3rd International Symposium on High-Temperature Metallurgical Processing

Edited by Tao Jiang, Jiann-Yang Hwang, Patrick Masset, Onuralp Yucel, Rafael Padilla, and Guifeng Zhou

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3rd International Symposium on High-Temperature Metallurgical Processing

Proceedings of a symposium sponsored by the Pyrometallurgy Committee and the Energy Committee of the Extraction and Processing Division of TMS (The Minerals, Metals & Materials Society)

Held during the TMS 2012 Annual Meeting & Exhibition
Orlando, Florida, USA
March 11-15, 2012

Edited by
Tao Jiang
Jiann-Yang Hwang
Patrick Masset
Onuralp Yucel
Rafael Padilla
Guifeng Zhou

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Preface

This book collects selected papers presented at the 3rd International Symposium on High-Temperature Metallurgical Processing organized in conjunction with the 2012 TMS Annual Meeting in Orlando, Florida, USA.

As the title of symposium suggests it is on thermal processing of minerals, metals and materials and intends to promote physical and chemical transformations in the materials to enable recovery of valuable metals or produce products such as pure metals, intermediate compounds, alloys, or ceramics through various treatments. The symposium was open to participants from both industry and academia and focused on innovative high-temperature technologies including those based on non-traditional heating methods as well as their environmental aspects such as handling and treatment of emission gas and by-products. Since high-temperature processes require high energy input to sustain the temperature at which the processes take place, the symposium intends to address the needs for sustainable technologies with reduced energy consumption and reduced emission of pollutants. The symposium also welcomed contributions on thermodynamics and kinetics of chemical reactions and phase transformations that take place at elevated temperature.

Given the spread among numerous journals - not always easily accessible to many researchers – we decided to compile information on research activities in the area of metallurgy at elevated temperature in an easily accessible source and this book is the result. The availability of focused scientific information into a few accessible resources should be attractive and gratifying to many researchers.

Over 300 authors have contributed to the symposium with a total of 94 presentations. After reviewing the submitted manuscripts, 62 papers were accepted for publication on this book. The book is divided into eight sections and each section has different focus. It includes: High Efficiency New Metallurgical Technology, Reduction and Titanium Production, Basic Research of Metallurgical Process, Alloy and Materials Preparation, Sintering and Synthesis, Energy and Environment, Treatment and Recycling of Solid Slag/Wastes, and Pelletizing and Raw Materials Processing.

This is the second book exclusively dedicated to this important and burgeoning topic published in the 21 century. We hope this book will serve as a reference for both new and current metallurgists, particularly those who are actively engaged in exploring innovative technologies and routes that lead to more energy efficient and environmentally sustainable solutions.
This book could not materialize without contributions from the authors of included papers, time and effort that reviewers dedicated to the manuscripts, and help from the publisher. We thank them all! We are also grateful to Ms. Yanfang Huang and Mr. Guihong Han for their assistance in collating the submitted abstracts and manuscripts.

Tao Jiang, Jiann-Yang Hwang, Patrick Masset, Onuralp Yucel, Rafael Padilla, and Guifeng Zhou

December 2011
Editors

Tao Jiang was born in 1963 in Anhui, China. Tao Jiang received his MS degree in 1986 in metallurgy and Ph.D. degree in mineral processing in 1990, both from Central South University of Technology, China. Then he worked at the university for ten years as an assistant professor and full professor (from 1992). From 2000 to 2003, he was a Visiting Scientist in the University of Utah.

Since 2003, Dr. Jiang has been a Professor in the School of Minerals Processing & Bioengineering at Central South University. He was elected as Specially-appointed Professor of Chang Jiang Scholar Program of China in 2008 and was appointed as dean of the school in 2010. Some of his current research activities include beneficiation, agglomeration, reduction and utilization of complex iron ores, and extraction of refractory gold ores. He has accomplished more than 30 projects from the government and industry, including National Science Fund for Distinguished Young Scholars program. Dr. Jiang has published 248 technical papers, 5 books, holds 25 patents and has more than 30 conference presentations.

