

Proposed Project 10: Effects of Carbonate Minerals on Filtration Rates

Objective(s): Determine how carbonate minerals that either occur naturally in the ore, or are added as flux, affect the filtration rate of iron ore concentrates.

Justification: In a current project, the investigators have determined that filtration rate variations in an operating plant are not due to changes in particle size distribution or variations in particle shape, and are only partially accounted for by changes in the Zeta potential of the concentrate. A substantial part of the filtration rate change is due to addition of calcium carbonate or dolomite fluxes. When these minerals are added to the filter slurry, the filtration rate decreases markedly. This decrease is not accompanied by a corresponding change in Zeta potential. Variations in filtration rate with no corresponding change in Zeta potential are also seen for ore from different parts of the deposit, which could be due to variations in the levels of carbonate minerals such as ankerite and siderite. In order to prevent this decrease in filtration rates, it is necessary to determine exactly what it is that the carbonate minerals are doing to the behavior of the ore in the filters.

Description of Proposed Work: Ore and flux samples will be obtained from the Minntac deposit, and will be characterized to measure their levels of carbonate minerals both by X-ray diffraction and by thermogravimetric analysis. Filtration rates of concentrates with varying levels of both naturally-present carbonates and added flux solids will be measured in laboratory filtration experiments. Water chemistry will be analyzed by atomic absorption spectroscopy to determine what ions are being dissolved from the carbonate fluxes, and the results will be analyzed to attempt to determine the actual mechanism of the decrease in filtration rates that is caused by carbonate minerals.

Proposed Project 1: Metal/Slag Separation in Iron Nugget Production

The separation of liquid metal and molten slag from each other is expected to be controlled by two factors: (1) Fluid viscosity, which controls the speed with which metal droplets and molten slag droplets move past each other so that they can coalesce and separate from each other, and (2) Surface tension of the metal and of the slag, which determines how completely the two phases will separate from each other. The important information needed in order to properly design and control iron nugget production facilities are:

1. What are the effects of temperature and composition on the viscous and surface tension effects during nugget formation? These will be examined by determining the morphology and microstructure of iron nuggets and slag and comparing with known microstructures.
2. How do fluxes interact with slag compounds and metals to control nugget and slag properties? Studies are needed to determine how this impacts slag separation and removal, thermal requirements, and the mechanisms of generation of airborne particulates or other pollutants by this process

Project Objectives: The objective is to determine how the slag viscosity and slag/metal surface tension is related to the composition and temperature of the slag and metal, and to measure how variations in these properties alters the rate and completeness of the separation of metallic droplets from the slag.

Proposed Deliverables: A model of the separation of slag and metal from each other as a function of composition, temperature, and time.

Proposed Methodology: Surface tensions will be calculated based on microscopic measurements of the air/slag/metal interfaces in specified configurations, where the geometry can be used to determine how the surface tensions are related. Viscosities will be calculated based on the flow of slag. Modeling will be carried out using the FEMLAB multiphysics software, with capability for modeling fluid flow.

Milestones and Time to Completion: The overall project is expected to require 3 years to complete. The major milestones will be: (a) Production and analysis of iron nugget/slag assemblages suitable for analysis to determine ranges of slag chemistry and geometry of slag/metal contact – 3 months; (b) Determination of slag viscosity as a function of temperature and composition – 8 months; (c) Determination of slag/metal interfacial tension by microscopic geometrical measurements of metallographic samples – 10 months; (d) Development and validation of mathematical model to predict slag/metal separation behavior based on slag chemistry, time, and temperature – 15 months.

Proposed Project 2: Advanced Furnace Modeling

The transformation of iron oxide/reductant pellets into metallic iron nuggets is highly time- and temperature-sensitive, and so it is crucial that the furnaces be designed and controlled so that all pellets are transformed completely and uniformly. The furnace environment is a complex system with temperature profiles that can vary considerably over short distances depending on how the furnace is operated. A fundamental knowledge of the gas and heat flows in the furnace, as well as heat exchange between the pellets and the heat source, is needed to ensure that the process zone of the furnace can be adequately controlled to produce uniformly high-quality pellets. Current furnace technology performs poorly in this respect, with large variations in iron nugget quality due to inhomogeneities in the furnace heating (Anameric and Kawatra, 2007). The industry will need to be able to maintain higher levels of reproducibility in order to produce nuggets as a viable product.

