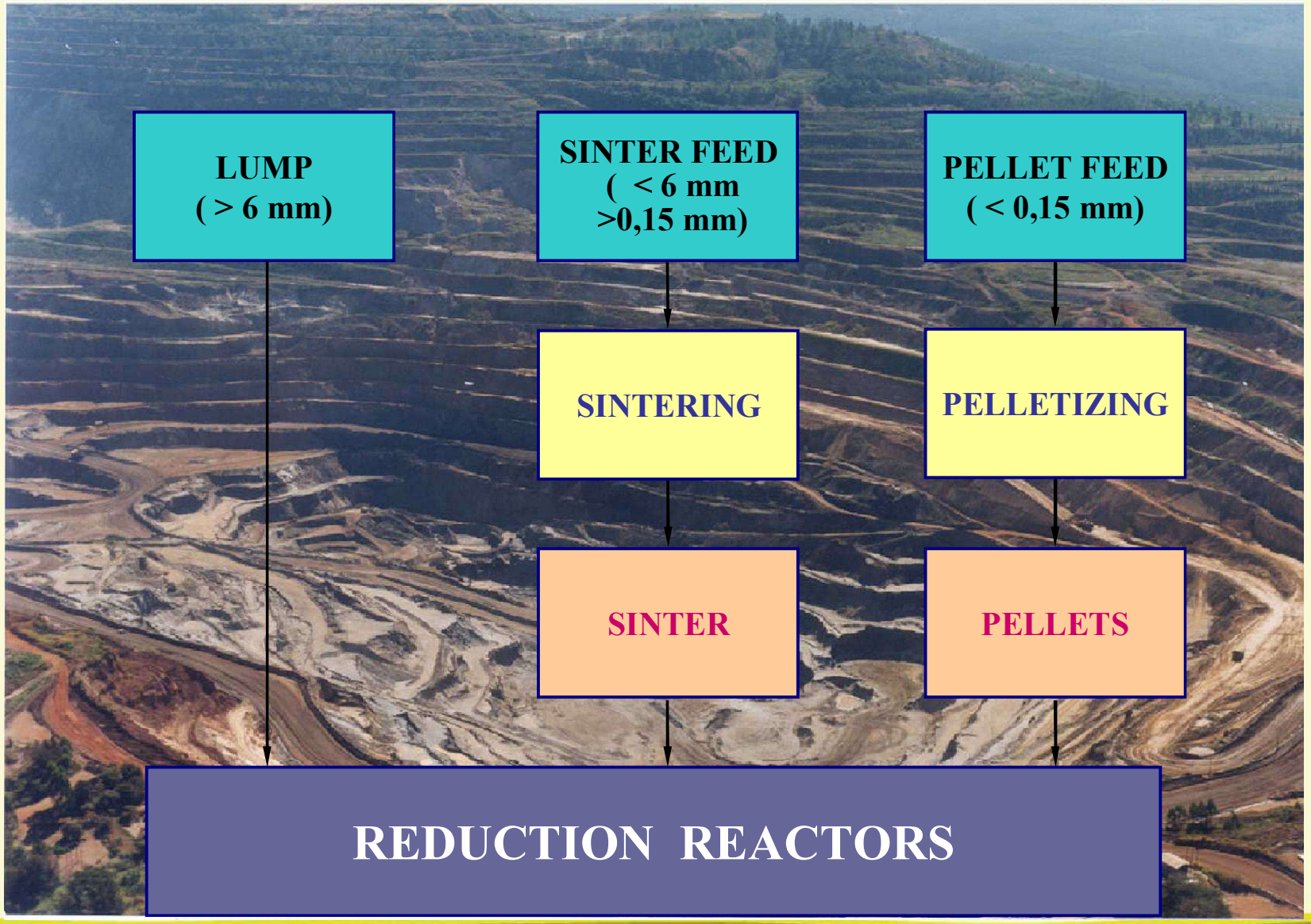
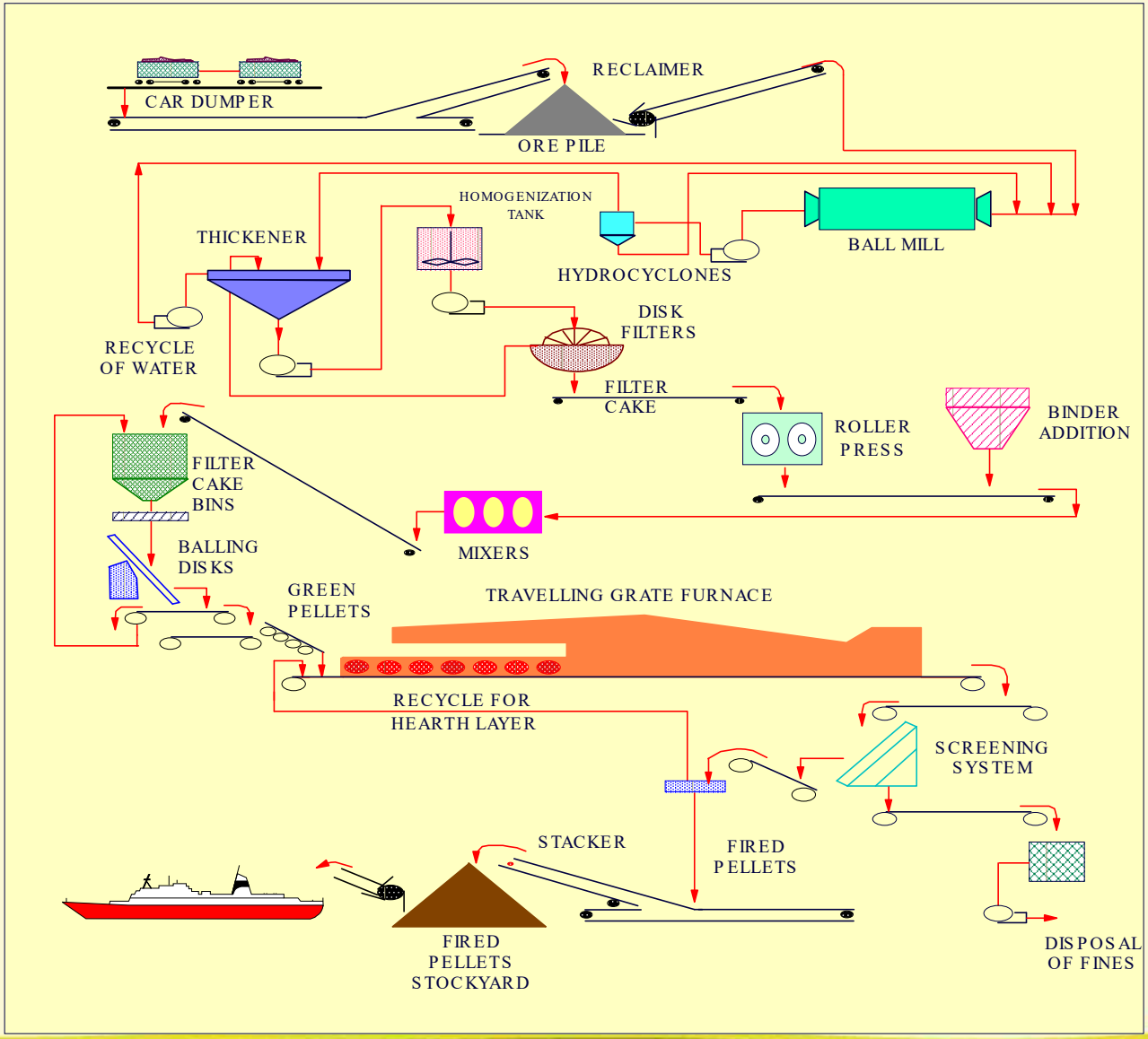
Pelletizing Process – Why?



Pelletizing Process

- In mining and ore dressing operations, specially when grinding to concentration is needed, there are a lot of fines (< 100 #) generation. These fines cannot be used in sintering because lack of bed permeability . Pelletizing is an alternative agglomeration route to these fines.
- Pelletizing is an agglomeration process that transforms the ore fines in a spherical product - 8 to 18mm size.
- Ore fines are mixed with additives and binders, pelletized and “fired” in temperatures in the range of 1200 ~1350^{o}C.
- There are two types of pellets, according to their applications:
  - Blast Furnace
  - Direct Reduction

Pelletizing Process – General Flowsheet



Vale's Pelletizing Complex – Tubarão Flowsheet



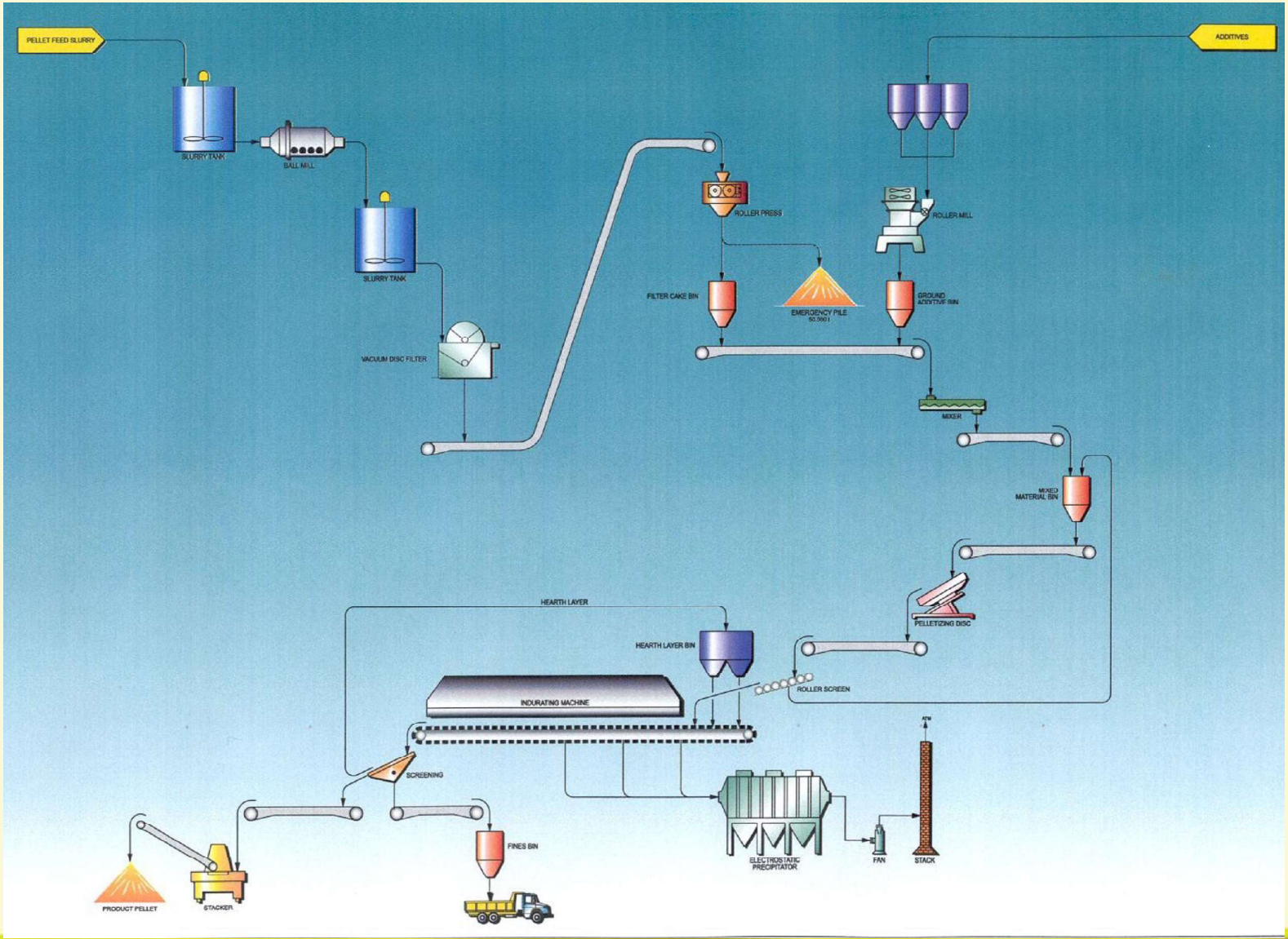
Vale's Pelletizing Complex – São Luis Flowsheet



Vale's Pelletizing Complex – Fábrica Flowsheet



Vale's Pelletizing Complex – Vargem Grande Flowsheet



Pelletizing Process – Production Steps

- Concentration
- Stocking and Homogenizing
- Grinding and Classification
- Thickening
- Homogenizing Tanks
- Filtering
- Roller Press
- Additives Dosage
- Mixing
- Balling
- Green Pellets Screening
- Firing
- Fired Pellets Screening

Pelletizing Process - Concentration

- Iron ore beneficiation operation
- Metallic iron content enrichment
- Impurities are partially removed (SiO_2, Al_2O_3, P, Mn, etc.)
- Concentration methods: washing, gravimetric or magnetic separation, conventional or column flotation

Pelletizing Process - Concentration

Pellet Feed for Pelletizing Process

		PF - A	PF - B	PF - C	PF - D	PF - E	PF - F
Fe	%	65,80	68,00	67,80	66,50	67,00	66,60
SiO_2	%	1,40	1,10	1,40	2,50	1,80	2,10
Al_2O_3	%	1,60	0,70	0,60	0,70	0,70	1,00
P	%	0,045	0,028	0,030	0,035	0,045	0,045
Mn	%	0,55	0,08	0,10	0,15	0,23	0,15
+1,0mm	%	1,0	2,0	2,0	2,0	-	2,0
-0,15mm	%	94,0	90,0	86,0	84,0	97,0	90,0
-0,045mm	%	60,0	36,0	30,0	35,0	60,0	50,0

