The HIsmelt Technology

From Australia to China….and Back Again?

N. J. Goodman

CEO, Acadia Iron, Vancouver BC V6E 4N7 Canada. neil.goodman@acadiairon.com

ABSTRACT

After more than thirty years of research starting in the 1980's, and expenditure of more than one billion dollars, the HIsmelt process was successfully proven by Rio Tinto in Kwinana, Western Australia. Due to the economic conditions in 2008, the Kwinana plant was closed and in 2014 some of the Kwinana equipment was transferred from Australia to China. The new HIsmelt plant is located near Shouguang Port in Shandong Province, and is owned and operated by Molong Petroleum Machinery Limited, a private steel company.

The Molong HIsmelt plant started up in 2016 and has produced more than 1,000,000 tonnes of hot metal at a cost lower than the local small blast furnaces previously used by Molong. The hot metal ladles are delivered via road trucks to the Molong basic oxygen steelmaking plant located 40km south of the HIsmelt plant.

In 2017, Molong purchased the HIsmelt intellectual property from Rio Tinto, and will license the technology to other users in China and overseas.

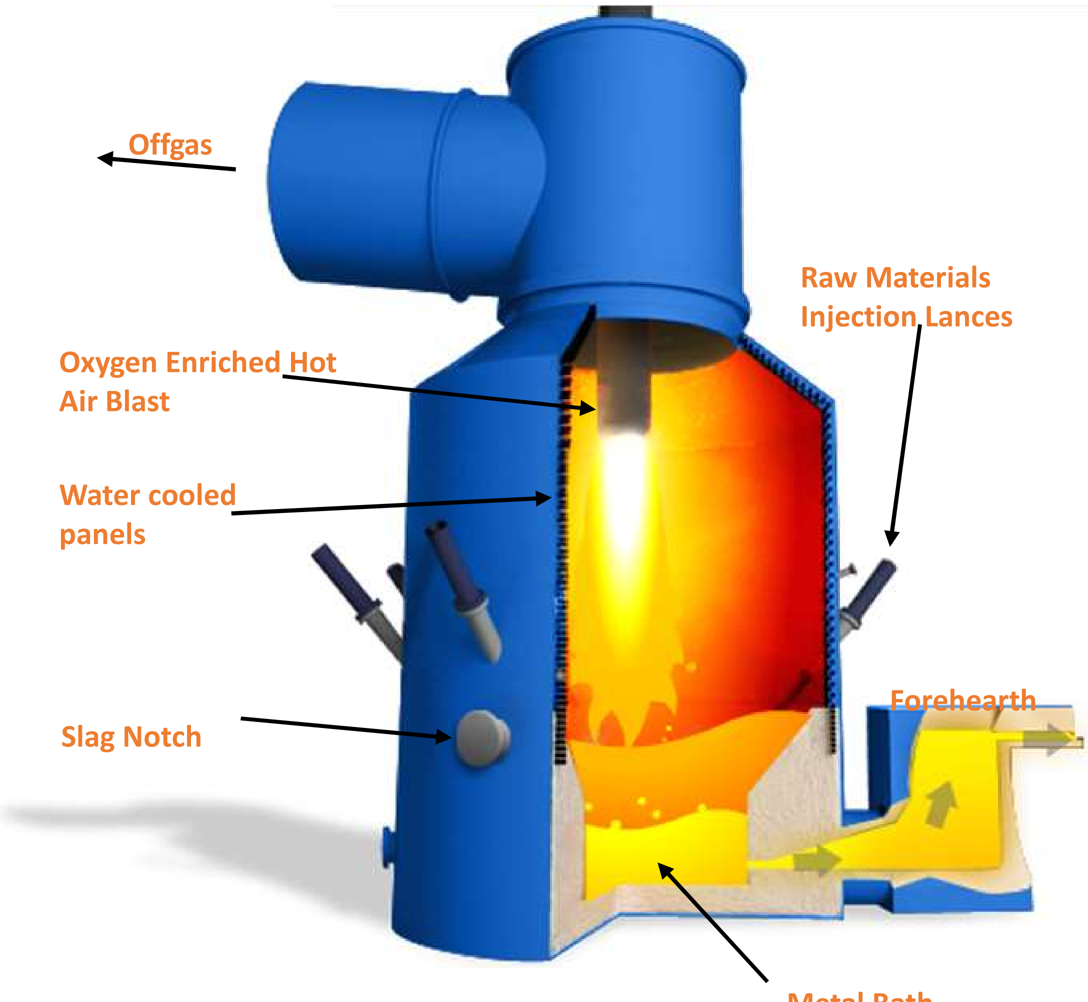
The inherent flexibility of the HIsmelt process allows many types of iron bearing resources to be smelted. This flexibility could be used to monetise iron bearing resources that cannot be economically smelted in blast furnaces due to high levels of impurities such as phosphorous, titanium and alkalis, or that have very fine particle sizes such as steel plant dusts and sludges

