# Iron Ore Pellets: North America, BF and DR Grade, Supply and Quality


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# BF Grade Pellet Supply NAFTA

# NAFTA Blast Furnace Pellet Balance 2012

| Compamy | Pellet Demand | Equity Supply | Cliffs | IOC | AMMC | Brazil |
|---|---|---|---|---|---|---|
| AHMSA | 4.6 | 4.1 | 0.5 | | | |
| ArcelorMittal | 20.9 | 12.7 | 8.0 | 0.2 | 2.2 | |
| AK | 4.9 | | 1.4 | 2.0 | 1.5 | |
| Essar Algoma | 3.5 | | 3.5 | | | |
| RG Steel | 1.3 | | 0.6 | 0.4 | | 0.3 |
| SeverstalNA | 2.9 | | 2.9 | | | |
| USSteel | 21.9 | 20.7 | 1.2 | | | |
| Available for export/DR | | | 0.9 | 7.1 | 5.1 | |
| Total | 60.0 | 37.5 | 19.0 | 9.7 | 8.8 | |

# Changes in NAFTA BF Pellet Supply/Demand

- decrease in demand, namely the liquidation of RG Steel.
- pellet supply increases (MTPY):
- o Essar Minnesota: 4.1 to 7.0
- o USSteel KeeTac Expansion: 3.0
- o Magnetation/AK Steel: 3.5

- → BF Pellet Oversupply in NAFTA

# Changes in Overall NAFTA Pellet Supply

- BF Pellet Oversupply in NAFTA
- Needs to be balanced by increased DR pellet demand:
- Potential for DR pellet demand increases (MTPY):
- o Nucor Louisiana DRI plant: 3.7
- o Other DRI plants:
- (Bluescope, USSteel/Republic, Gallatin, Severstal NA ?) ?

# DR Grade Pellet Supply NAFTA

# Atlantic Basin DRI Iron Unit Sourcing

| Company | Plant | DRI | Annual | Pellet | | | | Lump | |
|---|---|---|---|---|---|---|---|---|---|
| | | Furnace | Production | Consumption | | Equity | Market | Consumption | |
| | | | (KT) | kg/T | KT | KT | | kg/T | KT |
| **ArcelorMittal** | Montreal | 1 | 248 | 1,450 | 360 | 360 | 0 | 0 | 0 |
| | | 2 | 454 | 1,450 | 658 | 658 | 0 | 0 | 0 |
| | Point Lisas | 1 | 315 | 1,480 | 466 | 0 | 466 | 0 | 0 |
| | | 2 | 296 | 1,480 | 438 | 0 | 438 | 0 | 0 |
| | | 3 | 1,096 | 1,470 | 1,611 | 1,611 | 0 | 0 | 0 |
| | Lazaro Cardenas | Midrex | 1,369 | 1,430 | 1,958 | 1,958 | 0 | 0 | 0 |
| | | HyL | 1,762 | 1,430 | 2,520 | 2,520 | 0 | 0 | 0 |
| **Nucor** | NuIron Trinidad | | 1,323 | 1,470 | 1,945 | 0 | 1,945 | 0 | 0 |
| | Louisiana Iron | HyL | 2,500 | 1,450 | 3,625 | 0 | 3,645 | 0 | 0 |
| **Ternium** | Monterey | 3M | 800 | 1,430 | 1,144 | 1,144 | 0 | 0 | 0 |
| | | 4M | 1,120 | 1,430 | 1,602 | 1,602 | 0 | 0 | 0 |
| | Puebla | 1 | 800 | 1,375 | 1,100 | 1,100 | 0 | 75 | 60 |
| | | | 12.1 | 1,442 | 17.4 | 11.0 | 6.5 | 5 | 0.1 |

# Current , Potential DR Grade Pellet Supply to Nafta, Trinidad

| Company | Plant | Annual Production (KT) | Equity KT | Market KT | Comments |
|---|---|---|---|---|---|
| Cliffs | Northshore | 5,200 | 0 | 5,200 | tested DR grade prod. |
| | Wabush | 5,000 | 0 | 5,000 | now idle |
| USSteel | MinnTac | 14,500 | 14,500 | 0 | potential conversion to DR |
| USSteel | KeeTac | 6,000 | 6,000 | 0 | potential conversion to DR |
| ArcelorMittal | Mines Canada QCM | 9,200 | 9,200 | 0 | 4,500 DR grade limit |
| | Lazaro Cardenas 1 | 3,500 | 3,500 | 0 | on site DRI/EAF consump |
| Rio Tinto | IOC Lab City | 12,500 | 0 | 12,500 | entiire plant served by flot |
| Ternium | Las Ecinsas | 3,500 | 3,500 | 0 | no outside sales |
| JV AM/Ternium | Pena Colarada | 4,000 | 4,000 | 0 | " ' |
| VALE | Tubarao No 1,2 | 5,200 | 0 | 5,200 | may be shutdown |
| “ | Hispanobras No 4 | 3,800 | 1,900 | 1,900 | AM portion used for DR |
| VALE | Vargem Grande | 7,000 | 0 | 7,000 | BF, DR grade |
| Samarco | Point Ubu No 1 | 7,000 | 0 | 7,000 | BF, DR grade |
| “ | “ No 2 | 7,000 | 0 | 7,000 | BF, DR grade |
| “ | “ No 3 | 7,600 | 0 | 7,600 | BF, DR grade |
| LKAB | Kiruna No 1,2 | 8,800 | 0 | 8,800 | BF, DR grade |
| | Malmberget No 1,2 | 6,800 | 0 | 6,800 | BF, DR grade |
| | Svappavaara No 1 | 3,800 | 0 | 3,800 | BF, DR grade |
| totals | | 120.4 | 42.6 | 77.8 | |