Pelletizing Process – Stocking/Homogenizing

- Reduce properties variations of raw materials and additives
- Key factors: SiO_2, grindability index, ore genesis
- Possibility of adding flux and solid fuel
- Typical pile: 45.000 - 50.000 t or 100.000 t – depends on the pelletizing plant capacity

Pelletizing Process – Stocking/Homogenizing



Pelletizing Process – Grinding/Classification

- To fit the physical properties of the feed to balling requirements
  - Size: 80-90% < 0,045 mm (325 mesh)
  - Specific Surface: 1750 - 1950 cm^2/g
- Tubular mill + grinding media (balls or cylpebs)
- Circuits:
  - Wet x Dry
  - Open x Closed
- High cost step (electric energy)

Pelletizing Process – Grinding/Classification



Density
Size Distribution
Blaine Index
Pressure
To Thickening
Hydrocyclone
Density
Ore Feed Rate
Grinding Media Supplement
Fines from Stockyard
Ball Mill
Discharge Density
Water
Pump

- Quality Parameter
- Process Parameter

Pelletizing Process – Grinding/Classification

		Ball Mills				"Pebble mill"
		Wet Grinding		Dry Grinding		
		Circuit				
		Open	Closed	Open	Closed	
Surface Area	cm^2/g	1600	1600	1600	1600	1600
Energy	Kwh/t	18,0	14,5	21,0	15,5	16,5
Wet Green Pellets Strength	daN/p	0,7	0,7	0,8	0,8	0,7
Drop Number (46cm)	-	4,0	3,5	3,6	3,6	4,4
Green Pellets Moisture	%	8,5	8,2	7,4	7,5	8,2
Dry Green Pellets Strength	daN/p	1,4	1,4	0,9	0,9	0,9
Cold Compressive Strength (Fired Pellets)	daN/p	300	350	360	340	320
Abrasion (-0,6mm)	%	3,5	3,2	3,5	4,3	3,4
Swelling (JIS)	%	15,0	14,0	14,0	21,0	16,0
Productivity of Indurating Machine	t / m^2 . dia	24,0	25,0	26,5	24,0	23,0

- Different grinding systems have an impact on the pellets quality

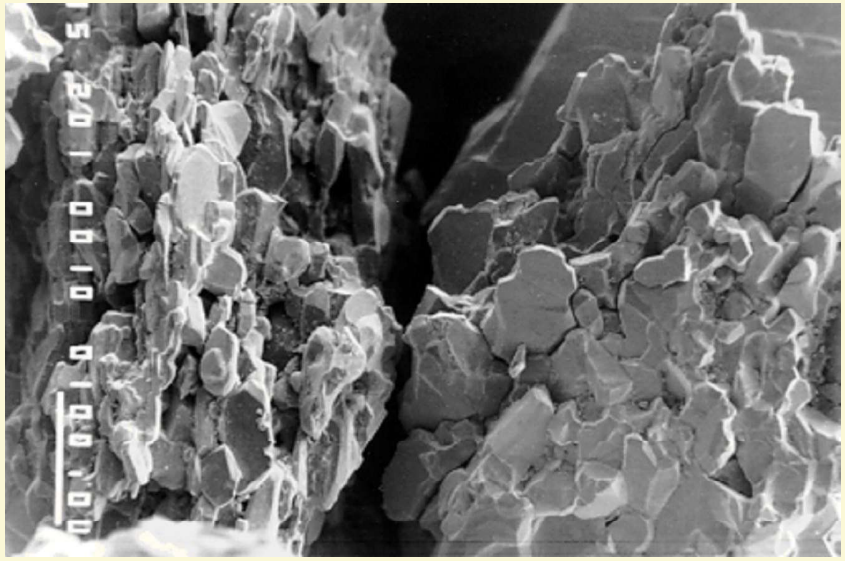
Pelletizing Process – Grinding/Classification

Pellets	Feed Rate (t/h)	S.S. (cm^2/g)	% <0,045mm	Circuit
DR	250	1750	93,0	Closed
BF	260	1700	89,0	Closed
BF	200	1950 - 2100	85,0	Open
BF	275	2000	86,0	Closed
BF	300	1600	84,0	Closed

- Different products and iron ore request different grinding specifications
- Differences in feed rate are due to ball mills capacities

Pelletizing Process – Grinding/Classification

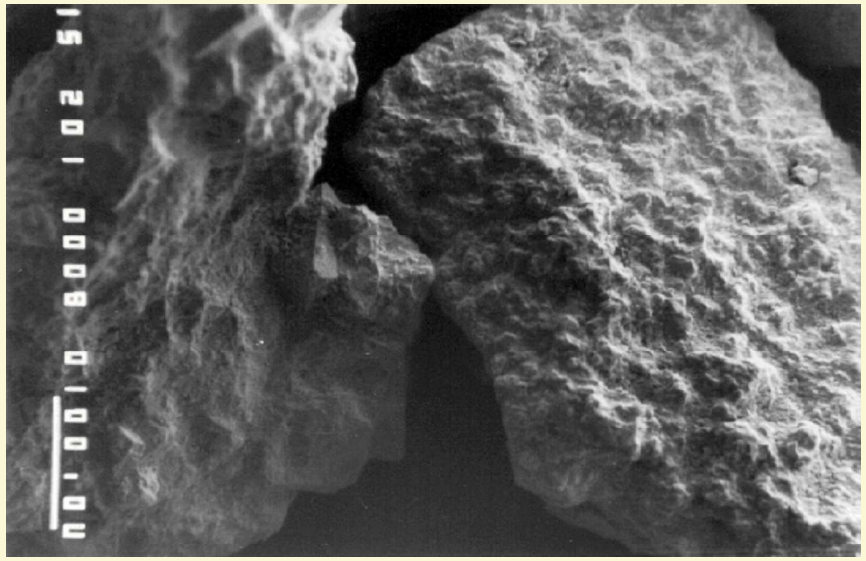
METAMORPHIC



Enlargement 200x : 0,500 mm > d > 0,250 mm

Ex.: Cauê, Conceição

SEDIMENTARY



Ex.: Carajás, Alegria

Pelletizing Process – Grinding/Classification

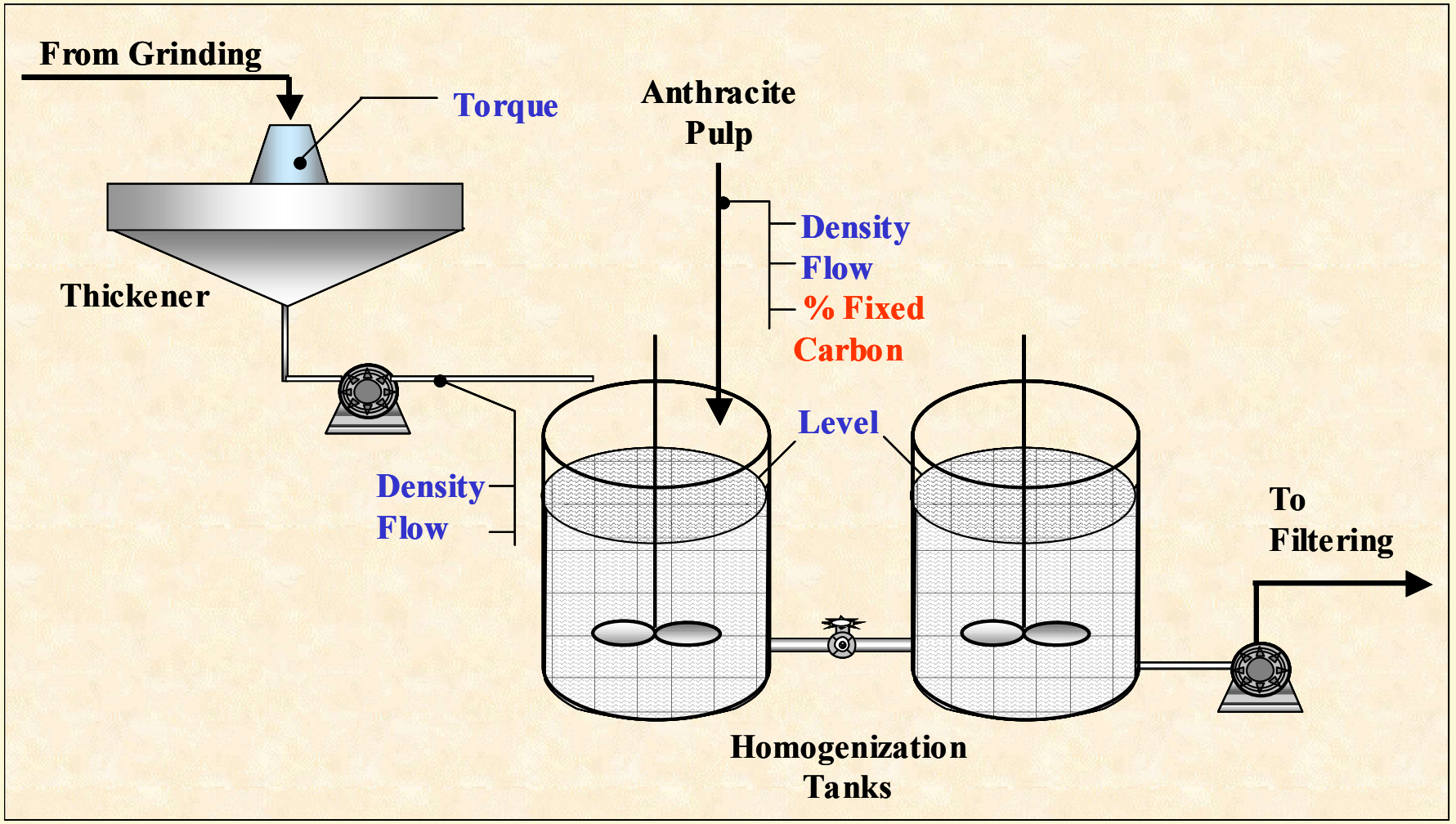
Iron ore genesis and its impact on the grinding performance

METAMORPHIC	SEDIMENTARY
✦High extent of metamorphism ✦Growing and flattening of the cristal	✦Low extent of metamorphism ✦Enrichment by weathering
✦Compact ores ✦Cristal size from fine (0,01-0,04 mm) to coarse (0,22 mm) ✦Bluish appearance	✦Porous ores ✦Cristal size from very fine (< 0,01mm) to fine (0,01-0,04 mm) ✦Brown appearance
✦Little hydrated ✦Low impurities	✦Very hydrated ✦High impurities
✦High decrepitation (lump) ✦Low reducibility	✦Low decrepitation (lump) ✦High reducibility
✦Low grindability ✦Easy filtration	✦High grindability ✦Hard filtration

Pelletizing Process - Thickening

- Only required where there is wet/closed grinding circuit
- Thickening of cycloned pulp: % solids = 20 to 70%
- Recovered water is recycled to the grinding process
- Some ore requires flocculants in order to increase sedimentation rate

Pelletizing Process - Thickening



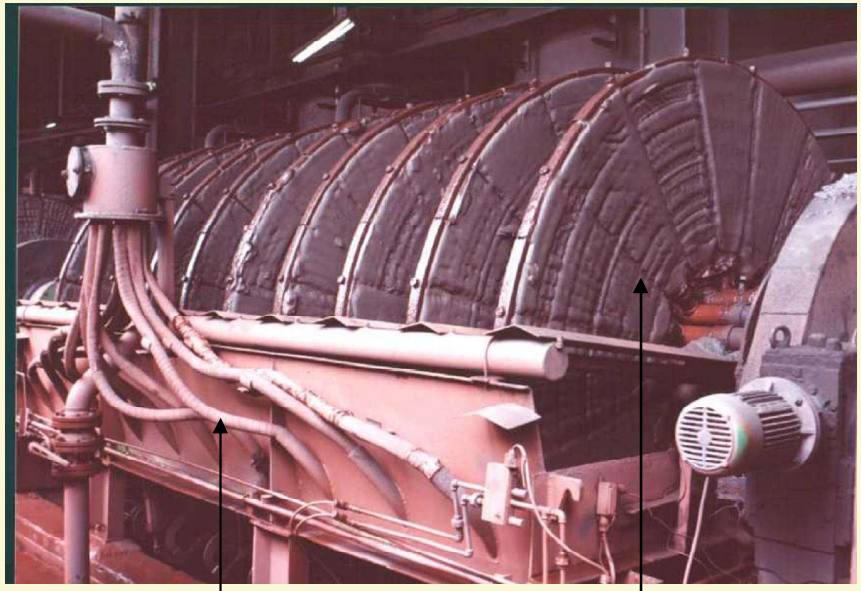
Pelletizing Process – Homogenizing Tanks

- Maintain solids in suspension by mechanical agitation
- Homogenizing tanks are also used as a buffer
- Possibility of adding solid fuel (in a pulp form) – Tubarão site
- After the tanks, the pulp is pumped to filtering area

Pelletizing Process - Filtering

- Required in plants with wet grinding circuit
- Vacuum rotary disc filters:
  - Quantity: up to 12 discs/filter
  - Diameter: 2-3 m
  - Filtering area: up to 100 m2
  - Productivity : 0,4 - 1,5 t/h/m2
- Cycle: formation / drying / discharge
- Filter cake moisture: 8% - 10%
- Depending on the iron ore genesis, filtering auxiliaries (polymer) can be requested

