clear water or solution. Then determine moisture con-
tent and density of pulp by weighing and drying.

**Calculating thickener area**

Thickener area required is then calculated by applying the above-determined data in the following formula:

\[ A = \frac{41.67 \times (F - D)}{R} \] (Coe and Clevenger)

A = Thickener area in square metres per metric ton of dry solids thickened in 24 hours.

F = Initial w/s.

D = Final w/s to which pulp will settle or w/s at which you want to discharge pulp from thickener. Usually it is desired to discharge pulp from the thickener at its final w/s as shown in the above test. However, if you want to discharge pulp more diluted than the actual final w/s, the w/s desired should be used in above formula rather than the final w/s to which the pulp will settle.

R = Settling rate in mm per hour.

Calculations of indicated thickener area from each of the three settling rates obtained in tests will indicate any change in settling rate in the different zones of the thickener, and the largest area obtained from the three calculations should be used.

Assume the following data were obtained from the above tests:

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At 4:1 dilution, R = 153 mm per hour
At 3:1 dilution, R = 92 mm per hour
At 2:1 dilution, R = 46 mm per hour
Final density D = 1:1.

Applying these data to above formula, one obtains:

\[ A = \frac{41.67 \times (4-1)}{153} = 0.82 \text{ m}^2/\text{ton}/24 \text{ hours.} \]
\[ A = \frac{41.67 \times (3-1)}{92} = 0.91 \text{ m}^2/\text{ton}/24 \text{ hours.} \]
\[ A = \frac{41.67 \times (2-1)}{15} = 0.91 \text{ m}^2/\text{ton}/24 \text{ hours.} \]

**Factor of safety**

Normally a 25 per cent factor of safety is allowed in determining the thickener area. Thus, in the above case, 0.91 m$^2$ (largest of three figures) plus 25 per cent factor of safety, equals 1.13 m$^2$ area required per metric ton of dry solids fed to the thickener per 24 hours.

If the pulp reached its final density during the 19-hour test, a standard depth thickener is considered adequate. However, if additional time was required to reach final density, the thickener volume would have to be large enough to retain the pulp for this extra time.

**Storage capacity**

Another factor to be considered is the storage capacity desired in a thickener. For example, it may be necessary to shut a filter down for repairs and at the same time keep the remainder of the plant in operation. In this case the thickener will act as a storage reservoir. Where storage capacity in a thickener is of importance such as in many of the non-metallic flotation plants, a larger factor of safety, say 2, should be applied in calculating the area. Greater depth should not be used unless the lift of the thickener mechanism can also be increased.
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Duplicating thickener action
Many times a pulp standing without agitation will not settle to as low a final
density as when aided by movement of thickener rakes in actual operation.
The DECO Test Laboratory developed a miniature thickener mechanism
which is used in determining final density under actual operating conditions.

APPENDIX 18.4
Filtration Rate Determination

Figure 18.8. Apparatus for measuring filtration rates.

Apparatus required
(1) 500 ml Buchner flask and stopper.
(2) 120 mm dia. Buchner funnel if filtering medium is filter paper. Alter­
natively, a filter funnel 120 mm dia. × 70 mm deep with a plastic grid
base over which a filter cloth is fitted.
(3) 200 ml measuring cylinder.
(4) Vacuum hose.
(5) Vacuum gauge.
(6) Beakers.
(7) Pipette for flocculant addition.
(8) Retort stand.
(9) Stopwatch.
(10) Constant vacuum supply and valves.

Method
(1) Set up the apparatus as shown in the Figure 18.8.
(2) Prepare representative 200 ml or 250 ml samples of the pulp to be tested
in beakers.
(3) Open vacuum valve A and while keeping B closed pour a stirred sample
of pulp into the funnel, which is held vertically so that the base is
horizontal and the pulp spreads evenly over the cloth or filter paper.
(4) Open valve B; start the stopwatch and note the vacuum gauge reading.
(5) As soon as the solution disappears from the surface of the filter cake,
record the time required for the forming of the filter cake.
Pulp tested:
Pulp W/S:
Filtration area of funnel: m²
Flocculant tested:

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Pulp vol. ml</th>
<th>Vacuum</th>
<th>Cake form time, sec.</th>
<th>Wash water, ml</th>
<th>Wash time, sec.</th>
<th>Dry time, sec.</th>
<th>Total time, sec.</th>
<th>Cake wet, g</th>
<th>Cake dry, g</th>
<th>Moisture, %</th>
<th>Calculated filter duty, t/m²/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>0</td>
<td>38</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>38</td>
<td>210</td>
<td>155</td>
<td>26,2</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>0</td>
<td>38</td>
<td>100</td>
<td>20</td>
<td>15</td>
<td>73</td>
<td>206</td>
<td>154</td>
<td>25,2</td>
<td>152</td>
</tr>
</tbody>
</table>

