



## RECOVERY AND USE OF STEELMILL IN-PLANT WASTES

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### ABSTRACT

In 2005 over 1 billion tons of steel were produced worldwide, an increase, over the last few years, from around 800 million due to developing markets in China and a few others. This increase in steel production, and resultant use of raw materials, iron ore and coking coal, has spurred a major shortage in the raw materials and more than doubled the price for the entire world. New strategies are being developed to secure raw materials for the future, investments in mines, investments in scrap steel and exports, opening of new mines or re-opening of old ones and so on and so on.

All the while, during the processing of iron ore from the mine to the rolling mill, 10% of the iron ore used to make this billion tons of steel is thrown away as waste. That seems to be a figure of over 100 million tons of iron bearing materials is mostly thrown away. According to the steel mill operators, this waste is too difficult to handle, it will upset the normal operations, there's more where that came from, let the accountants deal with it. If you look at the invested cost in producing the waste, perhaps the accountants should deal with it. What is the cost of steel, for example, in the rolling mill? On average, mill scale accounts for 10% of the waste, is the highest quality iron oxide you can find and has an invested cost to the steel maker of over \$400 a ton. In the US, the normal practice of getting rid of mill scale is to sell it to cement plants for \$10 per ton, or less, while striving to purchase other iron units and repeat the practice. This same philosophy of handling waste iron units from ore screenings and dust, mill scale and spillage, hazardous waste handling, landfill costs and fees has to be reviewed with a strict analysis on cost, environmental effect, wasted energy and replacement of raw materials. Restricting progress in overcoming the environmental, energy and waste issues has been the inability to treat fine materials. Some methods that have tried to recover wastes or to use fines contribute to further use of energy and pollution.

The iron and steel industry in the U.S. has issued criterion for an iron and steel making process, for the future, that should be developed over the next 20 years. The process criterion, uses coal directly, eliminates wastes, reduces emissions, reduces costs and energy and uses iron ore fines.

A new process that meets all the criterion has been developed which provides for an agglomeration of iron bearing materials fines, premixed with coal or other carbon sources and fed directly to a smelter, eliminating the need for coke, pre-processing of feed materials, sintering and pelletizing and eliminating air pollutants and energy consumption from those processes, while also recovering iron bearing wastes and utilizing other wastes from iron and steel making processes.

The technology, called the RBI Process, for which T.C.Inc. has been issued a U.S. Patent, includes the agglomeration of feed materials, mixed with a carbonaceous fuel, to produce a self reducing feed to a smelter. The selected agglomeration technique is a hydraulic ram briquette machine, which will produce feed material to withstand any handling, maintain strength and integrity during processing, penetrate any slag barrier and maintain strength during the reduction. The ram briquette machine was also selected to reduce or eliminate use of binders due to its inherent ability to make an agglomerate of high density. The research phase of the RBI Process was completed in the 80's. Technology and designs now developed include the methods to make hot metal from the waste and ore fines, use of coal instead of coke, operating a steel mill 100% waste free, reducing capital costs, reducing or eliminating in some cases, greenhouse gases, reducing energy and building an iron making or steel making plant from 50,000 TPY and up on a competitive scale with large capacities.

While the selection of a smelter for direct iron making is anticipated to follow the route of an oxygen furnace, the technology will utilize any existing melter/smelter for the recovery of waste, since most wastes recycling has to be site specific. Additional technology is now being developed to utilize this processing method for the non-ferrous and ferrous –alloy industries.

## REVIEW OF TECHNOLOGY

In the 1980's it became apparent that iron and steel plant wastes, emissions and effluents were a cause of concern due to, ground water contamination from stockpiling or land filling, air born particulates were contaminating soils in surrounding plant areas and there was concern of the greenhouse effect from gas emissions. As a result, restrictions were put on land filling and stockpiling of wastes and air born emissions from plants and a new era of monitoring and control was established. The added cost to iron and steel making then dictated that new technologies be developed for collecting the emissions and effluents and treating the collected materials to reduce leaching into groundwater and potential health hazards. The iron and steel industry, since, has incorporated new technology in reducing particulate emissions from air born sources and in collecting wastes. Some methods have also been incorporated to recycle, through existing processes, the sinter plant for example, wastes that have no ill effect on production capacity or quality from contaminants. Greenhouse gas emissions have also been reduced with increased plant efficiencies. However, no technology had been implemented, en-masse, to recover and use waste materials.

