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Efficient Technologies for Greenhouse Emissions Abatement

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Pasquale Cavaliere
Department of Innovation Engineering
University of Salento
Lecce, Italy

ISBN 978-3-030-21208-7 ISBN 978-3-030-21209-4 (eBook)
https://doi.org/10.1007/978-3-030-21209-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

World steel demand and production is continuously growing. Being a high energy-intensive and high-impact industry, the energy consumption and the greenhouse gases emissions are destined to double by 2050 if the actual processing routes are *completely* preserved. To avoid this, new paradigms must be developed and approached in order to transform the sector, making it sustainable in the future and compatible with the global warming reduction. By introducing and optimizing energy-efficient solutions to the actual route, only a maximum of 25% of global saving is expected; this target is insufficient for the goals, leading to global warming control and reduction. So, based on current climate change forecast, it is predicted that the steel industry will face greater challenges which cannot be solved with the past incremental technologies in the future. US and European reports underline that if the global warming should be avoided, the only way is to develop and apply breakthrough technologies very fast. The book describes the main available technologies employed in the traditional or innovative routes capable of reducing the energy consumption and the dangerous greenhouse emissions as well as the research efforts that see many scientists involved all around the world from industry, academia, and research centers. Obviously, the energy topic is largely described, taking into account the direct and indirect consumption per each analyzed technology and suggested solution. Regarding coke making, the last years' technological innovations led to lowering air emissions and to the deep limiting of hazardous solid wastes. It is showed that the different technological choices are driven by regional and logistic issues. The treatment of wastewater as a very crucial issue in coke making is largely described. The development and the diffusion of technologies, such as coke dry quenching and coke stabilization quenching, are discussed. The use of coke oven gas in order to abate the dangerous emissions is largely taken into account. Those technologies leading to operational efficiency, coke quality, and productivity are underlined. Another fundamental process for raw materials preparation in the integrated ironmaking/steelmaking route is sintering. CO_2, NOx, SOx, PCDD/Fs, and particulate matters are continuously produced during the whole sintering cycle; this is because of the fuel combustion, carbon in the fed material, and other carbonaceous sources such as limestone and dolomite. All those solutions leading to these dangerous compounds' abatement are described. The employment of biomass as inhibitor and the energy consumption reduction solutions are underlined. Heat recovery at the sinter plant is a means for improving the efficiency of sinter making. Exhaust gases are processed, adsorbed, decomposed, and/or collected as nontoxic by-products to increase the quantity and improve the quality of steam recovery, reaching high fuel savings; all the most efficient methods are reviewed. Computer control technologies for the sintering process were developed along with sinter technology, as sinter quality requirements for the blast furnace were upgraded. Many parameters are involved during sintering. The optimization of these parameters control can lead to the increase in productivity and in the quality of the sintered ores. All the emissions optimized sintering technologies are largely described. The technological evolution of the blast furnace plants led to high efficient reactors very close to their thermodynamic limits. The blast furnace-based production route covers the majority of the steel production all around the world with hundreds of plants. One of the main disadvantages of the integrated route is the necessity of a coke plant with high energy intensity and very high emissions levels. In the direction of reducing these impacts, the injection of carbon-bearing reductants at the tuyere level has given new impetus to blast furnace operational practice to reduce the coke consumption significantly. Another important innovation is represented by the top gar recovery technologies. In the new-generation blast furnaces, oxygen is employed as substitute of the air. Many online process monitoring and control are in use or under development with the overall goal of increasing the process efficiency and fuel consumption and environmental impact reduction. Conversion operations are necessary in the integrated steel plant. Large effort has been devoted to the energy efficiency improvement and to the greenhouse gases emissions reduction. The actual converting technologies are based on a combination of blowing oxygen from the top laces and inert gas or oxygen plus inert gases from the bottom of the reactors. Today's highly efficient electric arc furnaces consume roughly 300 kWh/t-steel. The appropriate greenhouse gas reduction strategy is strongly influenced by the source of electricity generation (i.e., fossil fuel or nuclear). Reduction of indirect emissions requires reducing electrical energy consumption. The current trend toward increased addition of fuel and oxygen has resulted in chemical energy sources supplying a greater proportion of the furnace's energy inputs. Oxyfuel burners in the furnace have become a necessity to increase the rate of scrap melting in cold spots and thereby make scrap melting more uniform and to reduce the electricity needing for the metal fusion. Waste gases recovery and utilization as well as foamy slag practices allow to reduce energy consumption. The bottom stirring practice is getting more and more important and even essential, especially for the furnaces having big temperature gradient in the bath, such as big shell furnace. Modern controls which use a multitude of sensors help to achieve power saving and precise process monitoring to a greater extent than older controls. Direct reduced iron production is destined to increase in the next and far future. This is due to the continuous innovations of the plants leading to less energy consumption and carbon dioxide emissions. In this direction, the technological solutions push toward the waste energy recovery and the use of CO and H_2 as reductant agents. The gas-based processes are located in those regions where natural gas is available in abundance and at reasonable prices. Hydrogen production from water electrolysis to obtain the reducing agent is under development and appears exceptionally promising for the zero-emissions ironmaking. The current CO_2 capture and usage solutions that are available or under development are reviewed. Only the capture of CO_2 will be responsible for the achievement of the goals of the Blue scenario. Intergovernmental Panel on Climate Change (IPCC) scenarios associated with a more than even chance of achieving the 2 °C target are characterized by average capture rates of 10 $GtCO_2$ per year in 2050, 25 $GtCO_2$ per year in 2100, and cumulative storage of 800–3000 $GtCO_2$ by the end of the century. Carbon capture, storage, and utilization are recognized as crucial in climate change mitigations and in particular in a NET contest to limit warming well below the 2 °C scenario. The capture technologies are grouped as chemical/physical absorption, solid adsorbents capture, membranes or molecular sieves physical separation, cryogenics separation, and carbonation. Obviously, this best available technology could be applied globally at current production levels, taking into account precise energy balances, economic feasibility, transition rates, and regulatory and social factors. The principal iron ore electrolysis routes under investigation and development are the molten oxide electrolysis and the electrowinning. Since electrolysis produces no CO_2, it could theoretically be zero-carbon but only if the electricity needed to power the process is produced without generating CO_2 emissions (renewable sources). They are very promising even if at a basic research and pre-industrialization stage.

