THE SEARCH FOR A NEW IRONMAKING PROCESS TOWARDS SUSTAINABLE DEVELOPMENT

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Background
1. Do we need carbon for making virgin iron.
2. The role of carbon.

New Processes for making liquid iron
4. Two-Reactor system with coupling.
5. De-coupled Two-Reactor system
MAJOR STEPS IN AN INTEGRATED PLANT

Iron Ore and Coal

Reduction, Endothermic

Liquid iron at 1500°C

Oxidation, Exothermic

Liquid steel at 1600°C

Solidification, Exothermic

Semi-Product

Rolling

Products
BLAST FURNACE IRONMAKING

It is vertical shaft furnace with counter-current solid (ore and coke)-hot reducing gas flows
CAN CARBON BE REPLACED IN IRONMAKING?

Theoretically, carbon, hydrogen and electrons can all be the reducing agent; and electricity can also be the source of energy.

• Making metallic iron from ore is not difficult chemically.

• Making money by making iron is not easy!

• Making money by making iron with less carbon consumption is one of “the challenges of our time”
## Geosphere Sinks

<table>
<thead>
<tr>
<th>Sink</th>
<th>Global (Gt CO₂)</th>
<th>Capacities -Canada (Mt CO₂)</th>
<th>Capacities -Alberta (Mt CO₂)</th>
<th>Retention -Time (Years)</th>
<th>Storage Rates -Alberta (Mt CO₂/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOR</td>
<td>238</td>
<td>330</td>
<td>220</td>
<td>10s</td>
<td>2.2</td>
</tr>
<tr>
<td>Coalbeds</td>
<td>300-964</td>
<td>14,680-28,900</td>
<td>18,350</td>
<td>100,000s-1,000,000s</td>
<td>18</td>
</tr>
<tr>
<td>Deleted Oil &amp; Gas Reservoirs</td>
<td>630</td>
<td>18,350</td>
<td>12,850</td>
<td>100,000s-1,000,000s</td>
<td>13</td>
</tr>
<tr>
<td>Deep Aquifers</td>
<td>183-51,333</td>
<td>No Estimate</td>
<td>19,800</td>
<td>100,000s-1,000,000s</td>
<td>20</td>
</tr>
</tbody>
</table>
Worldwide Experience with Geological Storage of CO2 in 2004

76 Enhanced oil recovery operations (67 in the U.S., 2 in Canada), since the 60’s

60 Acid gas storage operations (45 in Canada, 15 in the U.S.), since 1989

1 CO₂ storage operation into an aquifer (Sleipner in the North Sea), since 1996

1 enhanced coalbed methane recovery operation (San Juan basin, U.S.A.)
On Thursday, February 28, 2008 reported by the Globe and Mail

Saskatchewan’s provincially owned utility “SaskPower” will spend $758 million (+ $240 million from Ottawa) to retrofit 100 megawatt plant to capture a million tonnes a year of CO₂, to cut its greenhouse gas emissions of SaskPower by 7.2% from 2006 level.

Carbon dioxide will be captured from the flue with a scrubber technology and it will be piped to nearby oil fields, where it will be injected underground to boost the recovery of crude. It is the first plant of this kind in North America, a demonstration project.

This plant is located at Boundary and near an EnCana operation (for seven years) which has been widely studied. It uses carbon dioxide piped from North Dakota in an enhanced oil recovery project, and scientists believed the CO2 injected there will remain trapped for thousands of years.
Capturing CO₂ from Flue Gas

Flue Gas

Separation
$ 30 - 50/t

Compression
$ 8 - 10/t

Pipelining
$ 0.7 - 4/t Per 100 km

Injection
$ 2 - 8/t

Geological Formations

$20/t ?
THE CONCEPT OF CENTRAL PROCESSING OF FLUE GAS FOR CARBON MANAGEMENT

DISTRICT FLUE GAS PROCESSING CENTER

Flue Gas
Factories of Manufacturers

Long distance CO₂ Pipeline

Sequestration site
for Underground storage for thousands of years

to atmosphere
The role of carbon in old and new processes
ROLES PLAYED BY CARBON IN IRONMAKING

Carbon can be oxidized in two stages:
C + “O” ----» CO
CO + “O” ----» CO2

If the oxygen atom “O” is from molecular O2, the reaction is combustion to release heat.