Iron and steel plant wastes are normally categorized into iron bearing materials, refractories and carbonaceous materials. Methods to recover any or all of the wastes needed to be developed. Waste materials from iron and steel making plants were studied. This included mining and beneficiation and pelletizing operations, material shipping, sinter plants, coke oven plants, integrated iron and steel plants and EAF and DRI operations. The physical characteristics of the wastes revealed that, with the exception of slag, most iron bearing materials were in the form of minus ¼ inch, most refractories were in the form of brick or large particles, carbonaceous materials were liquid, dust or breeze or in the form of graphite rods. The chemical or elemental form of wastes, especially the iron bearing materials from various iron and steel plants each had compositions specific to those iron and steel plant operations and products. The refractory waste and carbon graphite needed to be separately reviewed due to size and potential reuse. The major emphasis was put into finding a means to handle iron bearing wastes of all the various operations for a case by case and site specific scenario.

Handling the fines and dust and collecting them was not the issue, as technology and equipment was readily available to do this. Making the iron bearing wastes a reusable product or in some cases a non-hazardous product became the objective. To do so various technologies were reviewed:

- a. Pelletizing and induration and cold bonded pelletizing. These required the materials to be ground to normal pelletizing grade feed, required the addition of unwanted binders, and added an element of handling in induration or curing. The product pellet still generated dust and fines and added to chemical constituents undesirable in further processing. The cost associated with any site specific case could not be justified. Shipping materials to a central location for a more economically sound project only added to the cost in handling the materials and the materials would then be mixed and unacceptable to any specific site for reuse.
- b. Roll type briquetting or brick making This technology provided that any materials of less than ¼ inch could be used without grinding. However, binders were required far in excess of pelletizing adding to the unwanted chemical constituents in further processing. The briquettes also had to be cured to increase the strength, but, handling and shipping still caused generation of fines and dust. Again, the cost of briquette operations and high maintenance costs of machines eliminated the justification for commercial use.

In both type technologies, pelletizing and briquetting, or brick making only integrated iron and steel plants could reuse the materials for recycling. EAF operations waste iron bearing materials contained hazardous materials not suitable for recycling and the EAF operations are not an iron making or iron reduction facility.

- c. Pre-reduction studies were then made in order to provide a feed material that was of more value to the iron and steel maker. Processes were developed to use the technology of pelletizing or roll briquetting for a cold bonded feed to rotary kilns, rotary hearths and shaft furnaces with carbon added to the pellet or briquette. The technology was adapted in some operations and subsequently shutdown due to high operating costs, high capital costs with few benefits to the iron and steel maker. The technologies also required carbon sources of the highest quality, coke, and added the same chemical constituents from binders, defeating any benefits to steel making.
- d. Pre-reduction and smelting, as a combined process was also studied, not only for recovery of in-plant wastes but to directly make iron from fines. This technology also requires the highest quality feed and carbon sources, pelletizing and major capital investments. Operating costs can only be justified with large scale plants, therefore contributing to added iron and steel overcapacity. The only recognized benefit is the use of coal instead of coke. Later developments abandoned the recycling of wastes.
- e. Direct steelmaking has been considered, to use fines and coals, not of coke quality, and smelt/reduce materials directly. This had been considered as the most viable technology under development, which could use recycled iron units, dust and fines, directly, however, no studies are being conducted to use waste materials. The technology also is limited to only large scale operations to justify operating and capital costs and is not viable for site specific cases in recycling wastes. Material losses from fume exhaust also reduce efficiency and carbon additions are far in excess of the requirements of stoichiometric reduction. Fines and dust feed do not penetrate slag barriers without injection systems.

## PROCESS DEVELOPMENT

The requirements to handle the iron bearing wastes and fines had the following criterion:

- Carbon wastes products or non-coking coals should be used.
- Site specific
- As-available iron bearing wastes, with the exception of slag, had to be considered.
- Product must have the integrity to withstand the reduction phase during reduction/smelting.
- Product must withstand any handling or shipping with minimal losses.
- Product must be heavy enough to penetrate any slag barriers.
- The addition of a carbon source should be limited to carbon required for reduction of oxides and the carbon equilibrium in the hot metal.
- Product should be able to be fed to any melter/smelter.
- Minimal energy use.
- Minimum additions of materials, such as binders. Maximum use of other in-plant waste, such as refractories
- Iron fines of less than ¼ inch had to be used.

Hydraulic ram briquetting was then reviewed and it met all the criterion listed. Historically, the ram briquette machine had been used commercially since the 1930's for the "punch pressing" of machine shop turnings and borings for feed to a foundry. This practice has been continued through today. Tests were then conducted on various iron and steel mill wastes, singularly without binders. Both iron bearing wastes and carbon sources were tested, then in combinations, simulating typical site specific cases. In some instances refractory material was crushed and added. If dust collection material was used, only, the product briquette was somewhat weaker. This was compensated for by the addition of a tar or pitch or coal and in some cases ground refractory. By mixing dissimilar sized particles, no binders were required. However, by adding a carbon source of some waste materials or coal, it was found that the material had an inherent binder. It was also found that oxides would be self reducing upon feed to a smelter.

