NEW TiO_2 SLAG PLANT FOR CYMCO USING 30 MW DC FURNACE

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ABSTRACT

Building on Bateman's track record in the heavy minerals industry, Bateman was appointed in 2006 by China Yunnan Metallurgical Company (CYMCO) to provide process technology and engineering design for a 30MW DC furnace ilmenite smelting facility in China's Yunnan province. Using locally mined ilmenite, it will produce 85,000 tpa of high-grade (>87%) titanium dioxide slag for use as feedstock to CYMG's future pigment and titanium sponge plants. 60,000 tpa of low-manganese pig iron will also be produced as a valuable by-product of the ilmenite smelting.
The advantages of using DC furnace technology compared to conventional rectangular and circular AC furnace technology include a more compact process vessel, the avoidance of an agglomeration step and improved process control and reaction kinetics. Critical considerations during the design of CYMCO's furnace include optimising the furnace geometry, selection of reliable anode technology, minimising arc deflection, accurate feed control and the requirement to operate with a stable slag freeze lining. As CYMCO's technology providers, Bateman conducted smelting test work and provided process guarantees, a basic engineering package for all process units, furnace operator training and control system design and programming. Bateman also played a leading role coordinating a team of major equipment suppliers and a Chinese design institute through the design, supply, construction and commissioning phases of the project. The critical process equipment, including the furnace vessel, gas treatment plant, DC power supply and slag milling/classifying was imported from prominent equipment suppliers;- SMS Siemag, Theisen, ABB and Loesche respectively. The remainder of the equipment was procured from Chinese suppliers. Furnace commissioning plans are also briefly discussed in this paper.

1 INTRODUCTION

Titanium dioxide (TiO_2) is used mainly in its pure form as an opacifier to give whiteness to pigment for paints, plastics, paper and cosmetics. A smaller portion of TiO_2 is used for the production of titanium metal for specialized lightweight high-strength applications such as aircraft components. Exploitable deposits of TiO_2 occur in the form of ilmenite (mainly $FeTiO_3$), either within beach or alluvial mineral sands deposits or in rock deposits containing typically 37-54% TiO_2[5]. The most common method of extracting TiO2 from ilmenite is by carbothermic reduction to separate the iron, as a saleable by-product, and slag containing 75-87% TiO_2. The slag can be further processed to produce TiO_2 pigment using either the chloride or sulphate process.

The major producers of TiO_2 slag include QIT in Canada, RBM and Exxaro in South Africa, and Norway's Tinfos. A number of low-volume Chinese operations also produce TiO_2 slag for local consumption. However, a number of Asian industry players are increasingly looking to vertically integrate slag and pigment production. Such organizations are also looking towards larger scale operations to improve economies of scale and product quality. In 2006, China Yunnan Metallurgical Company (CYMCO) decided to enter the TiO_2 industry by exploiting the TiO_2 deposits in China's southwest province of Yunnan. Following a technology search CYMCO selected the DC Furnace smelting route to produce the TiO_2 slag and appointed Bateman Engineering as technology providers. Since 1999, Bateman has viewed DC furnaces technology as a significant growth market and focus area for processing of fine materials such as Ilmenite, and has invested significant effort into research, development and feasibility studies in this area.

2 BACKGROUND TO CYMCO AND ITS TIO_2 AND TI PROJECTS

China Yunnan Metallurgical Company (CYMCO) operates numerous metallurgical mines and extraction plants in China's Yunnan province, including the production of zinc, lead, aluminium, and manganese. CYMCO is listed on the Shanghai stock exchange, but remains a state-controlled company. When CYMCO decided to enter the Ti industry a new subsidiary, Yunnan Xinli Non-ferrous Metals Company Ltd, was formed. Xinli is majority owned by CYMCO with some minority private foreign shareholding.