In addition, the HIsmelt process can use many types of carbon containing resources as the reductant including biomass. This offers a pathway to reduce the exposure of carbon taxes to iron smelting.

Molong and Acadia Iron are presently in discussions with more than ten companies that are interested in employing the HIsmelt technology in China, North America, Europe and Australasia.

INTRODUCTION

The heart of the HIsmelt technology is the Smelt Reduction Vessel (SRV), see below:



The SRV comprises a steel pressure vessel with a refractory lined hearth, and water-cooled panels around the inside shell of the barrel and roof. During operation, the refractory hearth contains a bath of liquid iron (hot metal) at approximately 1400C, with a layer of molten slag on top of the hot metal. Dry iron ore fines, fluxes and non-coking coal are injected pneumatically downward through the slag into the hot metal bath via water cooled lances. Hot air blast (HAB) at 1200C, enriched by oxygen to a total oxygen content of 40%, is supplied by hot blast stoves and injected into the SRV via a water cooled and refractory lined lance to post combust the offgas inside the SRV.

The smelt reduction reaction between the iron oxides and carbon generates a large volume of combustible offgas that erupts from the hot metal bath and throws a large volume of slag droplets into the top space of the SRV. In this top space, the post-combustion of the offgas by the HAB generates a high temperature flame above the slag surface. The energy from the flame is transferred to the slag droplets, which in turn, transfer their heat to the endothermic smelting zone in the hot metal.

The liquid hot metal sinks to the hearth of the SRV flows out via a refractory lined forehearth which acts in a similar manner to a manometer. The hot metal is collected by refractory lined ladles which are transported to the steel making plant or transferred to pig iron casting machines.

The iron ore gangue and coal ash are melted into a liquid slag that is periodically discharged from the SRV via a water-cooled slag notch. The slag notch is opened with a steel rod every two hours and resealed after thirty minutes with a refractory mud. The slag is not completely drained from the SRV as the slag layer insulates the hot metal from the oxygen in the HAB and therefore reduces the oxidation of the iron to FeO.

The offgas from the SRV is cooled from 1500C to 800C by a radiative boiler hood, partially cleaned in hot cyclones and then further cooled to 200C via a convective boiler system. The radiative and convective boilers generate saturated steam that flows to a steam drum located on an offgas boiler.

The SRV offgas exiting the convective boiler is quenched, scrubbed and cooled via water sprays and reticulated via ducts for use as fuel for the hot blast stoves and the offgas boiler. In the offgas boiler, the excess SRV offgas is combusted and superheats the saturated steam from the radiative, convective and offgas boilers. This superheated steam flows to steam turbines that generate sufficient power to operate the HIsmelt plant, ancillaries, and send excess power to the local grid.

The exhaust gasses from the offgas boiler and stoves are scrubbed with a lime slurry to remove the sulphur in the gas before being vented to atmosphere.

DEVELOPMENT OF THE HISMELT TECHNOLOGY

The HIsmelt technology was originally developed by Rio Tinto from 1982 to smelt high phosphorous iron ore fines with non-coking coals. The intellectual property rights for HIsmelt were sold by Rio Tinto to Molong Petroleum Machinery Limited, in 2017.

