WHAT SCALE SHOULD YOUR SMELTING TESTWORK BE DONE AT, AND WHAT DO YOU GET FOR THE MONEY YOU SPEND?

I J Geldenhuys and RT Jones
Mintek

Abstract

Pyrometallurgical testwork is carried out in order to mitigate risks at various stages of a project. Many factors influence the choice between laboratory and pilot-scale smelting testwork. This paper describes the different types of result that can be obtained from two different scales, namely a 10-ton test on a 200 kW furnace, and a 100-ton test on a 2 MW DC arc furnace. The cost of the larger test is a bit more than twice that of the smaller test, but the type of information obtained is quite different.

1 Introduction

During the life of a metallurgical project, testwork is carried out at various stages, to reduce uncertainty and mitigate risks (both financial and process-related). Pyrometallurgical testwork is often seen as particularly important because of the high capital cost of the equipment, and the serious consequences if something goes wrong in an industrial plant. Some of the significant risks are: the process might require more energy than expected, recoveries might be lower than required, the desired process throughput might not be achieved (or might not be achieved quickly enough), or the furnace might fail altogether. Engineers are confronted with the question of why large-scale testwork should be done instead of smaller and less expensive tests. This paper addresses the choices faced by someone needing to carry out smelting testwork, and focuses particularly on pilot plants. Although each set of tests needs to be designed to address the specific needs of a particular project, a general methodology does apply when deciding what scale would provide the best possible solution, taking into account the various constraints that might apply.

1.1 Laboratory tests

In the early stages of a project, it is often appropriate to start working on a small scale until it is very likely that the project will go ahead. Small scoping tests are typically conducted in a high-temperature laboratory. Laboratory crucible tests are exclusively batch tests, with a typical single-pass outcome. Laboratory tests require small quantities of materials, and often focus on variability and fundamental metallurgical investigations. The results from these tests can be applied by using fundamental or empirical models to interpret the data. Despite typically being viewed as providing indicative results only, often due to time constraints, limited availability of feed materials, or during early scoping studies, this type of study provides relatively quick results without the need for large quantities of material. Laboratory tests also allow for the testing of a wide range of chemical compositions (specifically with regard to reductant additions, or fluxing regimes if applicable) within the constraints associated with smelting at this scale (issues such as crucible compatibility, crucible effects, and temperature limits). The results obtained from laboratory tests are often used to evaluate the viability of a new resource, metallurgical application, or modification to a process. Fundamental metallurgical testwork can be conducted in the laboratory where conditions are firmly under the control of the experimentalist.

However, industrial smelting is usually not a batch process, and many variables influence recovery and product grade when operating a smelter. Scale-up from small-scale tests is generally perceived as high-risk, especially when applying new technology where limited references or industry standards are available. The introduction of new technology or the application of existing technology to different process chemistry or even just a new ore body, are also perceived (with good reason) to be fraught with risk and uncertainty (especially if an existing competing technology is well established and the new technology is unproven). Commissioning and ramp-up to nameplate capacity of a full-scale plant is often delayed by a lack of fundamental understanding of the process and the shortage of operating experience. New pyrometallurgical projects can seldom afford the perception of high risk, or a slower ramp-up to nominal capacity than that assumed in the economic model. However, while it might be beneficial to conduct a very large pilot campaign (say 6 000 tons over three months, for example), this is not always possible (some exceptions do exist) or affordable.

1.2 Combination of laboratory and pilot-plant work

Many risks can be addressed via a suitable development program that could include scoping work (laboratory-scale) followed by pilot-plant testing. Real and perceived risks can be addressed through large-scale demonstration testwork (perhaps a twentieth to a tenth of the proposed commercial scale), but this may not always be possible. In order to establish the ideal smelting conditions and other important operating and furnace design parameters, such as energy requirement, slag properties (physical and electrical), recoveries, and product grade, Mintek typically recommends conducting pilot-plant testwork at about the 100 to 200 ton scale. It is also possible to evaluate the process on a small-scale pilot furnace, about 5-10 tons for example, but generally scale-up risks are better addressed through larger-scale demonstration testwork (>100 tons processed). While the results from the smaller test campaigns are valuable and it is possible to evaluate the suitability of the process even at the smaller scale, the confidence level and accuracy of measurements (such as electrical and physical properties of the slag, product grade, and quality) is significantly higher, if compared to measurements from smaller campaigns.