Xinli plans to operate a complete vertically integrated production chain including:

- Ilmenite mining and concentration at a central concentration plant close to the mining areas;
- Ilmenite smelting to produce TiO_2 slag and iron, adjacent to the concentration plant;
- TiO_2 pigment production via the fluid bed chlorination route at a separate site;
- Ti sponge production and processing to produce finished metal shapes.

2.1 Xinli's TiO_2 Slag Project

Xinli's TiO_2 slag project started in March 2006 with the signing of a technology supply contract with Bateman Engineering to provide the technology to smelt ilmenite using DC furnace technology.

Table 1: Selected design parameters of Xinli's TiO_2 Slag Smelting Plant

TiO_2 Slag Production	>85,000 tpa
Slag Composition	>87% TiO_2
Furnace Rated Power	30 MW

The plant comprises one 30MW DC furnace with a single graphite electrode and conductive bottom anode. The furnace off-gas is cooled and cleaned in a wet scrubber, and re-used in other parts of the plant. Upstream of the furnace, the ilmenite and anthracite are dried in fluid bed driers fuelled by furnace gas. The feed of ilmenite and anthracite to the furnace is independently and continuously controlled by accurate feed control systems. The mixed feed is then introduced to the furnace via a hollow electrode and/or peripheral feed chutes. The furnace is operated with an open-bath (no un-reacted burden) and open-arc. Slag is tapped intermittently into 15 ton slag pots and left to solidify and cool before crushing and milling. Iron is tapped intermittently into 35 ton ladles and then de-sulphurised and re-carburised before being cast into saleable 7kg ingots.

Test work done during the early stages of the project verified the possibility of using a flash pre-heater upstream of the furnace to pre-heat the ilmenite to 900°C to reduce furnace power consumption. However, during the engineering design phase, a decision was made against the installation of a pre-heater in Xinli's plant for various reasons. Cogeneration to reduce overall electrical energy consumption are currently considered for other ilmenite smelting opportunities.