Small Scale Pilot Plant (SSPP)

The first pilot plant, the SSPP (approximately 1 tonne per hour of hot metal) was operated in Germany in partnership with Klockner from 1982 to 1986. The SRV was based on a bottom-blown steel making vessel with coal and ore injected via bottom tuyeres, and the vessel was rotated to tap metal in batches. The photograph below shows the SSPP being tapped. The results of the SSPP trials showed that smelting iron ore fines with coal in a bath of hot metal was feasible, and the decision was made to build a larger pilot plant

HIsmelt Research and Development Furnace (HRDF)

In 1990, Rio Tinto partnered with Kobe Steel and Midrex to build and operate the HRDF in Kwinana, Western Australia. The HRDF was designed to produce approximately 10 tonnes per hour of hot metal, and the SRV originally had bottom blown tuyeres that injected coal and iron ore fines, with hot air blast (HAB) from hot blast stoves injected into the top space. The vessel was rotated to tap metal in batches. Although the process operated efficiently, the refractory wear rate was very high, and Kobe Steel and Midrex decided to exit the technology.

The photograph below shows the horizontal version of the HRDF SRV being tapped.

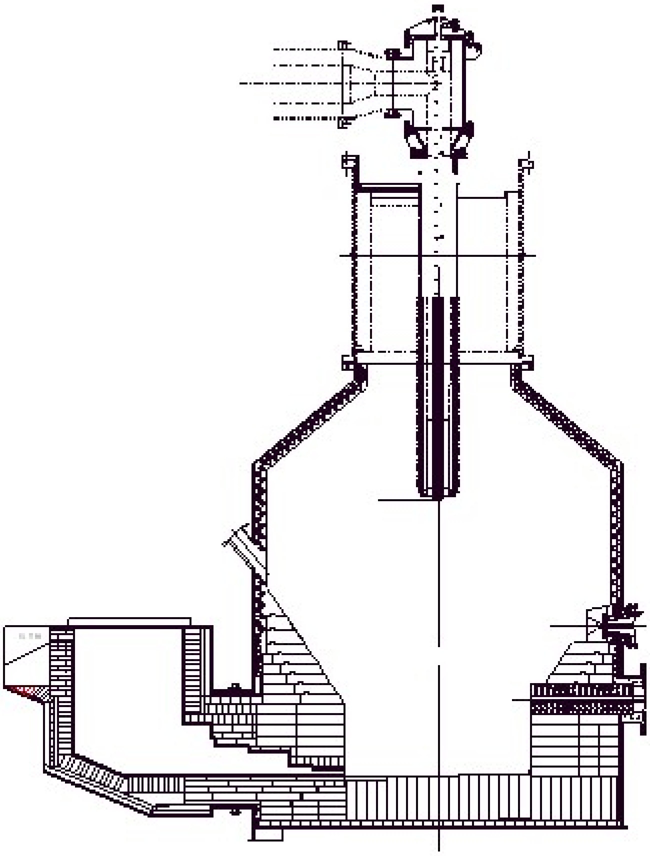
In 1996, Rio Tinto decided to change the SRV to a fixed, vertical design with the following changes:

Injection of coal and ore via water-cooled lances above the hot metal

Replacement of all refractories above the injection lances with water-cooled panels

Continuous tapping of hot metal via a ‘forehearth’ which allows hot metal to flow from the bottom of the SRV via an external refractory lined vessel that acts in a similar manner to a manometer

The figure below shows the layout of the HRDF vertical SRV which had an internal diameter of 2.7m



The results of campaigns with the vertical vessel from 1997 to 1999 were positive, and the SRV successfully smelting a range of ferrous feeds (including iron ore fines, concentrate, steel plant waste and DRI) and coals (ranging from coke breeze to high volatile thermal coals). In 2000 Rio Tinto decided to build a commercial scale HIsmelt plant.

