'Necessity the mother of invention'—a reflection on the requirements for successful innovation in the metallurgical industries

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Synopsis

The complexities that exist in the nature of the basic feedstock to the metallurgical process call for a high degree of ingenuity from the extractive metallurgist in seeking the best possible treatment method for a particular ore. Drawing from personal experience the author presents four case studies that demonstrate the value of creative thinking in addressing the challenges typically encountered by the extraction metallurgist. It is concluded that creative expression most often occurs in response to a perceived strong need within an organization. By deliberately laying down meaningful challenges management can stimulate innovative thinking and achieve extraordinary results.

Introduction

Nature provides a seemingly limitless array of challenges for the extractive metallurgist. For millions of years the corrosive impact of the geological process has served to combine and confound the basic elements of matter into a sweeping spectrum of chemical and physical forms. It is the general task of the metallurgist to unravel these complex natural puzzles and by clever manipulation restore within economic time the hidden value of the metals and minerals hidden in the Earth's crust.

Each ore presents a unique chemical and physical signature that requires decoding and interpretation before its value potential can be released. This variability in the nature of the starting material for the metallurgical process calls for a high degree of ingenuity from the extractive metallurgist and places a premium on the value of creativity in developing the best possible treatment method for each ore.

How best to stimulate this creativity?

The presentation draws upon experience gained from a career in extractive metallurgy to attempt to answer this question. Using a simple model to describe the essential character of the 'creative process' reference is made to examples from personal experience that serve to illustrate a number of key learning points about how best to foster innovative thinking in an organization. Innovation is 'most often a natural human response to an intense need' is an observation made by the Greek philosopher Plato. This sentiment and its better known derivation 'necessity is the mother of invention' provide the main theme for the presentation.

The key proposition of the presentation is that it is possible to enhance the likelihood of successful metallurgical innovation occurring within an organization. The reasons for reaching this conclusion are explored briefly in the four case studies of the presentation.

A simple model of the 'creative process'

A simple model illustrating the nature of the 'creative process' is used to provide a framework for discussion of the different case studies. The form of the model is shown in Figure 1.

The stimulus for embarking upon creative endeavour is frequently a perceived opportunity or threat to an organization and typically, although not always, it is top management that first becomes aware of this situation.

A close analysis of the circumstances of the stimulus will generally result in management deciding upon the need for some form of action. Where the response is not obvious and requires an element of investigation the need can be translated into a challenge directed towards an appropriate sector of the organization.

Once the challenge is issued the process of 'idea generation' begins. The manner in which the challenge is issued and the way in which ideas are sought, collected and considered are critical aspects affecting the probability of a successful outcome.

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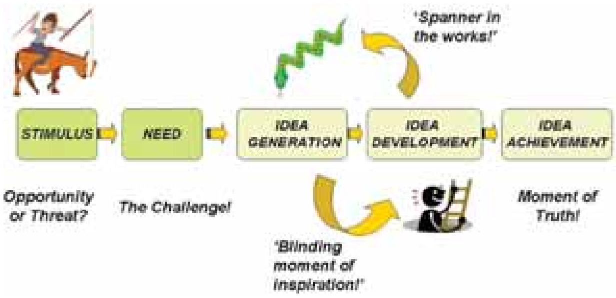

Figure 1—Simple model illustrating the nature of the 'creative process'

In just a few cases there may be a 'blinding moment of inspiration' from an individual or group that appears to offer a breakthrough solution outside of the current norm. This is a rare occurrence and is often the result of recombining existing ideas rather than a true flash of inspiration and unprecedented invention.

Once identified, the selected idea, whether evolutionary or radical in nature, moves into the critical and often protracted phase of 'idea development'. Here the idea is tested and subjected to critical review within the cauldron of public opinion. Many good ideas founder at this stage of development for want of influential support. It is also quite common for an idea to fail at the proving phase due to an unanticipated problem or 'spanner in the works' that undermines the integrity of what is being proposed.

Finally, for those ideas that survive through to commercial implementation there is the ultimate litmus test of 'idea achievement' measured by performance relative to expectation. The learning curve is real and new ideas are particularly susceptible to the hard knocks and value destruction that occurs in moving up this curve.