1.3 Demonstration-scale smelting

Demonstration-scale smelting, prior to industrial implementation of a process, offers an opportunity to address many of the risks associated with pyrometallurgical operations (process, operational, and implementation). There are many obvious benefits to undertaking large-scale pilot testing as part of the development path for a new project. Large-scale testwork provides the opportunity to evaluate some of the critical design aspects, evaluate operational issues, and address problems that could cause costly delays during commissioning early on. It provides an opportunity to evaluate the specific application and develop suitable engineering solutions. For a pyrometallurgical process, containment of high-temperature products (and therefore selection of appropriate refractories) and the general equipment design is paramount to the successful implementation. Implementation often hinges on the ability to contain the liquid products as well as the achievement of a high degree of recovery of the valuable metals. Often these two objectives are not compatible, and very specific engineering solutions are required to address these aspects.

Insufficient testing can result in poor operational performance and retard the adoption of new technology. Problems sometimes only become apparent once a plant has been in operation for a significant period, and many industries have had to make significant design modifications shortly after commissioning of a new plant, at a significant capital cost, usually incurring loss of production which may lead to a (sometimes unwarranted) 'loss of faith in the technology'. The latter point is particularly damaging if viewed in the context of new technology. Often acceptance by industry of new technology hinges greatly on how 'successfully' the first application is implemented.

2 Identification of the testwork objectives

The starting point is to identify the objective of the testwork. In the case of a new, undefined deposit, a laboratory-scale variability or characterisation testwork program will often suffice. The outcome from this type of study provides the necessary information on which to base further exploration or resource development. After the testwork, the recoveries, product grades, and metallurgical data are provided to the client in a formal report for reference. A provisional process interpretation, if applicable, is typically provided too. Once a resource is defined and significant quantities of raw material are available, a pilot-plant campaign is often targeted by the developer. The selection of the most appropriate scale for this type of testwork is the primary focus of this paper. Long-term testwork (although ultimately desirable) is not always feasible. Designing an experiment that will provide answers to the critical questions is the primary objective. Some concessions might be required, as practical constraints need to be taken into account.

3 Choice of scale of pilot-plant testwork

This paper briefly reviews two scenarios for pilot-plant smelting testwork utilising DC arc furnaces. Pilot-plant testwork addresses, amongst others, product quality, recovery, and process parameters, thereby adding significant value to projects. The operational and metallurgical data from these test campaigns are processed and evaluated to provide input into feasibility and, ultimately, design studies. Mintek has developed significant expertise in this field of pyrometallurgical research, from demonstration testwork through to providing furnace and power-supply design specifications.

Deciding what scale to conduct testwork on is not just a financial choice, as many other factors requires consideration. In overview, the following aspects play a part in the determination of the scale.

1. Quantity and quality of the raw material of interest
    a. How much material is accessible and available for testwork?
    b. Is the bulk sample representative (quality) of the resource or an area in the resource?
    c. What pre-treatment is required (drying, calcining, pre-reduction, upgrading)? Matching the scale of smelting testwork with the available pre-treatment options (pilot plant or other alternatives) is often one of the main constraints when determining the scale of the smelting test.
2. Budgets and timing
    a. Affordability, including collection of a bulk sample, shipment, taxes, testwork, disposal costs
    b. How long will it take to get the sample to the pilot plant, including issues like local weather conditions, legalities, shipping, and pre-treatment requirements (drying, calcining, pre-reduction, upgrading).
3. The technical objectives
    a. Required deliverables
    b. Desired deliverables

Collection of a good-quality representative sample for a demonstration-scale test (100 to 200 tons) is not straightforward. Issues related to weather conditions, accessibility, and preparation of the ore often restrict the scale of a test. Project requirements for a greenfield project are often very rigorous and large-scale tests are viewed as a requirement in order to demonstrate the feasibility of the new ore deposit to potential investors. Demonstrating that the ore is either similar to other known deposits, or has some unique advantage (grade, composition, or physical property) can increase the value of a project substantially.

Within these constraints, it is therefore very important to quantify or understand the genealogy (origins) of the sample. Although it is generally not practically possible to mine or collect a perfectly representative sample, it is very important to understand what the sample represents, as this information often provides valuable context when interpreting the results from the testwork. For example, it may only be possible to collect a surface sample from a new deposit, which may be weathered or be of lower grade than the average projected plant feed. Realising the implications of the history or nature of a sample is critical when selecting the scale of the testwork. For example, if access is restricted, variability testing may be an important aspect to include. Variability testing may be done, firstly via a suitable laboratory test program (if applicable), or consideration could be given to evaluating multiple sub-samples utilising a smaller pilot-plant furnace, for example.