My special thanks to all the Springer editorial office people for their professionalism. Finally, I would like to dedicate the work to my “miracle” son Alessandro.

Lecce, Italy Pasquale Cavaliere

Contents

Abbreviations

$A/O^1/O^2$	Anoxic/aerobic^1/aerobic^2
A^2/O	Anaerobic-anoxic-aerobic system
AA	Annual average
AC	Alternating current
ACARP	Australian Coal Industry's Research Program
AcC	Activated carbon
ADP	Aquatic depletion potential
AER	Adsorption-enhanced reforming
AFT	Adiabatic flame temperature
AISI	American Iron and Steel Institute
AOD	Argon oxygen decarburization
AOP	Advanced oxidation process
AP	Acidification potential
ARA	Auxiliary reducing agents
ASCM	Adsorption-selective carbon membrane
ASU	Air separation unit
BAT	Best available techniques
BET	Brunauer-Emmett-Teller
BF	Blast furnace
BFB	Bubbling fluidized bed
BFD	Blast furnace dust
BFR	Blast furnace route
BFS	Blast furnace slag
BFSG	Blast furnace shaft gas
BFTG	Blast furnace top gas
BHZ	Bottom heat exchange zone
BIS	Blast furnace inner reaction simulator
BM	Biomass
BOD	Biochemical oxygen demand
BOF	Basic oxygen furnace
BOFG	Basic oxygen furnace gas

BOFS	Basic oxygen furnace slag
BOP	Basic oxygen process
BOS	Basic oxygen steelmaking
BTP	Burn-through point
BTX	Benzene toluene xylene
CA	Chronoamperometry/chronoamperogram
CaL	Calcium looping
CAP	Long-term CO_2 capture scenario
CBP	Composite burnout potential
CC	Continuous casting
CCA	Carbon composite agglomerates
CCD	Charge-coupled device
CCF	Cyclone converter furnace
CCPP	Combined cycle power plant
CCS	Carbon capture and storage
CCSC CO_2	Capture by slag carbonization
CCU CO_2	Carbon capture and utilization
CCUS	Carbon capture use and storage
CDA	Carbon direct avoidance
CDLC	Coal direct chemical looping
CDQ	Coke dry quenching
CDRI	Cold direct reduced iron
CE	Counter electrode
CFB	Circulating fluidized bed
CFP	Carbon footprint
CHG	Compressed hydrogen gas
CHP	Combined heat and power
CLC	Chemical looping combustion
CLH	Chemical looping hydrogen
CMC	Coal moisture control
CMCP	Coal moisture control process
CMSM	Carbon molecular sieving membrane
CN	Cyanide
CNT	Carbon nanotube
COD	Chemical oxygen demand
COG	Coke oven gas
COS	Carbonyl sulfide
COSS	Continuous optimized shaft system
COURSE50 CO_2	Ultimate reduction in the steelmaking process by innovative technologies for cool earth 50
CP	Coke plant
CP/C	Chronopotentiometry/chronopotentiogram
CRACCK CO_2	Recycling and conversion to CO in Korea
CRI	Index of reactivity to CO_2

