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ARC Research Hub for Advanced Technologies for Australian Iron Ore – An Introduction

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ABSTRACT

The Australian Research Council has recently established an Industrial Transformation Research Hub in the area of iron ore, focussed on iron ore characterisation, beneficiation, materials handling and end-use functionality. The research hubs are part of a new initiative aimed at building stronger relationships between industry and universities, while addressing issues of national significance. “The ARC Research Hub for Advanced Technologies for Australian Iron Ore” will focus its attention on developing innovative approaches for creating enhanced value across the full value chain, through characterisation of different ore types, beneficiation, and materials handling and transport. This hub brings together five industrial organisations and a research team formed from well-established research groups based at the Newcastle Institute for Energy and Resources (NIER). These groups have a record of working closely with industry, creating opportunities. Examples include new beneficiation technologies such as the Reflux Classifier for achieving gravity separation, the expertise of TUNRA Bulk Solids in materials handling, and the Iron Making Centre at Newcastle, a capability maintained by BHP Billiton since the closure of its Technology Centre in 2009. The purpose of this paper is to provide an outline of the research hub, and its objectives, while providing some background on the research groups which now form the hub, and the strategy adopted for developing and implementing new technologies. The paper then describes a range of novel technologies that have the potential to be developed and applied to iron ore beneficiation.
INTRODUCTION

Australia has long held a competitive advantage as a low cost producer of iron ore, and reliable provider in the seaborne trade of this commodity. For nearly a decade demand for iron ore grew to unprecedented levels, with the price rising from as little at $25/t in 2000 (Office of the Chief Economist, 2015) to more than $190/t in 2011. Indeed the 5-year average to 2013 was $135/t. More recently, we have witnessed the balance between supply and demand shift back to more balanced levels due to the increased global supply, and reduction in economic growth in China. Prices fell to $80/t in 2014 (Metal Bulletin, 2014), and to below $50 in 2015. However, long term demand for steel is forecast to continue to grow at more traditional rates, in order to accommodate the needs of growing populations and affluence in India, Africa and other parts of Asia.

With unprecedented levels of production, Australia has to focus its efforts to maintain its global market share, given the growing mix of ore types being sourced, including the effects of mining below the water table, and challenges in meeting customer requirements. In this context, a new Industrial Transformation Research Hub, concerned with “Advanced Technologies for Australian Iron ore”, has been established, with equal funding from the Australian Research Council and industry collaborators.

The Industrial Transformation Research Hubs (ITRH) represent a new initiative of the Federal Government, in particular the Australian Research Council, to improve the translation of university research into industrial applications. Australian universities have performed well according to traditional academic measures, especially in the citation rates of academic publications, but have sat well down the rankings in their engagement and translation of knowledge into industry (Department of Education and Department of Industry, 2014). It is recognised that there is significant scope for our universities to contribute much more, and that there is an onus on universities to achieve much more industrial impact, if current funding levels are to be maintained or in fact increased. The introduction of the ITRHs has occurred at a time when the Cooperative Research Centres (CRC) program has come under increased scrutiny in the form of a major review (Australian Government, 2014). Thus, the introduction of the ITRHs has the potential to become the primary vehicle for major university engagement with industry.

This “ARC Hub in Advanced Technologies for Australian Iron Ore” is centred at the University of Newcastle on the site of the former corporate research laboratories of BHP Billiton. Newcastle’s capability in this area stems from the historical legacy of the BHP Steel Works (1915-1999) and the establishment of the BHP Central Research Laboratories in 1957, later known as the BHP Billiton Technology Centre. Newcastle remains a major coal producer and exporter and, for nearly a century, was a significant steel producer. The legacy also underpins the strong engineering faculty of the University of Newcastle. While the Hub has the appearance of being Newcastle Centric, each of the collaborators has a strong Perth connection and base.

The Newcastle Institute for Energy and Resources (NIER), formally part of the University of Newcastle, was established on the former BHP Billiton site in 2009. BHP Billiton maintained critical capability in iron making research and characterisation through the establishment of the Centre for Ironmaking Materials Research
Newcastle has also developed new fine particle beneficiation technologies used world-wide in the mining industry to recover and concentrate fine particles via both flotation and gravity separation, including the Jameson Cell, and the Reflux Classifier. Newcastle is also home to TUNRA Bulk Solids, widely known for providing research services and testing into raw materials handling, bin design and transport. The Industrial Transformation Research Hub focuses on three research programs covering (i) beneficiation (ii) raw materials handling, and (iii) end-use functionality.