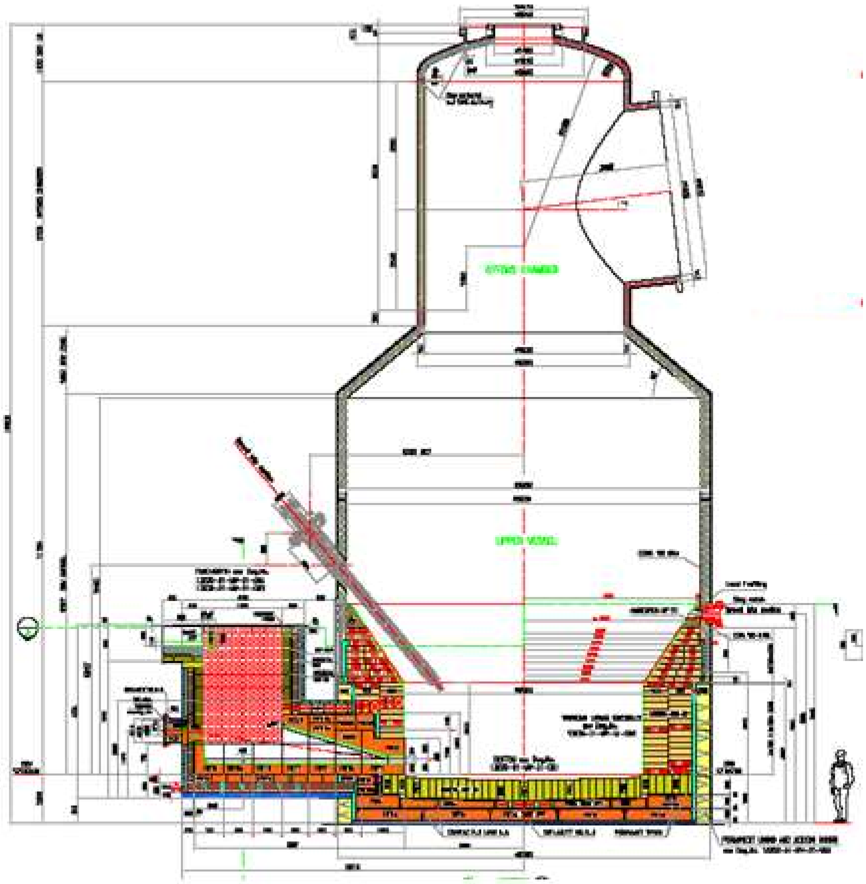
HIsmelt Kwinana Joint Venture (HKJV)

In 2001, Rio Tinto partnered with Nucor Steel, Mitsubishi and Shougang Steel to build a commercial scale HIsmelt plant producing approximately 800,000 tonnes per year of pig iron in Kwinana. The plant was constructed from 2003 to 2005, operated from 2005 to 2008, and produced approximately 400,000 tonnes of pig iron that was delivered to electric arc furnaces in the USA and Asia.

The HKJV plant suffered from a series of problems with ancillary equipment that caused low availability and damaged the refractories. However, the production rate and availability improved steadily, and by Q4 2008, the plant was producing up to 1,800 tonnes per day of hot metal with 90% availability. This production level matched the design rate of the plant when smelting hematite, and the process was considered proven.

Unfortunately, the global financial crisis of 2008 forced Rio Tinto to put the HKJV plant into ‘Care and Maintenance’, and the plant was mothballed for several years.

The figure below shows the layout of the commercial scale SRV at Kwinana (6m diameter hearth)



MOLONG PETROLEUM MACHINERY LIMITED (MOLONG)

In 2012, Rio Tinto signed an agreement with Molong to ship a portion of the Kwinana equipment to China, support Molong during the engineering and construction of the new HIsmelt plant, and to train Molong's personnel to operate and maintain the HIsmelt plant.

The Molong plant started construction in 2013 and started operation in 2016.

Molong's Decision to Select the HIsmelt Technology

Molong Petroleum Machinery primarily produces pipes, tubes and castings for the oil industry and makes most of the liquid steel required for the casting of round billets via a basic oxygen furnace. Before the HIsmelt plant was built, Molong would purchase approximately 500,000 tonnes per year of liquid hot metal from local small blast furnaces (typically less than 500 tonnes per day capacity) that were delivered in 40 tonne refractory lined ladles via road trucks.

In 2012 the Chinese Ministry of Industry and Information Technology (MIIT) issued a regulation that banned the construction of new small blast furnaces with capacities less than 1,000,000 tonnes per year and ordered the gradual closure of all small blast furnaces for environmental reasons. However, the MIIT specified that two technologies met the revised environmental standards and could be used to replace small blast furnaces. These technologies were HIsmelt and Finex. After reviewing both technologies, Molong decided to adopt the HIsmelt technology to supply 500,000 tonnes per year of hot metal their basic oxygen furnace, with excess hot metal delivered to a new foundry facility.