In addition to these aspects, practical constraints are often encountered if some form of pre-treatment is required. Size reduction may be a critical aspect, but crushing and screening equipment is usually not difficult to acquire. However, if upgrading, sorting, or thermal pre-treatment (drying, calcining, pre-reduction, *etc.*) is required, availability of equipment often restricts the sample size that can be produced for the testwork.

Thus evaluation of the technical objectives should be conducted in parallel with an understanding of the quantity and quality of the test sample that will be available for the testwork. Clearly defined and identified material is as important as identifying the technical scope of work for a test. Knowledge of the sample will improve the ultimate quality of the testwork results, as challenges related to the sample quality can be addressed during the testwork campaign.

4 Testwork options (a case study)

The case study used as an example here is based on the choice between two testwork scenarios. In both cases, the equipment involved a pilot-scale DC arc furnace utilising a single (solid) electrode configuration with side-feeding of the raw materials. The options are characterised in terms of the tonnage of feed material treated, the outside diameter (OD) of the furnace shell, and the duration of the test. The two possible scenarios are:

Option A: 7-10 ton scale, 1 m furnace, about 7-10 day campaign

Option B: 100-200 ton scale, 2.5 m furnace, about 14-21 day campaign

The primary objectives of the case study are defined as follows:

a) To demonstrate the smelting of chromite in a DC furnace and evaluate product quality and recovery
b) To generate sufficient process information for furnace scale-up as would be required for commercialisation of the process

Mintek is in a good position to interpret and apply the results from testwork to a commercial DC furnace design based on previous experience with the commercialisation of DC arc furnace technology for chromite smelting, ilmenite smelting, cobalt recovery from slag, and the ConRoast process, amongst others.

Mintek's pilot plant facilities include a dedicated research facility typically operated with a 1 m OD shell, as well as a larger-scale demonstration facility, typically operated with a 2.5 m OD shell. Although a variety of other combinations and sizes are available, these two options illustrate the flexible nature of the pilot facilities available at Mintek and address the issues of quantity and quality as well as technical objectives as defined for this case study.

The equipment options are described in more detail in the following sections.

4.1 Option A: 7-10 ton scale, 1 m furnace, about 7-10 day campaign

If a limited quantity of feed material is available, or a process is already well established, the smaller-scale pilot-plant test setup is often selected for testwork. Typically, a sample size of about 10 tons is proposed, but the type of ore tested will determine the minimum and maximum sample size. The smaller facility is typically operated at a power level of about 200 kW of which about 30% of the energy input is effectively used by the process itself.

The smaller furnace is relatively easy to install, and installation costs are significantly lower than for the larger furnaces. In addition, refractory availability is often addressed by using castable refractory instead of refractory bricks; this allows for fast-track testwork if required.

If a client opts for small-scale furnace testwork (about 10 tons), the testwork is usually conducted in a 1 m OD DC furnace. The small-scale furnace consists of a refractory-lined cylindrical water-cooled shell, a roof, and a hearth. The roof, lined with an alumina castable refractory, contains the single, central entry port for the graphite electrode. Additional ports for the feed, and access to the furnace bath for inspections and dip samples, are located in the roof (as shown in Figure 1). The standard testwork hearth consists of a high-magnesia dry ramming material in combination with the standard Mintek, mild-steel pin-type anode. The DC arc furnace setup has a single electrode (the cathode) positioned above the molten bath. The bottom anode, installed in the hearth, in combination with the molten metal, completes the electrical circuit. (This facility may also be installed in three-electrode AC or twin-electrode DC configuration.)

The furnace is installed with a single tap-hole consisting of a 30 mm diameter hole drilled through a refractory block, typically with no additional cooling. The single tap-hole design is dictated by the size of the furnace shell. A typical installation of this scale setup in DC mode, is shown in Figure 1 below.