Currently, Dr. Jiang serves as vice-Chair of the TMS Prometallurgy Committee, member of Ironmaking Committee, Chinese Society for Metals.

Jiann-Yang (Jim) Hwang is a Professor in the Department of Materials Science and Engineering at Michigan Technological University. He is also the Chief Energy and Environment Advisor of the Wuhan Iron and Steel Group Company. He has been the Editor-in-Chief of the Journal of Minerals and Materials Characterization and Engineering since 2002. Several universities have honored him as a Guest Professor, including the Central South University, University of Science and Technology Beijing, Chongqing University, Kunming University of Science and Technology, etc.

Dr. Hwang received his B.S. degree from National Cheng Kung University (Taiwan) in 1974, M.S. in 1980 and PhD in 1982, both from Purdue University. He joined Michigan Technological University in 1984 and has served as its Director of the Institute of Materials Processing from 1992 to 2011. He has been a TMS member since 1985. His
research interests include the characterization and processing of materials and their applications. He has been actively involved in the areas of separation technologies, pyrometallurgy, microwaves, hydrogen storages, ceramics, recycling, water treatment, environmental protection, biomaterials, and energy and fuels. He has more than 20 patents, published more than 200 papers, and founded several companies. He has chaired the Materials Characterization committee and the Pyrometallurgy committee in TMS and has organized several symposiums.

Patrick Masset was born in 1974 in Saint Pierre d'Albigny (France), Patrick obtained his Ph.D thesis at the National Polytechnic Institute of Grenoble in 2002. From 2003 to 2005, he was a post-doc at the Institute for Transuranium (European Commission) in Karlsruhe (Germany) before joining Dechema in Frankfurt/Main (Germany) as a Research Associate. In 2009, he was appointed as Research Group Leader at the Technical University of Freiberg (Germany). In 2010, he obtained his habilitation in the field of High Temperature Materials at the University of Pierre and Marie Curie in Paris, France and is a lecturer at the University of Freiberg and the University of Savoy (France). Since January 2012, he is the Head of the Department “New Materials” at the Research Centre ATZ in Sulzbach-Rosenberg in Germany. His research activities are focused on the development of new materials for energy and power engineering.

Onuralp Yucel was born in 1961 in Diyarbakir, Turkey; Onuralp completed his technical education with a PhD in Metallurgical Engineering from Istanbul Technical University (ITU) where he is currently holding the post of Professor since 2002. He was a Visiting Scientist in Berlin Technical University between 1987 and 1988. He carried out Post Doctoral Studies at New Mexico Institute of Mining and Technology, Socorro, USA between 1993 and 1994. Prof. Yücel has as many as 147 publications/presentations to his credit, which include topics like, technological developments in the production of wide range of metals, ferroalloys, advanced ceramic powders and application of carbothermic and metallothermic processes among others. He is currently the director of ITU, Applied Research Center of Material Science & Production Technologies since 2006.
Dr. Rafael Padilla received his Ph. D. and M.Sc. degrees in Metallurgy from the University of Utah in 1984 and 1977, respectively, and Professional Engineering Title as Metallurgical Engineer from the Technical University of Oruro, Bolivia in 1975. Dr. Padilla joined the Department of Metallurgical Engineering, University of Concepcion, Chile in 1986, and currently holds the rank of Professor in that Department. He has conducted research involving thermodynamics and kinetics of metallurgical reactions in both pyrometallurgy and hydrometallurgy, volatilization of toxic minor elements in copper metallurgy, mathematical modeling of solvent extraction processes, atmospheric leaching and pressure leaching of refractory copper and arsenic sulfides. His present research interests continue on the development of new processing methods for primary sulfides including chalcopyrite, enargite, and molybdenite.

Guifeng Zhou received his BS degree in Materials Science and Engineering from the Northwest Industry University (China) in 1984, his MS degree in Materials and Heat Treatment from the HuaZhong University of Science and Technology in 1990, and earned his Ph.D. degree in Materials Physics and Chemistry from the University of Science and Technology Beijing in 2000. He did some research regarding microalloying technology at University of Pittsburgh for a year and a half as a senior visiting scholar.