This paper seeks to outline the objectives of the new Hub, while providing some background on the research groups which now form the Iron Ore Hub, and the strategy adopted for developing and implementing new technologies. The paper then focuses its attention on a range of new technologies that have the potential to be applied to iron ore beneficiation.

AUSTRALIAN CONTEXT

Australia, with its very large mining industry, and relatively small population, has become one of the world’s largest exporters of energy and mineral resources worth AU$195 billion in 2013/14 across all of the commodities (Bureau of Resources and Energy Economics [BREE], 2015). In particular, iron ore has been Australia’s most significant export commodity for over a decade. In 2010-11 exports were worth AU$54 billion (BREE, 2011) and in 2013/14 exports had increased to AU$74 billion (BREE, 2015). The majority of these exports come from the Pilbara region in Western Australia which has 22% of the world’s economically accessible iron ore.

Production has risen from 159 Mt in 2000 to over 650 Mt in 2013/14 (BREE, 2015). These dramatic increases in production have come about through the rapid expansion of the industry associated with new projects and increases in productivity of existing mines. The expansion into new mining areas has meant that Australian ores now cover a wide range of porosity, mineralogy, composition and other physical properties. This, combined with differences in clay type and gangue composition, can cause serious problems during transportation and storage. Increasing fines content and variations in composition also impact on ironmaking performance in ways that will need to be characterised in order to improve the acceptance of these products. Opportunities to enhance the product grade through beneficiation, especially in a more competitive market, may become much more important in the coming years.

INNOVATION AND INDUSTRIAL TRANSLATION OF RESEARCH

Beneficiation

Beneficiation is concerned with recovering and concentrating the valuable ore from the run-of-mine feed, with different technologies applied to specific particle size ranges. Fine particles are usually well liberated, and thus have the potential to produce high grade concentrate. However, this theoretical potential is not
realised in practice due to the presence of the colloquially termed ‘slimes’, including clays that report with the water that associates with the product. The performance of existing beneficiation technologies such as spirals deteriorates below 75 µm, while reverse flotation starts to rapidly deteriorate below particle sizes of 20 µm.

The Reflux Classifier (FIG 1) consists of a set of parallel inclined channels mounted above a vertical fluidised bed. These channels create a large effective settling area via the so-called Boycott effect (Boycott, 1929), greatly increasing the capacity compared to a conventional fluidised/teetered-bed separator. The inclined channels produce a high shear rate, resuspending the low-density particles, and then transporting these particles to the overflow, thus promoting a density-based separation (Galvin & Liu, 2011). The technology was developed through collaboration between Ludowici Australia and the University of Newcastle. Initially commercialised in 2005, further research led to a new mechanism for separation, and the launch of a new design in 2009. By working closely with an equipment manufacturer, engineering design company, and an end-user, the research was successfully translated into industry, with more than 80 full-scale units installed in 8 countries.

![FIG 1: Photos of (left) Laboratory-scale Reflux Classifier and (right) full-scale RC™3000 unit with a 3 m diameter (Courtesy FLSmidth-Ludowici).](image)

Existing installations of the Reflux Classifier have focussed on the beneficiation of particles in the 0.250 to 2.00 mm size range. Significant interest has emerged in the coal industry in the processing of particles up to 4.0 mm in size, with new research funding directed to the establishment of a full-scale facility (FIG 2), located at a plant just one hour from the University. Again, collaboration has involved input from university researchers, equipment manufacturers, engineering design companies, and end-users.
Materials Handling

The high fines and moisture content of future ores may create problems with stickiness. In the export of iron ore, the mine-to-port chain of operations includes numerous storage and handling steps during the various mining, overland transport and ship loading stages. In such a system, the overall performance is only as good as the weakest link. So, for example, a blockage in a single transfer chute can seriously disrupt the entire system, leading to significant delays and lost production costs. While the cost of a belt replacement is ~ AU$1M, the associated costs due to downtime can be up to a staggering AU$70M. Similarly, incorrectly designed storage bins, chutes, feeders and belts can experience severe wear, which causes further production losses due to the more frequent stops for maintenance work. “Silo quaking” during discharge from hoppers can cause structural support problems. At sea, the liquefaction potential of iron ores needs to be identified and managed to mitigate the potential loss of ship and crew. Hence the bulk properties of these systems need to be quantified to ensure robust design of handling, storage, transport, and dust-suppression equipment.