Pelletizing Process - Filtering



Feeding Tubes

Bad Condition



Good Condition

Pelletizing Process - Filtering

Influence of iron ore on grinding, filtering, balling and green pellet quality

Iron Ore	% Fe	Grinding		% Moisture	Compressive Strength (N/p)		Pellet Size (mm)
		% <0,045mm	S.S. (cm^2/g)		Wet	Dry	
Magnetite	68,30	70,0	2000	7,1	11	7	12 - 15
Hematite	66,00	90,0	1900	9,0	13	3	12 - 15
Earthy Hematite	65,00	74,0	2050	10,5	14	30	12 - 15

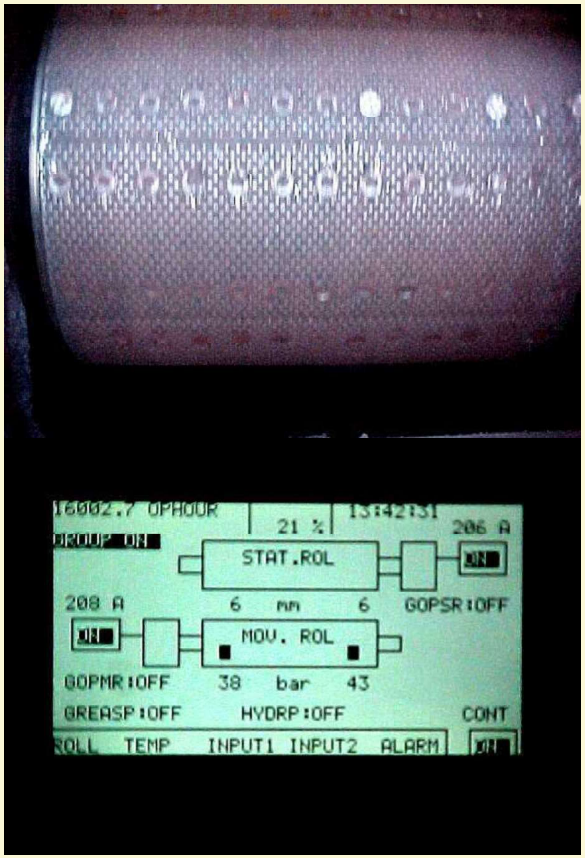
- Iron ore genesis has an impact on the green pellet quality
- Ground and filtered pellet feed are deeply impacted by its genesis

Pelletizing Process – Roller Press

- Comminution technology which uses high specific pressure over ore particles
- It is a good solution for increasing grinding productivity and decreasing energy consumption
- Typical specific surface gain: 400 to 1000 cm^2/g
- Restrictions: (1) ore and/or mixture moisture content; (2) ore/mixture contamination by scrap or metallic parts
- Roll wear monitoring is necessary
- Balling and filtering improvement – granulometric control and coarse filter cake to be filtered
- Decreasing of green ball moisture
- Granulometry improvement (%<45μm): ± 5,0%

Pelletizing Process – Roller Press





Pelletizing Process – Additives Dosage/Binders

- Leading to green pellets physical strengthening to handling and transportation from the balling area to indurating machine and to avoid green pellets thermal shock during heating

- Types:
    - ❶ Inorganics: Bentonite and Hydrated lime
    - ❷ Organics: CMC, HEC e Polyachrilamide

- Leading to salt bridges formation during pellet's drying and heating processes

Pelletizing Process – Additives Dosage/Binders

BENTONITE

- Argillaceous material, has the montmorillonite as the main mineral besides of small amount of quartz, mica, feldspar and kaolin
- It has lamellar structure with a great capacity of water absortion among layers → swelling
- Typical composition: SiO_2=60% Al_2O_3=18% Na2O=2%
- Typical Dosage: 0,5% or 5 kg/t mixture
- Restriction: incorporates acid gangue to the fired pellets

HYDRATED LIME

- Burnt lime is bought from the market (CaO) – got from limestone ($CaCO_3$) calcining
- Lime hydration: CaO + H_2O → $Ca(OH)_2$ (exothermic)
- Product has a high specific surface (12.000 cm^2/g)
- Typical composition: 74% CaO; 23% LOI
- Typical Dosage: 2,5% or 25 kg/t mixture
- It is also source of CaO

ORGANIC

- Polymeric compounds (long carbon chain, high molecular weight)
- Great value: don't incorporate gangue to the pellets (decomposed during heat treatment)
- Main commercial types: PERIDUR (CMC), ALCOTAC (PAM) and CARBINDER (HEC)
- Typical Dosage: 0,035-0,060% or 0,35-0,60kg/t mixture
- Low dosage but high cost

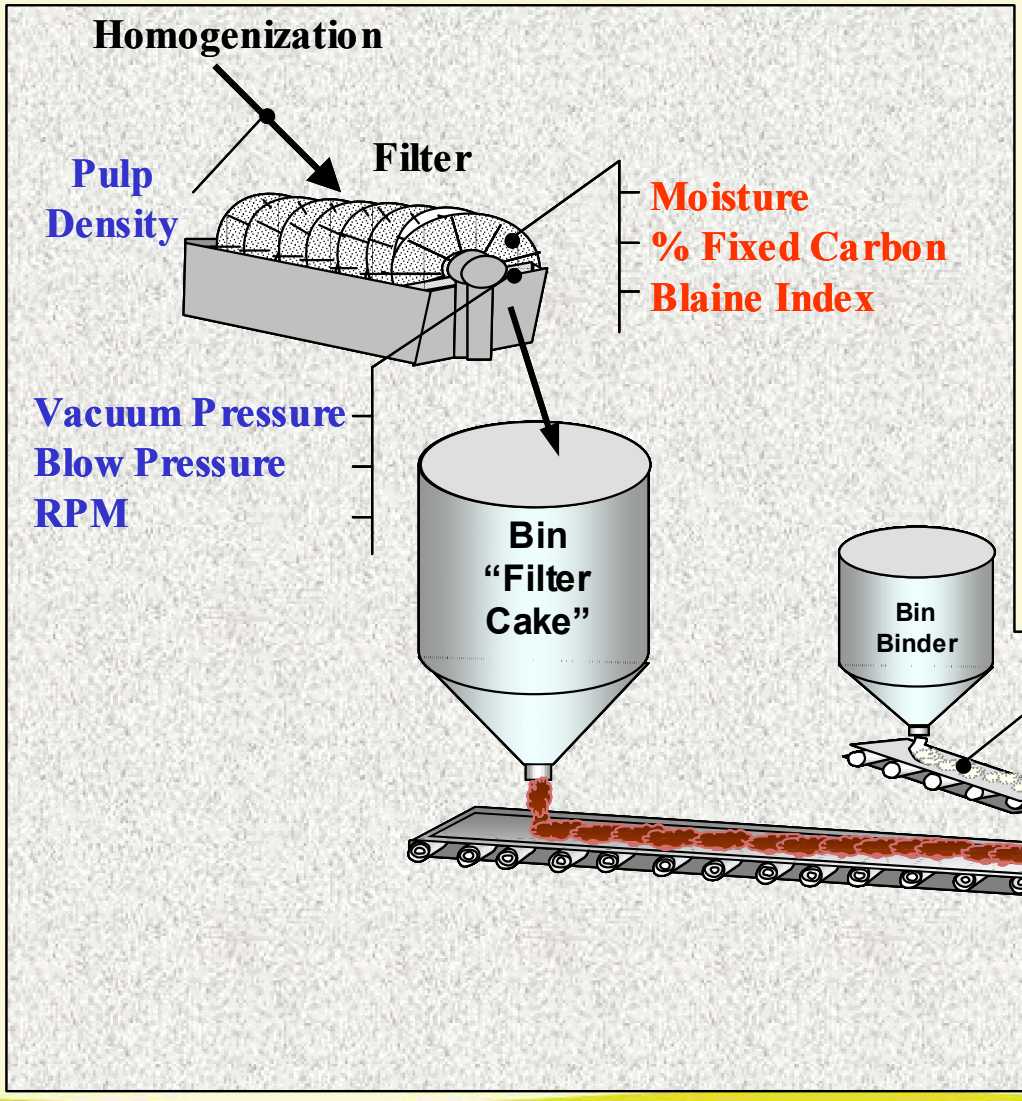
Pelletizing Process – Additives Dosage/Binders

		SiO_2	Al_2O_3	CaO	MgO	LOI	Typical Dosage (kg/t pellet)
FLUX	➲ LIMESTONE	1,4	0,7	53,4	0,3	42,8	13,0
	➲ DOLOMITE	2,2	0,2	37,0	15,1	43,8	18,0
	➲ DUNITE	38,8	3,5	2,5	34,6	13,8	25,0
	➲ MAGNESITE	0,7	1,5	1,1	46,8	49,5	30,0
BINDER	➲ BENTONITE	59,8	16,4	0,9	2,6	9,7	5,0
	➲ HYDRATED LIME	0,9	0,1	72,9	0,3	24,6	27,0
	➲ ORGANIC BINDER	50% Carboximetilcelulose - 30% Na_2CO_3 - 20% NaCl					0,4

		Fixed Carbon (%)	Voláteis (%)	Ash (%)	S (%)	Heat Value (kcal/kg)	Typical Dosage (kg/t pelota)
SOLID FUEL	➲ ANTRACITE	68,9	11,6	19,6	1,2	6600	14,0
	➲ PETROLEUM COKE	89,6	9,8	0,6	1,8	7890	12,0

- Based on different flux and binders several types of pellets can be produced
- Solid fuel type and dosage depend on iron ore, type of pellets and process characteristics

Pelletizing Process - Mixing



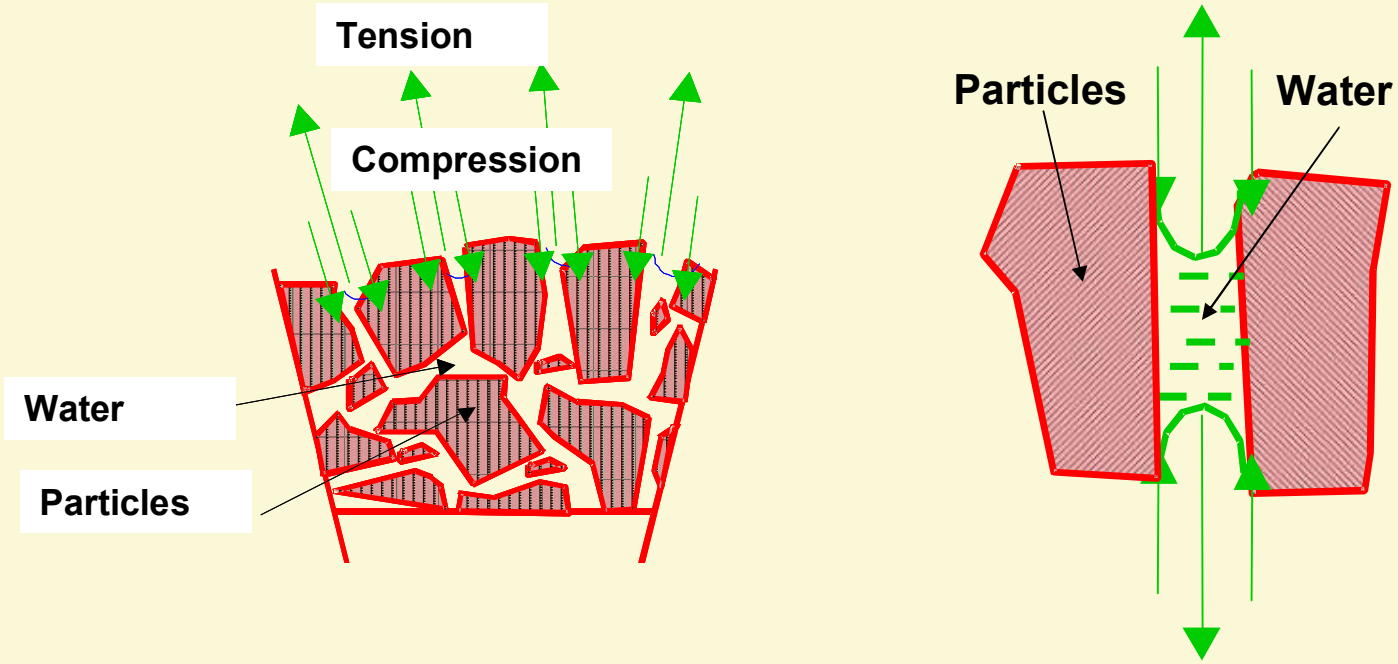
- Critical step due to low binder addition
- High mixing efficiency is very important to assure good quality of the green pellets during balling
- High mixing efficiency can bring about significant reduction in the binder specific consumption

Pelletizing Process - Balling

- Balling is responsible for green pellet formation with suitable size and mechanical strength to heat treatment.
- Mechanism is based on the action of capillary forces in the system: ore particle – water – air.
- Critical Factors:
  - Moisture of blending
  - Ore/mixture size and specific surface
  - Ore genesis
  - Type and amount of binder
  - Equipment (disc or drum) and operational conditions