Dr. Zhou is the vice director of the R&D Center of Wuhan Iron & Steel (Group) Corp., also is a professor and Ph.D. advisor of Wuhan University of Science and Technology. His work is concentrated on new steel product development, microstructure and mechanical property of materials. Dr. Zhou has published over 20 technical papers, holds 4 patents, and won national progress prize in science and technology for three times. He is an expert with the State Department on special allowance, a member of the editorial board of RESEARCH ON IRON AND STEEL, and has been the member of the Chinese Metals Society, the Quality Control Society of China and the Science and Technology Association.
3rd International Symposium on
High-Temperature Metallurgical Processing

High Efficiency New Metallurgical Technology

Session Chairs:
Tao Jiang
Merete Tangstad
A LABORATORY INVESTIGATION OF THE REDUCTION OF THE SIDERITE IRON ORE TO IRON NUGGET

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Siderite, Rotary Hearth Furnace, ITmk3, Iron Nugget

Abstract

The Bakal (South Ural, Russia) deposit of iron ore bearing iron carbonate (siderite) with the capacity of more than 1 billion tones belongs to the MMK. This ore cannot be fully processed via blast furnace technology because of high content of MgO. According to the investigations carried out in the USA and Japan in 1999-2004 the ITmk3 (Ironmaking Technology mark three) RHF technology is a breakthrough in Ironmaking. Four iron ore types (hematite, magnetite, high and low Al2O3/SiO2) were tested. Reduction, melting and slag removal can be achieved in just 10 min. The main objective of the investigation is to establish optimum operation conditions for the production of iron nuggets from iron carbonate bearing ore via the ITmk3 by means of the lab scale testing. Green pellets were processed via a lab tube (chamber) furnace to simulate RHF conditions. This preliminary test work provides valuable information which may be used for large-scale testing in a commercially sized RHF.

Introduction

The ITmk3 process upon which this paper focuses was developed by Kobe Steel in its research facilities in 1996 [1]. After pilot testing at Kobe Steel's Kakogava Works in 1999-2004 the pilot demonstration plant was built and operations were successfully carried out by Mesabi Nugget joint venture in 2002-2004. Steel Dynamics has committed to building the commercial plant at the Mesabi Nugget site in Hoyt Lakes (Minnesota). Only 4 iron ore types (hematite, magnetite, high Al2O3/SiO2 and low Al2O3/SiO2), as well as 4 coal types with range of volatility, ash and fixed carbon were tested. Results were consistent with nugget characteristics confirming ITmk3's flexibility with respect to raw material inputs. At the same time, no research in the field of nugget from iron carbonate bearing ore with high content of MgO has been done. Such kind of iron ore is restricted for charging into the blast furnace due to contamination of MgO. The reason for restriction is the limitation of load of MgO in the blast furnace. If a lot of MgO enters the blast furnace, slag becomes viscous. The viscous slag is obstacle for stable operation of the blast furnace.
Objectives of Investigation

The main objective is to find optimum operation conditions for the production of iron nuggets from the iron carbonate (siderite) bearing ores via the rotary hearth furnace by means of the laboratory testing.

Methodology

The first step in the investigation involved performing lab scale testing on the iron nugget components. Samples of iron ore, fluxes, binder (clay), coal fines and coke breeze (as reductant) were chemically and physically analyzed.

Typical ore testing included particle size analysis, % S, % CO₂, % metal components, % gangue components. Typical reductant testing included particle size analysis, % carbon, % sulfur, % volatiles, % ash and ash analysis for % metal and gangue components.

A pellet blend developed from this testing, defining carbon reductant addition, binder, particle size. A blend was mixed followed by rolling green pellets.

Green pellets were processed via a lab tube furnace or a chamber furnace. Using such kind of furnaces to simulate RHF conditions, was it possible to vary several parameters such as furnace retention time (10-15 min), temperature (1350-1450°C).

After the allotted time in the hot furnace, the nuggets and slag were quenched, then analyzed for % C, % S, % Fe in iron nuggets, and % gangue components in slag.

Results and Discussion

Each raw material is different in distribution of the particle size and chemical compositions (See Table 1).