Since the ram briquetter is a known technology, can produce an agglomerated product from fines with mixtures desirable to the iron and steel maker, can utilize and agglomerate any iron and steel wastes and can provide a self reducing feed material, it is expected that the technology meets the criterion for direct iron and steel making. The technology is viable, in that it can be utilized at any site specific plant, in any size to meet the requirements of capacities. The only inputs required, other than feed equipment apparatus

are cooling water for hydraulic cooling and power, making it also environmental friendly, as compared to any other process which may require induration, pelletizing or pre-reduction and therefore use of hydrocarbon fuels with resultant gaseous emissions. This process can claim total use or recovery of all iron and steel wastes.

The process also will utilize direct feed of as mined iron oxide feed, not ground to meet pelletizing or concentrated feed to sinter plants. The material feed will be mixed with coal fines or waste carbon sources and ram briquetted to provide a smelter with a feed material that is self reducing. This will eliminate the need for pelletizing or sintering and the use of coke making plants. As compared to pelletizing, sintering and coke plants, no fuels are used, no gaseous emissions are experienced, there are no losses of materials, capital expenditures and operating costs are reduced.

Other benefits are derived from using the ram briquetted technology, in that imports of feed materials can be reduced and curtailed, or an area of low need for iron or steel goods can build a micro plant, suitable for its local needs and using low quality ore and carbon sources.

The potential application to the iron and steel industry is the recovery and use of all iron bearing wastes, the potential application to replace sinter and pellet plants, the potential of replacing coke ovens and using coal directly.

The research objective addressed the specific need for improvements in the iron and steel industry to; increase efficiency through recovery of iron and steel wastes and through the use of iron oxide fines in making iron, decrease the dependence on coke by using coal directly, decrease the gaseous emissions in pre-processing, sintering, pelletizing of iron oxides and coke making plants and decrease the energy consumption in pre-processing, sintering, pelletizing, coke making and energy losses due to waste materials. In 2005, over 1000 trillion Btu's were invested in energy to produce waste iron bearing materials and over 1500 trillion Btu's were used to pre-process, pelletize and sinter iron oxide fines. The goal is to recover the energy invested in wastes by utilizing the waste and to reduce the energy consumption in pre-processing, pelletizing and sintering. The objective is to use coal directly, eliminating the need for coke making. Additionally, it is the objective to eliminate the gaseous emissions by eliminating some steps in pre-processing and to eliminate sintering, pelletizing and coke making. These goals will be accomplished by using an alternate method of agglomeration, iron oxide mixed with a carbon for direct feed to a smelter and feeding any type smelter that hot metal can be produced. It will not be necessary to develop a new machine for agglomeration as the process technology uses a well know hydraulic ram briquetting machine.

## **TECHNICAL FEASIBILITY**

To make iron and subsequently steel, carbon is used, under heat, to chemically extract the oxygen from the natural oxides of iron. Most processes convert some sort of carbon source or hydrocarbon source into a reductant CO and/or H<sub>2</sub> to be introduced as a gas, externally to the iron oxide and extract the oxygen from the iron, by forcing the gas through the iron oxide particle, producing somewhat of a pure iron, then the iron is melted. The process is more complex as there are also other elements combined with the iron and carbon sources that are dealt with separately and there are major considerations as to how to get the gas into the iron oxide material. However, simplistically, this is what occurs. In order to make this processing as efficient as possible, iron oxides have been meticulously beneficiated, such that, a maximum value of other materials is reduced, but, the iron oxide is then in a form that can't be used unless it is agglomerated, normally by sintering or pelletizing. Shaft furnaces, namely the blast furnace also has been designed for the purpose of accepting iron oxides in the form of sinter and pellets. In order to have a carbon source for reduction in the blast furnace, efficiency dictated that coal could be used but it had to be beneficiated by removing the volatiles and other matter that would interfere with quality of hot metal and the coal had to be more permeable to achieve efficiency, resulting in the processing of coal to coke. It is the intent of using a ram briquetted mixture of iron oxide particles and coal particles, tightly bound through compression as feed to a smelter. At elevated temperatures in a smelter the carbon will oxidize by the extraction of oxygen from the iron in the particle next to it. Gas flow and bed permeability is, therefore not a concern, only heat. The ram briquette becomes a self reducing material and in the smelter, within minutes is

reduced of oxides and melted into hot metal. Since the reduction takes place inside the ram briquette, it is anticipated that close to stoichiometric carbon, plus carbon equilibrium, can be achieved