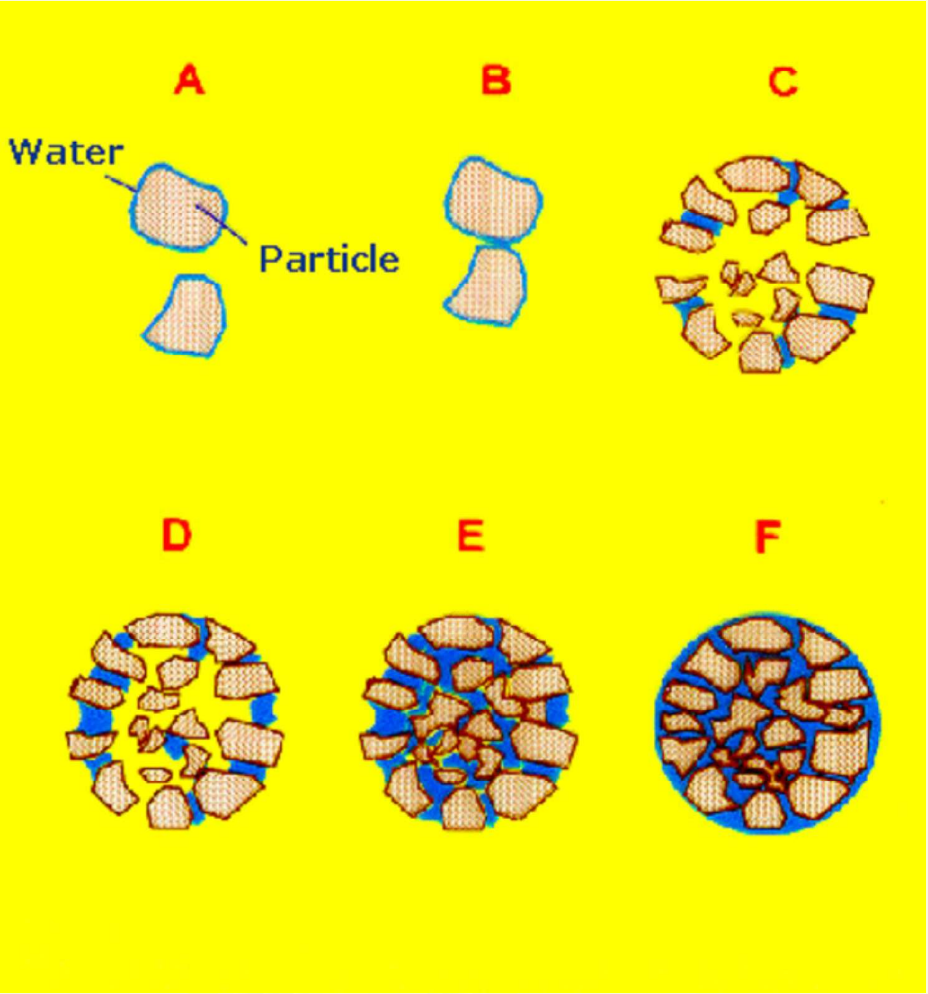
Pelletizing Process - Balling

Effect of capillary forces on the agglomeration mechanism



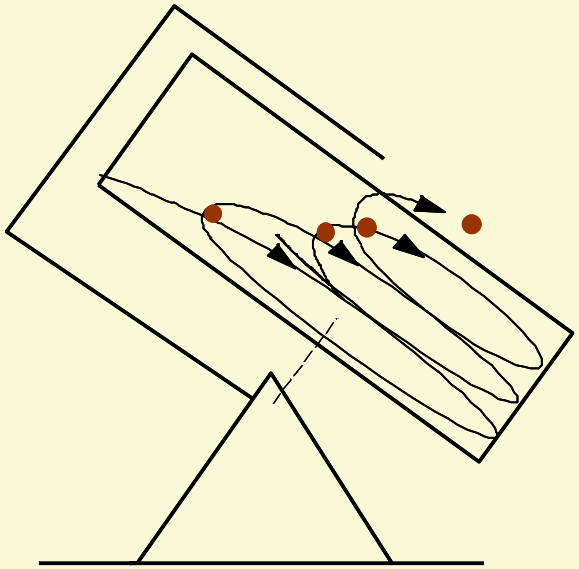
Pelletizing Process - Balling

Mechanism of green pellet Formation – Effect of water addition

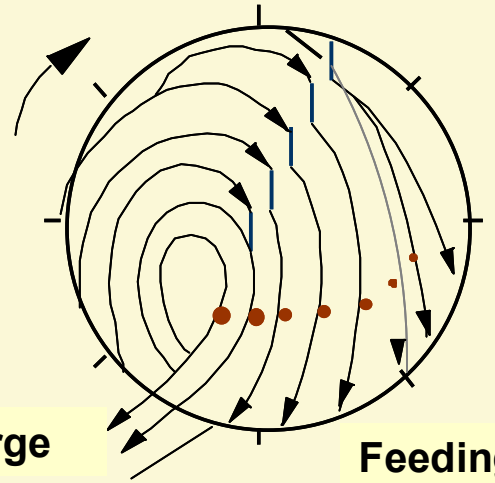


Pelletizing Process - Balling

Material and green pellets movement inside the disc



Transversal View



Top View

Pelletizing Process - Balling

Critical Parameters

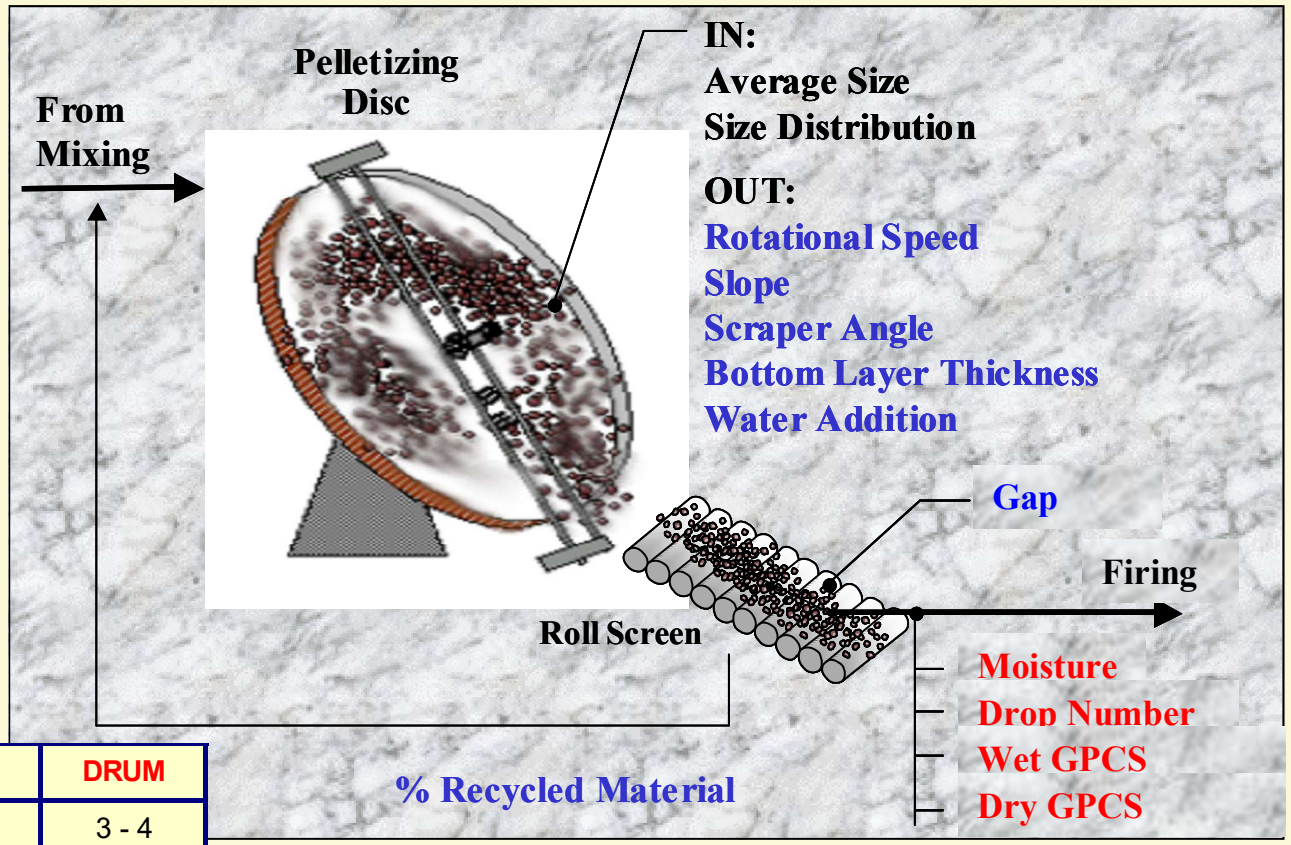
Discs:

- Height and surface of bottom layer
- Slope
- Scrapers – wearing e angle
- "*Forks*"
- Disintegration of green pellets return
- Discharge cleaning
- RPM
- Feeding point
- Feeding rate
- Filter cake moisture
- Binder addition
- Filter cake specific surface

Drum:

- Filter cake moisture
- RPM
- Water addition
- Binder addition
- Feeding rate
- Filter cake specific surface
- Green pellets return rate
- Slope

Pelletizing Process - Balling



	DISC	DRUM
Diameter (m)	5 - 7,5	3 - 4
Lenght (m)	-	9 - 11
Slope	45 - 50	5 - 10
Rotation (rpm)	6 - 7	8 - 15
Capacity (t/h)	90 - 140	90 - 130
Recirculation (%)	20 - 30	200 - 400

- Wet Green Pellet Compressive Strength
- Dry Green Pellet Compressive Strength

Pelletizing Process - Balling

Balling Disc



Pelletizing Process - Balling



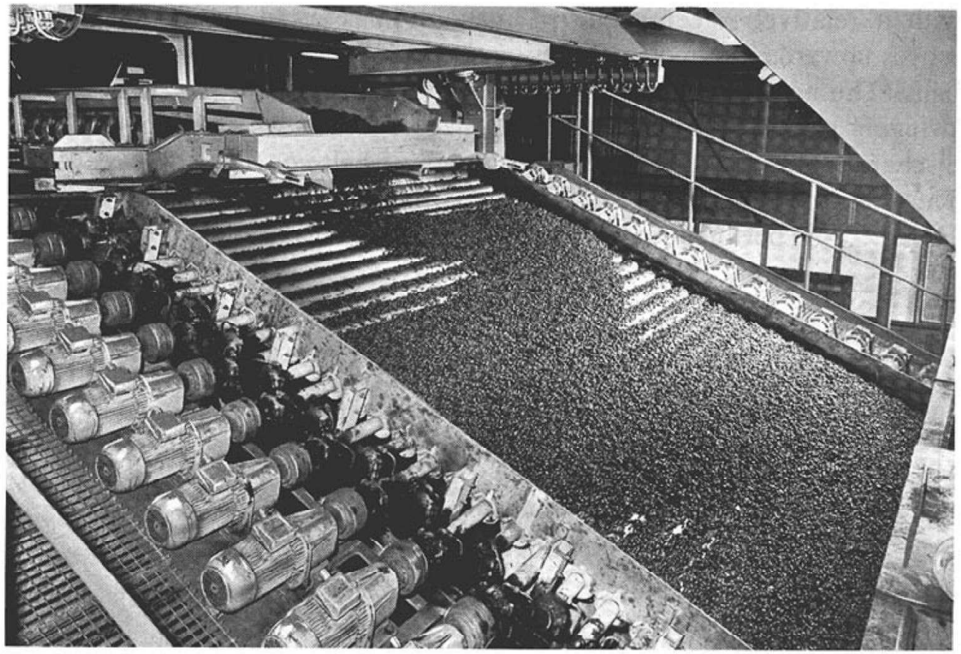
Balling Drum

Diameter (mm)	Length (mm)	Green Pellets Production (tph)
1800	6100	20
2745	9150	80
3050	9755	120
3660	9753	170

Slope: 6° - 10°, Speed: 8 - 14 rpm, depend on iron ore



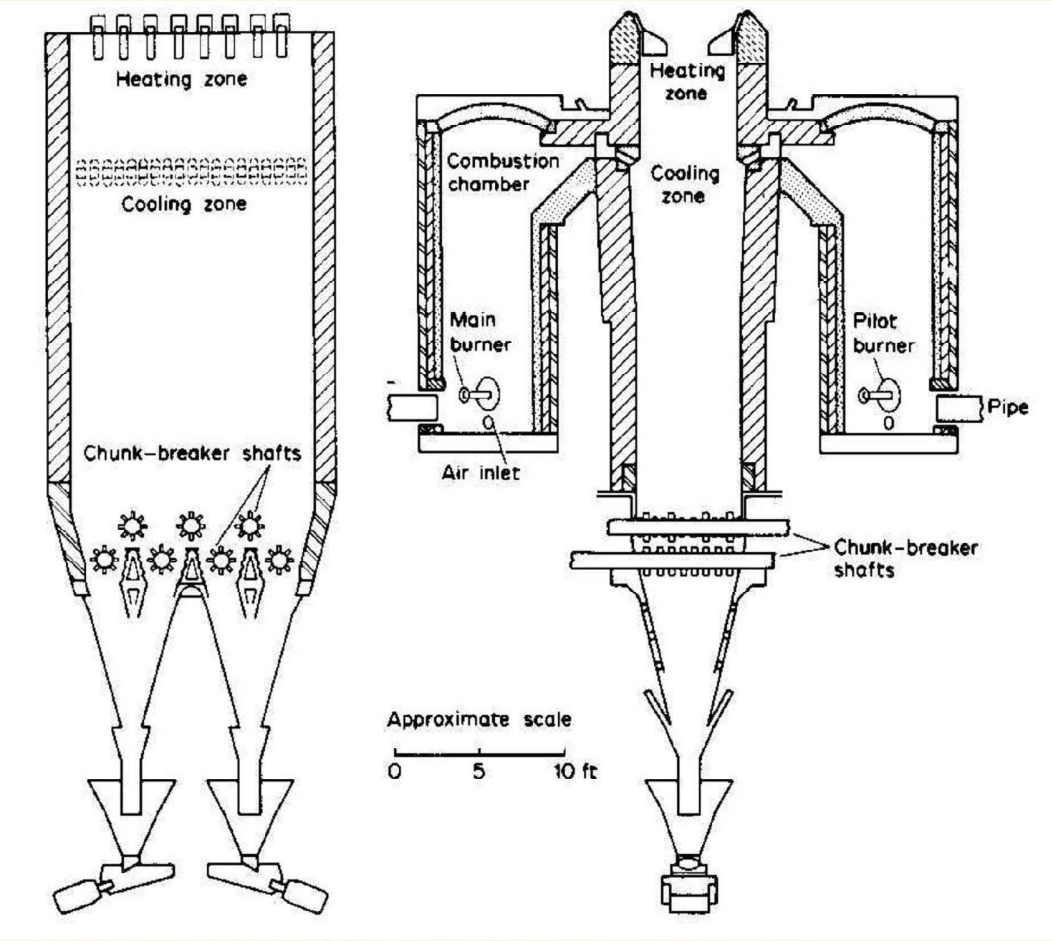
Pelletizing Process – Green Pellets Screening