Table 1. Dry Chemical Composition of Raw Materials, wt. %

<table>
<thead>
<tr>
<th>Material</th>
<th>Fe</th>
<th>CaO</th>
<th>SiO₂</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>CO₂</th>
<th>C</th>
<th>CaF₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakal Iron Ore</td>
<td>34.0</td>
<td>2.2</td>
<td>3.2</td>
<td>9.8</td>
<td>1.2</td>
<td>29.0</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Coke Breeze</td>
<td>0.9</td>
<td>0.7</td>
<td>8.0</td>
<td>0.3</td>
<td>3.1</td>
<td></td>
<td>87.0</td>
<td>-</td>
</tr>
<tr>
<td>Quartzite</td>
<td>0.5</td>
<td>0.4</td>
<td>95.6</td>
<td>-</td>
<td>0.6</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Clay</td>
<td>1.8</td>
<td>0.4</td>
<td>51.0</td>
<td>0.8</td>
<td>35.3</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Fluor-spar</td>
<td>-</td>
<td>1.0</td>
<td>36.8</td>
<td>0.5</td>
<td>0.6</td>
<td></td>
<td></td>
<td>52.5</td>
</tr>
</tbody>
</table>

Mainly considered are raw material preparation (weighing, blending, grinding), pelletizing, heating, reacting and melting control. In particular, material preparation is very important, since influence of the properties of raw materials on operational results (especially...
the temperature of melting of gangue) is large. Thus a precise preparation work for raw materials is needed for desirable and stable operation.

Raw materials were blended in a disc grinder at a predetermined mixing ratio to reach desirable temperature (1300-1400°C) of melting of gangue [2]. Gangue composition is shown below (See Table 2).

<table>
<thead>
<tr>
<th>Table 2. Chemical Composition of Gangue, wt.%</th>
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<tbody>
<tr>
<td>CaO</td>
</tr>
<tr>
<td>20.0-41.5</td>
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</tbody>
</table>

Particle size of -200 meshes for raw materials usually results in higher iron metallization. More intimate contact between carbon and iron oxide speeds reaction. Ability to pelletize determines maximum particle size. The mixing ratio was determined to give good conditions of pelletizing and the reactions in the furnace. The ratio of fix carbon to iron oxides and other properties of raw materials were analyzed. Then the mixing ratio was determined (binder - 1-2%, coke breeze -18-20%, fluxes -12-18%, iron ore -60-69%) with this information. The mixture was fed on the pelletizing disc, and made into green pellets. Diameter of green pellet is less than 20 millimeters. If the pellet is too large, heat transfer rate is too slow inside the pellet. Green pellets were dried in the chamber furnace (150-300°C). The dried pellets were fed in the roasting furnace. To reach conditions for better reactions and heat exchange entire pellet bed must be heated to 1350-1450°C. Nuggets contained 96-97% of iron and 2-3% of carbon.

Carbonates (siderite, magnesite, dolomite, etc.) in the pellets dissociate when temperature of the pellets is above 600°C.

FeCO₃ = FeO + CO₂  
MgCO₃ = MgO + CO₂  
CaCO₃ = CaO + CO₂

Carbon and iron oxide react when temperature of the pellets is above 1100°C.

C + CO₂ = 2CO  
FeO + CO = Fe + CO₂  
FeO + C = Fe + CO

Formation of pig iron and melting of nuggets and slag from gangue take place when temperature of the pellets is above 1300°C.

3Fe + C = Fe₃C  
3Fe + 2CO = Fe₃C + CO
Thus, the RFH should have heating, reduction and melting zones. Temperature in each zone should be controlled to get a good performance that is required in each zone. In heating zone, heat transfer for heating up the pellets and dissociation of carbonates should be taken into account. Oxidation of the gas is high here, because no reduction reaction takes place. In reduction zone, temperature and atmosphere of the gas should be controlled to get a high reaction rate. The reduction reactions in this zone are very fast. At last, in melting zone, the conditions should be controlled to promote the reduction reactions, formation of pig iron (iron nugget) and melting of pig iron and slag.