In the extractive metallurgy discipline, progress is made typically through the continuous implementation of clever ideas and process enhancements. This 'incremental innovation' characterizes the industry and has been the source of much value generation. Very occasionally a radical innovation event occurs that revolutionizes the structure and nature of the industry. The introductions of solvent extraction for copper in the early 1980s and to a lesser extent zinc in the late 1990s are two such examples.

Four case studies

The case studies summarized below are modest examples of the way in which innovation occurs in the field of extraction metallurgy in response to perceived threats and opportunities. The focus is on the learning that can be drawn from each of the examples.

Case 1: Flotation of oxide copper minerals at Nchanga (1968)

In 1968 Zambia was the third largest copper producer in the world and Nchanga was the largest copper concentrator in Zambia, treating approximately 700 000 ton per month of a mixed sulphide/oxide ore grading about 3.7% Cu.

Geological exploration at the time indicated that there would be an increase in the oxide component of the ore at Nchanga and this trend was recognized by management to have far reaching consequences for Nchanga Consolidated Copper Mines (NCCM). Oxide copper, principally malachite, was recovered using a technique of sulphidization and flotation with a 'fatty acid' collector (a mixture of palm kernel oil and dieseline). Effective as it was for recovery of the oxide minerals, the approach resulted in the production of low grade oxide concentrates due to the non-selective nature of the flotation. Increasing the quantity of low grade oxide concentrates would have major adverse consequences on both the Rokana smelter and Nchanga leach plant. Many approaches had been tried over the years to improve oxide flotation performance at Nchanga but improvements had been relatively modest.

This case study is included primarily because it occurred at the very beginning of my career as a metallurgist and because it introduced me to a remarkable individual whose dynamism and approach has had a profound influence on my subsequent career and I believe on those of my colleagues of the time.

Filip Ser, a dedicated flotation specialist with an international reputation, was recruited by NCCM management to try to inject new thinking into the Nchanga situation. He arrived on the Copperbelt in 1968 with the impact of a mini-tornado and within a short space of time had transformed the small mineral processing unit of the R&D group into a hammer of the organization. Typically arriving to work in overalls ready for hands-on action, Filip placed extreme demands on his team. Each setback was met with further new ideas and each success was moved rapidly out of the laboratory and onto the plant for testing. He challenged the existing system constantly, but importantly had the ear and support of top management. Gradually a window of opportunity opened for the oxide float at Nchanga. The details are described in a technical paper that was presented to the IX International Mineral Processing Congress, Prague, 1970.[1]

The essence of the innovation in oxide copper flotation was a change from 'fatty acid' collector to sulphydric collector using carefully staged additions of sulphidizer. In reality the intervention was much more than that, being a total change in approach and attitude to the flotation of oxide copper minerals at Nchanga. The laboratory and pilot test work indicated the potential for an oxide concentrate grade improvement of up to 10%; history shows that the reality was about half this value due mainly to limitations imposed by the condition of the plant flotation cells. Nevertheless, this was still a very significant positive change for Nchanga.

During the time Filip Ser spent in Zambia he introduced the concept of 'sands flotation' to a number of concentrators and also pioneered a radically new method of upgrading cobalt minerals using an amine collector and flotation under acidic pH conditions.

Perhaps his most lasting legacy was to inspire members of his team with the belief that with specialized knowledge and strong personal commitment it is possible to overcome entrenched attitudes and to realize radical improvement within a short period of time.

It is to NCCM management’s credit that it recognized the threat associated with the change in ore character at Nchanga and responded by recruiting an individual with the talent and personality to address the challenge.

Case 2: Cobalt recovery from converter slag at Rokana (1976)

Cobalt is a valuable by-product in certain of the Zambian Copperbelt ores. In 1976 ZCCM (the new company) produced cobalt metal by selective flotation of a Co-Cu concentrate at the Rokana concentrator followed by recovery of cobalt and copper at the Rokana cobalt plant.