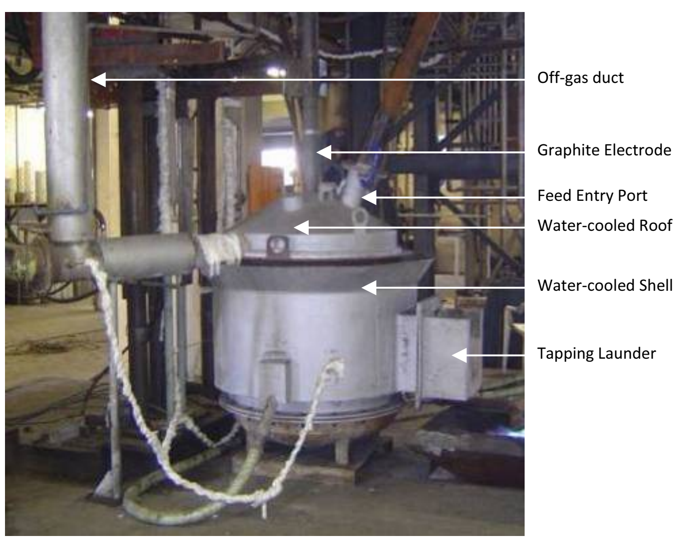

Figure 1: Typical setup of small-scale facility

Testwork in this facility allows for evaluation and confirmation of process chemistry. Process design parameters and product quality can be predicted utilising the results. A typical testwork plan includes the establishment of a baseline or starting recipe and operating conditions with minimal process optimization. Fluxing and reductant addition is evaluated (if applicable) but not optimized, although relative comparisons may be included in the testwork schedule.

The expected duration of smelting testwork using the 1 m OD furnace facility is about 7 days, with the furnace being operated continuously. The primary objective of small-scale testwork is typically to confirm product quality and process parameters. It is, therefore, critical to stabilise the furnace and process the sample in a systematic way to ensure adequate experimental results are produced. Generally, the smaller furnace, with the relatively small inventory of reaction products, allows for a relatively quick response to changes. Although fairly substantial changes to the operating recipe are easily implemented on the smaller scale, the energy balance of the small furnace is more susceptible to operational interruptions. Temperature-sensitive reactions are often challenging. A fairly large standard deviation on the average tapping temperature is normal, due to the low thermal efficiency and smaller thermal mass of the equipment at this scale.

The following information is recorded during the installation of the furnace and the execution of the testwork:

- Photographs, calibration certificates of scales and furnace installation measurements
- Consumption figures for raw materials
- Chemical composition and masses of all raw materials fed to the furnace
- Chemical composition and masses of solid products: metal, slag, and off-gas dust (via suitable analytical methods, excluding gas). Limited information is expected regarding the dust composition due to the small quantities of dust collected, but all dust collected is weighed and assayed appropriately.
- Electrical parameters, energy consumption, average power, voltage (accuracy of electrical parameters are approximately within about 15% at this scale)
- Thermal efficiency of the small-scale furnace is relatively low at approximately 30 to 40% (compared to the demonstration scale furnace of typically greater than 70%)

4.1.1 Description of experimental procedure

The furnace is tapped via the single tap-hole at the conclusion of each batch. A batch consists of a suitable mix of raw materials, fed to the furnace whilst balancing the energy input to achieve the desired operating temperature and reaction. The reaction products, typically slag and metal, are tapped from the same single tap-hole, and separation takes place (after solidification and cooling) by hand. All product streams are weighed and sampled for purposes of the overall and elemental mass balance. Products are stored for return to the client or for disposal via a suitable, environmentally acceptable route.

At this scale, a single tap-hole operation is the practical solution. However, due to post-tap-hole mixing, collection of slag and metal samples from the liquid stream during tapping is significantly more challenging than with a two-tap-hole setup. Slag and metal are tapped together, and, due to the small volumes tapped, rapid cooling may prevent optimum separation of metal and slag in the ladle. It is standard testwork procedure to collect samples from the liquid stream, but it is often found that some cross-contamination occurs on the small scale. Droplets of metal are easily trapped in relatively viscous slag, but this represents artificial entrainment rather than an actual process restriction. The entrainment issue is significantly reduced as the scale of the furnace increases and two separate tap-holes are used to withdraw liquid products from the furnace.

In addition to the standard measurements obtained from testwork, some supplementary information can be obtained by using Mintek's Pyrosim computer software package (a steady-state pyrometallurgical process simulator that incorporates thermodynamic data). For example, the gas composition can be estimated either by assuming chemical equilibrium or by using an empirical model.