If the oxygen atom “O” is from iron oxides, the reaction is reduction of iron ore.
SIMPLE-MINDED STOICHIOMETRY

Let us mark the oxygen atoms in air black as “O” and oxygen atoms in iron ore red as “O”.

The Blast Furnace reactions may be described as follows:

\[
\begin{align*}
2 \text{C} + \text{O}_2 & \rightarrow 2 \text{CO} + \text{heat} \\
2 \text{CO} + \text{“O”} & \rightarrow \text{CO} + \text{COO} \quad \text{in exit gas}
\end{align*}
\]

The consequences:

(1) two C atoms for one atom of oxygen from the ore.
(2) 50% of carbon oxides leaving the reactor as CO, with its chemical energy un-released.
THE ALTERNATIVE ROUTE OF USING CARBON

\[2 \text{ C} + 2 \text{ O} + \text{heat} \rightarrow 2 \text{ CO}\]

\[2 \text{ CO} + \text{O}_2 \rightarrow 2 \text{ COO} + \text{heat}\]

The consequences are:

- 1 C atom for 1 “O” from the ore
- Carbon leaves the reactor as dioxide.
- Heat is generated in oxidation region
- Heat is needed in reduction region
Single Reactor Processes
Smelting Reduction
The idea of : SMELTING REDUCTION

\[(\text{FeO})_{\text{slag}} + C \rightarrow \text{liquid iron} + \text{CO/CO}_2\]

In general, a single reactor, is a “Bad Idea” Because of high coal rate, due to high CO/CO2 Ratio and high sensible heat in gases at high temperature.
Figure 2  Vertical SRV
Fig. 6. The Romelt smelting reduction process flow\textsuperscript{10).}
IN LAST FOUR DECADES

Smelting reduction processes have two fundamental problems to result in high carbon rate:

1. Reduction temperature should be lower than melting temperature for thermodynamic advantages.

2. Re-Oxidation cannot be eliminated.
$O_2$ Oxidizes all things in contact, carbon, iron, etc.

Fig. 3 Physical image in SRF.
SOME GENERALLY ACCEPTED CONCLUSION

• An oxy-coal *melting vessel is needed* to produce liquid iron and to separate hot metal from gangue and ash.

• Single reactor system of 100% smelting reduction is **unacceptable** for very high coal rate.

• Two-reactor system (DIOS, AISI, etc.):
  (1) pre-reduction at lower temperature.
  (2) less smelting reduction in the vessel.
Two-Reactor system with coupling through gas
COUPLED TWO-REACTOR OPERATION

**COUPLING:**

**GAS** from Melting/Refining Reactor
to be used

as the reducing reagent in a low temperature Reducer.
Fig. 1  Process flow sheet of the DIOS pilot plant.
CY: cyclone, f. ore: fine ore, c. ore: coarse ore
COREX® - FINEX® Processes

Comparison of the Process Flow Sheets

**COREX®**

Lump Ore, Pellets

Reduction Shaft

Coal

Melter Gasifier

Hot Metal and Slag

Export Gas

Reduction Gas

**FINEX®**

Fine Ore

Fluidized Bed System

Coal

Melter Gasifier

Hot Metal and Slag

Export Gas

Reduction Gas

Oxygen

Oxygen
COUPLING THROUGH “GAS”

The total coal rate has been higher than that in blast furnace operation.
De-coupled Two-Reactor system
TWO-REACTOR SYSTEM FOR HOT METAL PRODUCTION

(1) Reduction Reactor
Sized ore and high VM coals are used “directly” to produce highly metallized DRI. It is the challenge!