- Usually, many pelletizing plants have a double deck roller screening before the indurating machine
- Upper deck is responsible for coarse pellets removal
- Bottom deck is responsible for fines removal and the on size green pellets to the indurating machine
- The roller screen efficiency is critical for firing process and indurating machine energy savings

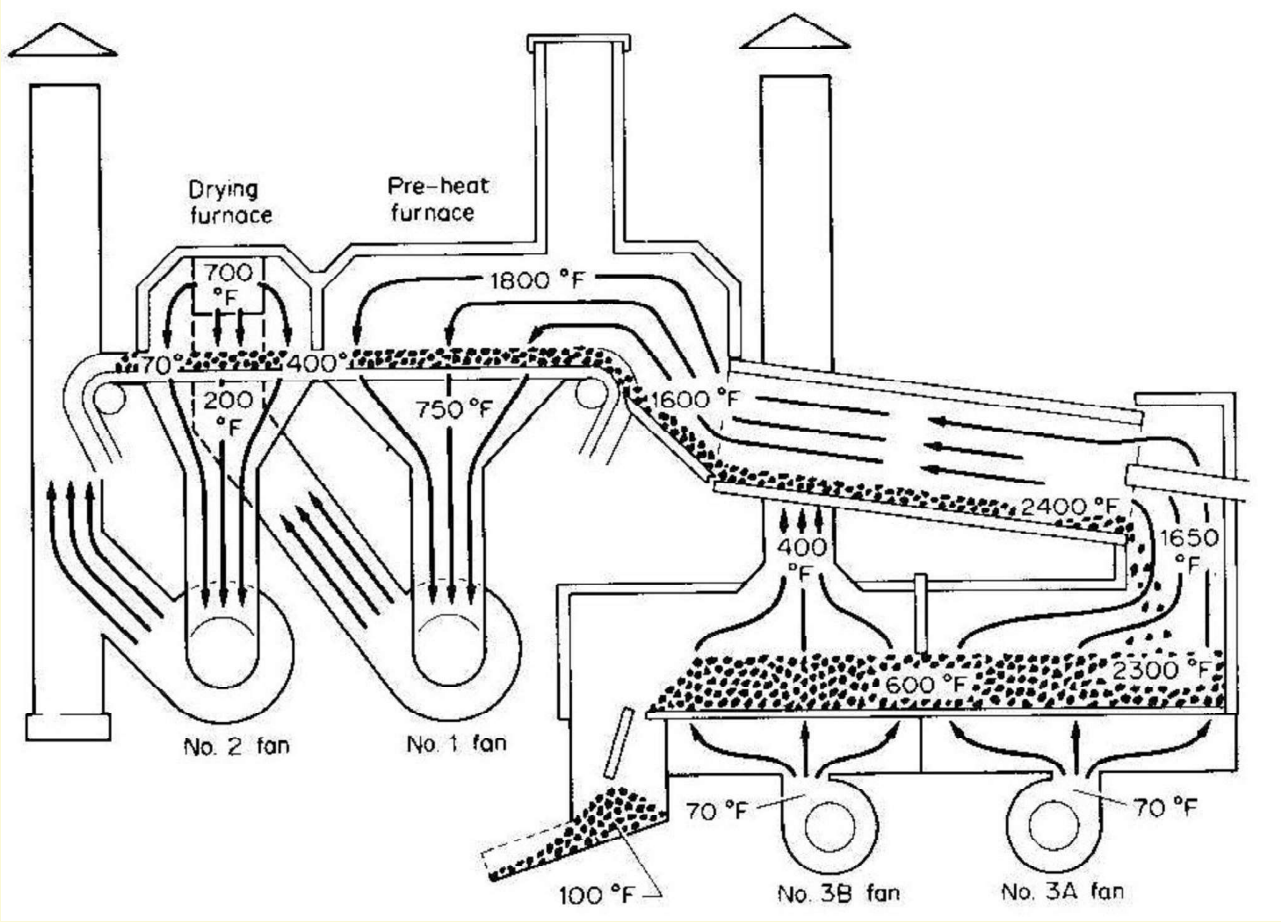
Pelletizing Process – Firing

Vertical shaft-furnace



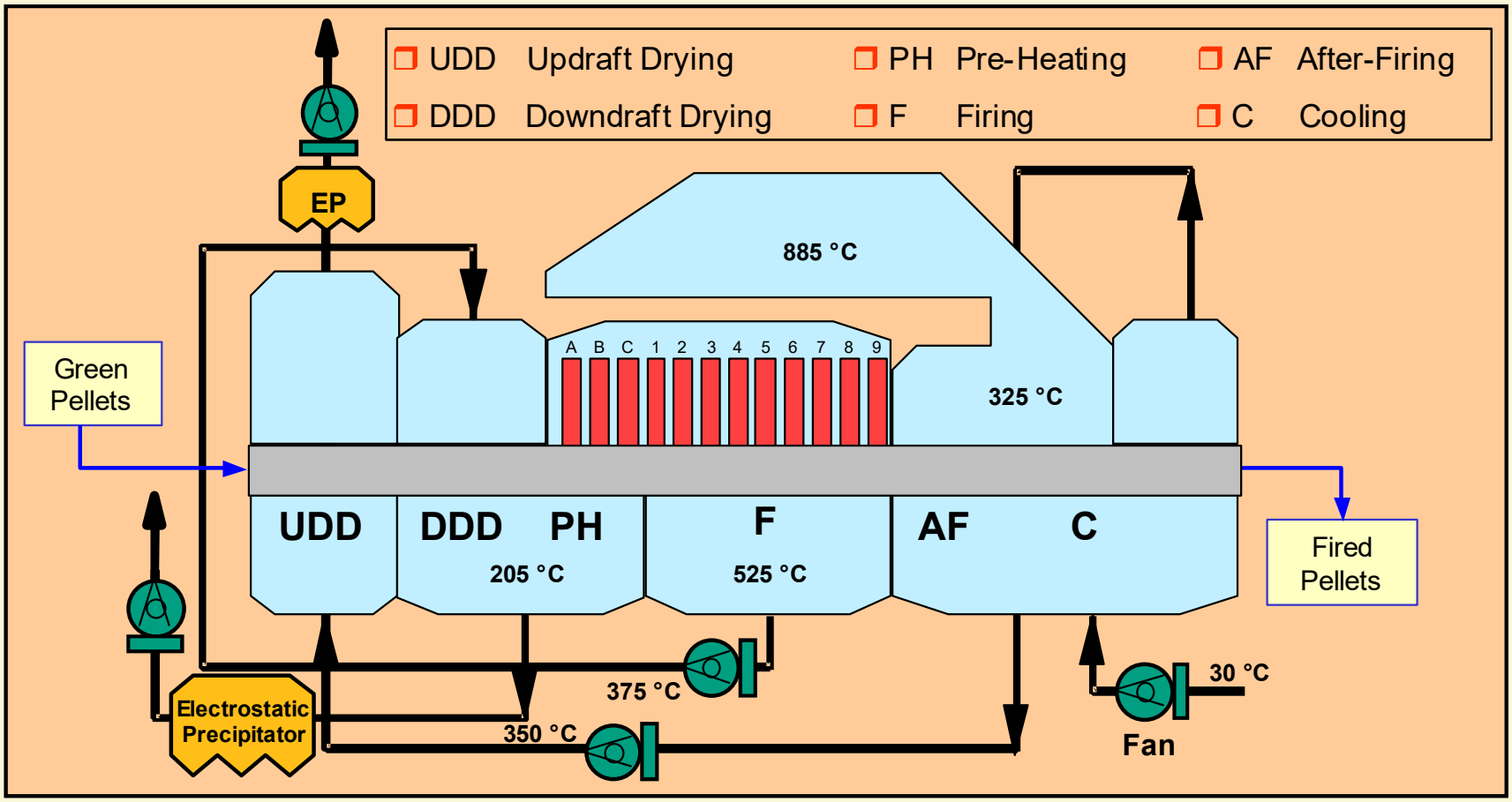
Pelletizing Process – Firing

Grate-kiln system and annular cooler



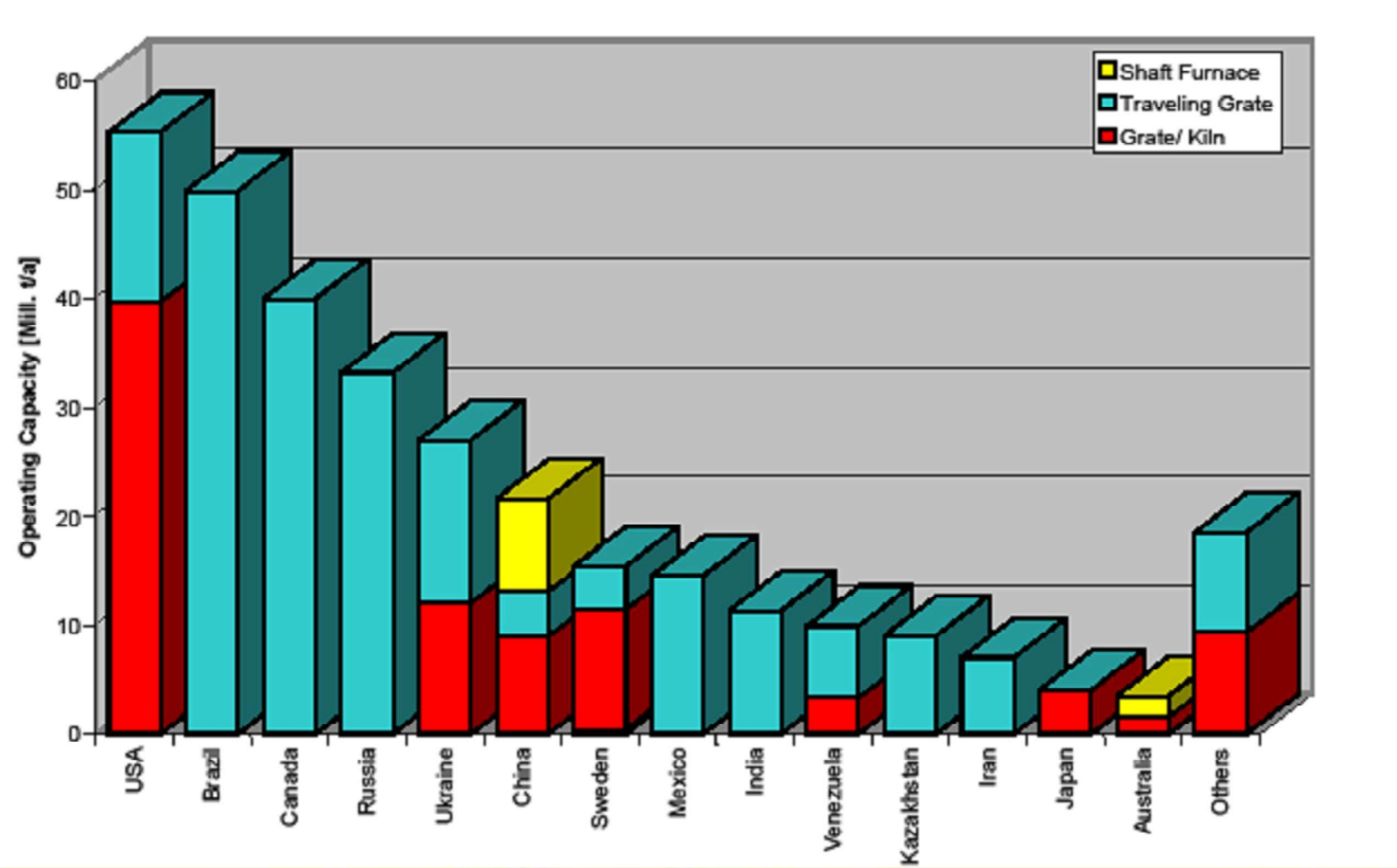
Pelletizing Process - Firing

Traveling Grate – Indurating Machine



Pelletizing Process - Firing

Traveling Grate x Grate Kiln x Shaft Furnace



Pelletizing Process - Firing

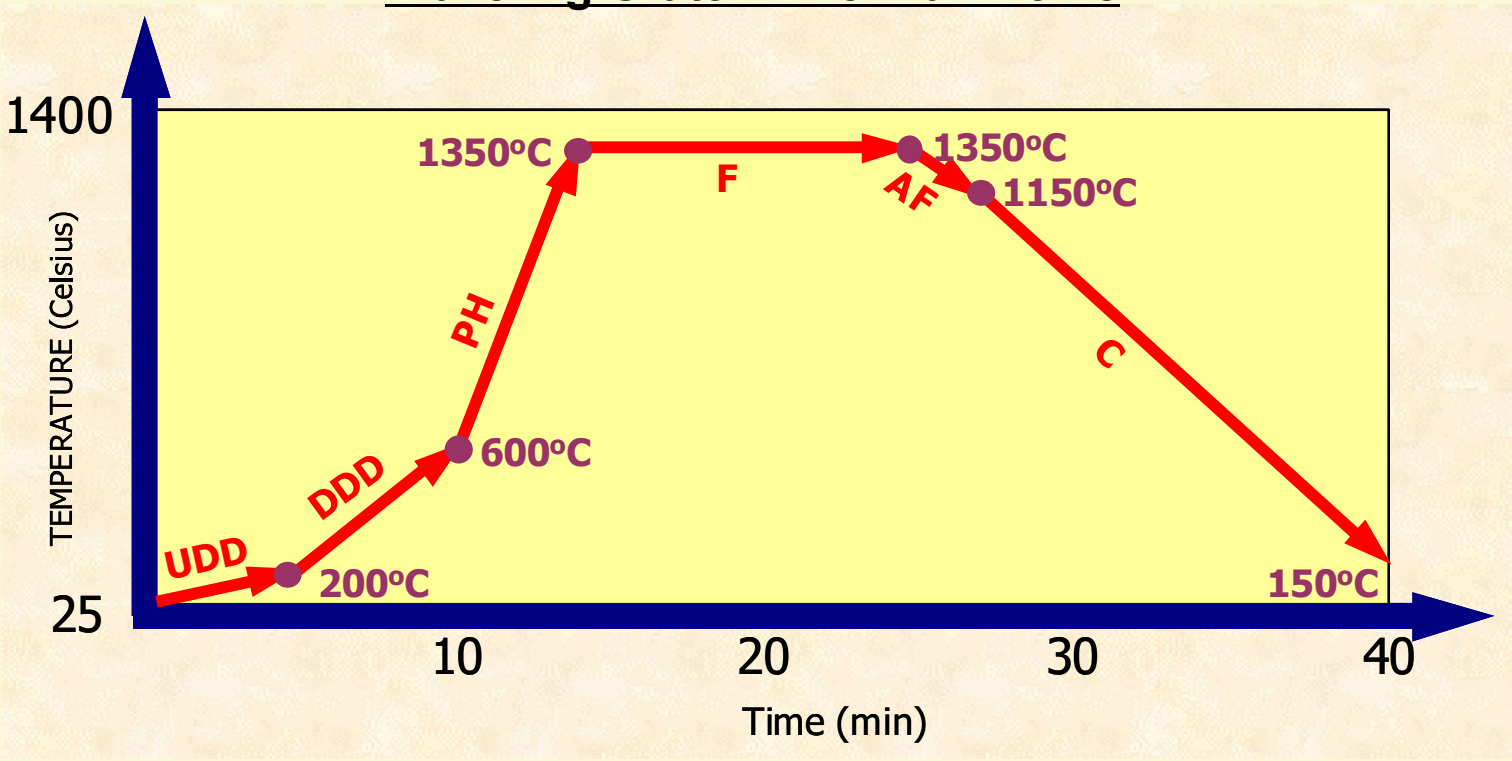
Green Pellets Thermal Treatment

ZONE	T (oC)	PHENOMENA
DRYING	300 - 350	Water partial removal
PRE-FIRING	600 - 900	Crystalizing water removal Calcination and avoid thermal schock
FIRING	1300 - 1350	Consolidation of iron and slag reactions
AFTER FIRING	900 - 1000	Heat homogenizing Magnetite reoxidation Microstructure consolidation
COOLING	80 - 150	Qaulity consolidation Heat recovering

- To give the pellets high mechanical strength and metallurgical properties suitable to the metallurgical reactors