The average feed-on availability for this facility is typically less than 50%, which includes downtime for operational and process related maintenance (*e.g.* off-gas cleaning, electrode maintenance, bath inspections, tapping, and sampling). The overall availability of the small-scale test furnace is lower than that of the larger pilot-plant furnace, which is related to the scale of operation and not the process. As the scale increases, generally the overall availability of the furnace (feed-on time as a proportion of total time) improves.

The smaller-scale furnace provides an opportunity to test a wider range of metallurgical conditions, as the composition of the furnace inventory is easily changed due to the small volumes contained in the vessel. Any recipe adjustments are therefore easily accomplished and this allows for evaluation of metallurgical sensitivities relative to a variety of plant conditions, or an evaluation of variability within a new deposit. However, smaller-scale tests are not operated with the same degree of thermal stability, as the thermal efficiency of the furnace is very low. Any disruption disturbs the thermal balance of the furnace, so measured energy consumption and temperatures might not be accurate. Mintek has developed empirical correlations to interpret the results from the smaller-scale tests to address many of the scale issues.

4.2 Option B: 100-200 ton scale, 2.5 m furnace, about 14-21 day campaign (Demonstration-scale furnace)

If a client opts to conduct a demonstration-scale testwork program (typically processing about 100 to 200 tons of materials), Mintek typically utilises a 2.5 m OD pilot-plant furnace shell. The installed furnace consists of a refractory-lined cylindrical shell, a base, a water-cooled roof, and a refractory roof plug rested on top of the roof. The materials are subjected to smelting in a DC furnace (typically open-arc operation). The smelting campaign provides an opportunity to evaluate the process metallurgically whilst also providing evaluation of DC-specific aspects or advantages, where application of the DC furnace is considered. Electrical and physical properties of the slag are evaluated during the testwork campaign. Many aspects are not DC-specific and can be applied to AC applications as well, thus providing large-scale smelting testwork appropriate to the metallurgical application rather than focused exclusively on a DC furnace. In Figure 2, the typical facility setup and plant layout is shown, illustrating the process flowsheet (feed to product) followed for most testwork campaigns.

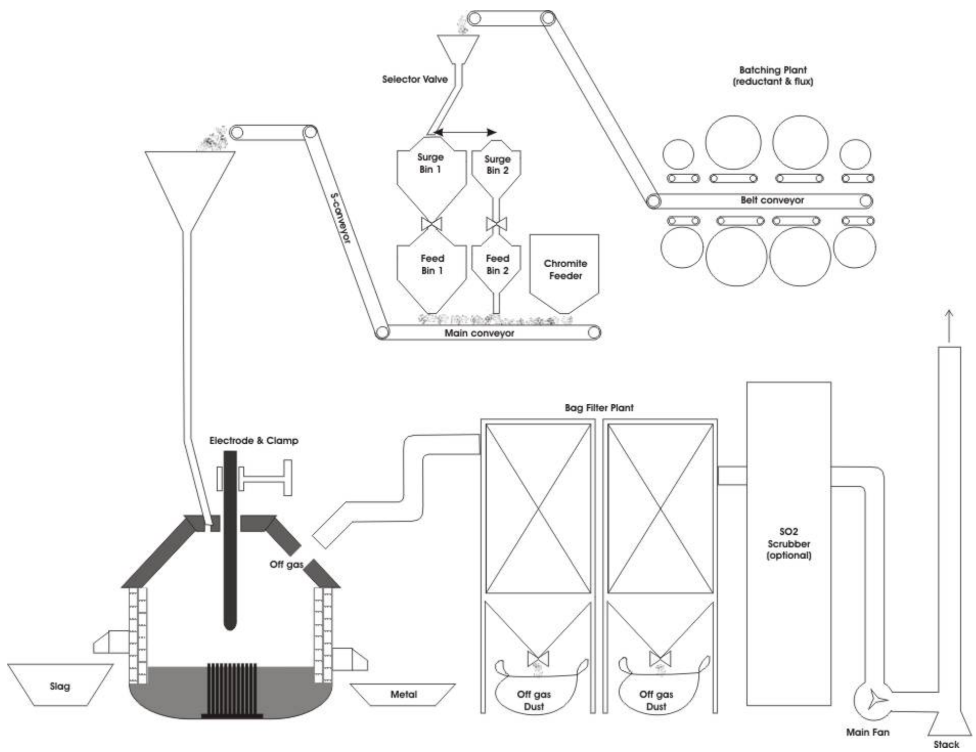

Figure 2: Layout of Mintek's pilot-plant facility

Figure 3 shows the general refractory installation and final installation of the demonstration-scale furnace. Each installation is specific to the project. Refractory selection and tap-hole design is process specific. The diagram illustrates the differences between the 1 m OD and 2.5 m OD shell, most specifically the two-tap-hole design which significantly reduces sample contamination during tapping, as well as decreasing the entrainment uncertainty associated with tapping from a single tap-hole.