CRR	Coke replacement rate
CRW	Cold-rolling wastewater
CS	Cold steel
CSCB	Coal stamp charging battery
CSN	Crucible swelling number
CSQ	Coke stabilization quenching
CSR	Coke strength after reaction
CTM	COG to methanol
CTMCR	COG to methanol with CO2 recycle
CTMWOSC	COG to methanol without supplementary carbon
CTMWSC	COG to methanol with supplementary carbon
CV	Calorific value
CV/V	Cyclic voltammetry/voltammogram
CW	Combined water
CW-EDI	Concentrated water from electrodeionization
CWHS	Coke oven gas with H_2 separation
CWOHS	Coke oven gas without H_2 separation
CWQ	Coke wet quenching
CWW	Coke wastewater
DAC	Direct air capture
DAPS	Dry-cleaned and agglomerated pre-compaction system
DAV	Direct alloying with vanadium
DC	Direct current
DDQ	Double dry quenching
DEA	Diethylamine
DFB	Dual fluidized bed
DHE	Dynamic hydrogen electrode
DI	Deadman inlet
DIPA	Disopropanolamine
DIPAM	Tetrahydrothiopene
DMR	Dry methane reforming
DRI	Direct reduced iron
DRIP	Direct reduction iron plant
DSG	Dry slag granulation
DTCR	Dry-type top-gas cleaning and recovery
DTF	Drop tube furnace
DU	Drying unit
EAF	Electric arc furnace
EAFD	Electric arc furnace dust
EBF	Experimental blast furnace
EBT	Eccentric bottom tapping
EC	European Commission
ECOARC	Ecologically friendly and economical arc
ECS	Evaporative cooling system

ED	Electricity demand
EF	Anodic electro
EII	Energy-intensive industry
EINO	Emission index of NO
EMF	Electromotive force
EMS	Electromagnetic stirring
EMSy	Environmental management system
EoL	End of life
EOR	Enhanced oil recovery
EOS	Emissions optimized sintering
EP	Eutrophication potential
EPA	Environmental protection agency
EPB	Environment protection bureau
EPOSINT	Environmentally process optimized sintering
EQ	Equilibrium
EQS	Environmental quality standards
EROI	Energy return on investment
ESCS	Electrostatic space cleaner super
ESP	Electrostatic precipitator
ETC	Energy transitions commission
ETS	Emissions trading system
EU	European Union
EUA	European emission allowances
EUD	Energy utilization diagram
EW	Electrowinning
EWC	European waste catalogue
EWHR	Exergy of waste heat recovery
FA	Fly ash
FAETP	Freshwater aquatic ecotoxicity potential
FAF	Fuel arc furnace
FB	Fluidized bed
FC	Fixed carbon
ffs	Flame front speed
FGR	Flow gas recirculation
FGR	Flue gas recirculation
FGRS	Flue gas recirculation sintering
FIT	Flash ironmaking technology
FOG	Fluidized bed reactor's off-gas
FSCM	Fixed site carrier membranes
FST	Final sinter temperature
FT	Fischer-Tropsch
FWC	Freshwater consumption
GA	Genetic algorithm
GAC	Granular activated carbon