Project Objectives: The objectives of the project are to develop computational fluid dynamics (CFD) models of the furnaces used to produce iron nuggets, and to use these models to relate the thermal profiles within the furnace with the metallographic characteristics of the nuggets produced. These models will need to take into account the heat transfer to and from the nuggets, heat transfer within the furnace volume, exothermic and endothermic reactions that occur within the nuggets, and reaction rates of the individual metallic iron grains with slag and with carbonaceous or hydrogen-rich reductants.

Proposed Deliverables: A CFD model of the furnace type that will be used in the production of iron nuggets, and a thorough understanding of the exact time and temperature conditions needed to produce high-quality iron nuggets that completely separate from slag impurities.

Proposed Methodology: The CFD modeling will be carried out using the FEMLAB multiphysics software. Model results will be validated against performance of actual furnaces to the maximum extent possible, and the predicted transformations will be validated against the observed behavior of the pellets as they transform into metallic iron nuggets.

Milestones and Time to Completion: The overall project is expected to require 3 years to complete. The primary milestones will be: (a) Modeling of the thermal profiles of the interior of a rotary hearth furnace, of the type used for large-scale iron nugget production – 9 months; (b) Modeling of the heat flow from the surface of the individual pellets to the interior, incorporating the exothermic and endothermic reactions that occur as the temperature increases – 15 months; (c) Overall thermal behavior of the pellet bed as the pellets transform, as a function of position within the thermal profile of the furnace – 12 months.

Proposed Project 3: Capture and Sequestration of CO₂ from Iron and Steelmaking

Objective

The objective of the project is to determine the optimum conditions for capturing and sequestering the maximum amount of CO₂ produced by iron and steel production.

Justification

Government regulations on CO₂ emissions from ironmaking and steelmaking are inevitable in the near future. It is therefore necessary to develop methods for capturing and permanently sequestering carbon dioxide in an effective, economical way so that these regulations can be met.

The sequestration methods must meet the following requirements:

1. The CO₂ must be scrubbed from the plant exhaust gases with high efficiency and low cost.
2. The scrubbing agents used must be readily available in the quantities needed for the industry.
3. The CO₂ must be sequestered into forms that will not be released into the atmosphere at a later date.

The investigators have already identified potential scrubbing agents that will greatly facilitate the capture of CO₂, and its subsequent transformation into stable minerals. This will utilize existing materials, of which an estimated 8 billion tons are produced every year. Use of these materials will make it possible to sequester carbon dioxide without causing environmental harm due to mining of new minerals, or development of new disposal sites.

Description of Proposed Work

The Investigators will carry out experiments with the potential scrubbing agents to determine the optimum conditions for capturing the maximum amount of CO₂ at a minimum cost, study the conversion of the CO₂ into a stable form that can be sequestered, and examine the properties of the stabilized CO₂ to determine its potential for profitable utilization in high-volume industries (such as construction) while preventing the CO₂ from being re-released into the atmosphere.

Proposed Project 4: High-Efficiency Removal of Mercury from Plant Emissions

Iron ore processing and steelmaking are being recognized as potentially significant sources of mercury emissions, even though the ore as mined does not contain a high level of mercury. The mercury emissions are due to the high volatility of metallic mercury and its compounds, which results in the small quantities of mercury present being efficiently vaporized by the heat of processing. A large fraction of this mercury is in the elemental state, which is unreactive, easily vaporized, and can be transported worldwide over a period of years before it finally oxidizes and precipitates as a contaminant.

Project Objectives:

Since the absolute concentrations of mercury in the emissions is in the parts-per-billion range, it is highly uneconomical to have a dedicated scrubber that captures only the traces of mercury. It is much more feasible to “piggy-back” the mercury capture capacity with scrubbers for high-volume pollutants, particularly sulfur and carbon dioxide, so that a single unit can remove all of the major pollutants of concern at once. The objective of this project is therefore to study the oxidation states of mercury that are produced by the iron and steel industry, and their interactions with novel scrubbing agents for the capture of sulfur oxides and carbon dioxide. Methods for control of the reduction/oxidation environment of the scrubber will be of particular interest, as operation under sufficiently oxidizing conditions will convert the mercury into the more easily-captured oxidized state. The mercury concentration and leachability in the final scrubber sludge will also be investigated, to ensure that it does not leach into groundwater.