Examples of calculations:

1) Filter duty (t/m²/h)  
(Filter area 0,01131 m²)  
$$\text{Filter duty} = \frac{3600 \times \frac{1}{a} \times \text{Dry cake wt (g)}}{1000 \times 100000}$$  
$$= \frac{3600}{38} \times \frac{1}{0,01131} \times \frac{155}{1000 \times 100000}$$  
$$= 1,298.$$  

2) Filter duty (t/m²/h)  
$$= \frac{3600}{73} \times \frac{1}{0,01131} \times \frac{154}{1000 \times 100000}$$  
$$= 0,67.$$
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(6) Remove and weigh the wet filter cake.
(7) Dry the filter cake and weigh again.
(8) Measure the amount of filtrate collected.
(9) This method is used to compare the filtration rates of different pulps or pulps with added flocculant.
   If wash and drying time is to be included in the filtration tests, step 5 is altered and a standard amount of water, say 100 ml, is poured over the filter cake when the last of the pulp solution is filtered, and the time for this water to be filtered is measured. A standard drying time may also be added to the total filtration time if required.
(10) When testing flocculants the desired amount is gently stirred into the pulp before the latter is poured into the funnel.
   Table 18.5 is a suggested form for tabulating the results.

APPENDIX 18.5
Cyanidation Tests using Rolling Bottle Method

1. Sample preparation
Samples can be received as pulps, mill feeds or boreholes cores. Generally, pulps will require no grinding and can be air dried before splitting, or split as a pulp. Where samples require grinding, a grinding curve may be constructed using the procedure described in Appendix 18.1.

2. Procedure
2.1 The normal residual cyanide and lime values after a leach test should be about 0.020% both for lime (CaO) and cyanide (NaCN) in solution. Values in the range of 0.015 - 0.025% are acceptable but values outside this range indicate that the test should be repeated with a suitable adjustment in cyanide/lime additions to correct the residual values. Before tests are performed, the percent active ingredients of the reagents should be determined by titration.
2.2 Clean, dry, 5 litre cyanidation bottles are weighed and the empty mass recorded on the bottle.
2.3 Weigh a sample and if necessary grind it at 50% solids to the required degree of fineness. 1 g of lime is usually added to the grinding mill prior to grinding the sample.
2.4 The ground pulp is filtered, the filtrate being used to wash out the grinding mill, and the filter cake is transferred to the cyanidation bottle. Tests are normally performed at 50% solids on 1 kg of sample and thus, the cyanidation bottle is placed on a scale and the filtrate used to make the pulp up to 50% solids, 2 kg of pulp being the norm.
2.5 If the sample was received as a pulp, then the required volume of pulp for 50% solids by mass is transferred to the bottle, or if the pulp was
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dried, the required mass of sample is transferred to the bottle and pulped with an equal mass of water.

2.6 More lime is now added to the pulp, and the bottle swirled carefully to ensure that all solids are in suspension before carefully placing the bottle on the bottle rolls. For 1 kg of sample the lime addition will be approximately 2.5 g or if the sample was received as a pulp, 3.5 g of lime.

2.7 Cyanidation tests are usually carried out at ambient temperatures, but can be performed in a water bath at a controlled temperature (normally 20 – 25°C). The pulp is first aerated on the rolls for the required period, usually between two to six hours, the bottle being left uncorked.

2.8 The bottle is removed from the rolls after the aeration period has elapsed and the pH of the pulp is checked. The ideal is a pH of about 11, and if less then some lime should be added. Sodium cyanide is now added to the pulp. As a guideline, for 1 kg of solids approximately 0.30 g of sodium cyanide will be required, equating to approximately 15 ml of a 2% sodium cyanide solution. Addition as a solution will ensure good mixing of the cyanide throughout the pulp. Swirl the uncorked bottle and place carefully on the rolls for the required cyanidation period, which can be from sixteen to forty hours.

2.9 After the required cyanidation period has elapsed, the bottle is wiped to remove any moisture on the exterior, and then weighed, the total mass of the bottle and pulp being recorded. The pulp is now filtered, the filtrate being used to wash out the cyanidation bottle. The residue is now washed three times with tap water, dried, weighed and then assayed for gold. The volume of the filtrate is determined, some of it is transferred to a sample bottle, this being assayed for gold and the remainder kept for residual cyanide and lime concentration determinations by titration. The methods may be found in the book entitled Assay and Analytical Practice in the South African Mining Industry (Lenahan and Murray-Smith, 1986).

Table 18.6. Calculation of the gold recovery in a cyanidation test.