Conclusions

The possibility of production of iron nugget from iron carbonate bearing ore with high content of MgO via ITmk3 process has been established. The initial promise shown by the ITmk3 process in laboratory tests may be used for large-scale testing in a commercially sized RHF.

ITmk3 technology is a simple process with a single-step furnace operation. Reduction, melting and slag separation completes within 10-15 minutes. Process temperature is 1350-1450°C.

ITmk3 technology makes no harmful impact on environment since the process does not require coking and sintering plants.

References

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COMPOSITE AGGLOMERATION PROCESS OF IRON FINES

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Keywords: Sintering, Pelletizing, Composite Agglomeration, Blast Furnace Burden

Abstract

Composite agglomeration process (CAP), as an innovative method for preparing blast furnace
burden, was developed and has been put into operation in China. CAP is different from
traditional agglomeration processes of iron-bearing materials involving sintering and
pelletizing. Compared to the traditional agglomeration processes, CAP is characterized by
several strengths such as permission of diverse iron-bearing materials in production, obvious
improvement of permeability in the feed bed, decreasing the fuel consumption and
remarkably increasing the productivity of sintering machine. Furthermore, the use of the
composite agglomerates prepared with CAP is capable of obviating the negative effects
caused by the differences in quality of sinter and pellets on the operation of blast furnaces.
This paper mainly presents an overview of the principle and applications of CAP.

Development Background and Principle of CAP

The traditional agglomeration processes including sintering and pelletizing have been the two
predominant methods for preparing ironmaking burden from iron-bearing materials. Sintering
is a way for agglomeration by heating the coarser fine ores (general granularity 0~10mm).
The mechanical strength of irregular porous sinter is obtained by the solidification of molten
phase at high temperature process. It has been shown that the production of high basicity
sinter (R=1.8~2.2) is characterized by low energy consumption and high efficiency compared
to low basicity sintering. Meantime, the finished high basicity sinter is characterized by good
mechanical strength and metallurgical performance. Pelletizing is another way for
agglomeration by firing wet green pellets, which are balled from the fine grained iron ores or
concentrates. Based on the differences of chemical compositions, the finished pellets can be
divided into acidic oxidized pellets, fluxed pellets, magnesium-bearing pellets, and so on. The
acidic oxidized pellets are the dominant products of modern pelletizing.

At present, the combination of self- or super-fluxed sinter and acidic oxidized pellets is the
common application of their products in blast furnace in China and most of other countries.
However, there are several shortcomings with the use of acidic oxidized pellets along with
high basicity sinter. First, the higher bulk density leads to the tendency for pellets to "sink"
into the coke layer during burden descent, resulting into the segregation of burdens although

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some approaches has been undertaken to offset the differences among the varied iron bearing burdens, effects of varied iron bearing burdens on the operation of blast furnace are still inevitable. Second, this kind of burden structure is not readily achieved considering that commercial pellets are only produced in a few countries and pelleting plants must be built to meet the increasing demand of pellets in most of countries, particularly in China. The last but important is that, the increasing inferior or non-traditional iron-bearing materials such as fine grained concentrates obtained from refractory ores through grinding and concentrating mill, and iron-bearing wastes (dust and slug) from various plants can't be efficiently employed by single sintering process or single pelleting process, and call for new agglomeration process.

Composite agglomeration process (CAP) was developed in order to overcome the weakness of oxidized pellets associated with their ball shape and make the best of the increasing non-traditional iron-bearing materials [1-10]. An innovative technological thought in CAP is proposed based on the differences in the properties of pelleting, sintering and firing of varied iron-bearing materials. In the CAP, all of raw materials are classified into pelleting feeds and matrix feeds. Subsequently, those two classified feeds are pretreated respectively, and fired together in sintering machine. The pelleting feeds include fine grained ores, concentrates obtained from the grinding process of refractory and complex iron ores, iron-bearing secondary resources, binders and fuels sometimes. A small amount of ground fuel addition (less than 1.0 mass %) in the pelleting feeds contributes to the quality of finished pellets when hematite or specularite concentrates are pelleted, while fuel addition in pelleting feeds can be neglected for magnetite pellets feed. The matrix feeds consist of coarser ore fines, fluxes, fuels and return fines. Sometimes, iron concentrates are also included in matrix feeds when the proportion of iron concentrates to the whole iron-bearing materials is above 60%.