The photograph below shows the Molong HIsmelt plant at Shouguang Port near Yangkou, Shandong Province

Design Changes from the HKJV to Molong

Molong made several changes to the HIsmelt plant design which have increased the availability of the plant

Iron Ore Preheating and Pre-Reduction by Rotary Kiln

The HIsmelt SRV can smelt a wide range of ores, and its productivity can be increased by preheating and/or pre-reducing the iron ore externally. For example:

- Smelting dry hematite, a 6m SRV can produce 1,500 tonnes per day of hot metal
- Smelting hematite at 800C will increase production to 1,800 tonnes per day
- Smelting magnetite at 800C will increase production to 2,400 tonnes per hour of hot metal
- Smelting DRI (80% pre-reduced) will increase production to 4,800 tonnes per day

In the HKJV, the hematite was preheated to 800C via the combustion of natural gas in a circulating fluid bed (CFB). Ultimately, the HKJV planned to combust SRV offgas in the CFB to produce magnetite at 800C, but this was never commissioned. The availability of the CFB was very poor during the first two years of operation at the HKJV (approximately 50% availability during the first year of operation), and although this improved during the final year of operation, Molong decided not to use the CFB technology.

Molong decided to preheat the hematite ore using two rotary kilns in series. In the first rotary kiln the moisture is removed, the ore is heated to 200C and delivered to the second rotary kiln where it is heated to 800C via the combustion of pulverized coal. In future, Molong plan to pre-reduce the ore via the addition of coal mixed with the ore.

During operation, the rotary kilns are very reliable (>90%) but they presently require a 40-day shutdown twice a year to reline the refractories. In future, Molong plan to feed cold ore directly into the SRV when the rotary kilns are being relined.

Decoupling of the Boiler and the Process

The offgas from the smelt reactions is typically 60% post-combusted in the SRV, and after cleaning and cooling approximately 50% of the offgas is used as a fuel gas for the hot blast stoves. The remainder of the offgas is combusted in a boiler to generate steam to drive turbines.

In the HKJV HIsmelt plant, a portion of the steam was used to drive the blowers for the hot blast stoves and the oxygen plant. This meant that if the HIsmelt plant stopped, then the boiler stopped generating steam. This in turn stopped the stoves and oxygen plant blowers, and the boiler and turbines had to be restarted. Therefore, a short stoppage of the SRV resulted in long outages that significantly reduced availability of the HKJV HIsmelt plant.

Molong decided to install electric drives for the stoves and oxygen plant blowers, and all the steam was sent to a turbine-generator to produce electricity for the plant and export to the grid. Therefore, a short stoppage of the SRV did not affect the stoves or oxygen plant, and overall availability increased significantly.

Operational Results at Molong

Molong has started the SRV 14 times so far and produced approximately 1,000,000 tonnes of hot metal over 700 operating days at an average coal consumption rate of 900kg per tonne of hot metal. The cost of the hot metal produced by the HIsmelt plant is approximately 10-20% lower than the cost of the small blast furnaces previously used by Molong.

The SRV hearth lining comprises the original refractory bricks with only minor repairs needed using castable refractory.

Operation in 2016

The Molong SRV first started up in August 2016 but was shut down several times that year due to design problems with the water pumps for the offgas hood. In total, the SRV was started and stopped 6 times in 2016 and produced 60,000 tonnes of hot metal over 80 operating days. However, the HIsmelt process was proven to operate at the design output of 1,800 tonnes per day when smelting hematite at 800C, which matched the maximum output achieved in Kwinana by the HKJV plant.

Operation in 2017

The Molong SRV started up in January 2017 and produced 81,000 tonnes of hot metal over 69 days (1170 tonnes per day) which beat the Kwinana production record of 60,000 tonnes over 54 days (1115 tonnes per day). However, the rotary kilns and ore injection systems suffered from design problems and had to be repaired, and the SRV was not restarted successfully until September 2017.

Following this restart, Molong extended the production record to 84,000 tonnes over 59 days (1447 tonnes per day), and the SRV was stopped to reline the rotary kilns.

In total, the Molong SRV produced approximately 180,000 tonnes of hot metal over 150 operating days in 2017

Operation in 2018

The first operating period in 2018 increased the production record to 166,000 tonnes over 115 days (1448 tonnes per day), and the record was further increased during the second operating period to 225,000 tonnes over 143 days (1555 tonnes per day).