<table>
<thead>
<tr>
<th>Mass of bottle + pulp at end of test</th>
<th>Mass of bottle empty</th>
</tr>
</thead>
<tbody>
<tr>
<td>2302.1 g</td>
<td>295.3 g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass (g)</th>
<th>Assay (Au g/t)</th>
<th>Au (mg)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulp 2006.8</td>
<td>4.16</td>
<td>409.06</td>
<td>4.90</td>
</tr>
<tr>
<td>Residue 997.7</td>
<td>0.41</td>
<td>409.06</td>
<td>4.90</td>
</tr>
<tr>
<td>Solution 1009.1</td>
<td>7.86</td>
<td>7931.53</td>
<td>95.10</td>
</tr>
<tr>
<td>Calculated head 997.7</td>
<td>8.36</td>
<td>8340.59</td>
<td>100.00</td>
</tr>
<tr>
<td>Assayed head 997.7</td>
<td>8.77</td>
<td>8749.83</td>
<td></td>
</tr>
</tbody>
</table>

% Extraction based on calculated head and washed residue = 95.10%
% Extraction based on assayed head and washed residue = 95.32%

Grinding curves and worksheets should be appended to the report.
3. Calculation of results
Table 18.6 shows the method of calculation of the percentage recovery of gold in a cyanidation test.

APPENDIX 18.6
Muffle Roasting of Sulphide Concentrates

(1) Place the 100 g sample to be roasted in a silica dish 145 mm long, 85 mm wide and 20 mm deep. This leaves 3 to 5 mm of freeboard above the sample.

(2) Put the sample in the cold furnace, set thermostat at 320°C and switch on. The furnace door must remain about 25 mm open throughout the roasting period, to ensure an unrestricted supply of oxygen.

(3) Rabble the sample every 15 minutes. Use a rabbler consisting of 2 toothed steel plates fastened to a steel rod in order to obtain efficient mixing.

(4) Raise the temperature by about 100°C every hour until the roasting temperature is reached. This can be done in four steps, e.g. about 25°C every 15 minutes. It takes about 7.5 hours to reach 750°C.

(5) Leave the sample in the furnace at target temperature for a further two hours, while still rabbling every 15 minutes.

(6) If the calcine is to be cyanided, it must be washed very thoroughly by repulping. Grinding the calcine before cyanidation usually improves gold extractions.

NOTE: If several dishes are used simultaneously in one furnace, the dishes should be swapped, front dish going to the back, about one hour before the end of the test, to ensure that all dishes have a reasonable time at the target temperature, as indicated in Figure 18.9.

![Figure 18.9. Rotating the positions of dishes in laboratory muffle roasting.](image)
APPENDIX 18.7

Determination of Activated Carbon Parameters

1. Determination of the equilibrium gold adsorption capacity constant

Because gold adsorption onto activated carbon is very sensitive to such parameters as temperature, pH, cyanide concentration and to ionic strength, any method used for measuring the equilibrium adsorption capacity of carbon must involve the control of these parameters. The method as used at the Anglo American Research Laboratories (AARL) for the adjudication of commercial products is as follows:

(1) Riffle out approximately 10 g of the carbon sample and crush the sample using a pestle and mortar before screening within the range 0.15 – 0.43 mm. The screened carbon is then boiled in a similar volume of 3 percent hydrochloric acid (vol/vol) for 10 minutes. Decant and wash the carbon twice with equal volumes of cold distilled water before oven drying at 110°C overnight.

(2) Prepare a borate buffer solution as follows:

Dissolve 15.46 g H₃BO₃ and 18.64 g KCl in approximately 4 litres of distilled water (solution A). Dissolve 10.00 g NaOH in 0.5 litres distilled water and add to solution A while stirring until pH 10.0 is reached (check with commercial buffer standard). Add 0.740 g KAu(CN)₂ and make up to 5 litres with distilled water, i.e. 100 g/t Au. To every 1 litre of this bulk solution add 20 mg NaCN prior to use.

(3) Weigh out five portions of the prepared carbon as in (1) following cooling in a desiccator, such that the masses are 0.10, 0.20, 0.30, 0.40 and 0.50 g respectively. The masses of each portion must be recorded to four decimal places.

(4) Place each sample of carbon in a 250 ml conical flask. Add 100 ml of the buffered gold solution as prepared above (2). Stopper the flasks. Agitate the flasks in a thermostatically controlled shaking machine at 25°C for 20 hours at a medium speed.

(5) Filter off the carbon quickly using Whatman No. 541 filter paper. After discarding the initial 10 – 20 ml filtrate, determine the concentration of gold in the filtrate obtained from each sample.