The principle of CAP can be seen from Fig.1. As displayed in Fig.1, pelleting feeds are mixed and agglomerated into green pellets with 8~16 mm diameter; matrix feeds are blended, granulated and made into a primary mixture with 3~8 mm diameter. Afterwards a secondary mixture is prepared by mixing those green pellets with the primary mixture, and the secondary mixture is subsequently distributed onto the sintering machine. Finally, the mixture is produced into the composite agglomerates consisting of basic sinter and acidic pellets by ignition and down draft firing. In the composite agglomerates, acidic pellets are well embedded in basic sinters. According to the study of the mineralization mechanism, the mechanical strength of acidic pellets in mixture is obtained by solid phase consolidation; and the mechanical strength of matrix is due to fusion phase bonding.

Compared to traditional agglomeration processes, CAP is characterized by several strengths such as permission of diverse iron-bearing materials in production, obvious improvement of permeability in the feed bed, decreasing the energy consumption and absolutely increasing the productivity of sintering machine. For example, overall basicity of composite agglomerates can be adjusted from 1.2 to 2.2 by changing the proportion of acidic pellets. The use of the composite agglomerates is capable of eliminating the negative effects of burden segregation which are caused by the different property of sinter and pellets in blast furnaces. Meantime, the problems accompanying with the use of the increasing complex ores or non-traditional iron-bearing materials can also be solved by CAP.
Preparation of Ironmaking Burden Characterized by Low Basicity

The iron-bearing materials were obtained from Lianyuan Iron and Steel Plant, China. Under the condition of feed bed height 600 mm, the preparation of ironmaking burden characterized by low basicity using CAP and traditional sintering process (TSP) were respectively conducted in lab. The results are shown in Table I.

As displayed in Table I, the tumbler index of finished products obtained from TSP is decreased from 63.0% to 52.7% with decreasing the overall basicity from 2.0 to 1.5, accompanying with the productivity decreasing from 1.65 t·m\(^{-2}\)·h\(^{-1}\) to 1.47 t·m\(^{-2}\)·h\(^{-1}\). When the overall basicity is 1.2, the tumbler index of finished products and the productivity are separately 45.9% and 1.37 t·m\(^{-2}\)·h\(^{-1}\).

It can also be seen from Table I, although the tumbler index of finished products obtained from CAP is decreased with the decrease of overall basicity, the tumbler index of finished products, the sintering speed and the productivity of CAP are obviously high. The tumbler index of finished products is 58.7% under the condition of the overall basicity 1.2. And the coke dosage and the suction negative pressure in the CAP can be obviously lowered.
Table I. Comparison of CAP and TSP in the Field of Preparing Ironmaking Burden with Different Basicity

<table>
<thead>
<tr>
<th>Process</th>
<th>Experimental conditions</th>
<th>Experimental indexes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall basicity</td>
<td>Suction negative pressure (kPa)</td>
</tr>
<tr>
<td>TSP</td>
<td>2.0</td>
<td>10</td>
</tr>
<tr>
<td>CAP</td>
<td>2.0</td>
<td>8</td>
</tr>
<tr>
<td>TSP</td>
<td>1.6</td>
<td>10</td>
</tr>
<tr>
<td>CAP</td>
<td>1.6</td>
<td>8</td>
</tr>
<tr>
<td>TSP</td>
<td>1.5</td>
<td>10</td>
</tr>
<tr>
<td>CAP</td>
<td>1.5</td>
<td>8</td>
</tr>
<tr>
<td>TSP</td>
<td>1.4</td>
<td>10</td>
</tr>
<tr>
<td>CAP</td>
<td>1.4</td>
<td>8</td>
</tr>
<tr>
<td>TSP</td>
<td>1.2</td>
<td>10</td>
</tr>
<tr>
<td>CAP</td>
<td>1.2</td>
<td>8</td>
</tr>
</tbody>
</table>

Preparation of Ironmaking Burden from High Iron and Low Silica Materials

The high iron low silica materials were firstly balled into pellets. The overall basicity of the final mixture is fixed at 1.9. The results for preparation of ironmaking burden using CAP are listed in Table II.