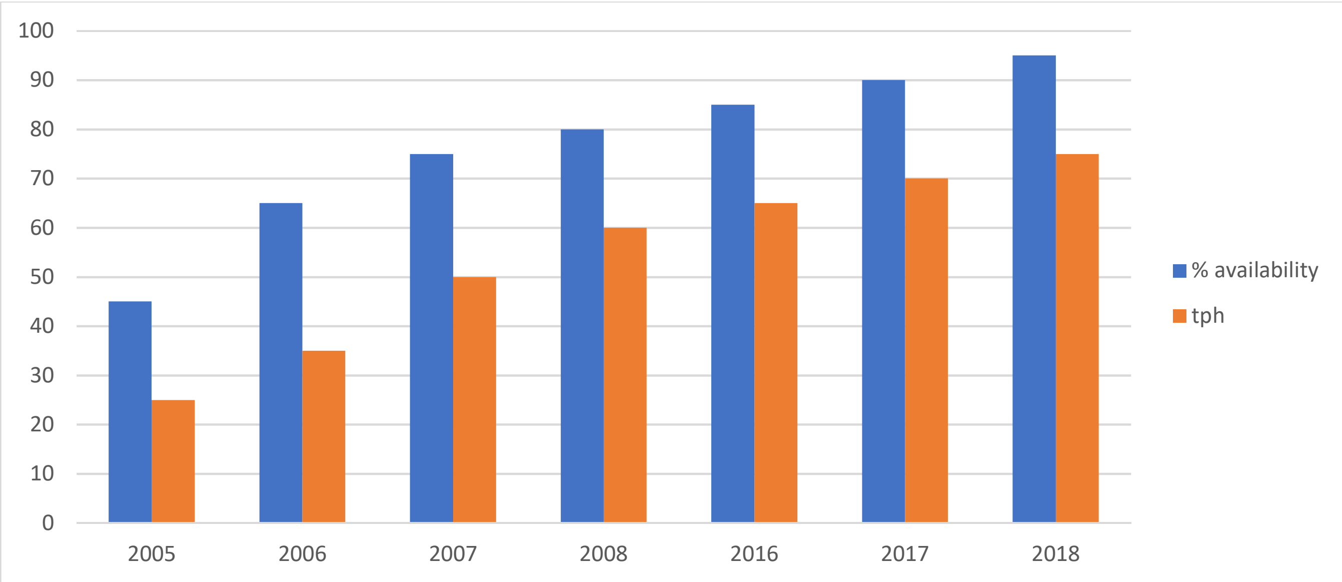
In total, the SRV operated with 92% availability except for 2 outages to reline the rotary kilns and produced approximately 420,000 tonnes of hot metal over 280 operating days in 2018.

Operation to date in 2019

The first operating period in 2019 produced 160,000 tonnes over 104 days (1528 tonnes per day) and ended because of leaks in the boiler and an injection lance.

The present SRV operating period started in March 2019, and to date (May 2019) has operated continuously, producing an average of 1600 tonnes per day with an availability of >90% and a coal consumption of <900 kg per tonne of hot metal.

The graph below shows the continued improvement in availability and production during operation in Kwinana (2005 to 2008) and by Molong (2016 to 2018)



FUTURE DEVELOPMENTS FOR HISMELT

Molong are investigating the use of low cost titano-magnetite beach sands at their plant in Yangkou, and Acadia Iron are investigating the use of the HIsmelt technology to smelt ores and waste materials in several locations including Quebec, the U.S.A., Europe and Australasia. In addition, studies are being performed to use biomass instead of coal as the reductant to reduce the exposure to potential future carbon taxes

Operation with Titano-Magnetite Beach Sands

Titano-magnetite beach sands that can be concentrated easily to more than 50% Fe are common around the world, especially in areas of volcanic activity such as the Pacific Rim countries of Indonesia, Chile and New Zealand. These beach sands typically contain 5 to 10% TiO_2 which causes major slag conditioning problems for the blast furnace. Therefore, beach sands are not consumed by integrated steel plants in large quantities and have only been used by niche steel plants such as Highveld in South Africa and New Zealand Steel. Highveld and New Zealand Steel both use rotary kilns and electric furnaces to reduce and smelt the ore to produce liquid iron. These processes operate at high temperatures and consume large quantities of coal and electrical power.