Reducing current energy usage, recovering iron and steel making wastes and eliminating steps in pre-processing, sintering, pelletizing and coke making, using coal directly and reducing gaseous emissions were the achievements desired. Selecting the type smelter to achieve the desired hot metal results will be a goal as well as type of heat input. It will be a goal to review the potential of heat recovery in off gases for cogeneration of power based on various types of carbon input. Another goal, and considered in the developmental phase, is to apply the technology to the non-ferrous and stainless industries, such as nickel laterites and aluminum bauxites and others.

## **BENEFITS**

The energy consumption for the RBI process to recover the world's 100 million tons of iron bearing wastes is 30 trillion Btu's/yr, as compared to 1000 trillion Btu's used to make the waste. The per unit energy consumption is calculated at 40 kWh per ton electrical power input. (per unit installed process is an engineering calculation of a ram briquetting facility, including all materials handling, mixing, feeding mechanisms and the machine requirements of a hydraulic system.) There is no comparable or competing technology that is used to recover and use iron and steel plant wastes. Some captive sinter plants are feeding some acceptable wastes into the process, however, sinter plant energy use is about 1.6 million Btu's per ton of combined energy consumption. Therefore if wastes were recycled through sinter plants the energy required would be about 160 trillion Btu's.

Processes that use iron oxide agglomeration and pre-reduction, such as rotary hearth technologies or other techniques before feed to a smelter will consume a minimum of 15 million combined Btu's per ton. In recovering the iron bearing wastes the energy consumption is 1500 trillion Btu's. As compared to ram briquetting the energy savings with RBI is 98%.

To replace coke ovens, sinter and pellet plants, the blast furnace would also have to be modified or replaced with an alternate smelting/steel making technology, for example an oxygen furnace. Overall benefits to the iron and steel industry are in the preparation of materials, the development of a site-specific technology, reduction of effluents and total recovery of wastes.

The technology is designed to recover iron and steel plant wastes in the form of iron bearing materials, carbon products and other wastes, such as refractories or lime dust. Through this technique, about 10% of total steel production can be recovered and reused, improving the productivity and cost of making steel. The proposed technology also has the potential of replacing processing steps in iron and steelmaking in materials preparation for smelting. It is anticipated that by using the patented process of ram briquetting, hot metal can be produced at a significant savings over conventional methods through energy savings alone. If capital costs, operating costs and maintenance costs of conventional equipment were included, it is anticipated the savings in costs per ton of prepared materials would be in excess of one half.

## **ENVIRONMENTAL BENEFITS**

There are no wastes associated with using ram briquetting technology as a feed preparation for materials to the iron and steel sector. 100 million tons per year of iron bearing wastes associated with the iron and steel sector are already being produced which can be recovered with ram briquetting. With existing technologies, sintering or pelletizing of iron oxides and coke making, CO2 emissions would be eliminated by using ram briquetting technology. Currently the amount of CO2 emissions are calculated from sintering (assuming pelletizing uses the same relative amounts of fuel) and pelletizing at 69 pounds/ton of steel and coke making at 102 pounds/ton of steel. Wastes and by-products of coke making are also eliminated, but, with new smelting technologies, effluents now that exist will be changed and have to be studied. It is suspected that the selection of the smelting furnace with the ram briquette will greatly enhance the use of all carbon and hydrocarbon products in coal and reduction of NOX with the use of enriched air.

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**T.C.Inc.** is an international project development and consulting firm dealing in iron and iron bearing materials in the fields of agglomeration, beneficiation, pelletizing and reduction. The makeup of T.C.Inc. includes associates and associated companies with expertise in iron and steel making technologies, gas reforming and burner systems and syngas technology. T.C.Inc. provides services in technology development and evaluation, project evaluation, process evaluation and application, project, construction and operations management, plant commissioning and training and operations optimization. T.C.Inc. also offers patented technology in Direct Reduction of Iron Oxides with any fuels and the patented RBI Process for Direct Iron and Steel Making and Waste Recovery.

**Thomas J. Coyne, Jr.**, the author has published papers in iron and steel making technology that cover such areas as raw materials for iron making and direct reduction, direct reduction plant operations, shipping and reoxidation of direct reduced iron, pelletizing of magnetite, gas flows and pressure considerations in shaft furnaces, shaft furnace balances and assumptions, raw material plants mass balances, international project development and management.

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