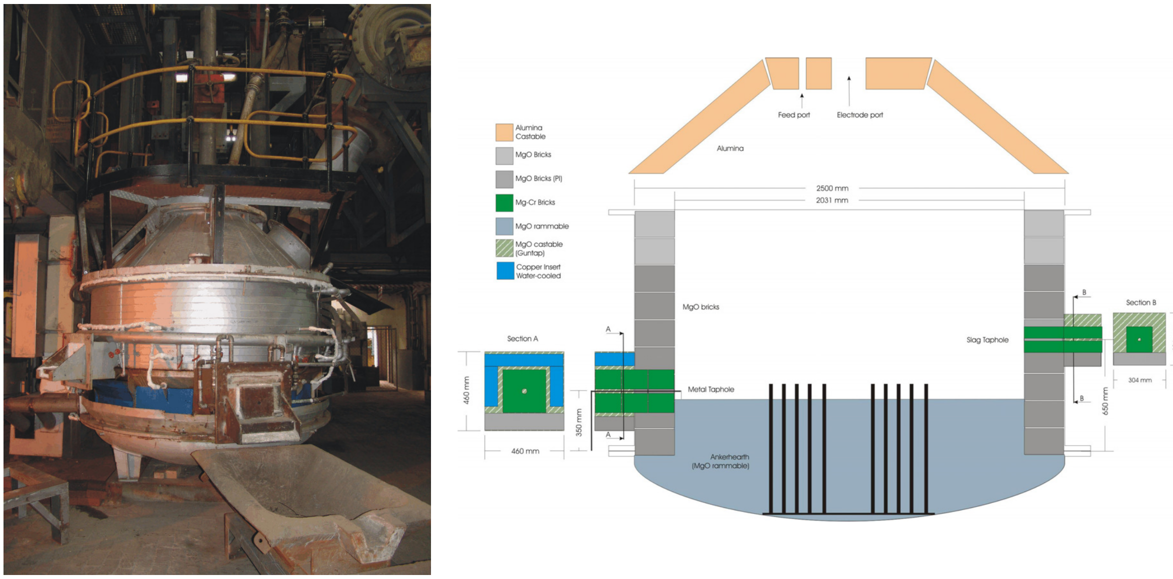

Figure 3: Generic installation of demonstration-scale pilot furnace

The pilot-plant furnace shell shown here has an unlined shell diameter of 2.5 m, but other sizes are also available (ranging from 1.5 m up to 4.25 m). A demonstration-scale test furnace is designed with two openings in the shell. The tap-hole blocks are seated in the openings, resulting in two dedicated tap-holes approximately 300 mm apart. The lower tap-hole is typically utilised to drain metal while the top is usually dedicated to slag removal. The shell and roof are equipped with water-cooling. Three water-cooled copper inserts are typically installed in the metal tap-hole area, while a copper insert is only installed in the slag tap-hole if required for process reasons. The roof plug contains a feed port, positioned to ensure an acceptable feed angle into the furnace. By-passed feed and other fumed oxides are collected at the bag-filter plant and are weighed and sampled for mass balance purposes. As with the small-scale facility, the pilot-plant setup has a dedicated feed system; calibration and mechanical modifications are conducted on a per project basis to ensure reliable and accurate feed measurement into the furnace.

A pilot-plant campaign is conducted with shift teams operating the furnace continuously for about 14 days, to process about 100 to 150 tons. Operation of the furnace follows a semi-continuous batch process, as for the smaller-scale test, namely a feed period linked to a furnace tap at the end of the batch.

The furnace power is ramped up during the warm-up phase and the operating parameters optimized to achieve a baseline operating condition. Typically, the first recipe and operating targets are close to the targeted values. The total throughput achieved per day will depend on the operating parameters as well as the physical properties of the feed material. The average feed-on availability is between 80 and 88%, which relates mostly to process downtime for operational and process-related maintenance (*e.g.* off-gas cleaning, electrode maintenance, bath inspections, tapping, and sampling). The overall availability of the test furnace will be lower than is expected for a commercial operation, which is specifically related to the scale of operation and not the process.