Recovery of cobalt from Rokana ore to finished metal was only 25–30% due to losses in flotation tailings and smelter slags. Furthermore, smaller but significant quantities of cobalt from other Copperbelt ores were not recovered at all, the cobalt values also ending up in the smelter slag. An initiative was mounted in the early 1970s to examine whether a new cobalt process could be developed based on recovering cobalt from Rokana converter slag. Cobalt is concentrated in the converter slag during the iron blowing of the copper matte. Details of the project are given in a paper delivered to the IMM Extractive Metallurgy Conference in London (1977).[2]

The motivation for undertaking the project was strong as cobalt production could be increased from about 1 725 ton per year to over 4 000 ton per year. The concept for cobalt recovery involved treating the converter slag by carbothermic reduction in an electric arc furnace to produce a Co-Cu-Fe alloy and a reduced slag for recycle within the smelter. A ‘lime-coke’ melt-in technique similar to that employed by Outokumpu[3] was successfully trialed in small-scale pot-smelting tests and was the basis on which pilot-scale tests were conducted by Elkem in Norway.

The piloting at Elkem showed up a major problem. The converter slag after lime addition was superheated and highly electrically conducting. It was not possible to operate with ‘cold-top’ furnace conditions, slag attack on refractories was acute and furnace power consumption was high.

In management’s eyes the integrity of the new process was now in question and progress on the project was slowed until an acceptable solution could be found. This was a major setback for the project team.

The eventual solution to the problem was a triumph of clever deductive reasoning. It was proposed by Bryn Harris, a member of the project team who had been given the task of looking at a different way of recovering cobalt from the slag. Working initially with thermodynamic data and slag phase diagrams Bryn came to the conclusion that operating with a basic slag (lime addition) was the problem and that a better approach was to replace lime with silica in order to drive the slag composition towards silica saturation and a higher liquidus temperature.

The approach was successfully tested at a small scale and then referred to Elkem. The subsequent piloting demonstrated a remarkable turnaround in performance. A cold-top operation was possible and a freeze lining was readily achieved. Furnace operation was very stable and power consumption reduced from 800 KWh/ton to 450 KWh/ton. In Elkem’s words, the ‘pyrometallurgical process was transformed radically for the better’.

From a project perspective, management confidence was restored and approval was given to proceed to feasibility study.

In this case, the major factor contributing to success was the project team’s ‘back to basics’ approach using a person with the necessary skills and enquiring mind. This eventually led to an innovative new approach where the basic reduction smelting concept was redefined in a manner contrary to the established mindset of the time. The rewards for the project were highly significant.

Case 3: Development of a novel carbon-in-pulp contactor (Anglo American 1987)

This case study is included because it represents a personal journey from failure to eventual success and is indicative of a route to creative success that is very often trod.

In the early 1980s carbon-in-pulp technology was the talk of gold metallurgists everywhere and particularly in South Africa. Many new projects were contemplating the use of this new technology that offered the potential to transform recovery economics, particularly for low grade gold ores and wastes. The basics of the process were known but little practical know-how existed and the ‘learning curve’ beckoned. In South Africa Mintek coordinated an industry research initiative to try to develop a scientific base for CIP along with the appropriate operational know-how.

The CIP approach relied upon a separation of granular activated carbon from gold containing slurry at each stage of the countercurrent process and this introduced inter-stage ‘screening’ as a critical unit operation.

The Afrikander Lease (AFL) gold plant commissioned in 1981 was the first plant in South Africa to treat primary underground ore and to encounter the scourge of ‘woodchips’ in the context of pulp screening. It was also my first introduction to CIP as a process design metallurgist. The AFL adsorption tanks were designed with simple air-swept peripheral screens that were in no way adequate to separate the activated carbon from slurry containing fine slivers of wood derived from the milling of tramp wood from underground.

Many sleepless nights were experienced by the early CIP plant operators. Gradually through the combined efforts of Mintek and the mining companies, innovative techniques and equipment were developed to achieve effective pulp screening. Progress was from simple air-swept screens to equalized pressure (EPAC) screens to mechanically swept screens of different types and configurations[4]. Anglo American was at the forefront of many of these initiatives on major projects such as the Ergo and Daggafontein CIL plants.

At Mintek, Chris Fleming was advancing a CIP model of the adsorption process and along with others I attended regular updates at the regular industry feedback meetings. I recall Chris tabling evidence to show that as the number of

CIP stages increased so the inventory of gold and the carbon necessary to recover the gold, decreased significantly. In answer to my question he confirmed that, yes indeed, if an increased number of stages were used then the benefits implied by his model would be very significant. However, quite rightly he warned of the difficulty of having so many stages of pulp screening.

