Case Study

Renewable energy for zero-emission iron making

Iron making is an energy intensive process, as it relies on the use of coking coal as the reducing agent and burns coal to provide the heat. FEnEx CRC researchers are now investigating alternative iron smelting processes that use renewable energy sources and reduce greenhouse gas emissions. Ammonia is a renewable, carbon-free fuel and reducing agent, but needs to be demonstrated as a viable replacement for coal in the production of iron from iron ore.

The Challenge

Iron is currently produced from iron ore by reducing it with coking coal in a blast furnace, producing raw liquid iron. While a very efficient and simple process, iron smelting is very energy intensive and contributes about 10 per cent of global greenhouse gas emissions annually.

To decarbonise the iron making industry and halt its greenhouse gas emissions, renewable energy must be used, and coking coal must be replaced by a non-carbon reducing agent.

Direct reduction iron (DRI) is an alternative process, where iron ore is reduced to metallic iron using a gaseous reductant without heating it to temperatures that liquify it. The reduction of iron ore takes place in the solid state directly and produces a porous 'sponge' iron as the oxygen is removed from the iron ore. This is a lower energy approach than blast furnace technology for iron making, and is used on a smaller scale. The DRI process relies on using either natural gas or synthesis gas (carbon monoxide and hydrogen, produced by steam reforming of natural gas) as the reducing agents in a shaft furnace.

This process could be decarbonised by using renewable hydrogen directly as the reducing agent, but producing, transporting and storing renewable hydrogen at the scale required for iron making is still challenging.

The Solution

Ammonia is an excellent hydrogen carrier, and a practically effective means of exporting renewable hydrogen on a large scale. It decomposes into nitrogen and hydrogen at moderate temperatures, and is itself a reducing agent. As such, ammonia and its decomposition products could also be used in the direct reduction of iron ore to iron.

Theoretical and experimental studies have already proven the feasibility of reducing iron ore with ammonia. A FEnEx CRC project is now extending this work to determine the mechanisms of direct ammonia reduction of iron ores and establish the reaction kinetics, to provide a scientific basis and the real-world data required to design an industrial process.

The first stage of the project is to understand the fundamentals of how ammonia and hydrogen react with different types of iron ore, particularly Western Australian iron ores. Using a laboratory-scale fixed bed reactor and a magnetic suspension thermogravimetric analyser, the team can control every facet of the reduction reaction, from the ore type and ammonia concentration to the temperature of reaction and the contact time. By measuring the gaseous reaction products as they form, and studying the composition, morphology and structural evolution of the iron ore sample at various stages throughout its reduction, they are establishing the reaction mechanisms and rates for each step of the reduction process.

Because direct-reduced iron stays in the solid state and does not liquify, any other mineral impurities in the ore also remain, and may affect how the reduction process progresses. High purity iron ore may react so thoroughly with ammonia that a metallic iron which has a lower melting point may form a shell on the surface of iron ore particles, preventing gaseous ammonia penetrating to the centre of the particles and completing the reduction. The impurities in lower quality iron ores may keep the particles porous enough that reduction can continue to completion. By analysing not only the chemical purity of the iron product but also its physical structure and morphological characteristics, also considering the distribution of any remaining impurities and how it affects melting characteristics, data from these experiments will determine how best to configure and operate reactors to suit particular iron ore types.

This fundamental knowledge of the process will then allow the team to determine the reaction rate of reduction of different iron ores, and develop a kinetic model for the direct reduction of iron ore by ammonia under practically-relevant conditions. This knowledge is essential to be able to design and operate a reactor for the process.

Case Study

Outcomes and Impact

One year into the project, the thermodynamics of the reduction reactions are understood, and preliminary experimental work has shown that pure iron oxides can be completely converted in the solid state into metallic iron using ammonia. Laboratory experimentation will continue to test all of the major types of iron ore found in Western Australia, and lower quality iron ores from major international producers.

Once the kinetic model for the direct reduction of iron ore by ammonia represents the behaviour of the major iron ore types across a range of reaction conditions, work will shift to modelling to identify the best reactor types and operating conditions for iron making by this route, considering the whole process from raw materials to finished product.

In the final stages of this project, a laboratory-scale pilot reactor will be designed, built and commissioned to collect the real-world data needed to optimise operating conditions for a continuous process. This will enable reactor scale up for commercial production of direct reduced iron with ammonia.

Future Horizons

By the end of the project, there will be well-advanced scientific understanding of the process conditions, kinetics and optimal reactor configuration and operation to progress to pilot plant demonstration with industrial partners.
This represents a tangible step towards implementing direct reduction of iron ore with ammonia, replacing traditional iron making with a low-emission and environmentally friendly iron making process.

"Professor Dongke Zhang presented the Angang Group with the visionary prospect of using hydrogen and ammonia reduction of iron ore in 2017, well before the steel industry had grasped the concept of 'green steel'. As a result of his vision, Angang can now see the future of non- blast furnace iron making, and a pathway towards zero carbon emissions for the industry. As a major consumer of Western Australia's premium iron ore, it makes perfect sense for Angang to be part of this exciting project."

Dr Guangyu Ma
Director Research and Development, Angang Steel

Contact:

Project 21.RP2.0060

Prof. Dongke Zhang
Dongke.zhang@uwa.edu.au