The demonstration-scale furnace, because of its larger volume, requires a longer start-up period, and changes to the recipe or thermal balance require more time. The operation is, however, less sensitive to minor thermal, mechanical, or metallurgical events, which increases the accuracy of measurements of energy and electrical factors. Metallurgical results are often better than those obtained from smaller-scale furnace campaigns, and higher recoveries are therefore measured, which is mostly due to scale factors and not process-related issues.

5 The test plan

A detailed test plan is developed for each individual test program, but some basic guidelines are followed when deciding on the test parameters. The recipe decided upon prior to the start-up of the campaign is adjusted and optimized during the testwork campaign, typically in consultation with the client, to ensure that the objectives of the testwork are achieved.

General objectives for a testwork program may include the following:

- An overall mass and energy balance, including a breakout of the furnace refractories as part of the overall mass balance (Option A: complete excavation with primary objective to evaluate overall mass balance, limited evaluation of refractory performance possible at small scale, Option B: complete excavation with the intention of evaluation of refractory performance and to complete overall mass balance)
- Accountability and recovery of major constituents, and deportment to solid product streams (gas deportment by difference) including slag, metal, and off-gas dust. (Option A: limited evaluation of elements to the solid off-gas phase possible due to scale).
- Process energy consumption and evaluation of pilot-plant thermal efficiency in the context of the furnace facility utilised (equipment description included in final report)
- Electrode consumption, electrical properties, and refractory performance (furnace excavation measurements)
- Generate process information and process data (testwork mass and energy balance) that the client can supply to a competent technical entity from which process design parameters can be estimated.

To achieve testwork objectives the following parameters may be adjusted:

- Feed recipe (specifically reductant addition and fluxing regime, if applicable)
- Operating temperature
- Smelting intensity (power level, only practical for Option B)

A testwork report, collating the results as described, is issued at the end of each project. Test results are typically evaluated and discussed in light of the following aspects:

Table I: Items included in testwork report

Aspect	**Comment**
Overall mass balance Recovery of constituents to the metal phase Accountability of major elements Deportment of elements to the solid product streams	All feed and product masses are taken into account for the overall elemental mass balance. Once the overall mass balance is validated, typically, sub-periods are identified for further evaluation
Overall energy balance Rate of energy loss, and thermal efficiency of the equipment	Evaluated specifically by utilising the average power and feedrate for the baseline condition and subsequent higher-power-level periods. The aim being to establish a reliable process energy requirement.
Summary of product stream compositions	All assays results will be included in the report
Electrode consumption	Overall campaign measurement, but sub-periods may be evaluated if possible and realistic.
Electrical properties	Typically evaluated during a baseline condition, with additional tests if possible, or if specifically required.
Refractory performance (furnace dig-out measurements)	Post-campaign evaluation of refractory wear as part of the overall mass balance
Process observations and conclusions	Comments, suggestions, conclusions based on the general outcome of the project

6 Summary of technical differences, Option A versus Option B

Table II summarises the differences between the two test options as described in the equipment section.

Table II: Characteristics of Testwork Options A and B

	Option A	Option B
Feed requirement (ideal)	7 (10) tons	100 (150) tons
Testwork duration days (including contingency)	7 (10) days	14 (21) days
Tap-hole	Single tap-hole	Separate tap-holes for slag and metal
Operating area or hearth area	0.49 m^2	3.37 m^2
Operating power, estimated range	~150 to 200 kW	~1.0 to 2.2 MW
Power flux	~300 to 400 kW/m^2	~300 to 650 kW/m^2
Thermal efficiency (improves with scale-up)	~40 - 50%	> 70%
Electrical properties of slag (relates directly to power supply specification)	Extrapolated from empirical correlations	Measured directly
Deportment of elements to product phases	Off-gas dust collection limited due to scale. Empirical deportments used (based on Mintek's experience and literature)	Good collection of off-gas dust/solids possible. Deportments calculated from testwork and correlated with Mintek's experience
Mass balance / Accountability	Major elements: Typically greater than 90% accountability Minor elements: Typically poor accountability of minors Due to uncertainties associated with single tap-hole & scale, metallic inclusions in slag are often experienced, increasing uncertainty. Very limited off-gas solid collections due to small scale.	Major elements: Typically greater than 97% accountability Minor elements: Typically greater than 90% accountability Due to scale, significant quantity of off-gas solids collected, 2 tap-holes and larger vessel contributes to good quality samples, artificial entrainment of metal in slag not as significant
Slag and metal temperature measurements	Single tap-hole prohibits accurate measurement of both stream temperatures during tapping	Two-tap-hole operation allows for measurement of slag and metal temperature during each tap
Process information	Typically more conservative due to scale; process parameters are estimated based on empirical correlations and Mintek's experience, as direct measurement is not practical or reliable	Direct measurement of many process parameters is possible because of the larger scale of the testwork