This conversation was the 'trigger' for the development of the AAC Pumpcell, an adsorption concept that is available from Kemix (Pty) Ltd under license to Anglo American which holds the patent. The development and features of the AAC Pumpcell have been described in several papers.[5,6]

The key feature of the Pumpcell is that it incorporates a low-head pump, screen-wiper blades and an agitation impeller on a single driveshaft. This multi-duty assembly is mounted together with a cylindrical wedge-wire screen inside an adsorption tank containing slurry and activated carbon. The 'cell' is an independent self-standing unit that can be combined with other such units to form a multi-stage adsorption circuit with all cells at the same level. Typically the circuit is operated in 'carousel' mode with the carbon remaining in the cell and the feed and discharge position changing approximately daily to provide the countercurrent effect. The residence times for a Pumpcell contactor are less than 10 minutes compared with 60 minutes for a conventional CIP contactor

The AAC pumpcell was developed and tested over the period 1987–1990; it was applied to scavenger duties from 1991–1997 and has been applied extensively to conventional duties since 1998. Today it represents 'best available technology' for CIP applications and in South Africa over 80% of gold produced is treated through Pumpcells or MPS screens (an offshoot product). Significant support and encouragement for development of the Pumpcell was given by management of Anglo American and Anglo Gold. Furthermore, Kemix has played a leading role in its evolution and has provided crucial technical back-up throughout the various stages of development.

The main advantage of the Pumpcell is that it achieves gold loadings on carbon that are approximately double that of a conventional CIP plant. This is due to superior mass transfer characteristics and reduced levels of backmixing in the Pumpcell circuit. The smaller sized adsorption tanks and higher gold loadings translate into significant capital cost savings on adsorption, elution and regeneration plant.

Although described in the context of gold recovery using activated carbon, the Pumpcell concept has potential applicability to base metals and uranium using the resin-in-pulp (RIP) process. These applications are presently being explored by Kemix in partnership with others. At the time of writing a major Pumpcell plant is presently being commissioned on a uranium ore in Malawi using the RIP approach.

The first learning point from the development of the Pumpcell is that its success arose out of early exposure to failure. Failure often constitutes a great challenge to personal pride and can provide a powerful stimulus for redemptive action.

Secondly, it is significant that the benefits of the concept emerged by extrapolating the limits of a model that was already being applied in a conventional situation.

Thirdly, the creative element involved the gathering together of established ideas and their combination in a new and beneficial manner. The individual unit operations of the Pumpcell are all well established but it is their use on a single driveshaft to achieve a desired process outcome that provides the distinctive advantage.

Finally, the Pumpcell development profited from the critical support of Anglo American and Anglogold management and the effective injection of engineering and commercial know-how from Kemix. The symbiotic business relationship between licensor and licensee contributed greatly to the success of the Pumpcell venture.

Case 4: Pioneering solvent extraction for mainstream Zinc recovery (Skorpion 2002)

The use of solvent extraction (SX) for recovery of zinc at the Skorpion mine in southern Namibia marks a world first for a primary zinc ore. This achievement constitutes a landmark event in extractive metallurgy, signalling industry acceptance of the use of SX for mainstream zinc production. The technical features of the Skorpion project are described in a number of papers.[7,8]

The application of SX for large-scale zinc production was not self-evident since unlike copper, there did not at first sight appear to be an extraction reagent that could transfer bulk quantities of zinc without a prohibitive economic penalty. The manner in which the zinc SX was achieved without requiring inter-stage neutralization is perhaps the feature that has been most responsible for unlocking value in Skorpion.

Skorpion is an oxide/silicate zinc deposit that was first discovered by Anglo American geologists in 1976. In 1996 Anglo decided that the difficult mineralogy and the relatively small size of the deposit (8 Mt at 11% Zn) would not provide an 'Anglo size' project and it gave an option to Reunion Mining to further develop the project. Reunion mounted an aggressive drilling campaign and eventually increased reserves to 25 Mt. Reunion also established contact with Noel Masson, a consultant familiar with the Padaeng oxide zinc deposit in Thailand, and it was Noel who provided the first flowsheet for Skorpion. This flowsheet included technology from Tecnicas Reunidas (Spain) for recovery of zinc by solvent extraction using an adaptation of its Modified Zincex Process (MZP)[9]. Pilot tests confirmed that it was possible to recover bulk quantities of zinc from solutions with relatively high levels of impurities and to do so without the need for inter-stage neutralization. In 1999 Anglo Base Metals bought Reunion Mining.