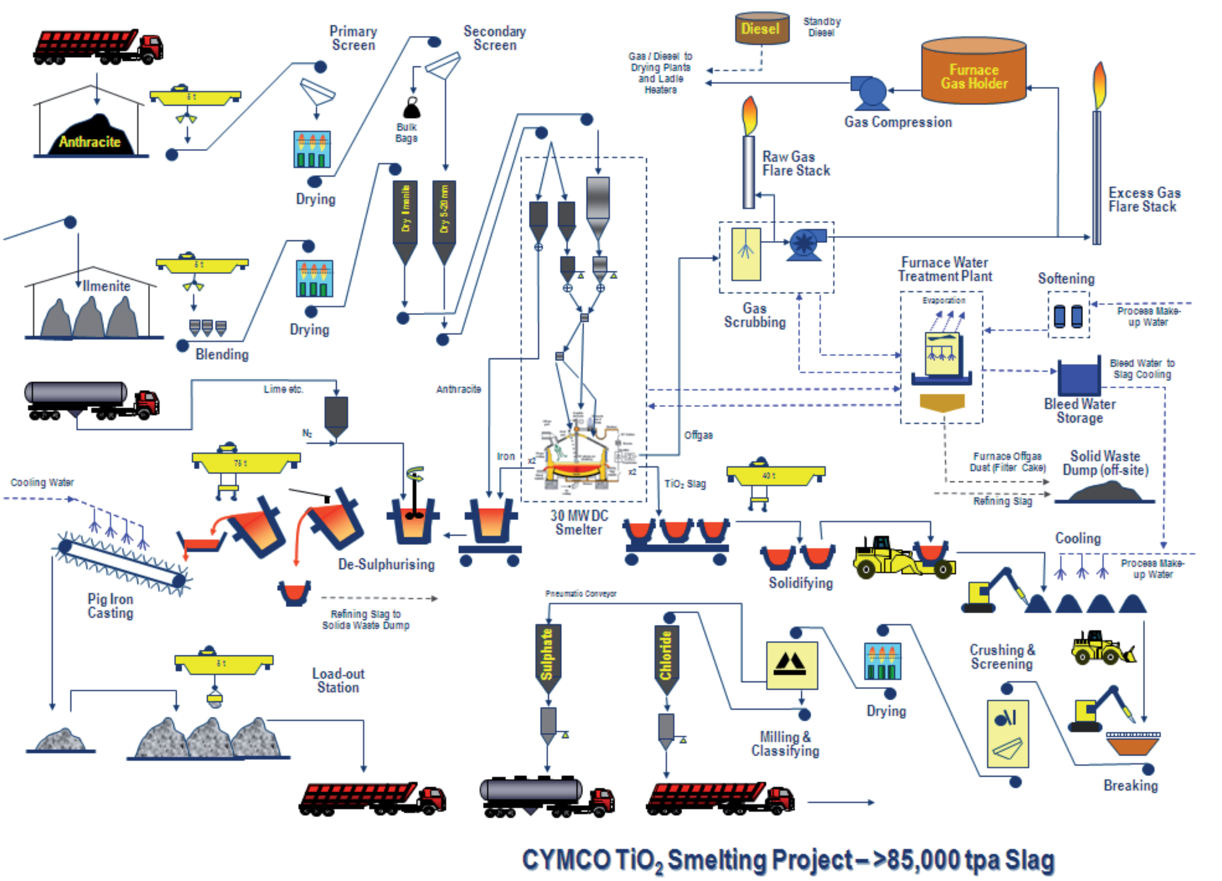

Figure 1: Summary of the Xinli TiO_2 Slag Plant Process

2.2 Test Work

Bateman's technology supply contract included smelting and pre-heating test campaigns to verify the main processing parameters for Xinli's ilmenite and anthracite.

2.2.1 Pre-heating testwork

The pre-heating tests enabled verification of energy consumption and fluidization and sintering characteristics of the ilmenite. This was done at the research centre of Polysius AG in Neubeckum, Germany. These tests demonstrated that ilmenite can be successfully pre-heated to >900°C.

2.2.2 Smelting testwork

Although ilmenite smelting in a DC furnace is well understood, such a smelting test enables verification of smelting parameters such as power and anthracite consumptions, slag impurities, dust losses and dust characteristics. Such test work is generally a requirement for Bateman to supply smelting process guarantees, as was required by Xinli. It also gave Xinli the opportunity to witness the smelting first hand and gain comfort in the technology. The smelting test involved the processing of 40 tons of ilmenite at the 3 MW DC test facility at the Mefos Research Institute in Sweden.

2.2.3 Project participants

Chinese authorities and companies are regulated to minimize the import of services and equipment to the absolute minimum in an attempt to stimulate local engineering industry and expertise. Therefore Bateman's contract was limited to a services contract to supply the process and basic engineering for the whole slag plant, detailed design of the furnace area and assistance with procurement for the major furnace equipment packages within the furnace area, which were procured by Xinli according to Bateman's specification. These included three major import contracts from ABB for the DC power supply system, Theisen for the gas scrubbing plant, and SMS Siemag for the furnace vessel, lining, and electrode system. Bateman's technology services also included the control system programming and the supply of a Process-Level Information System from Ex Mente, as well as construction and commissioning supervision and operator training.

A local design institute (Kunming Design Institute) was appointed by Xinli to perform all other design services, such as civil and structural design, raw material handling and plant services.