TUNRA Bulk Solids (TBS), the consulting arm of the Centre for Bulk Solids and Particulate Technologies (CBSPT) was established in 1975. Since then TBS has completed more than 4000 projects for clients from over 40 countries. Recent work has included Discrete Event Modelling (DEM), Finite Element Analysis (FEM) and Computational Fluid Dynamics (CFD) simulation to gain greater understanding of the mechanisms of wear and dust control, which has enabled the design of more reliable conveying, feeding and transfer systems (Donohue et al., 2012; Chen et al., 2012; Goniva et al., 2012). This work has led to many innovations in iron ore handling, such as successful improved stock pile reclamation. In addition, TBS has built its capability in developing the understanding of the liquefaction potential of bulk solids, and the mechanisms that by which they may liquefy (Williams et al., 2015).
Characterisation of wet sticky ores

The characterisation of bulk solids in relation to industrial bulk solids handling plant design and performance is now widely accepted and well proven in Australia and worldwide (Roberts, 2005). The work of TBS has extended the flow property test capability through the design of 300 mm diameter direct (FIG 3) and inverted shear cells which enable the testing of bulk mineral ores over more realistic size ranges relevant to mining operations as well as allowing adhesion and cohesion measurements to be obtained for transfer chute design. The foundation work in the development of the vibration shear test is of particular relevance (Roberts, 1997). Other developments include submerged shear tests for supersaturated bulk ore tests.

FIG 3: The 300 mm large direct shear testing cell.

Existing tests such as the Durham Cone are empirical and do not provide the quantified strength, and internal friction versus consolidation stress that is necessary for handling plant design and evaluation. An alternative to these so-called empirical tests is the “flowability” tester, developed by TBS (FIG 4). The principal aim is to characterise selected iron ore feeds employing the standard Jenike test along with the flowability test as well as selected empirical tests. One important aspect of the characterisation is the hitherto neglected correlation of the flow properties with relevant mineralogical properties of the ore and how these properties may have some bearing on moisture retention and release as well as bulk strength. Apart from the characterisation work, the application of the measured flow properties in conjunction with modelling and simulation aimed at optimising handling-plant performance will be undertaken.
Wear minimisation, dust control, and adhesion characterisation

Here the emphasis will be on both abrasive and impact wear and passive dust control. Following a period of development work in abrasive tests for bulk solids applications, a new, improved annular abrasive wear tester of 2 m diameter has been designed and constructed. This machine has provision for 4 samples of lining materials or conveyor belts to be tested simultaneously over an extended period of time. Mass loss and surface roughness of the samples are progressively recorded and, apart from the measurement of wear, the measured data provide the basis for surface roughness and particle interaction studies. For impact wear, the aim is to improve the reliability and repeatability of impact tests by using a vertical circular bucket wheel to continuously drop material onto the sample. This work will lead to further development of transfer chute design.

End-use functionality

The value of an iron ore is closely related to its performance and impact on the blast furnace process. The iron ore raw material covers a very broad particle size range, necessitating very different forms of evaluation with respect to its end-use functionality in the blast furnace. While iron ore fines and concentrate must be processed into sinter and or pellet prior to use in the blast furnace, lump ore can be directly utilised without any further processing. For this reason, lump is inherently more valuable than fines.

Australian lump ore is widely utilised and valued by customers in markets such as Japan, Korea and Taiwan (JKT). In China, the utilisation of Australian lump is lower, due in part to China’s preference for prepared burden (sinter and pellet) but also its supply of domestic concentrate which lends itself to pelletising. There
is therefore an opportunity to increase the utilisation of Australian lump by studying its behaviour in the furnace relative to sinter and pellet.

The aim of Program 3 is to study the properties of different ferrous materials and to investigate the link between these and their behaviour and performance in the blast furnace. While the program covers the efficacy of the fines in granulation and the preparation for sintering, the current emphasis is on the response of the lump ore to increased reduction time and the inclusion of hydrogen, especially at the stage when the ferrous burden softens and melts. Thus the program goes beyond standard testing. Tests will also include quenching beds of lump ore at different stages (FIG 5 and FIG 6) in order to preserve changes in bed porosity and in turn permeability. The load acting on the sample will be altered to understand the effect of furnace size. Together with detailed mineralogical study of the reduction products, this project will provide firm conclusions about the role of lump ores properties in various furnaces.