Table II. Preparation of Ironmaking Burden from High Iron and Low Silica Materials using CAP

<table>
<thead>
<tr>
<th>Process</th>
<th>Experimental conditions</th>
<th>Experimental indexes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion of Pellets (mass %)</td>
<td>SiO₂ (mass %)</td>
</tr>
<tr>
<td>TSP</td>
<td>0</td>
<td>4.51</td>
</tr>
<tr>
<td>CAP</td>
<td>10</td>
<td>4.37</td>
</tr>
<tr>
<td>CAP</td>
<td>20</td>
<td>4.26</td>
</tr>
<tr>
<td>CAP</td>
<td>40</td>
<td>4.06</td>
</tr>
</tbody>
</table>

As seen from Table II, the tumbler index of finished products obtained from CAP, the vertical sintering speed and the productivity of CAP are increased with the increase of the proportion of pellets. The tumbler index of finished products, the vertical sintering speed and the productivity of CAP are respectively 71.12 mass%, 24.98 mm·min⁻¹ and 1.71 t·m⁻²·h⁻¹ under
the condition of the ratio of pellets 40 mass%.
Compared with TSP, the tumbler index of finished products, the vertical sintering speed and the productivity of CAP are obviously high. Meantime, it can be seen that the content of SiO2 is decreased, while total iron (TFe) grade is increased.

Achievement of Ultra-high Feed Bed in Preparation of Ironmaking Burden

The iron-bearing materials were also obtained from Baosteel Company, China. Experimental conditions are fixed as follows: the proportion of balling concentrates 40 mass%, overall basicity 1.9 and suction negative pressure 8 kPa. The effects of feed bed height on the experimental indexes of CAP are shown in Table III.

<table>
<thead>
<tr>
<th>Process</th>
<th>Feed bed height (mm)</th>
<th>Vertical sintering speed (mm·min⁻¹)</th>
<th>Productivity (t·m⁻²·h⁻¹)</th>
<th>Tumbler index (+6.3mm, mass %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP</td>
<td>600</td>
<td>19.85</td>
<td>1.65</td>
<td>63.0</td>
</tr>
<tr>
<td>CAP</td>
<td>600</td>
<td>24.56</td>
<td>2.23</td>
<td>60.9</td>
</tr>
<tr>
<td>CAP</td>
<td>700</td>
<td>23.33</td>
<td>1.97</td>
<td>63.0</td>
</tr>
<tr>
<td>CAP</td>
<td>800</td>
<td>21.45</td>
<td>1.80</td>
<td>65.2</td>
</tr>
<tr>
<td>CAP</td>
<td>900</td>
<td>20.98</td>
<td>1.73</td>
<td>65.9</td>
</tr>
</tbody>
</table>

As seen from Table III, the feed bed height has an obvious improvement on the tumbler index of finished products obtained from CAP. Although the productivity and the vertical sintering speed are both decreased with increasing the feed bed height, the productivity of CAP with the bed height of 900 mm is still higher than that of TSP at 600 mm.

Preparation of Ironmaking Burden from Refractory Iron-bearing Materials

Specularite. Specularite concentrates are characterized by bad high-temperature reactivity, which restrict the large-scale application of them in either pelletizing or sintering production. The effects of the proportion of specularite concentrates are shown in Table IV.