Figure 2: Xinli's 30MW DC Furnace Plant

Figure 3: Tapping cars and iron treatment bay

3 MOTIVATIONS FOR SELECTING DC TECHNOLOGY FOR CYMCO'S TiO_2 SLAG SMELTING PROJECT

DC furnace technology in ilmenite smelting was developed as an alternative to the existing six-in-line AC furnace technology. In the 1990's the development of this technology was led by Mintek (a South African state-owned research institute) and Anglo American Corporation (with Namakwa Sands' two DC furnaces). Kumba Resources subsequently built two DC furnaces at their Ticor operation in South Africa. Recently the Namakwa and Ticor operations have been merged within Exxaro. This technology is now a well-proven alternative to AC smelters (rectangular 6-in-line and circular), and offers a number of significant benefits which played a key role in the selection of DC furnace technology for CYMCO's project:

- The design and sealing of the DC furnace roof is simplified by having only one electrode and few feed ports. It is possible to easily implement a self-supporting spray-cooled roof solution which has minimal risk of serious water leaks. Gas sealing of the roof is also much easier, resulting in less air ingress and higher quality furnace gas;
- Compared to a rectangular 6-in-line AC furnace, the DC furnace offers less structural challenges in terms of furnace shell and refractory lining stability;
- Due to the non-symmetrical arrangements of 3-phase electrodes the AC furnace are prone to hotspots on the shell and localised refractory wear at the points where the electrode surfaces are closest to the furnace walls;
- DC furnace electrode consumption is generally considered to be lower than AC furnaces because the electrode is not in direct contact with the process. Electrode losses are limited to volatilisation of the cathode spot, side wall oxidation and joining nipple losses. Three AC-electrodes also have a larger surface area than the equivalent DC operation, hence suffer from greater sidewall oxidation damage.
- The DC furnace is able to sustain longer and more stable arcs than AC operation, with independent current and voltage control. As a result a significant reduction of electrode consumption, electrical disturbances, and noise can be obtained;
- The DC furnace are able to operate in a narrow slag chemistry band and a rapid response to process control are made possible through the independent control of furnace power, ilmenite and reductant feed as well as the relatively low slag residence time.

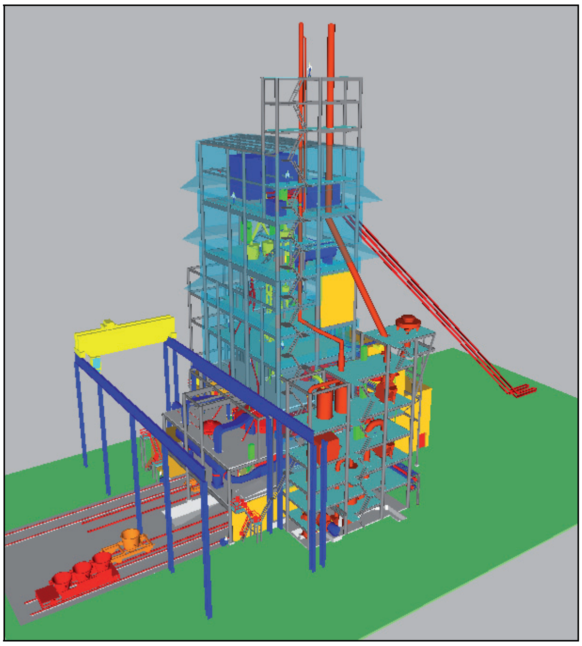

Figure 4: 3D CAD Rendering with gas scrubber in the foreground and slag tapping car on the left.

4 DESIGN CONSIDERATIONS FOR XINLI'S ILMENITE DC SMELTING FURNACE

There are a number of critical issues that have been considered in the design of Xinli's Ilmenite DC Furnace.