totals in MTPY

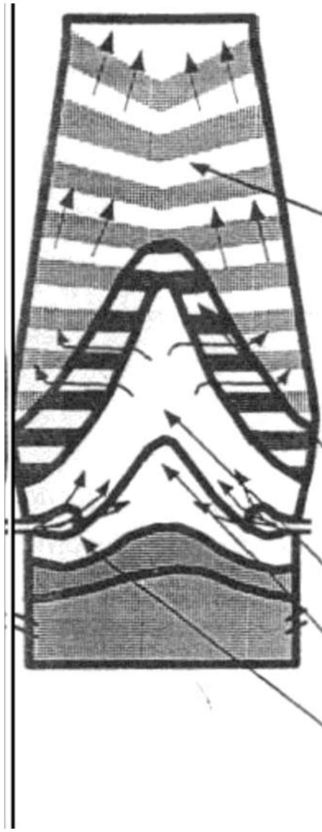
# Planned DR Pellet Plant Projects to Serve NAFTA

| Company | Annual Production (KT) | Equity KT | Market KT | Date of Start up | comments |
|---|---|---|---|---|---|
| Essar Minnesota | 7,100 | 4,000 | 3,000 | 2,014 | DR capability |
| AK Steel/Magnetation JV | 3,000 | 3,000 | 0 | 2,015 | DR capability possible |
| USS KeeTac expansion | 3,000 | 3,000 | 0 | ?? | DR capability possible |
| NML/Tata | 14,000 | 7,000 | 7,000 | ??? | seeking DR customer |
| Samarco Pont Ubu No 4 | 8,300 | 0 | 8,300 | 2,014 | BF, DR grade |
| VALE Tubarao No. 8 | 7,500 | 0 | 7,500 | 2,014 | BF, DR grade |
| totals | 42.9 | 17.0 | 25.8 | | |

*Source: RMI & WSD estimates*

# BF Pellet Quality

# Relationship of Burden Properties to the Internal State of a Blast Furnace



| Zone | Processes | Properties: Pellets & Sinter | Properties: Coke |
|---|---|---|---|
| Granular Zone | Charging, Drying, Preheating | • Size consistency<br>• Tumble index<br>• Compression strength | • Size consistency |
| Granular Zone | $3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$ | • Low temperature disintegration | • Stability |
| Granular Zone | $Fe_3O_4 + CO \rightarrow 3FeO + CO_2$<br>$FeO + CO \rightarrow Fe + CO_2$ | • Reducibility<br>• Swelling<br>• Compression strength after reduction | |
| Granular Zone | $FeO + CO \rightarrow Fe + CO_2$<br>$CO_2 + C \rightarrow 2CO$ | | • Reactivity |
| Cohesive Zone | $FeO + CO \rightarrow Fe + CO_2$<br>$CO_2 + C \rightarrow 2CO$<br>Gas-Metal Reactions | • Contraction<br>• Softening<br>• Melting<br>• Reduction | • Coke strength after reaction (CSR)<br>• High temperature strength |
| Active Coke Zone | Gas-Metal Reactions | | |
| Stagnant Coke Zone | Gas-Metal, Slag-Metal Reactions | | |
| Raceway | $2C + O_2 \rightarrow 2CO$<br>$H_2O + C \rightarrow H_2 + CO$ | | • Combustibility |

**Figure 1** Relationship of burden properties to the internal sate of a blast furnace ( 2-4 )

# DESIRED BLAST FURNACE PELLET CHARACTERISTICS

- High iron content
- minimal impurities
- high level of cold strength; tumbler > 95 %
  abrasion < 5%
- narrow size range, > 80 % 9.5 x 12.5 mm
- very low amount of fines, < 3 % < 6.3 mm
- high level of L.T.B. (low temperature
- breakdown) > 85 – 88 %, > 6.3 mm
  - good reducibility

# DESIRED PELLET CHEMISTRY

- Maximize Fe content
- Moderate amounts of basic oxides: CaO, MgO; acidic oxide, $TiO_2$
- Minimize:

  **moisture**

  **acidic gangue: $SiO_2$, Al203**

  **impurities –steelmaking impact- P, S, Mn, Cr, Ni, Cu, other minor elements**

  **elements harmful to ironmaking, Na, K, Zn**

# DESIRED PELLET METALLURGICAL PROPERTIES

## fluxed pellets vs. acid pellets

- lower coke rates: 15 – 30 kg/T
  - increased gas utilization
  - reduced flux calcination
- reduced wall thermal load
- reduced hot metal Si
- operate at higher flame temperatures

## Ranade's Burden Property Hierarchy

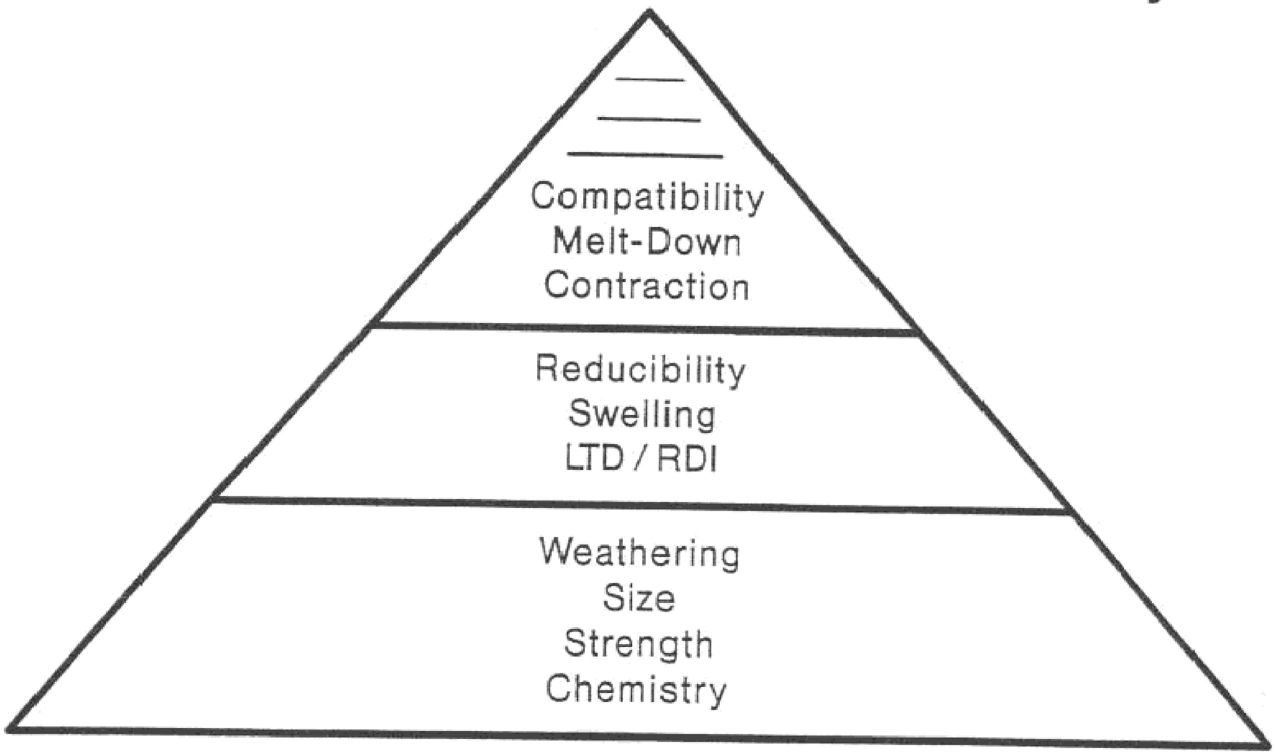



Figure 5 (8)