7 Factors influencing the choice of scale of testwork

Table III shows some factors that influence the scale of testwork to be carried out, and can be used to assist decision-making.

Table III: Factors influencing the choice of scale of testwork

	Option A	Option B
Limited sample available	X	
Time constraints	X	
Restricted budget	X	
Confirmation of technical viability (PFS – pre-feasibility study)	X	X
New (unproven) technology	X	X
High level of accuracy required Detailed engineering (BFS – bankable feasibility study)		X
Major capital investment (Mitigation of perceived risk for investors)		X

8 From testwork to industrial scale

Table IV shows the actual scale of testwork carried out prior to the commercialisation of some processes.

Table IV: Comparison of final testwork with industrial implementation of a number of processes

Process	Testwork Power, MW	Testwork Furnace diameter	Industrial implementation
Chromite smelting	0.3 to 0.5	1 to 2 m	11 MW (16 MVA) 25-30 MW (40 MVA) 40 MW (62 MVA)
Ilmenite smelting	0.5	1.8 m	25 MW then 35 MW
Cobalt recovery from slag	2.0	2.5 m	40 MW

9 Conclusions

Mintek believes that both test facility options can be used to generate process information and process data (testwork mass and energy balance) and Mintek has extensive experience with both options. Data from both these testwork options can be supplied to a competent technical entity from which process design parameters can be estimated. However, in the case of the smaller-scale test, the design parameters are generally specified more conservatively to allow for measurement uncertainties. A conservative specification may contribute to additional capital expense, for example.

This paper has focused particularly on the different types of result that can be obtained from two different scales of pilot plant, namely a 10-ton test on a 200 kW furnace, and a 100-ton test on a 2 MW DC arc furnace. The cost of the larger test is a bit more than twice that of the smaller test, but the type of information obtained is quite different.

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The Authors

Isabel Geldenhuys, *Head, Commercial Applications*, Pyrometallurgy Division, Mintek

Isabel graduated with a B.Eng degree in chemical engineering from the University of Pretoria in 1996, and has worked in the Pyrometallurgy Division at Mintek since then, with her greatest involvement in process development and DC arc furnace technology. Isabel was promoted from Chief Engineer to Head, Commercial Applications in November 2005. Isabel is also a registered Professional Engineer.

Rodney Jones, *Specialist Consultant*, Pyrometallurgy Division, Mintek

Rodney Jones has worked in the Pyrometallurgy Division at Mintek since 1985. He holds a BSc(Eng) degree in chemical engineering from the University of the Witwatersrand (Wits) in Johannesburg, a BA degree in logic and philosophy from the University of South Africa, and a MSc(Eng) degree in metallurgy from Wits University. He is a registered Professional Engineer, an Honorary Life Fellow and Council member of the Southern African Institute of Mining and Metallurgy (SAIMM), a Fellow of the South African Institute of Chemical Engineers (SAIChE), and a full member of the Computer Society of South Africa (CSSA). He was a Visiting Professor at the Center for Pyrometallurgy, University of Missouri-Rolla, during July and August 1996, and in 2002 and 2003 has also lectured in pyrometallurgy at Murdoch University, Perth, as an Adjunct Associate Professor. The National Research Foundation rated him in 2009 as an 'Internationally Acclaimed Researcher'. His main research interests are in the field of computer simulation and design of high-temperature processes, and the development of thermodynamic software. He is the author of Pyrosim software, for the steady-state simulation of pyrometallurgical processes. This software is in use in 22 countries around the world. Rodney is also one of the inventors of the ConRoast process, which has recently seen the demonstration of DC arc smelting of over 50 000 tons of PGM-containing materials at Mintek.