GaCTO	Coke-Oven Gas-Assisted Coal to Olefins
GBFS	Granulated blast furnace slag
GCCSI	Global carbon capture and storage initiative
GHG	Greenhouse gas
GOD	Gas-oxidation degree
GR	Gas recycling
GSC	Gas switching combustion
GWP	Global warming potential
HAP	Hazardous air pollutants
HB	Hot blast
HBI	Hot briquetted iron
HC	Hydrocarbons
HCI	Hot compacted iron
HCMB	High-carbon metallic briquettes
HDPE	High-density polyethylenes
HDRI	Hot direct reduced iron
HECA	Hydrogen energy California
HF	Hearth furnace
HHF	Hearth heating furnace
HHV	Higher heating value
HM	Hot metal
HOD	Heat of decomposition
HPALA	High-pressure ammonia liquor aspiration system
HpCDD	Heptachlorodibenzo-P-dioxin
HpCDF	Heptachlorodibenzo-P-furan
HR	High reactivity
HRC	Hot rolled coil
HRT	Hydraulic retention time
HS	Hot stoves
HTIR	High-temperature indirect reduction
HTP	Human toxicity potential
HV	High volatile
HVM	Heating value of mixture
HW	Hardwood
HxCDD	Hexachlorodibenzo-p-dioxin
HxCDF	Hexachlorodibenzo-p-furan
ICHB	Iron coke hot briquette
IEA	International energy agency
IGAR	Injection de GAz Réformé
IGCC	Integrated gasifier combined cycle
inj	Injected
IOSP	Iron ore sintering plant
IPCC	Intergovernmental panel on climate change
IR	Indirect reduction

ISF	Intensified sifting feeder
ISM	Integrated Steel Mill
ISO	International Organization for Standardization
I-TEF	International toxicity equivalent factors
JISF	Japan Iron and Steel Federation
JSM	Japanese Steel Mill
KET	Key enabling technology
KPI	Key performance indicators
LCA	Life cycle assessment
LD	Linz-Donawitz
LDG	Linz-Donawitz gas
LEEP	Low emission and energy optimized sinter process
LF	Lower furnace
LGMgO	Low-grade MgO
LHV	Low heating value
LIBS	Laser-induced breakdown spectroscopy
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LPM	Lignin-rich press mud
LPMC	Lignin-rich press mud-derived carbons
LPR	Liquid-phase reduction
LRI	Low-reduced iron
LS	Liquid steel
LSV	Linear scan voltammetry/voltammogram
LTIR	Low-temperature indirect reduction
LV	Low volatile
M	Moisture
M40	Percentage of coke remaining on the +40 mm round hole after 100 revolutions
MAC	Maximum allowable concentration
MAETP	Marine ecotoxicity potential
MBBR	Moving bed biofilm reactor
MBF	Magnetic braking feeder
MDEA	Methyldiethanolamine
MEA	Monoethanolamine
MEEP	Moving electrode electrostatic precipitator
MES	Multifunctional energy system
MFA	Materials flow analysis
MLSS	Mixed liquor
MOE	Molten oxide electrolysis
MP	Medium pressure
MPO	Methane partial oxidation
MSFB	Magnetically stabilized fluidized bed
MSR	Methane steam reforming

MSWI	Municipal solid waste incineration
MTL	Metallization
MTO	Methanol to olefins
MWCNT	Multiwalled carbon nanotube
NEDO	New energy and industrial technology development organization
NET	Negative emissions technologies
NF	Nanofiltration
NG	Natural gas
NGO	Nongovernmental organization
NHE	Normal hydrogen electrode
NI	Normal Inlet
NMI	Nonmetallic inclusions
O&M	Operation and maintenance
OBF	Oxygen blast furnace
OBM	Oxygen bottom Maxhütte
OCDD	Octachlorodibenzodioxin
OCDF	Octachlorodibenzofuran
OCOG	Original coke oven gas
ODP	Ozone depletion potential
OECD	the Organisation for Economic Co-operation and Development
OEE	Overall equipment effectiveness
OGS	Operation guidance system
OP	Oxygen plant
OPC	Ordinary portland cement
OR	Oxidation ratio
OSD	One-step decarbonization
OS-RVFLNs	Online sequential random vector functional-link networks
OTI	Optical texture index
PAH	Polycyclic aromatic hydrocarbons
PARAFAC	Parallel factor analysis
PCB	Polychlorinated biphenyls
PCC	Post-combustion capture
PCDDs	Polychlorinated dibenzodioxins
PCDFs	Polychlorinated dibenzofurans
PCI	Pulverized coal injection
PCM	Phase change materials
PCOP	Photochemical oxidation potential
PCR	Pulverized coal ratio
PE	Polyethylene
PeCDD	Pentachlorodibenzo-p-dioxin
PeCDF	Pentachlorodibenzo-p-furan
PEM	Proton exchange membrane
PET	Polyethylene terephthalate