# Direct Reduction Pellet Quality

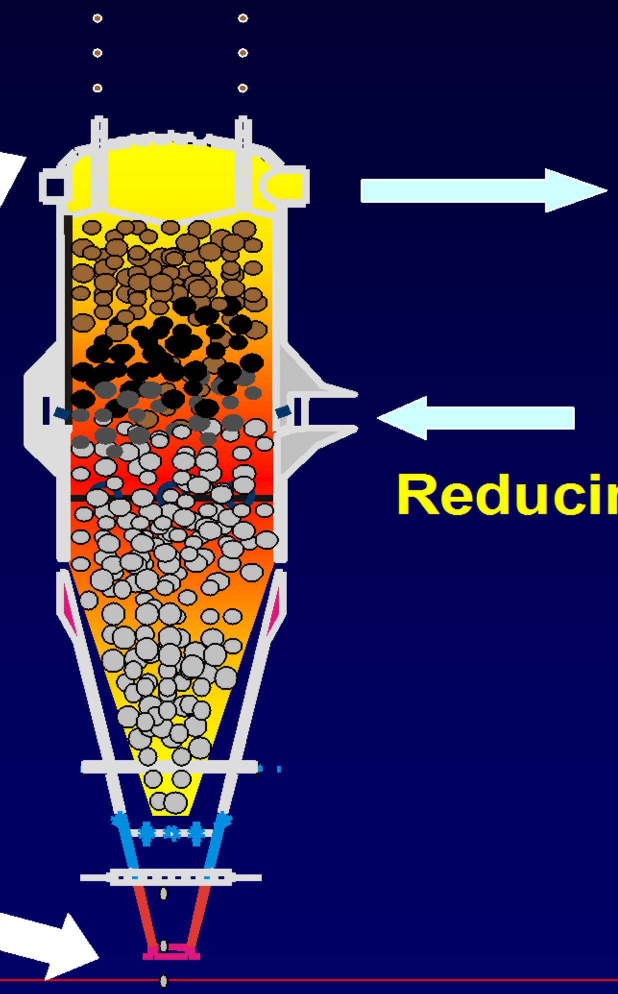
HBIA
HOT BRIQUETTED IRON ASSOCIATION

# Available Processes

## Lump ore & pellet based processes (HyL, Midrex)

Lump iron ore, pellet feed

Shaft furnace



Reducing gas

Hot metallized product to briquetters

# Chemistry Considerations

- direct reduction processes:
  - chemical change is removal of oxygen from ore
  - remaining constituents stay with direct reduced iron product but increase in concentration due to the removal of oxygen
  - these affect process economics of subsequent EAF melting vessel
- Blast furnace, smelting reduction processes
  - formation of refining slag allows modification of hot metal product to meet requirements of subsequent steelmaking process

# REQUIRED CHEMICAL PROPERTIES

**Direct Reduction Processes - Shaft Furnace Rotary Kiln, Fluidized Bed, Rotary Hearth processes :**

**Maximize: Fe, total iron > 67%.**

**Minimize: gangue, impurities, residual elements, moisture, LOI**

# REQUIRED CHEMICAL PROPERTIES

**Minimize: gangue**

**$SiO_2 + Al_2O_3 + TiO_2$, acid gangue**
**prefer < 2% but accept < 3%.**

**CaO + MgO, basic oxides**
**basic oxides (< 3.0 %) displace purchased flux in steelmaking;**

# REQUIRED PHYSICAL PROPERTIES

**shaft furnaces: pellets, lump ore**

**key physical properties are size consist, mechanical strength:**

**economic importance**

**(a) yield of pellet, lump ore converted to DRI**

**(b) performance of the shaft reduction furnace**

**unlike blast furnace, pellets (and lump ore) are only solid materials and so determine gas distribution, permeability, reduction behavior**

# DR Pellet Size Exceeds BF Pellet Size

- **DR pellets: >50 % + 12.5 mm vs.**
- **BF: 9.5 x 12.5 mm target**

- **Benefits of larger pellets :**

  **Increase in permeability, increased yield ( fewer smaller pellets degrading into fines), reduced clustering tendency (with a decrease in contacting surface area)**

- **Drawbacks of larger pellets :**

  **Decreased reduction & heat transfer efficiency and pellet strength (as larger pellets are more difficult to indurate).**

# REQUIRED METALLURGICAL PROPERTIES

**key pellet metallurgical properties are reducibility, sticking tendency, and metallization**

**<u>sticking of pellets minimized by</u>**

**additives, such as limestone or dolomite in pelletizing, or**

**oxide coatings after the pelletizing process.**

**reducibility, sticking tendency determine DR furnace productivity, fuel consumption**

# Physical vs. Metallurgical Properties

**metallurgical properties, such as reducibility, are important but the physical characteristics will dominate the behavior and performance of the pellets:**

**a highly reducible but weak and/or poorly sized pellet will impair permeability and gas-solid contacting effectiveness and minimize the benefit of inherent excellent pellet reducibility**

# CONSISTENCY OF BF, DR PELLET PROPERTIES

reduce pellet plant costs - set more aggressive targets for energy and additive consumption

blast furnace and DRI plant operators can set more aggressive targets for fuel rate and productivity

increased hot metal chemistry and DRI consistency leads to benefits in steelmaking, rolling operations.

# FUTURE IRONMAKING PROCESSES

- Hot metal production will continue to be dominated by blast furnaces
- DRI production will continue to be dominated by shaft furnaces ( Midrex, HyL )
- COREX (Pellets) , FINEX (Fines) are only commercial smelting/reduction process, but $$$$$
- Fines based processes: rotary hearth, HIsmelt, etc, still under (very slow) development

Pellet demand will continue to be strong

# Appendix

texts of 2004, 2008 papers available upon request:

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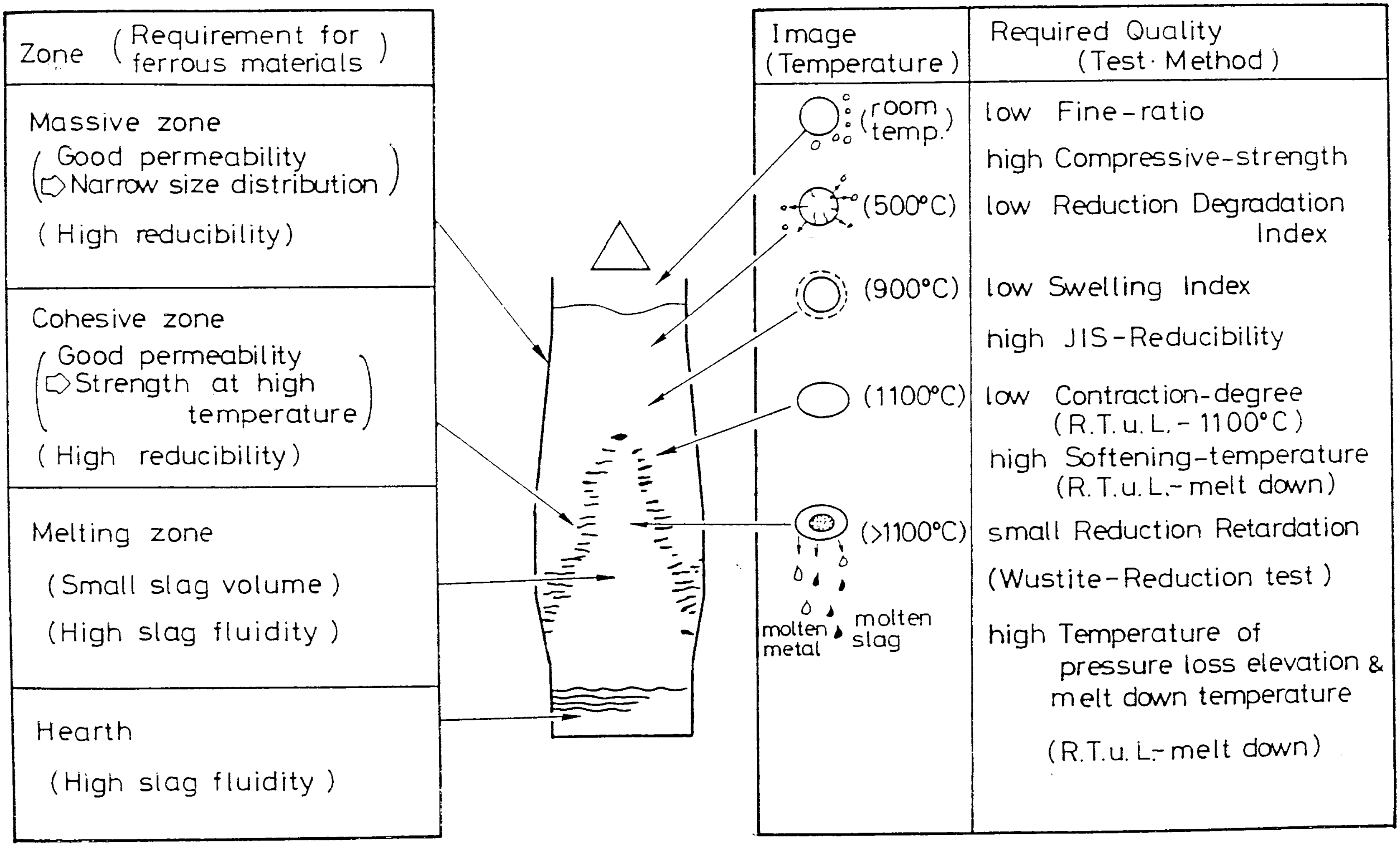


**Figure 2 Quality required for pellets (6)**

# Limits of Slag Volume Reduction

| Furnace Size | Hearth Diameter (m) | Slag Volume (kg/T) |
|---|---|---|
| very large | 13.7 | > 250 |
| large | 10 - 12 | > 200 |
| small/medium | 8 - 10 | > 150 |

# DESIRED PELLET PHYSICAL PROPERTIES

## Minimize Fines Charging and Generation

**Maximize Permeability & Gas Utilization**

| **increase in coke rate, kg/T** | **fines loading, kg/T** |
|---|---|
| **4** | **50** |