In 2000 Anglo Base successfully piloted the Skorpion process at Anglo Research and later in the year the project was approved. First zinc metal was produced in 2003 and the plant has subsequently operated consistently well producing approximately 150 000 ton per annum high quality zinc at low cost.

The key breakthrough in the zinc SX process is to operate the extraction circuit using the extractant di-2-ethyl-hexyl phosphoric acid (D2EHPA) to achieve a high net transfer of zinc (20 g/ℓ Zn) whilst accepting a low zinc recovery per pass (67%). The raffinate containing 10 g/ℓ Zn and 30 g/ℓ H_2SO_4 is not used for washing of leach residue (as is the case for copper ores) but is recycled back to the leach where the acid is consumed. The high raffinate acidity and the inclusion of wash and scrub stages provide selectivity against all major impurities other than ferric iron.

Had the circuit been operated in a conventional manner to produce a raffinate low in zinc suitable for discard or use as a wash solution, it would have been necessary to accept a low zinc transfer or to adopt an expensive inter-stage neutralization approach. This viewpoint was in fact the opinion of many in the industry who doubted that a reagent such as D2EHPA would find application for bulk Zn extraction applications.

The adjustment in thinking to tailor the Skorpion flowsheet to suit the pH characteristic of the Zn extraction isotherm opened the way to an elegant treatment solution for Skorpion. Taking what is known, but interpreting it differently to others, can be a simple but effective way of achieving a creative breakthrough.

Lessons from the Case Studies

The key proposition in this paper is that it is possible for an organization to enhance its ability to generate value through effective innovation.

Based on the example of the case studies that have been presented, what are the most important requirements to maximize the possibility of creative success?

The single most important factor, and the title theme of the paper, is that 'necessity' provides the compelling impetus for creative endeavour. It is the inclination of human nature to respond positively to a challenge and to want to achieve, but this challenge must be recognized as meaningful and genuine. Therefore arising out of strategic planning and an assessment of the external environment it is believed that management at all levels should seek deliberately to provide clear and well defined challenges within the organization. Management's positive role in setting such challenges is recognized in at least three of the case studies presented.

A key feature of many of the examples is the critical contribution of a single individual. In each case the individual had specific knowledge in the area of challenge and was able to adapt that knowledge and to apply it to a changed situation in order to come up with a new angle. Such 'game-breakers' typically exist within a mature organization and should be encouraged to participate in new areas of challenge.

The value of introducing outside talent is also seen. This type of intervention can break with established patterns and introduce new ideas and networks. The value of Filip Ser's contribution at Nchanga and Tecnicas Reunidas's contribution at Skorpion are cases in point.

While recognizing the particular value that an individual may have in introducing new ideas, it needs to be said that often the fastest way to progress creative thinking is to arrange for 'group-think' workshops attended by carefully selected participants with appropriate but differing skills sets. The valuable contribution of such gatherings at Anglo American in advancing the development of the Pumpcell is well appreciated.

The importance of having management's support cannot be over emphasized, particularly during the development stage of an idea when problems typically arise in implementation. Many successful ideas owe their final success to a particular project sponsor who decided to give support and influence to the initiative during its difficult proving stages.

The value of effective partnerships is seen in several of the studies. These partnerships have at their heart a shared-value benefit in the success of the new initiative. The roles of Kemix in the Pumpcell development and Reunion Mining and Tecnicas Reunidas in the zinc SX development are illustrative of this point.

A personal conclusion

It is my belief that the discipline of extractive metallurgy offers great opportunity for innovative expression and I consider those who decide to follow this fascinating profession fortunate in their career choice.

It is further my belief that it is possible to engender within an organization, by deliberate intent, a positive culture of creativity. The key requirements for creative success are firstly to provide clear and meaningful challenges and secondly to issue such challenges to people who have the talent and experience to adapt from 'what they know', to apply to 'what is needed'.

Acknowledgement

Whereas the views made in this paper are purely personal, the case studies all relate to situations arising during a career as an extractive metallurgist with Anglo American.

I am indebted to Anglo American for permission to use the case studies for the purpose of illustration of the topics of the paper. I am also grateful for the valued association that I had with many colleagues over the years who have exemplified the spirit of creativity that I have tried to portray in this paper.

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