Pelletizing Process - Firing

Traveling Grate – Thermal Profile



- Different products and iron ore request a suitable thermal profile
- The higher LOI content in the mixture the lower Firing and Cooling times/zones

Pelletizing Process - Firing

The influence of firing on pellet strength and hematite recrystallization

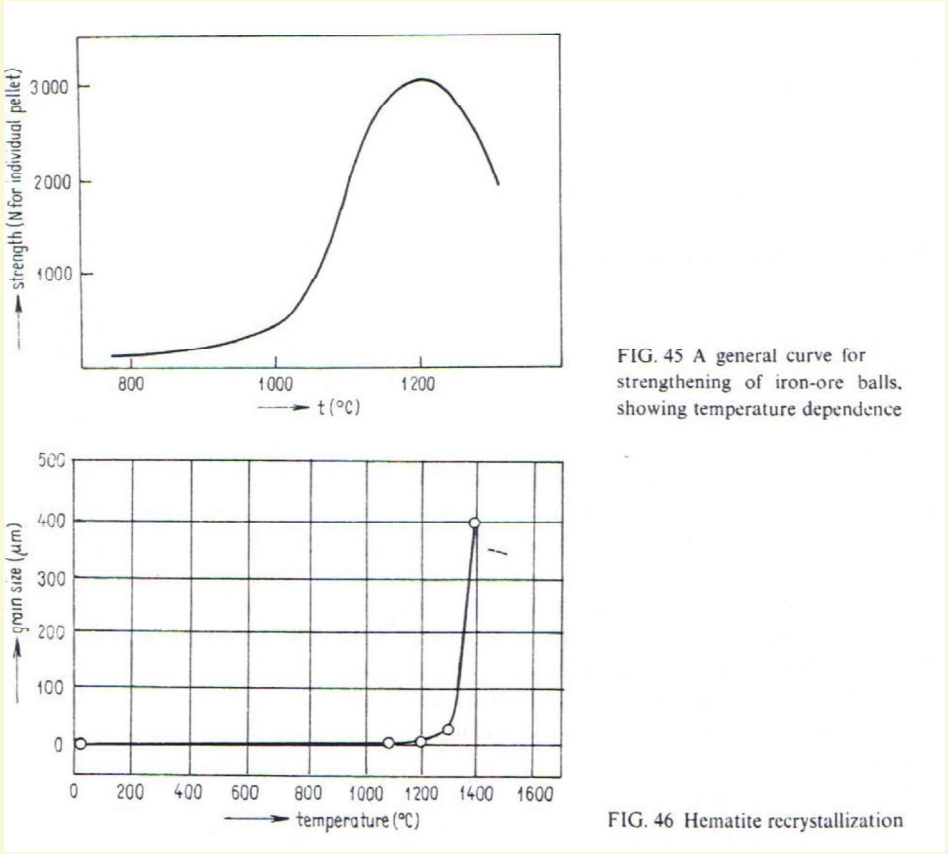


FIG. 45 A general curve for strengthening of iron-ore balls, showing temperature dependence

FIG. 46 Hematite recrystallization

- The higher firing temperature the higher compressive strength of fired pellets
- At high temperature, hematite transforms to magnetite, leading to microstructure weakening
- Hematite recrystallization takes place at high temperatures and reaches the maximum between 1300°C and 1400°C
- The recrystallization depends on temperature and time during firing

Pelletizing Process - Firing

Firing temperature x Residence time

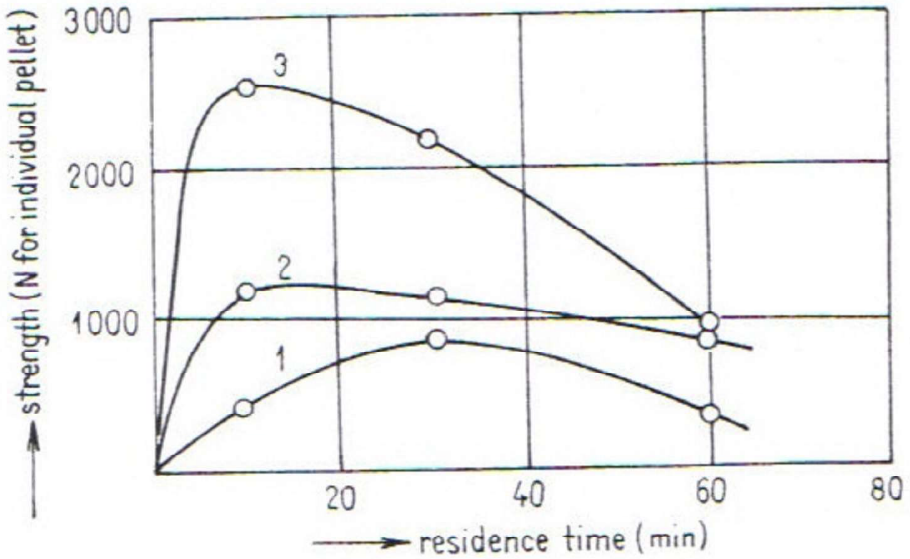
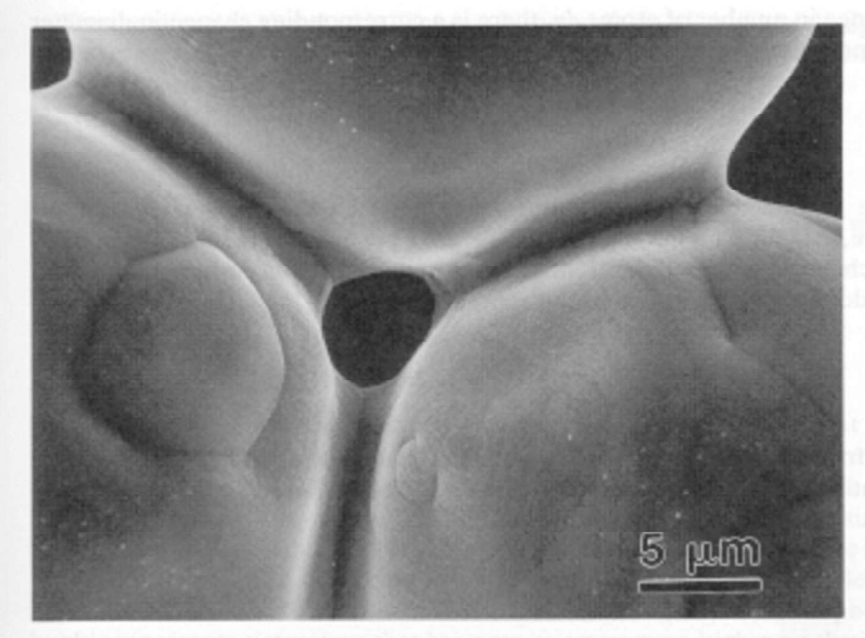


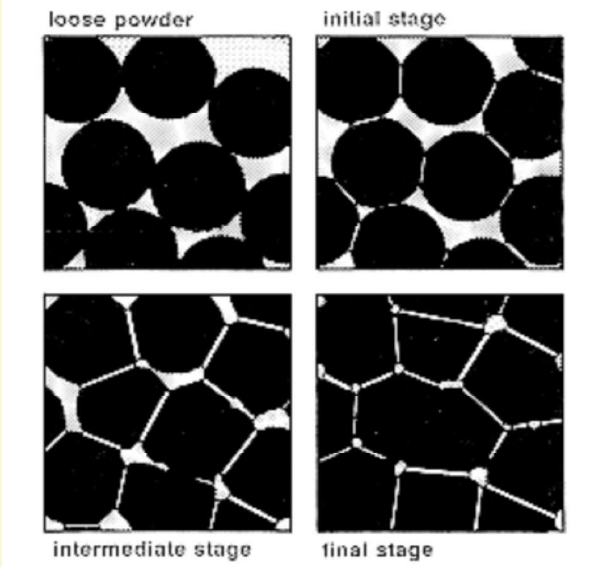
FIG. 47 Compression strength of pellets as depending on firing time
1 – 1 000 °C 2 – 1 100 °C
3 – 1 200 °C

- Fired pellets strength depend on time and temperature of firing
- The temperature affects the indurating machine design – the lower firing temperature the longer residence time and bigger firing zone