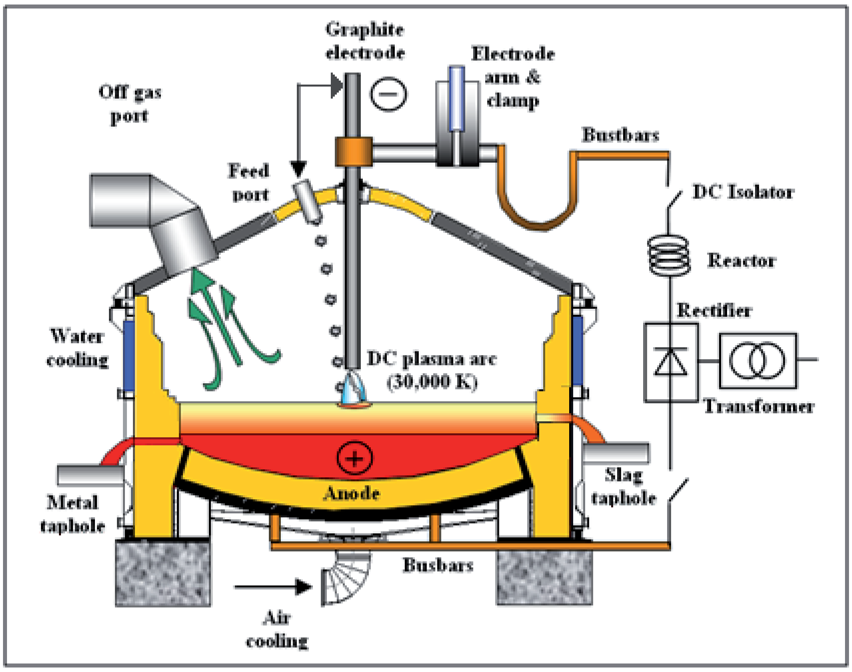

Figure 5: Schematic of a typical DC furnace as used for Xinli's TiO_2 slag smelting

4.1 Furnace Geometry

4.1.1 Aspect ratio

The design of the furnace geometry has been carefully balanced between the risk of over-heating certain parts of the vessel and the formation of problematic cold areas within the furnace:

- The internal diameter of the bath is designed to be large enough to minimise potential damage to the sidewall, but not too large to cause tapping difficulties;
- The metal heel is deep enough to minimise over-heating and erosion of the furnace hearth;
- The freeboard height has been optimised to reduce over-heating and excessive energy-loss from the roof, and simultaneously to avoid the formation of cold spots and the possible formation of large accretions and blockage of the off-gas extraction port.

4.1.2 Slag and metal inventory

The slag depth between the iron and slag tap holes is sufficient to enable complete separation of the slag and metal and to generate sufficient resistive heating within the slag. The TiO_2 slag is the main product and needs to be free of unwanted contained metallic iron. A sufficient degree of freedom to manage the slag and metal bath thickness is important to allow control of the hearth and metal temperatures.

4.1.3 Electrode diameter

The electrode diameter has been selected based on the design current and current carrying capacity of the graphitised carbon electrode.

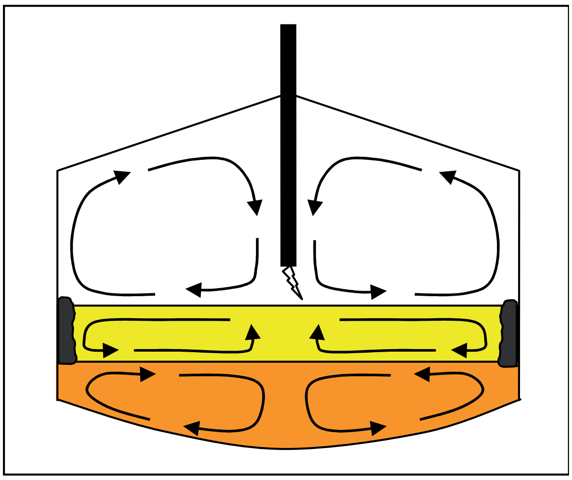

Figure 6: Schematic of circulation currents to be considered when designing furnace geometry

4.2 Anode Selection

The bottom electrode (anode) is a critical part of the furnace design. Key requirements for the anode are to reliably conduct electrical current without resulting in excessive resistive heating whilst maintaining its thermally insulating properties to avoid over-heating of the supporting steel structure. For the Xinli project an air-cooled conductive bottom anode as initially pioneered by ABB in the 1980's was preferred. The use of air cooling eliminates the risk of a water explosion in the event of a leak, and results in the least severe thermal gradients and thermal shocks within the system. Over the years this has proven to be the safest and most reliable anode system.