(6) Calculate the mass of gold adsorbed by the carbon by means of the difference in the gold concentration between the head solution and the filtrate obtained from each sample. Determine the k value of the carbon by plotting the empirical Freundlich isotherm, \( X/M = k c^{1/n} \), on log-log graph paper.

\[ \log X/M = \log k + l/n \log c. \]

where \( X \) = mass of gold loaded on carbon (mg)
\( M \) = mass of carbon sample (g)
\( c \) = equilibrium concentration of gold in filtrate (g/t)
\( k \) = constant defined as the carbon loading (mg Au/g C) in equilibrium with a residual solution gold concentra-
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tion, \( c \), of 1 g/t. This constant may be better expressed in kg Au/tC as the expression is more meaningful when related to a large scale CIP operation.

\[ l/n = \text{slope of plot as described above.} \]

The relative standard deviation of the above method was shown to be 3.5 percent.

2. Determination of gold adsorption rate

As the measurement of adsorption rates is entirely empirical, many different methods may be used provided good reproducibility is attained. In this regard strict attention needs to be given to the particle size of the carbon sample and to the preparation of the sample, while the control of temperature is also necessary. The method developed at the Klipfontein Organic Products laboratories and adapted by the AARL is as follows:

(1) Screen out 2 g of wet carbon in the size range 1.40 – 1.70 mm. Remove carbon fines from the screened sample using ultrasonic cleaning until no further fines are evident (several decant washings may be necessary). After oven drying at 110°C weigh out 1,000 g carbon sample for kinetic test. Moisten sample with 1 ml standard pH 10 borate buffer solution at least 1 h prior to use.

(2) Prepare 1 l of a fresh solution containing the following:

- 10 mg/l Au added as K (Au(CN))₂
- 100 mg/l Ca added as CaCl₂
- 100 mg/l CN added as KCN

Adjust the temperature of the test solution to 25°C before use.

(3) Place 1 litre test solution in a stoppered oblong plastic container (150 mm × 150 mm × 140 mm) and add the prepared carbon sample while noting the time of addition. Immediately commence shaking on a linear shaker adjusted to 130 oscillations/min. The linear shaker is housed in a thermostatically controlled glove-box at 25°C. Withdraw 5 ml aliquots after 0, 15, 30, 45, 60, 75 and 90 minutes for gold analysis.

The relative standard deviation of the above method was shown to be 3.4 percent.

3. Determination of attrition resistance

Carbon hardness or attrition resistance is a most important characteristic in any gold recovery circuit. Certain standard methods for the measurement of the attrition resistance of carbon, such as the A.S.T.M. test, involve the crushing action of a ball bearing on predried carbon. However, as these tests bear little resemblance to actual conditions in a CIP circuit and are perhaps too drastic, different methods for testing carbons for CIP have been developed. Two test procedures in common use are presented below.

The abrasion resistance method as developed by the Council for Mineral Technology involves the use of a laboratory float machine in order to simulate accelerated plant conditions. The method is as follows:
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(1) Sieve carbon to between 1.7 - 2.0 mm, wash and dry in an oven at 100°C for 16 hours.
(2) Place 30 g of this washed and sized carbon in 3 litres deionized water contained in a 4 litre capacity float cell. A Denver laboratory flotation machine, size D-12, is fitted with 9.5 cm stainless steel impeller and a 12.5 cm stainless steel hood.
(3) With the air inlet in the open position and at a constant speed of 1200 r.p.m. agitate the carbon and water for 60 minutes.
(4) Wash carbon onto a 0.850 mm screen. Dry the + 0.850 mm fraction in an oven at 110°C for 16 hours. Establish mass of this fraction and express as a percentage of the total carbon mass.

The measurement of carbon attrition as developed at the AARL makes use of a tumbling bottle as follows:

(1) 50 g of oven dried carbon (overnight at 110°C) which was initially wet screened to 1.00 - 2.36 mm is agitated with 100 ml water in a 1 litre "Consol" preserve jar or bottle for a period of 24 h. Agitation is carried out by rotating the bottle, end over end, at a rate of 40 r.p.m. (this is easily effected by wedging the bottle into a larger open ended plastic beaker or bottle and rolling on a set of rolls).
(2) Following the agitation for a period of 24 h, the carbon sample is wet screened through a 1.00 mm screen and the undersize carbon recorded as a percentage mass distribution of the original carbon sample. The test is carried out in triplicate and the results averaged for specification purposes.

The relative standard deviation of the above method was 4.7 percent.

4. Miscellaneous tests

Other carbon specifications which may be required in certain instances include the following:

(1) Particle size distribution. While the size distribution may be dictated by the efficiency of the interstage screens on a particular circuit, + 1.18 - 2.36 mm carbon is generally used in South Africa at present (1986).
(2) Bulk density. Bulk density data may be required in establishing plant balances.
(3) Solubles and moisture content. For payment purposes the weight of carbon will be calculated on a water washed, dry solids basis.
(4) Volatile content. The measurement of the carbon volatile content (B.S. 1016 : part 3 : 1965 : 3.4.2.) provides a most useful method of quality control with regard to carbon regeneration.