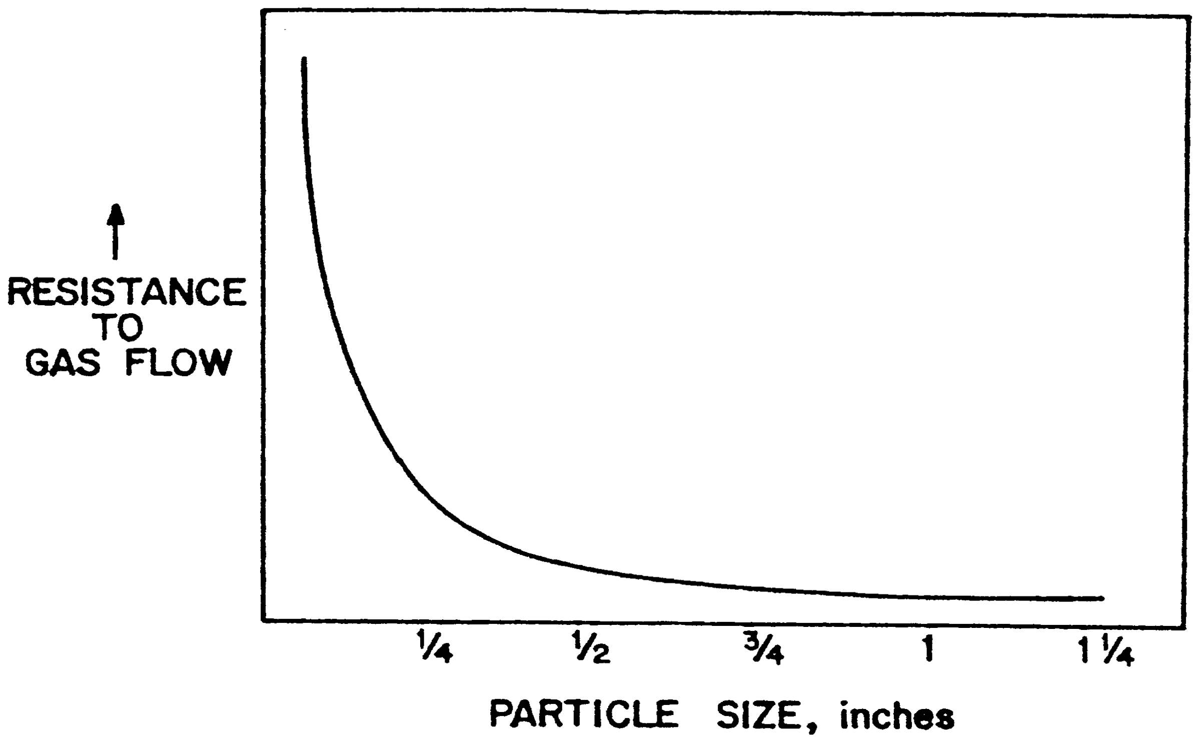


Figure 6 Relationship Between Particle Size and Gas Flow (20)

# DESIRED PELLET CHEMISTRY – SiO2

- blast furnace benefits of lower SiO2 levels are lower slag volumes.
- reduction of pellet SiO2 from 4.30 to 4.00% reduces slag volume by 10 kg/T which reduces coke rate by 2 kg/T and increases hot metal production by 0.5% or about 20 tons/day for a furnace initially producing 4000 tons/day.

# DESIRED PELLET PHYSICAL PROPERTIES

## Minimize Larger Pellets

**more difficult to preheat and pre-reduce in the stack region**

| | increase in coke rate, kg/T | loading of oversized ore, kg/T |
|---|---|---|
| **+ 12.5 mm** | **1.5** | **50** |
| **+ 25.4 mm** | **4.5** | **50** |

# DESIRED PELLET PHYSICAL PROPERTIES

## Maintain High Tumbler Strength

| increase in coke rate, Kg/T | decrease in tumbler strength,< 94 %/NT of pellets charged |
|---|---|
| 10 | 1 |

# DESIRED PELLET PHYSICAL PROPERTIES

## Effect of Transfer Points on Fines

| Sizing | Pellet Plant | Cargo Loading | Cargo Unloading ( Germany ) |
| --- | --- | --- | --- |
| + 16 mm | 2.6 | 2.3 | 1.9 |
| -16+9 mm | 94.7 | 92.9 | 92.5 |
| - 9+6.3 mm | 2.3 | 3.4 | 3.8 |
| - 6.3 mm | 0.4 | 1.4 | 1.8 |

# DESIRED PELLET PHYSICAL PROPERTIES

**Compression Strength:**

**lower threshold level for compression strength is below the range of 200 - 230 kg**

**further increase in compression strength will not reduce coke rate or increase production.**

# DESIRED PELLET PHYSICAL PROPERTIES

## Compression Strength Test Issues

**pressure is always referred to a plane surface:  not the case with pellets**

**smaller pellets yield a lower strength than those of a greater diameter**

# DESIRED PELLET PHYSICAL PROPERTIES

## Compression Strength Test Issues

| Pellet diameter ( cm ) | Pellet area ( $cm^2$ ) | Compression strength ( daN ) | Specific Compression strength, daN/$cm^2$ |
|---|---|---|---|
| 9.00 | 84.8 | 210 | 2.48 |
| 11.25 | 132.4 | 250 | 1.89 |
| 14.25 | 212.5 | 280 | 1.32 |

**smaller pellets actually have a higher specific compression strength**

# DESIRED PELLET METALLURGICAL PROPERTIES

LTB ( Low Temperature Breakdown )