(2) Melting and refining Reactor
In an oxy-coal vessel, hot DRI is melted for metal/slag separation and hot metal quality control.
NEW DRI UNIT NEEDED

Operating conditions:
• Using ore and coal directly
• Very little hot reducing gas available from the vessel
• Process temperature should be high enough for fast carbon gasification and low to keep product in solid stat.

Commercial technology available:
• By heating ore/coal composite agglomerates in a Rotary Hearth Furnace (RHF)
• Rotary Kiln (T?)
ORE/COAL COMPOSITE PELLETS

It is made of mixture of fine ore and coal
And chemically self-sufficient,
And needs to be heated to sustain reduction and metallization.

The best form of using renewable carbonaceous material to replace “coal”.
The protective gas flow from the interior to repel the oxidizing gases during reduction.

The risk of re-oxidation of sponge iron in a shallow bed in conventional RHF increases when the outward flow of gaseous reaction products weakens. In order to make DRI of high degree of metallization, excessive amounts of coal and burner fuel have to be used.
**ROTARY HEARTH FURNACE (RHF)**

**Shallow Bed** has contradictory requirements for fuel efficiency and protection of sponge iron:

- **Lower furnace temperature:** 1300~1350°C
- **Incomplete combustion** \((CO/CO_2 > 2.0)\) of fuel in reduction zone, more than a half of the total heat of the fuel can not be liberated in reduction area.
- The incomplete combustion atmosphere could only moderate the rate of re-oxidation of sponge iron.
- **Re-oxidation of DRI** produces slag of high FeO.
PAIRED STRAIGHT HEARTH (PSH) FURNACE RE-
OXIDATION IS PREVENTED THUS, GAINS IN
PRODUCTIVITY AND ENERGY EFFICIENCY

Flame: \( \text{CO/CO}_2 = 0.0 \)
\( 1600 \sim 1650 ^\circ C \)

Bed Height: \( 120 \text{mm} \), to
generate the protective gas flow

Coal: Higher Volatile Matter

\begin{itemize}
\item Up-Ward Gas Stream
\item Up to 1650\(^{\circ} C\)
\item Hot Gas, Fully Combusted
\item Burner
\item Gases generated in the bed
\item \( \sim 120 \text{mm} \)
\end{itemize}
PAIRED STRAIGHT HEARTH (PSH)

PSH FURNACE and TALL BED TECHNOLOGY

It is originated from McMaster University based on fundamental and applied research work sponsored by funding agencies of Canadian and US governments and AISI.

The problem of re-oxidation of sponge iron has been solved by the self shrouding with gaseous products due to (1) tall bed, (2) high process temperature, (3) high volatile coal and (4) fully oxidized flame to result in low coal rate and high metallized DRI.
PAIRED STRAIGHT HEARTH (PSH) FURNACE

Side View

Top View

Pellet Movement

Top View

Gas Movement
# Energy Consumption of hot metal production with an oxy-coal melter

<table>
<thead>
<tr>
<th>Items</th>
<th>Consumption</th>
<th>GJ/THM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>396 kg</td>
<td>11.47</td>
</tr>
<tr>
<td>Oxygen</td>
<td>96 Nm³</td>
<td>0.20 (0.61*)</td>
</tr>
<tr>
<td>Lime</td>
<td>95 kg</td>
<td>0.70</td>
</tr>
<tr>
<td>Electricity</td>
<td>60 kwh</td>
<td>0.21 (0.66*)</td>
</tr>
<tr>
<td>Gas credit (from hearth furnace)</td>
<td></td>
<td>-1.11</td>
</tr>
</tbody>
</table>

**Total** 11.47 (12.33*)

* including the losses for generation and transmission of electricity, following Stubbles[1]

To be compared with **18 Gj / tonne-HM** for good blast practice in US Steel industry in 1998 according to “Energy Use in the U.S. Steel Industry: A Historical Perspective and Future Opportunities” authored by John Stubbles, Sep. 2000, P8.
Thank you for your attention