For this project, the investigators will combine a laboratory-scale thermal processing unit with an instrumented fluidized-bed scrubbing reactor. This unit will examine the interactions of mercury with combustion gases and with scrubber chemistries, and will determine the conditions that most thoroughly capture highly dilute mercury vapors while still being compatible with high-efficiency scrubbing of sulfur oxides and carbon dioxide. Initial experiments by the investigators have shown that the mercury-capture effectiveness of a scrubbing agent could be increased by 9.1 times when an oxidizing agent was introduced into the scrubber to oxidize elemental mercury. The objectives of the research are therefore to (1) Determine what minimum oxidation potential is needed to oxidize the mercury so that it can be captured; (2) Examine methods for increasing the oxidation potential in the scrubber; (3) Measure the effectiveness of mercury absorption, and determine whether maximizing mercury capture can be accomplished while also maximizing capture of carbon dioxide, sulfur oxides, and other pollutants.

The primary scrubbing agents examined will be materials, which the investigators have been studying for use in sequestration of carbon dioxide. Use of these materials will make it possible to both capture mercury and sequester carbon dioxide without causing environmental harm due to mining of new minerals, or development of new disposal sites.

Proposed Project 5: Effects of Binder Type on Pellet Breakdown and Dust Production

Objective(s): Determine effect of the ore concentrate characteristics (surface chemistry and size distribution), binder dosage and type of bentonite on the pellet quality and on the dustiness of the pellets.

Justification: Dustiness and breakdown of pellets is a concern for all of the plants, and it has been assumed that bentonite quality and dosage affects pellet dustiness. However, this has never been confirmed, due to the lack of a method for directly measuring the dustiness of pellets. The industry is particularly interested in determining whether it is necessary to continue to use High-PWA bentonites, which are becoming more expensive. It is therefore important to the industry to determine whether use of the lower-cost Low-PWA bentonites will allow production of pellets without introducing dust problems. It is also important to determine the extent to which the surface chemistries of bentonite and of iron ore affect the pellet quality.

Description of Proposed Work: Pellets will be produced using the fluxed concentrate from an operating Minnesota plant, using bentonites of different grades and added at varying dosages. The surface chemistries of the bentonites and of the ore concentrate will be determined using streaming-potential measurements, so that the interactions between bentonite and ore particles can be determined. The PWA values will be determined with both distilled water, and with water that has the same composition as filter cake moisture. A custom-built dust tower at MTU, which is the only available facility for measuring pellet dustiness, will be used to evaluate the changes in dust production from fired pellets as the bentonite type and dosage are varied. This will be used to measure (a) Total dust; (b) Particles finer than 10 micrometers (PM_{10}) and 2.5 micrometers ($PM_{2.5}$); and (c) Particles finer than 1 micrometer ($PM_{1.0}$). Degradation of the pellets as they fall through the dust tower will also be measured.

Proposed Project 6: Review of Iron Ore Pellet Binders, With Emphasis on Organic Binders

Objective(s): Review the advances in pellet binder technology, and identify binders that could replace bentonite without introducing problems with dust or moisture control.

Justification: While bentonite is an effective binder for iron ore pellets, it does introduce silicates into the pellet that make it more difficult to meet the silica specification. Binders that do not contain silica and are cost-competitive with bentonite would therefore be of considerable interest, provided that they can continue to bind the pellets together at high temperatures until they begin to sinter. Methods for increasing the effectiveness of binders would also be valuable because this would reduce the quantities needed to achieve the desired pellet strength, both reducing costs and limiting the potential for contaminating the pellets.

Description of Proposed Work: The investigators will carry out an extensive update of their original review of binder technology that was prepared in 1997-98, with particular emphasis on new organic binders that are expected to be significantly more temperature-resistant than previous organic binders. In addition to reviews of the open literature, we will travel to operating plants (both in Minnesota and overseas) to consult with plant personnel and to review internal documents on binder use and behavior. The project will be divided into three parts: (a) An initial study of binders that are of most immediate interest to industry, to be completed in the first 3 months; (b) A thorough study to collect all available information, to be completed in the first year; and (c) A fully checked and fine-tuned final report, including follow-up of useful leads found in the first year, to be completed in the second year.