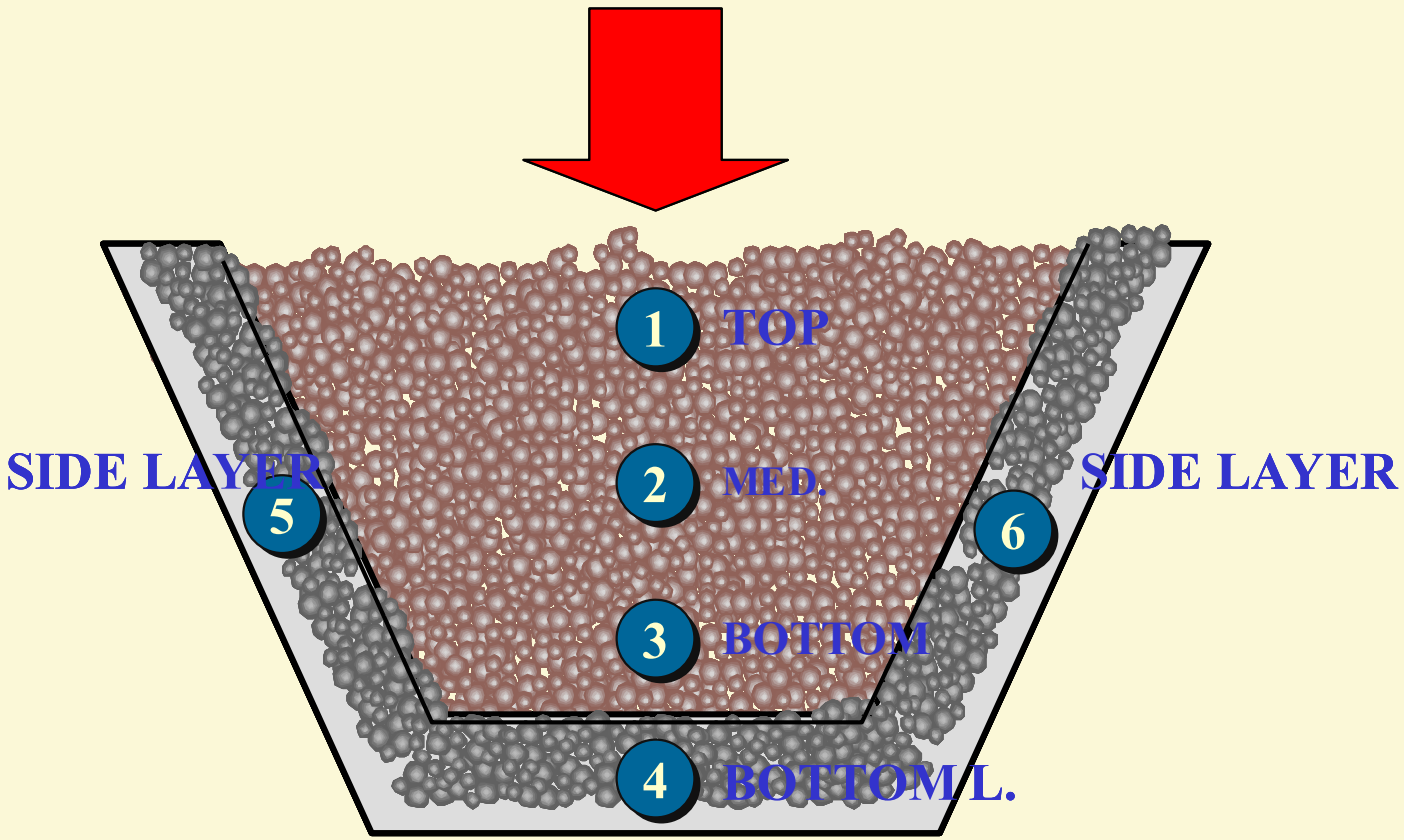
Pelletizing Process - Firing

Microstructure Evolution of Fired Pellets – Quality Improvement

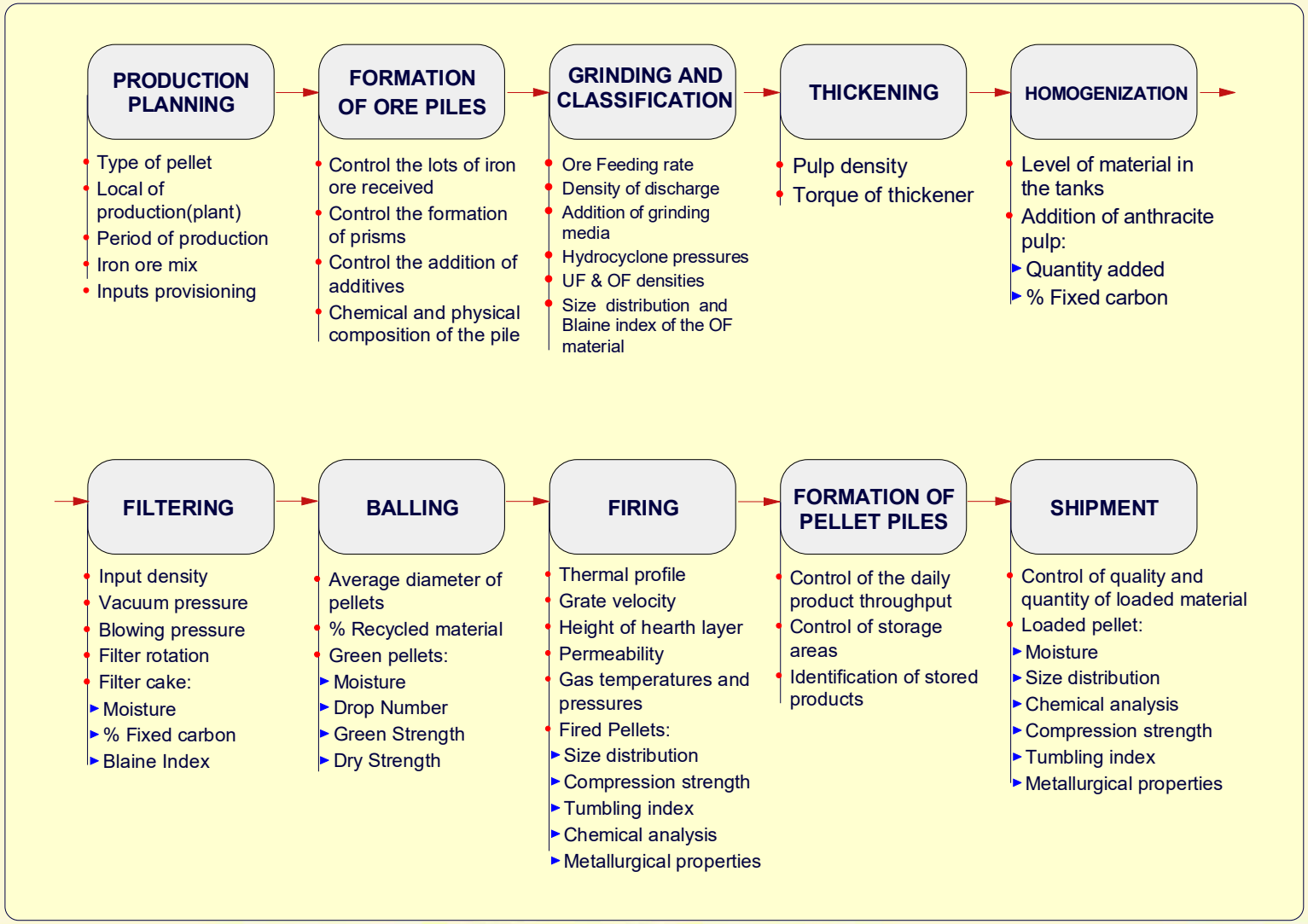




Pelletizing Process - Firing

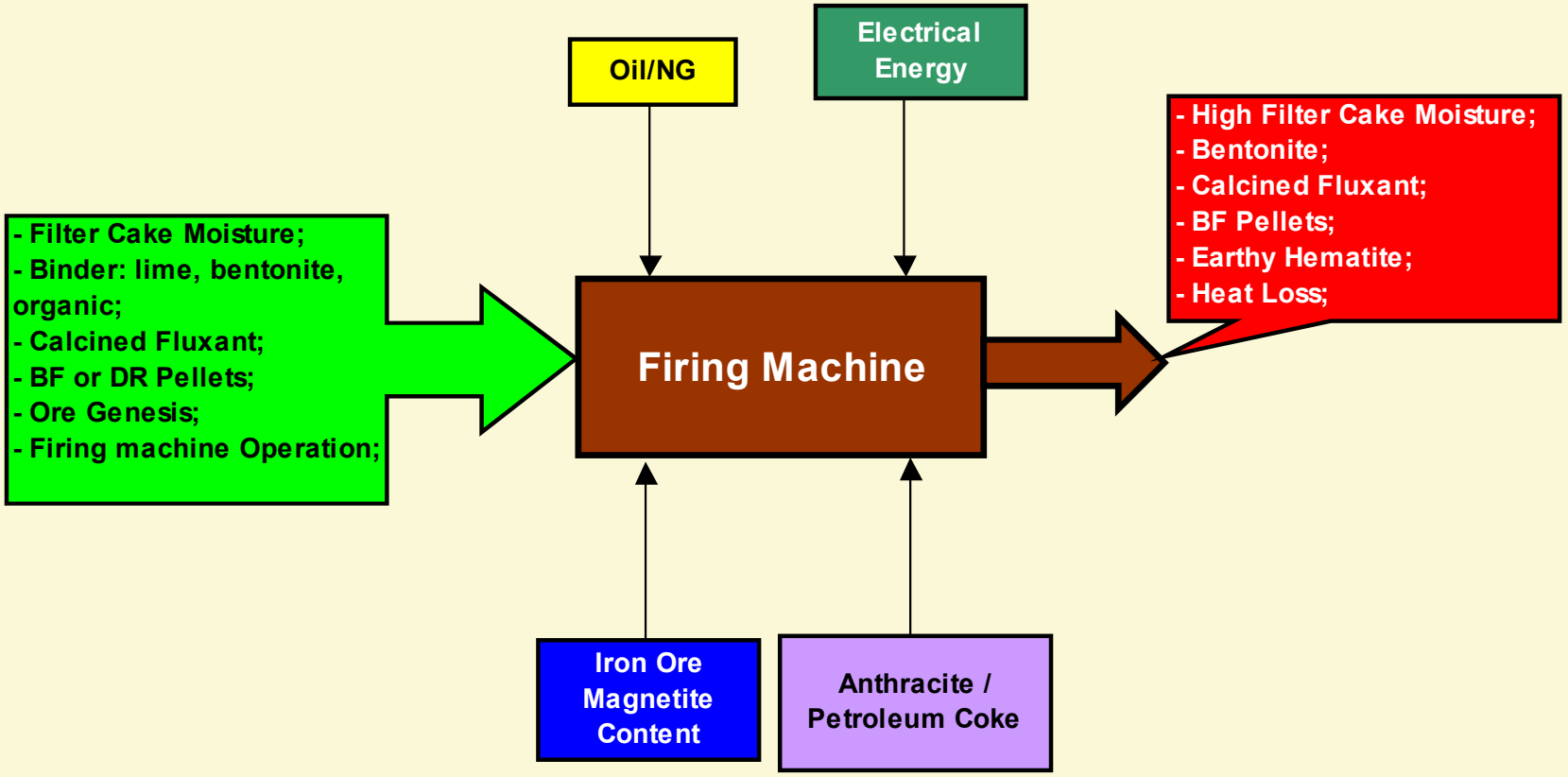


Pelletizing Process – Process Control

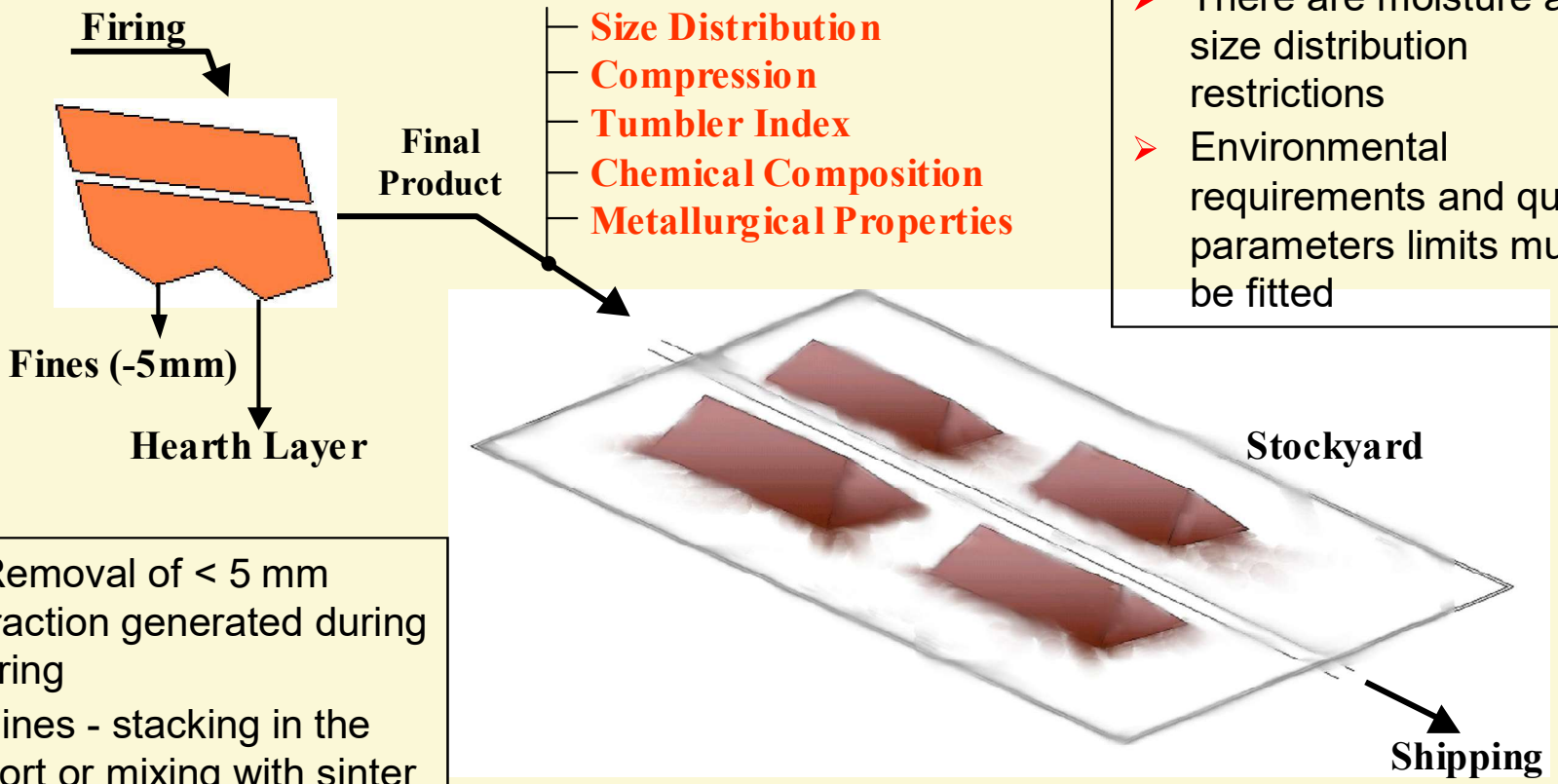


Pelletizing Process - Firing

Firing Process – Energy Balance



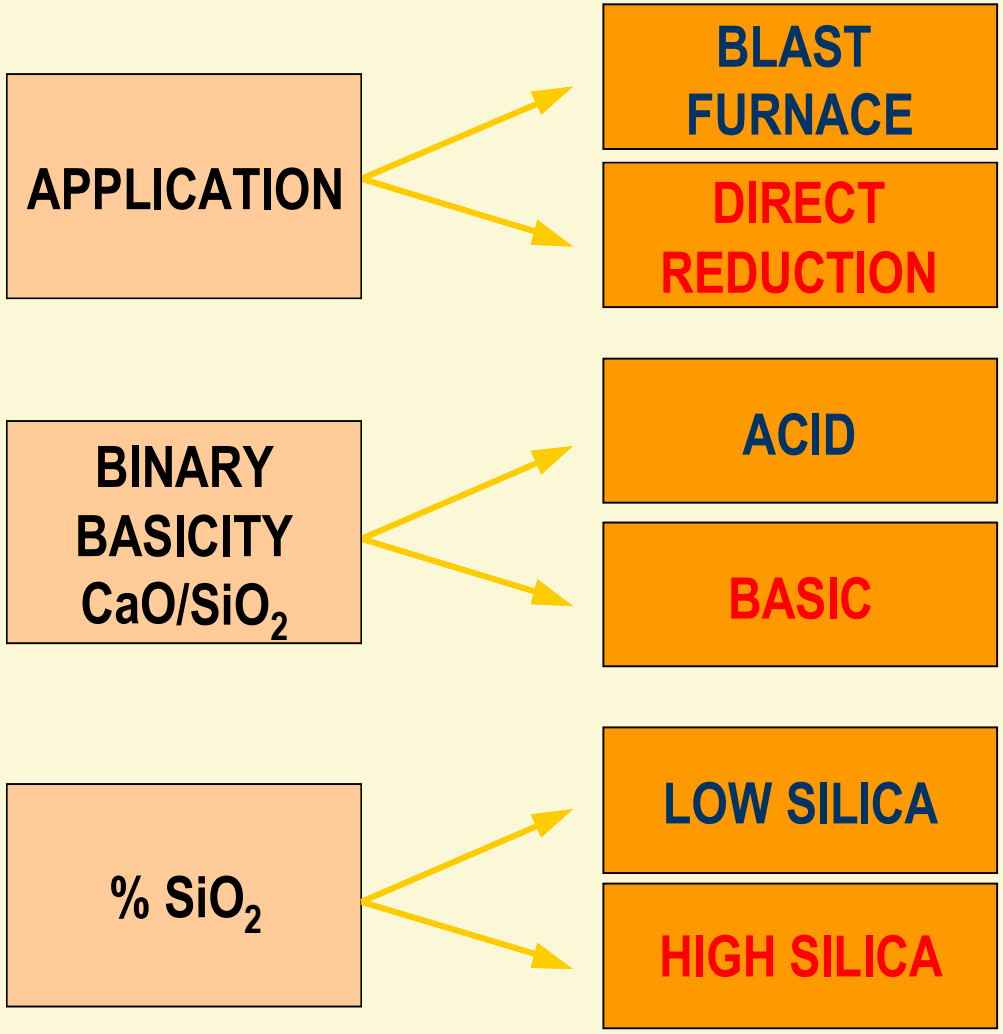
Pelletizing Process – Fired Pellets Screening



- Stacking procedure is used to avoid pellet segregation
- There are moisture and size distribution restrictions
- Environmental requirements and quality parameters limits must be fitted

- Removal of < 5 mm fraction generated during firing
- Fines - stacking in the port or mixing with sinter feed

Quality of Fired Pellets – BF and DR Applications



Quality of Fired Pellets – BF and DR Applications

BF Pellets and Burden Mix

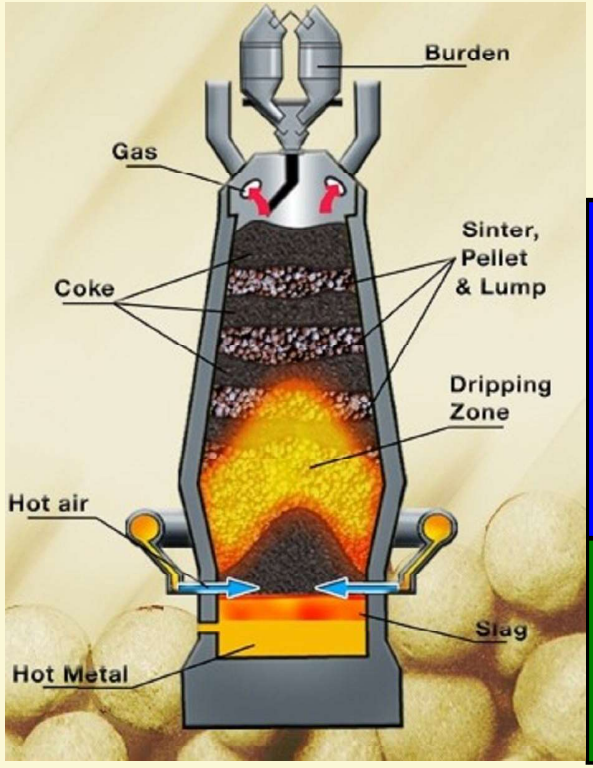
MARKET	BURDEN MIX	BF PELLETS
ASIA	LOW (5% - 15%)	LOW SILICA HIGH BASICITY
EUROPE	MEDIUM (30% - 70%)	LOW SILICA HIGH BASICITY
NORTH AMERICA	HIGH (100%)	HIGH SILICA HIGH BASICITY

Quality of Fired Pellets – BF and DR Applications

General Requirements of Quality Characteristics

- Suitable chemical quality for metallic burden mass balance of reduction unit
- Low impurities content (P, S, Na_2O, K_2O, Al_2O_3, Mn, ...)
- Suitable physical strength to handling and transportation without excessive fines generation
- Good size distribution (9 -16 mm)
- High reducibility
- Low swelling trend
- Low disintegration under reduction
- Low sticking trend
- Good softening & melting properties

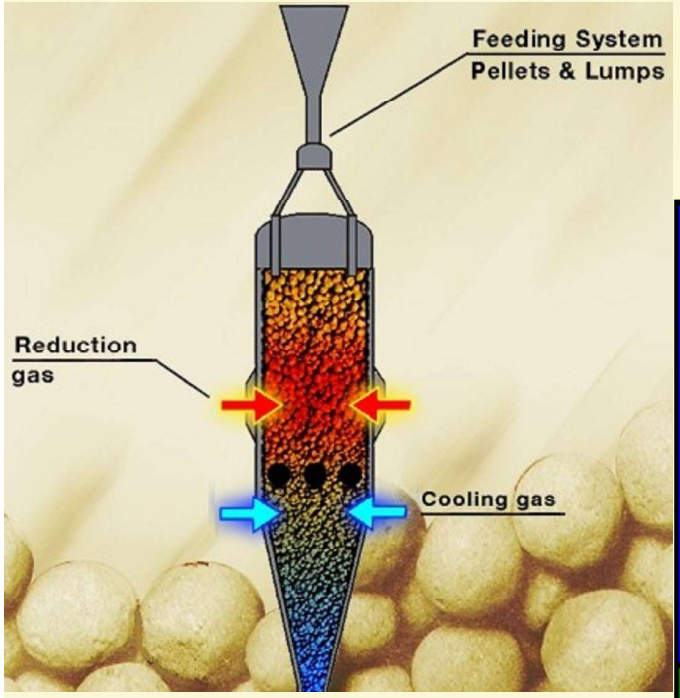
Quality of Fired Pellets – BF and DR Applications



BF Pellets

			PAF - A	PAF - B	PAF - C	PAF - D	PAF - E	PAF - F
Chemical Quality	Fe	%	65,20	65,90	65,80	62,80	63,00	64,50
	SiO2	%	2,70	2,35	3,00	4,30	4,00	5,00
	Al2O3	%	0,55	0,55	0,60	0,60	0,60	0,60
	CaO	%	3,25	2,60	0,70	3,90	4,00	1,25
	MgO	%	0,05	0,05	1,10	0,85	1,00	0,50
	P	%	0,028	0,028	0,025	0,027	0,026	0,027
	S	%	0,002	0,003	0,003	0,003	0,005	0,003
	Mn	%	0,10	0,08	0,10	0,40	0,20	0,20
	CaO/SiO2	-	1,20	1,10	0,25	0,90	1,00	0,25
Physical Quality	Tumbling	%+6,3mm	96,0	94,5	94,5	94,0	94,0	94,0
	Abrasion	%-0,5mm	3,5	4,7	4,4	5,0	5,0	4,5
	Cold Compressive Strength	daN/p	350	300	280	290	280	300
	Porosity	%	25,0	26,0	29,0	30,0	30,0	-
	Size range	% +8 - 18,0mm	96,0	96,0	96,0	96,0	96,0	96,0
