Effect of Magnetic field on Ironmaking Process

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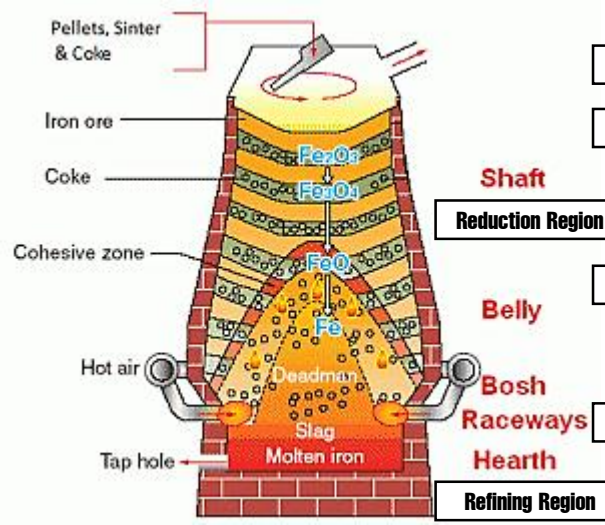
Contents

Introduction

Ironmaking Process



Reaction in Blast Furnace

1	$3\,Fe_2O_3 + CO = CO_2 + 2\,Fe_3O_4$	450 ℃	Indirect Reduction
2	$Fe_3O_4 + CO = CO_2 + 3\,FeO$	600 ℃	
3	$FeO + CO = CO_2 + Fe$	700 ℃	
	$FeO + C = CO + Fe$		Direct Reduction

Iron Ore Origin

- Water Deposition → Hematite (Fe_2O_3)
- Magma Segregation → Magnetite (Fe_3O_4)

Iron Ore Reduction

Iron Ore → Fe

Fe_2O_3 → Fe_3O_4 → FeO

Fe^{3+} → Intermediate → Fe^{2+}

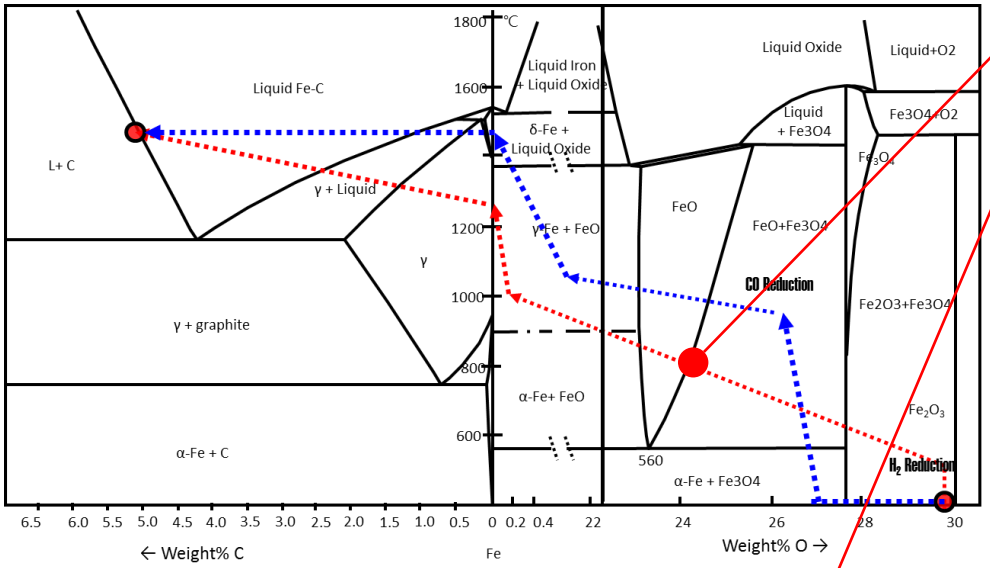
Utilization material

Direct	Solid (C / Al)	1850~1950 / Early Blast Furnace
Indirect	Gas (H_2 / CO / CH_4)	1950~ (Direct & Indirect Mixed) / Effectiveness