4.3 Slag Freeze Lining

TiO_2 slag is corrosive to all refractories and it is necessary to operate the furnace with a partially solidified layer of slag on the refractory sidewall (freeze lining) to assist with protecting the sidewall against liquid slag corrosion [3,4]. The monitoring and management of this freeze lining is a critical part of furnace operation and requires a proactive furnace operating strategy. To initiate the formation of a freeze lining, a key requirement placed on the refractory system was for optimum thermal conduction through the sidewall lining. Thorough design and the continual monitoring and alarming of all sidewall and hearth thermocouples are key engineering features incorporated in the design of the furnace. Due to the thermal conductivity and viscosity characteristics of the slag, no copper-cooling elements were installed in the slag zone.

4.4 Current, Voltage and Reactance Specifications

The correct specification of the current and voltage operating window for the power supply was a critical design factor to enable it to operate at the optimum furnace resistance and balance between slag bath- and arc power. During operation, the arc length is adjusted by raising or lowering the electrode to achieve the required operating resistance. In this manner it is possible to adjust the proportion of energy dissipated in the open arc versus that generated in the slag bath. Some of the radiant energy from the surface of the molten slag bath and the arc is absorbed by the dust in the furnace, but it mostly radiates to the walls and roof. An excessively long arc is able to entrain and heat the freeboard gas, thereby increasing the heat convected to the sidewalls and roof which can result in over-heating and damage to the refractory lining and water cooled components in these areas. Alternately, operating at a very low resistance with a short or 'brushed' arc results in too much energy being transferred to the slag bath. This causes over-heating of the slag and a more vigorous slag circulation (and splashing) due to forced convection and stirring, which can result in melting of the freeze lining. It can also result in overheating and increased circulation of the iron, which can result in over-heating of the furnace bottom. The typical operating resistance was confirmed during the smelting test work and scaled up for the specification of Xinli's furnace. It was also important to specify a high enough reactance for the DC reactor to guarantee stable arc operation and minimal electrical disturbances on the electricity supply network.

4.5 Arc Deflection

Due to the high DC currents in the conductors around the furnace, there can be a large magnetic field at the position of the arc, which can cause severe arc deflection as a result of the electromagnetic force. Such arc deflection can cause localized over-heating of the sidewalls, and can ultimately result in premature refractory failure. There are a number of methods available to minimize or counteract the magnetic field at the arc. For Xinli's furnace, the method used was to optimise the position and routing of the busbars using some additional lengths, so that the residual magnetic field at the arc position is minimised. This is a simple and reliable method, but since cancellation of the magnetic field in the arc region is not possible, an optimised solution is required to ensure that excessive arc deflection does not occur at the maximum operating current.

4.6 Slag Viscosity and Accuracy of Feed Control

The accurate balance between raw material feed (ilmenite and anthracite) and electrical power input is essential [2]. The viscosity of TiO_2 slag is dependent on the TiO_2 content and slag temperature. Higher %TiO_2 slags (i.e. lower %FeO content) results in a higher viscosity at a given operating temperature. This places a practical limit on the purity of TiO_2 slag that can be produced and is also one of the contributing factors that leads to the phenomenon of slag foaming caused by the CO gas not being able to escape freely from the viscous slag. A low-viscosity slag, on the other hand, could lead to an increased risk of equipment damage due to refractory erosion or uncontrolled slag tapping. The influence of raw material chemical variability and risks such as furnace overheating or -cooling and slag foaming is further alleviated by a well-designed sampling and reporting program.