Proposed Project 7: Flowsheet Development for Low-Grade Ores

Justification

With the increasing demand for iron production worldwide, there is new incentive for extraction of iron from low-grade sources that had previously been ignored. In particular, fully oxidized hematite (Fe_2O_3) and goethite (FeOOH) ores are frequently not utilized, due to the fact that they are not easily separated from silicate gangue minerals by magnetic separations. These ores occur not only as natural mineral deposits, but also as tailings impoundments that may contain more than 20% iron, but were discarded in the process of magnetically separating the more easily recovered magnetic iron oxide (magnetite, Fe_3O_4). Some technologies have been developed for upgrading these non-magnetic iron ores, such as the selective flocculation/reverse-flotation process that is in use at the Tilden concentrator in Ishpeming, MI, but there has not been much success in transferring this technology to other ore bodies. The reason for this lack of success is that the process used at Tilden was empirically developed without a fundamental understanding of how it actually works, and so there is no theoretical basis available for determining why it might work for one ore body, but not for another.

Objectives

The objective of this project is to improve our understanding of the surface properties of nonmagnetic iron ores, so that methods for separating them can be generalized to all ore bodies, and not simply restricted to the few ore bodies where methods have been empirically developed. This will not only allow the production of iron from new ore bodies that are not currently being exploited, but will also make it possible to recover iron from the material that existing mines are losing to their tailings, and to extend the life of mines by allowing them to exploit portions of their ore bodies that are not currently amenable to separation.

Description of Proposed Work

The project will result in the development of novel flowsheets specifically for low-grade, non-magnetic ore, with a theoretical framework that determines which ore properties are critical to the separation, and an understanding of how to adapt the flowsheet to any given ore type with minimal development work. This will be accomplished by study of the surface chemistry of iron oxides through measurements of zeta potential, examination of flocculation behavior, flotation experiments, and mineralogical studies.

Objective(s): Investigate the surface chemistry changes that occur throughout an operating plant as the ore is processed, with particular emphasis on how these changes affect filtration performance.

Justification: Recent work by the investigators has shown that the surface chemistry of the ore in operating plants is significantly different from what is expected based on the values for pure minerals that are reported in the literature. Since surface chemistry affects a number of processes in the plants, particularly filtration, thickening, and froth flotation, it is important to understand how the surface chemistry varies throughout the plants and how these variations affect plant performance. It has already been shown in one of the Minnesota operations that the surface chemistry was outside of the ideal range for filtration, and that alterations of the surface chemistry could have a marked benefit on filtration rates.

Description of Proposed Work: Personnel from MTU will conduct in-plant sampling at an operating plant, with samples collected at all stages of processing from comminution through filtration. These samples will be analyzed to determine changes in surface chemistry, using streaming potential measurements to measure zeta potential as a function of pH. The plant water in each stage will also be analyzed by atomic absorption spectroscopy to determine the levels of calcium and other dissolved ions that can have a strong effect on surface chemistry. This study will determine not only what the surface chemistry is at each point in the process, but also which processes and chemical additions produce changes in behavior that could impact the final dewatering stages.

Proposed Project 9: Review of Technology for Online Moisture Analysis

Objective(s): Review the advances that have been made in online moisture analysis, and determine whether any technologies can yet achieve the level of accuracy and reliability needed by the industry.

Justification: Rapid online moisture analysis of iron ore concentrate filter cake would be of great value in controlling the filtration and pelletization processes. To date, the online instrumentation that has been considered has not performed adequately, due to the similarity in the electrical and optical properties of magnetite and water. However, the technology has continued to advance since the online moisture analysis was last attempted in the industry, and it is not yet known whether the new generation of instruments will prove adequate.

Description of Proposed Work: A thorough literature review will be carried out to determine all of the available technologies that could potentially be able to measure moisture content of iron ore concentrate to the desired level of $\pm 0.1\%$ moisture. Methods of particular interest will be able to measure the bulk moisture content on a conveyor belt, and not simply measure the surface moisture, which may be significantly different due to evaporation. Once suitable instrument suppliers are identified, samples of concentrate will be selected from several Minnesota plants, and will be taken to the manufacturers to evaluate the accuracy and reproducibility of their instruments. Any instruments that have adequate performance will be considered for in-plant studies. Sampling considerations will also be examined, as it is important that the concentrate being measured is actually a representative sample of the entire material stream, and has not been partially dried or otherwise altered.