The HIsmelt technology is capable of smelting titano-magnetite beach sand concentrates due to the higher oxygen potential in the SRV compared to the blast furnace. This creates a more fluid slag at lower temperatures and avoids the slag conditioning problems experienced by blast furnaces.

In addition, titano-magnetite beach sands typically contain around 1% V2O5 and approximately 60% of the vanadium is expected to report to the HIsmelt hot metal. This vanadium can then be extracted via a soft blow of oxygen which will create a V2O5 rich slag that can be sold as a valuable by-product.

In studies performed for a New Zealand iron sand deposit, a HIsmelt plant could produce approximately 750,000 tonnes per year of pig iron at a cost $160 lower than the market price for pig iron. This offers a net revenue of $120m per year for an approximate capital cost of $450m, and a return on capital of 27% for the pig iron alone.

With 0.6% vanadium in the iron sand, approximately 6,000 tonnes of V2O5 slag could be produced annually and assuming a sales price of $10,000 per tonne of slag, the additional revenue would be $60m per year.

Additional equipment would be required to inject oxygen into the hot metal, and with this extra capital cost of $50m, the total capital cost would increase to U$500m. With a total revenue of $180m per year, the return on capital would increase to 36% with the production of the V2O5 slag.

Operation with Waste Materials

The HIsmelt plants in Kwinana and China have successfully smelted many different iron bearing waste materials including blast furnace and steelmaking dusts and sludges, millscale, and DRI fines. These waste materials are available at a lower cost than iron ore, and often have higher Fe contents which will increase productivity. Therefore, Acadia Iron is developing several projects worldwide whereby HIsmelt plants will smelt waste materials to produce valuable high-purity merchant pig iron for a cost much lower than a blast furnace.

Waste DRI and Oxide Fines

DRI plants using the Midrex and HYL processes generate significant amounts of DRI and iron oxide fines, with up to 15% of production lost to the generation of these fines. These fines are difficult to handle and are presently sold at a loss.

These fines can, and have been, smelted be in a HIsmelt plant and converted to pig iron. In studies for a HIsmelt plant in North America, a mix of 50% DRI/oxide fines and 50% iron ore concentrate could produce approximately 1,000,000 tonnes per year of pig iron at a cost $150 lower than the market price for pig iron. This offers a net revenue of $150m per year for an approximate capital cost of $450m, and a return on capital of 33%. Further benefits could be obtained by injecting slag from electric arc furnaces as they contain lime (which is used as a flux for the HIsmelt slag) and up to 30% FeO and so is a low-cost source of iron.

Waste Blast Furnace and Steelmaking Dusts

Blast furnaces and oxygen steel making plants also generate large quantities of waste dusts and sludges that contain iron and carbon and can be smelted in a HIsmelt plant. Historically most of these waste materials have been recycled through a sinter plant back to the blast furnace, but sinter plants are under severe pressure to be closed due to environmental issues.

In studies for a HIsmelt plant in North America, injecting a mix of blast furnace and steelmaking dusts and sludges could produce approximately 750,000 tonnes per year of pig iron at a cost $200 lower than the market price for pig iron. This offers a net revenue of $150m per year for an approximate capital cost of $450m, and a return on capital of 33%

HIsmelt Opportunities in Australia

As a thought experiment, several possible scenarios for HIsmelt plants in Australia are discussed below. The costs are indicative and are used for comparison only and should not be used for any investment decisions.

The following assumptions are used as the basis for the analysis (US$)

HIsmelt plant production 600,000 tonnes per year using hematite

Pilbara iron ore cost delivered to Kwinana $70/t (based on CFR Qingdao $60/t)

Iron ore consumption 2 tonnes per tonne of pig iron (2t/tp)

PCI coal cost delivered to Kwinana $100/t (based on CFR Qingdao $100/t)