Reduction of Iron Ore

Reduction Process

Phase diagram Fe-C and Fe-O



CO_2 Emission Problem

1	Increase Scrap (Fe) amount
2	Stirring gas ($N_2 \rightarrow O_2$)
3	Change Reductant ($CO_2 \rightarrow H_2$)

Application of Magnetic Field

"Improvent In The Reduction Of Ores"
A.T. Hay , Patent 133099 (1872)
Suggestion of using a magnetic coil in the reduction process

"Effect of Magnetic field on Reduction of Haematite"
R. Skorski , Nature Phys. Sci., 240, 97 (1972)
Rate of Reduction of a hematite by H_2 depends on the magnetic properties of H_2 itself

"Effect of Magnetic field on Reduction of Haematite"
I. Svare , Nature Phys. Sci., 244, 135 (1973)
Mechanism of reduction by H_2 using magnetic theory

"Effect of magnetic field on reduction of iron oxides : Magnetite and wustite"
M.W. Rowe, S.M. Lake, Rand R.Fanick, Nature, 266 (1976)
Comparison reduction rate by using magnetic field

"Influence of magnetic field on the reduction of hematite by hydrogen"
H. Krath, H.Alms, and J.M.D. Coey, J. Mater. Sci., 11. 12 (1976)
Observation reduction rate by magnetization measurements

Influence of Magnetic field on Reduction Iron Oxide

Principle of reduction mechanism by using magnetic field

$Fe_2O_3 + 3\,H_2 = 3\,H_2O + 2\,Fe$

1 Degree of Freedom

$Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow Fe$, $< 550\,^{\circ}C$

Relatively low temp.

Antiferro-magnetic → Ferro-magnetic

Applied magnetic field

Magnetic phase will be favoured

C.T. Peters, Nature Phys. Sci. 244, (1973)

Lower transformation temp.

Accelerate reaction rate at a given temp.

FeO has larger driving force than Fe_3O_4

M.W. Rowe et al. , Nature 260, (1976)

Contrary Results against Peter's explanation

Fe_3O_4 — Speed up → Fe

FeO — Speed down → Fe

Para - magnetic

NiO — No effect → Ni

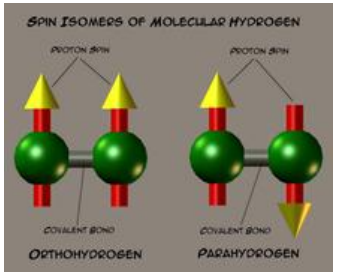
2 Paramagnetic behavior of H_2

Reducing gas

CO / CH_4 — Slow down — Dia-magnetic

H_2 — Increase reduction rate of Fe_2O_3 in magnetic fields (0~1400 Oe) — Dia-magnetic

Spin Isomers of Hydrogen



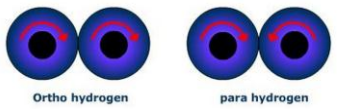
Wikipedia, Spin isomers of hydrogen

G.Buntkowsky et al., Phys. Chem. Chem. Phys. 8 , (2006)

0 K — Para-H_2 more stable

Room Temp. — Ortho-H_2 : Para-H_2 = 3 : 1

H effect



Para - magnetic

Dia-magnetic

Orthohydrogen are attracted by the magnetized ore powder undergoing reduction

Experimental Results in previous works

Effect of Magnetic Field

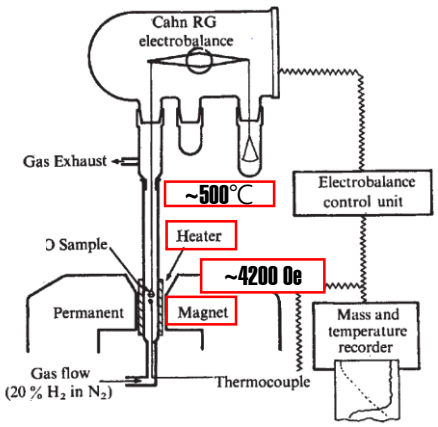


Fig. 2 Schematic diagram of the Cahn electrobalance used in this work. The system continuously records the weight of the sample as the reaction proceeds.