FIG 5: High temperature furnaces are used to simulate the behaviour of iron ore fines during sintering, and lump ore, sinter and pellet in a blast furnace.
FIG 6: Quenched beds are used to explain the differences in softening and melting behaviour of individual ferrous material types and blends, and the effects of reduction degree and chemical composition. The beds shown were quenched at 1300°C.

New Technologies

The “ARC Research Hub for Advanced Technologies for Australian Iron Ores” integrates three critical areas covering the characterisation of end-use functionality, beneficiation, and materials handling of iron ore. Beneficiation has not been widely used in the Australian iron ore industry due to the large, economically accessible resource of high grade ores. But, with continued strong demand for iron ore, and the increasing requirements of customers, it is likely beneficiation will play an increasingly important role in the future, greatly increasing the tonnes of saleable ore from a deposit. It is further recognised that traditional beneficiation technologies have significant weaknesses, and hence innovation is crucial in this area.

This Iron Ore Hub will focus on a suite of novel technologies, and their application into iron ore beneficiation. This work will range from alternative beneficiation approaches that reduce the moisture of the product, through to novel enhanced wet gravity separation of the ultrafine particles. The ore types have become highly variable, and hence it must be understood, through analysis of their properties, how this impacts on beneficiation, raw materials handling, and downstream processing. While the hub is based around three programs, integration will be achieved through the use of common ore samples within each of the programs. Beneficiation and raw materials handling will in turn be described with respect to the fundamental material properties.

The Reflux Classifier offers significant potential in the wet beneficiation of fine iron ore covering a wide range of nominal particle sizes, from 6.3 mm down to 1.0 mm, 1.0 mm to 0.1 mm, and 0.1 mm to 0 mm. We have recently achieved remarkable separation performance over the range 0.1 mm to 0 mm by applying the
Reflux Classifier to a well liberated haematite ore, with grades in excess of 65 % and Fe recovery reaching 80 % across the full size range, with the recovery approximately 50 % below 0.020 mm and greater than 90 % above 0.038 mm. This work extends the recovery to sizes below those targeted by Amariei et al. (2013). Of specific interest here will be the influence of ore porosity, which lowers the particle density.

We will also be investigating the potential to enhance the performance of the Reflux Classifier by incorporating the system within a high speed centrifuge, a new device known as the Graviton. Laboratory-scale semi-batch work on the Graviton has shown the capacity advantage of the inclined channels literally multiplies with the capacity advantages of the centrifugal force, permitting better than 1000-fold advantage with only 55 Gs (Galvin & Dickinson, 2013). Work is currently underway to perform pilot-scale continuous testing of this concept, utilizing 3-D printing technology to fabricate the inclined channel sections as modules that can be mounted into the centrifuge.

CONCLUSIONS

This paper has provided an outline of the new ARC Research Hub for Advanced Technologies for Australian Iron Ore, covering the goals of this new collaborative scheme for encouraging the translation of university research into industry. The new Iron Ore Hub is focussed on iron ore characterisation, beneficiation, and materials handling. With unprecedented levels of iron ore production, and associated new challenges with the greater range of ore types, it is likely that beneficiation will play a greater role in the future. Existing technologies are limited in their effectiveness hence there is the need to develop more advanced technologies. Similarly, there is increased need to develop more fundamental approaches for characterising end-use functionality, and quantifying materials handling, and addressing the presence of moisture.

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REFERENCES


FIGURE CAPTIONS

FIG 1: The petrologies of these three Australian iron ore types are quite different, and this influences their behaviour during sintering and reduction.

FIG 2: High temperature furnaces are used to simulate the behaviour of iron ore fines during sintering, and lump ore, sinter and pellet in a blast furnace.

FIG 3: Photos of (left) Laboratory-scale Reflux Classifier and (right) full-scale RC™3000 unit with a 3 m diameter (Courtesy FLSmidth-Ludowici).

FIG 4: a) 3-D design concept and b) nearly completed plant for testing of the Reflux Classifier at full-scale on particles up to 4 mm in size. Trials scheduled to commence in 2015.

FIG 5: The 300 mm large direct shear testing cell.

FIG 6: The innovative “flowability” tester developed by TBS.