Coal consumption 1t/tp

Labour cost at Kwinana 150 personnel @ $100,000 per year

Other fixed costs $30m per year

Pig iron market price $350/tp

Capital cost of Kwinana plant $450m

HIsmelt at Kwinana using Pilbara hematite

Iron ore cost 600,000 x 70 x 2 = $84m per year

Coal cost 600,000 x 100 x 1 = $60m per year

Labour cost 150 x 100,000 = $15m per year

Other fixed costs = $30m per year

Total annual cash cost = 84+60+15+30 = $189m

Unit cash cost = 189/0.6 = $315/tp

Pre-tax profit = (350-315) x 600,000 = $21m

Return on capital = $21m/$450m = 5%

HIsmelt at Kwinana using local hematite

A more obvious source of iron ore for a HIsmelt plant in Kwinana is local hematite delivered by rail to the port. Assuming a delivered price of $50/tonne, the pre-tax profit will increase by a further $24m, and the return on capital will increase to 10%

Cost reduction versus Pilbara = 2 tonnes ore x 600,000 tonnes per year pig x (70-50) = $24m

Pre-tax profit = 21+24 = $45m

Return on capital = $45m/$450m = 10%

HIsmelt at Kwinana using local magnetite

With magnetite, the production from the HIsmelt plant will increase to 700,000 tonnes per year and the unit consumption of coal will be reduced. Assuming a delivered concentrate price of $60/tonne, the return on capital will increase to 15%

Concentrate cost delivered to Kwinana $60/t

Concentrate consumption 1.7 tonnes per tonne of pig iron, cost $102/tp

Coal consumption 0.9 tonnes per tonne of pig iron, cost $90/tp

Labour cost $15m, $21/tp

Fixed cost $30m, $43/tp

Total operating cost = 102+90+21+43 = $256/tp

Pre-tax profit = (350-256) x 700,000 = $66m

Return on capital = $66m/$450m = 15%

HIsmelt at Kwinana using local titano-vanadium magnetite

The HIsmelt process has the ability to smelt titano-vanadium magnetite and has operated with slag levels with up to 20% TiO2 at pilot plant scale. Approximately 60% of the vanadium should report to the HIsmelt hot metal, and a V2O5 rich slag can be obtained by injecting oxygen into the hot metal after leaving the SRV.

Assuming 700,000 tonnes of pig iron are produced, and with 1% vanadium in the concentrate, approximately 10,000 tonnes of V2O5 slag could be produced. Assuming a sales price of $10,000 per tonne of slag, the additional revenue would be $100m per year.

Additional equipment would be required to inject oxygen into the hot metal, and assuming the capital cost is $50m, the total capital cost would increase to U$500m

Pig iron revenue $66m

V2O5 slag revenue $100m

Capital cost $500m

Return on capital = $166m/$500m = 33%

Use of Biomass in HIsmelt Plants

The HIsmelt process uses solid carbon to remove the oxygen from the iron ore and emits 1.8 tonnes of CO2 per tonne of iron as a result. With a projected carbon price of $50/t CO2, this imposes a carbon tax of $90/tp which will render most HIsmelt plants uneconomic. With this scenario, HIsmelt plants will be built in China and India but not in OECD countries.

However, biomass char has been successfully injected into a pilot scale SRV and this offers an opportunity to avoid carbon taxes. In addition, studies are underway in several countries to use biomass to pre-reduce iron ore by 50-70% and this pre-reduced ore could be injected into a HIsmelt SRV. Using 50% reduced iron ore, the HIsmelt plant production will be increased by approximately 50%.

CONCLUSION

The HIsmelt technology has been successfully restarted in China, and the Molong plant is producing 1,600 tonnes per day of hot metal at a cost lower than similar sized blast furnaces, and with greater than 90% availability of the SRV.

More than 1,000,000 tonnes of HIsmelt pig iron have been converted to steel via oxygen converters or electric arc furnaces around the world, and several new HIsmelt projects are being studied in China, North America, Europe, and Australasia.

The HIsmelt technology intellectual property is now owned by Molong Petroleum Machinery, Limited, of China; and Acadia Iron, a Canadian company, has the rights to licence the HIsmelt technology world-wide, outside China.

The flexibility of the HIsmelt process to use a wide range of iron bearing materials will allow the monetisation of previously uneconomic resources such as vanadium-titanium magnetite, high phosphorous and alkali hematite, and waste materials from DRI, iron making and steel making plants.

The flexibility of the HIsmelt process to use a wide range of carbon bearing materials will allow the use of biomass as reductant and possibly avoid the impost of potential carbon taxes.

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