> > 85 % + 6.3 mm - permeability
>
> < 13 % - 0.5 mm - flue dust, yield

Dynamic LTB

> > 80 % + 6.3 mm – permeability

Threshold levels – no benefit above these levels;

thresholds can increase in high performance BF operations

# DESIRED PELLET METALLURGICAL PROPERTIES

Reducibility ( ISO R40 )

gas utilization, high temperature properties

acid pellets: 0.6 to 1.0

fluxed pellets: > 1.2

**coke rate impact: 5 kg/T/0.1 R40**

# DESIRED PELLET METALLURGICAL PROPERTIES

High temperature properties

difficult to relate quantitatively
to furnace performance

Swelling – threshold levels

< 20 – acid pellets

< 15 - fluxed pellets

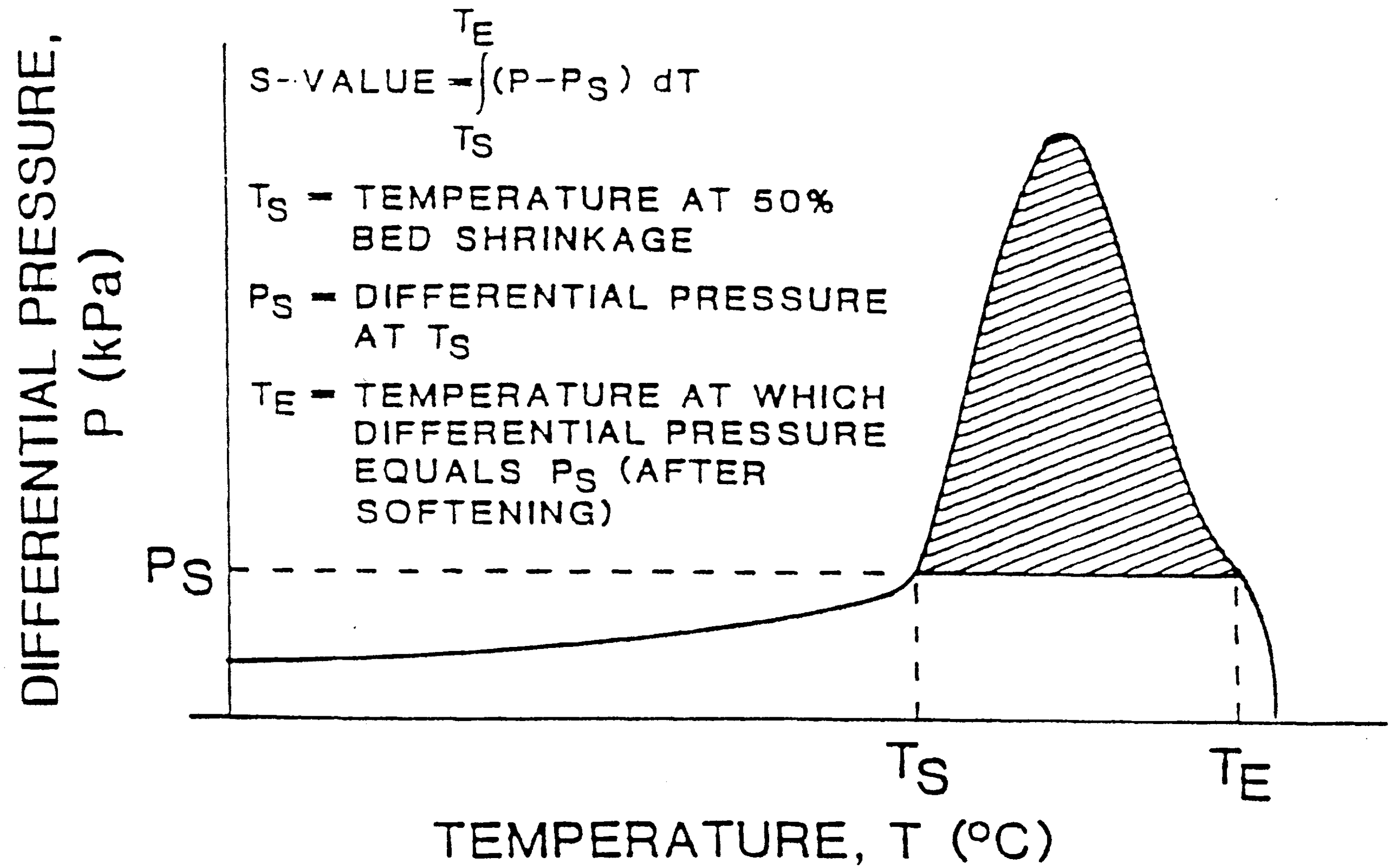


**Figure 3 Concept of the S-Value ( 19 )**

# Cohesive Zone Configuration with Acid & Fluxed Pellets

## Acid Pellets

- Thick, fewer coke slits for gases to "pass-thru" (Permeability↓, Rough Operation↑)
- Outer surface closer to walls, more "dead-end" coke slits causing gas impingement, (Heat Flux↑, Lining Wear↑, Rough Operation↑)
- Longer dripping distances (Si↑)
- Smaller lumpy zone ( CO Utilization↓, Fuel Rate↑)