4.7 Furnace Feed Ports

Feeding through the electrode minimizes the dust losses but increases electrode consumption and the complexity and time required for electrode addition. Xinli's furnace feed system has been designed to provide full flexibility to feed the furnace through the hollow electrode or through peripheral feed ports, or through any combination thereof. Computerised Fluid Dynamics (CFD) analysis has been used to optimise the position of the side feed ports in the roof to minimize dust losses.

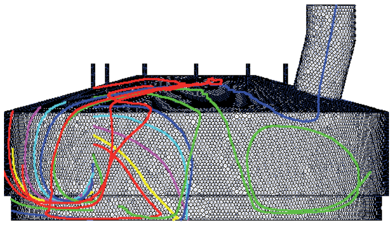

Figure 7: Bateman CFD Model of Peripheral Feed Particle Tracking

4.8 Cooling Emergency Systems

As with most high-temperature vessels, continuous cooling is essential to avoid mechanical damage or refractory failure and a resultant burn-through. It was therefore essential to consider emergency cooling systems including diesel-powered pumps, emergency header tanks and emergency power supply for cooling fans and pumps. The fail-safe operation and control of these emergency systems was considered during the design and thoroughly tested during the cold commissioning.

5 FURNACE HEAT-UP AND FILLING

The furnace was heated up using temporary diesel burners with adequate heating capacity to completely heat the refractories strictly according to the heat-up curve prescribed by the refractory suppliers. The installation of temporary thermocouples in the furnace was carefully considered to monitor and control the heat-up. The initial heat-up had the following main objectives:

- Removal of remaining water from the refractory mortars;
- Expanding the bricks to close all expansion gaps between the bricks before starting of melting;
- Gradually increasing the refractory material temperature close to the process temperature without thermal shocks that would cause refractory spalling.

A critical consideration during the heat-up was to prevent water vapour in the burner exhaust gas condensing on cold surfaces within the furnace and the water-cooled off-gas duct [1]. To minimize this risk, specially designed temporary refractory-lined exhaust ducts were installed to expel the burner exhaust gases.

After the heat-up the furnace was manually batch-filled with pig iron through ports in the roof. Between each batch the iron was melted. It was preferred not to produce the first fill of iron by ilmenite reduction due to the increased risk of damage that FeO has on the refractories. It was preferred not to start the ilmenite smelting process with an empty furnace, since the process of melting the initial iron fill offers the benefit of less complex conditions for hot commissioning of the electrode system, furnace cooling and iron tapping.

6 PLANT COMMISSIONING

At the time of writing the 30MW DC furnace has been approaching design capacity and production trials consistently yielded slags in excess of 87%TiO_2.

Figure 8: Xinli's first Iron Tap

Figure 9: Xinli's first Slag Tap

7 CONCLUSION

Xinli's furnace is the fifth commercial-scale DC furnace facility for the production of TiO_2 slag built world-wide. Given the benefits offered by DC furnaces it is likely that this technology will play an increasingly important role in the future of TiO_2 slag production for new smelter plants. A lot of interest is being expressed in this technology from new and existing producers, particularly in China, India and Vietnam.

Bateman has the expertise and capability in the fields of DC furnace technology, TiO_2 slag smelting and global project execution to be able to assist in meeting this demand for this technology.

8 REFERENCES

[1] Kotze, H., Bessinger, D., Beukes, J., "Ilmenite smelting at Ticor SA", Southern African Pyrometallurgy, SAIMM, 2006, pp.203-214.
[2] Pistorius, C., "Limits on energy and reductant inputs in the control of ilmenite smelters", Heavy Minerals, 1999, pp. 183-1888.
[3] Pistorius C., "Fundamentals on freeze lining behaviour in ilmenite smelters", Heavy Minerals, 2003, pp.167-174.
[4] Zietsman, J.H., Pistorius, P.C., "Modelling of an ilmenite smelting DC arc furnace process", Minerals Engineering, 2005.
[5] Zietsman, J.H., "Interactions between Freeze Lining and Slag Bath in Ilmenite Smelting", PhD Thesis, 2004, University of Pretoria.