M.W. Rowe et al., Nature 263, (1976)

Strong magnetic field | ~4200 Oe

Fe_3O_4 Reduction Rate

~385℃

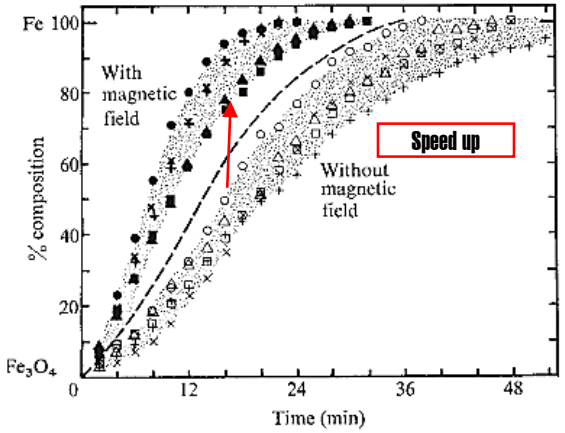


Fig. 1 Reduction of Fe_3O_4 to metallic iron with a 65-ml-min^{-1} flow of 20% H_2 in N_2 carrier at ~385 °C. Points were hand-read from a strip chart recording for construction of Fig. 1 so that data taken under the influence of a strong magnetic field can be directly compared with those without the strong magnetic field. The mass data were recorded continuously. Data on the left side of the dashed line in Fig. 1 were recorded after the insertion of an ~4,200-Oe permanent magnet. Initial sample weights (Fe_3O_4): ●, 0.98 mg; ⊦, 0.98 mg; ▲, 1.29 mg; ■, 2.27 mg; ×, 1.42 mg. Data on the right side of the dashed line in Fig. 1 were recorded in the Earth's magnetic field (~0.5 Oe). Initial sample weights (Fe_3O_4): ○, 1.24 mg; +, 1.53 mg; △, 2.22 mg; □, 1.54 mg; ×, 1.18 mg.

M.W. Rowe et al., Nature 266, (1977)

FeO Reduction Rate

~490℃

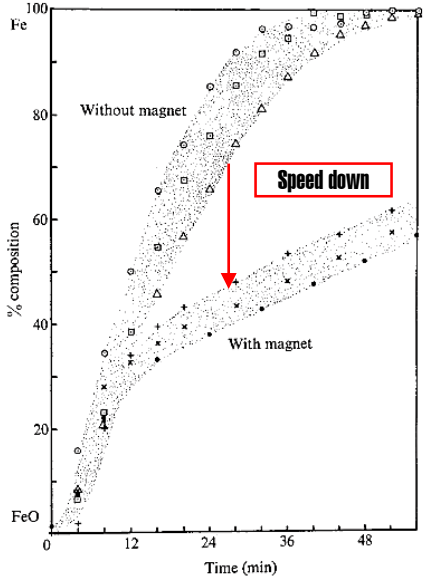


Fig. 2 Reduction of wüstite to metallic iron with a 65-ml min^{-1} flow of 20% H_2 in N_2 carrier at ~490 °C. Points were hand-read from a strip chart recording (see Fig. 1 legend). The mass data were recorded continuously. Data on the left side of Fig. 2 were recorded in the Earth's magnetic field (~0.5 Oe) those on the right side were recorded after the insertion of an ~4,200-Oe permanent magnet. Initial sample weights (FeO): ○, 1.31 mg; □, 1.76 mg; △, 2.51 mg; ●, 2.46 mg; +, 1.05 mg; ×, 2.25 mg.

M.W. Rowe et al., Nature 266, (1977)

$$FeO_x + x\,H_2 = x\,H_2O + Fe$$

Measurement

1 — *M.W. Rowe et al., Nature 266, (1977)*

Weight of sample

2 — *H.Krath et al., Nature 266, (1977)*

Loss of water

Results

NiO → Ni	No effect	$Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow Fe$
FeO → Fe	Speed down	$Fe_3O_4 \rightarrow Fe$

Speed up

When low temperature (~500℃), increase the rate of iron ore reduction by applying magnetic field

Application to Ironmaking Process

Ironmaking Process

1	Although low temperature, increase the reduction rate of iron ore	→	Save energy for reduction process
2	Possiblity of utilization hydrogen in ironmaking process	→	Decrease CO_2 emission

Task for application

1. Expensive price of Hydrogen
2. Safety problem of gas storage
3. Need relatively large magnetic field

   (~5 KG = 4.5 T)

Expectation

More effective and environment friendly process of ironmaking


Thank you for attention !