## Fluxed Pellets

- Thin, more coke slits for gases tc "pass-thru" (Permeability↑, Rough Operation↓
- Outer surface away from walls, fewer "dead-end" coke slits, less gas impingement (Heat Flux↓, Lining Wear↓, Rough Operation↓)
- Shorter dripping distances (Si↓)
- Larger lumpy zone ( CO Utilization↑, Fuel rate↓ )

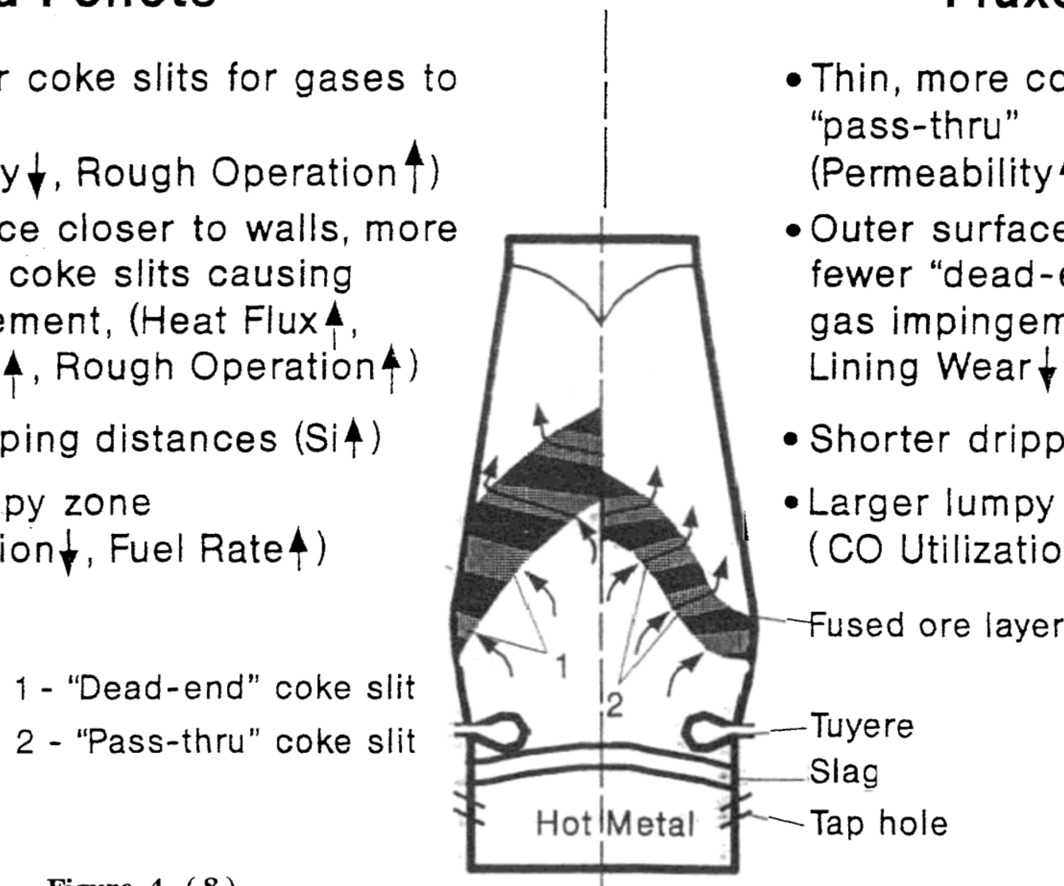


**Figure 4 (8)**

# FUTURE TRENDS IN BLAST FURNACE PRACTICE

- increased productivity
- · reduced reductant rates
- · increased injectant rates, mainly coal injection but also gas injection in NAFTA
- · extended campaign lives
- · ability to optimize hot metal quality

# FUTURE TRENDS IN BLAST FURNACE PRACTICE

Improved pellet quality, consistency to support increased productivity, higher levels of coal and/or gas injection, extended campaign lives

Increased use of fluxed pellets, continued use of acid pellets to complement fluxed pellets, sinter and in some lower productivity operations

# Effect of pellet size on tumbler strength, abrasion resistance

| | QCM 2000 | QCM 2007 | Pellet A | Pellet B | Pellet C |
|---|---|---|---|---|---|
| + 12.5 mm | 27.2 | 48.1 | 52.0 | 58.0 | 53.6 |
| Tumbler | | | | | |
| + 6.3 mm | 96.0 | 95.2 | 93.4 | 94.0 | 94.0 |
| - 0.5 mm | 4.0 | 3.9 | 5.6 | 4.0 | 5.5 |

# Thank You!