<table>
<thead>
<tr>
<th>Process</th>
<th>Proportion of Specularite (mass %)</th>
<th>Vertical sintering speed (mm·min⁻¹)</th>
<th>Yield (%)</th>
<th>Productivity (t·m⁻²·h⁻¹)</th>
<th>Tumbler index (+6.3mm, mass %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP</td>
<td>0</td>
<td>21.10</td>
<td>78.45</td>
<td>1.390</td>
<td>64.17</td>
</tr>
<tr>
<td>TSP</td>
<td>20</td>
<td>15.85</td>
<td>69.92</td>
<td>0.929</td>
<td>63.45</td>
</tr>
<tr>
<td>CAP</td>
<td>20</td>
<td>23.73</td>
<td>79.32</td>
<td>1.572</td>
<td>66.47</td>
</tr>
<tr>
<td>CAP</td>
<td>25</td>
<td>23.90</td>
<td>79.81</td>
<td>1.604</td>
<td>67.08</td>
</tr>
<tr>
<td>CAP</td>
<td>40</td>
<td>24.98</td>
<td>81.33</td>
<td>1.710</td>
<td>71.12</td>
</tr>
</tbody>
</table>
It can be seen from Table IV, the experimental indexes are decreased significantly with the increase of the proportion of specularite in TSP. Especially, the productivity of TSP is reduced by 30% or more when the proportion of specularite is increased from 0% to 20%. Compared to TSP, however, the experimental indexes of CPA are improved significantly with the increase of the proportion of specularite.

**Fluorine-bearing Iron Concentrates.** Former studies showed that addition of fluorine-bearing iron concentrates into sintering feeds decreases the mechanical strength of sinter by promoting the formation of low strength cuspidine. The addition of fluorine-bearing iron concentrates into pelletizing feeds can also deteriorate the quality of finished pellets. The fluorine-bearing iron concentrates in this section were obtained from Baotou Iron and Steel Company, China. The content of fluorine is 0.34%. The proportion of fluorine-bearing iron concentrates to iron-bearing concentrates is set at 40% (mass). And fluorine-bearing iron concentrates were firstly balled into pellets in CAP. The results are listed in Table V.

<table>
<thead>
<tr>
<th>Process</th>
<th>Overall basicity</th>
<th>Vertical sintering speed (mm·min⁻¹)</th>
<th>Productivity (t·m⁻²·h⁻¹)</th>
<th>Tumbler index (+6.3mm, mass %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP</td>
<td>2.2</td>
<td>21.52</td>
<td>1.395</td>
<td>57.71</td>
</tr>
<tr>
<td>TSP</td>
<td>1.6</td>
<td>18.32</td>
<td>1.420</td>
<td>51.45</td>
</tr>
<tr>
<td>CAP</td>
<td>1.6</td>
<td>20.08</td>
<td>1.504</td>
<td>64.05</td>
</tr>
</tbody>
</table>

As demonstrated in Table V, the tumbler index and the productivity in CAP are both higher than those in TSP. Compared to TSP, the tumbler index of finished products obtained from CAP is 64.05% when overall basicity is 1.6, with productivity is 1.504 t·m⁻²·h⁻¹.

**Iron-Bearing Dusts & Sludges.** With the rapid development of iron and steel industry, lots of metallurgical dusts and sludges are generated. When used in sintering or pelletizing production, they deteriorate the performances of production due to their poor hydrophilicity and bad ballability. Comparison of CAP and TSP in the field of preparing ironmaking burden from iron-containing dusts & sludges is displayed in Table VI.

<table>
<thead>
<tr>
<th>Process</th>
<th>Treatment of dusts &amp; sludges</th>
<th>Vertical sintering speed (mm·min⁻¹)</th>
<th>Productivity (t·m⁻²·h⁻¹)</th>
<th>Tumbler index (+6.3mm, mass %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP</td>
<td>Without dusts &amp; sludges</td>
<td>23.87</td>
<td>1.475</td>
<td>65.20</td>
</tr>
<tr>
<td>TSP</td>
<td>Blended into sintering mixture</td>
<td>21.65</td>
<td>1.355</td>
<td>63.41</td>
</tr>
<tr>
<td>CAP</td>
<td>Prepared into pellets</td>
<td>23.73</td>
<td>1.580</td>
<td>65.93</td>
</tr>
</tbody>
</table>

As shown in Table VI, the addition of dusts and sludges has an obvious negative effect on the tumbler index and the productivity in TSP. Compared to TSP, the productivity and the tumbler index of finished products in CAP are improved obviously by preparing dusts &