		% - 5,0mm	1,0	1,0	1,0	1,0	1,0	1,0
Metallurgical Quality	Swelling	%	13,0	13,0	13,0	15,0	15,0	20,0
	RDI / LTD	%+6,3mm	-	-	-	-	87,0	85,0
		%-0,5mm	-	-	-	-	10,0	10,0
	Delta p	mmCA	-	-	-	-	-	10,0
	Degree of Reduction	%	65,0		-	-	-	-
	Reducibility	$\%O_2$/min	-	69,0	68,0	1,10	-	1,0
	RDI	%-2,8mm	5,0	10,0	7,0	-	-	-

Quality of Fired Pellets – BF and DR Applications



DR Pellets

			PRD - A	PRD - B	PRD - C
Qualidade Química	Fe	%	67,85	68,10	66,70
	SiO2	%	1,20	1,00	1,40
	Al2O3	%	0,50	0,48	0,50
	CaO	%	0,70	0,65	1,60
	MgO	%	0,30	0,28	0,60
	P	%	0,025	0,025	0,025
	S	%	0,002	0,002	0,002
	Mn	%	0,12	0,12	0,12
	CaO/SiO2	-	0,58	0,65	1,14
Qualidade Física	Tamboramento	%+6,3mm	94,5	94,5	94,5
	Abrasão	%-0,5mm	5,0	5,0	5,0
	Resistência Compressão	daN/p	300	300	290
	Porosidade	%	31,0	31,0	32,0
	Granulometria	% +8 - 18,0mm	96,0	96,0	96,0
		% - 5,0mm	1,0	1,0	1,0
Metalúrgica	Desintegração	%-3,15mm	1,0	2,5	1,5
	Metalização	%	93,5	93,5	93

Quality of Fired Pellets – BF and DR Applications

Physical Quality

- Size range of fired pellets
  - Sieve: 5, 8, 10, 12,5, 16 e 18 mm
- Abrasion: Simulate handling and transport operation
  - Tumbling index (% > 6,30 mm)
  - Abrasion index (% < 0,50 mm)
- Compressive strength (daN/p)
  - 60 pellets – production procedure
  - 250 pellets – loading procedure

Quality of Fired Pellets – BF and DR Applications



Compressive Strength



Tumbling



Granulometry

Quality of Fired Pellets – BF and DR Applications

Metallurgical Quality

PARAMETER	STANDARD		MARKET
SWELLING	JIS M 8715	1990	Europe, Asia and South America
	ISO 4698	1994	North America and Europe
REDUCIBILITY	ISO 7215	1995	Relative Reducibility - Europe, Asia and South America
	ISO 4695	1995	North America
	ISO 7992	1992	RUL Test (Reduction Under Load) - Europe (Germany)
Disintegration under Reduction	ISO 4696-1	1996	Static RDI (2% H_2) - North America
	ISO 4692-2	1998	Static RDI - Europe, Asia and South America
	ISO 13930	1998	LTD - Europe (Germany)

Quality of Fired Pellets – BF and DR Applications

- $3\ Fe_2O_3 + CO = 2\ Fe_3O_4 + CO_2$
- $3\ Fe_2O_3 + H_2 = 2\ Fe_3O_4 + H_2O$

HEMATITE ⇩ MAGNETITE

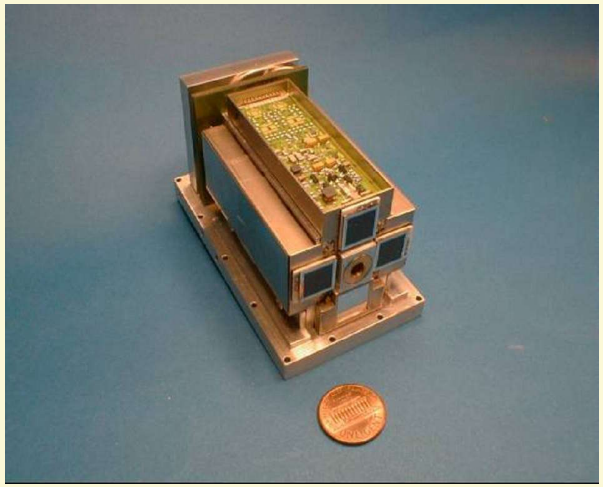
- $Fe_3O_4 + CO = 3\ FeO + CO_2$
- $Fe_3O_4 + H_2 = 3\ FeO + H_2O$

MAGNETITE ⇩ WUSTITE

- $FeO + CO = Fe + CO_2$
- $FeO + H_2 = Fe + H_2O$

WUSTITE ⇩ METALLIC IRON

Product Development and Quality Evaluation Facilities













Product Development and Quality Evaluation Facilities