PG	Process gas
PI	Pipe inlet
PID	Proportional integral derivative
PIT	Polymer injection technology
PLA	Waste plastics
PM	Particulate matter
PM_{10}	Particulate pollution (10 μm)
$PM_{2.5}$	Particulate pollution (2.5 μm)
PMDR	Point of minimum direct reduction
POP	Persistent organic pollutants
POR	Partial oxidation reforming
POSCO	Pohang Iron and Steel Company
POX	Partial oxidation
PP	Polypropylene
PS	Polystyrene
PSA	Pressure swing adsorption
PSu	Priority substance
PtCR	Post-combustion ratio
PU/TU	Pyrolysis/torrefaction unit
PVC	Polyvinylchloride
PwP	Power plant
Q-BOP	Bottom-blowing process
R&D	Research and development
R&I	Research and innovation
R/H	Reforming gas/hematite
RAC	Regenerated activated carbon
RAFT	Raceway adiabatic flame temperature
RC	Regression coefficient
RCA	Reactive coke agglomerate
RCAt	Rotary cup atomizer
RCLA	Rotary cylinder atomizer
RCOG	Reformed coke oven gas
RD	Reduction degree
RDI	Reduction disintegration
RE	Reference electrode
RHF	Rotary hearth furnace
RMP	Refractory material plant
RNG	Reformed natural gas
RPB	Rotating packed bed
RVI	Reduction velocity index
RWGS	Reverse water gas reaction
S/F	Sloping flue
S/S	Solidification/stabilization
SBR	Sequential batch reactor

SCF	Standard cubic feet
SCL	Syngas chemical looping
SCM	Supplementary cementitious material
SCNT	Thiocyanate
SCPS	Selective crystallization and phase separation
SCR	Selective catalytic reduction
SCS	Single chamber system
SDQ	Single dry quenching
SECOS	Sintering energy control system
SER	Secondary energy resource
SES	Synthesis energy system
SF	Sinter feed
SFu	Shaft furnace
SI	Shaft injection
Sil	Silicate
SL/RN	Stelco-Lurgi/Republic Steel-National Lead
SMR	Steam methane reforming
SMS	Steel melting shop
SNG	Syngas
SP	Specific Pollutant
SPARG	Sulfur passivated reforming
SPH	Scrap preheating
SR	Steam reforming
SRe	Smelting reduction
SS	Suspended solids
SSAB	Svenskt stål AB
SSB	Supersonic burner
SSDO	Solid-state diffusion of oxygen
SSW	Segregation slit wire
ST	Hot stoves
STA	Simultaneous thermal analysis
SW	Softwood
SWV	Square wave voltammetry/voltammogram
T	Tapping
TBF	Traditional blast furnace
TCDD	Tetrachlorodibenzodioxin
TCDF	Tetrachlorodibenzofuran
TCE	Thermal and chemical energy of hearth gases
TCLP	Toxicity characteristic leaching procedure
TCT	Theoretical combustion temperature
TEP	Terrestrial ecotoxicity potential
TFN	Technological fuel number
TG	Top gas
TGN	Technological greenhouse number

TGRBF	Top gas recycling blast furnace
THM	Ton of hot metal
THZ	Top heat exchange zone
TI	Tuyeres injection
TLS	Ton of liquid steel
TmI	Tumble index
TOC	Total organic carbon
TP	Torrefied pellets
TRL	Technology readiness level
TRM	Tri-reforming of methane
TRS	Thermal reactor system
TRT	Top-pressure recovery turbine
TRZ	Thermal reserve zone
TSG	Tata Steel Group
TSP	Total suspended particulates
TSPM	Total suspended particulate matter
TTN	Technological total number
TW	Terrified wood
TWC	Total water consumption
UBS	Unione di Banche Svizzere
UCS	Unconfined compressive strength
UF	Upper furnace
UHP	Ultrahigh power
ULCOS	Ultralow CO_2 steelmaking
UNFCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
UV	Ultraviolet
VAI	Voest-Alpine Industrieanlagenbau
VIU	Value in use
VLD	Vacuum ladle degasser
VM	Volatile matter
VOC	Volatile organic compounds
VODC	Vacuum oxygen decarburization converter
VPSA	Vacuum pressure swing adsorption
VSA	Vacuum swing adsorption
VSD	Variable speed drive
WAC	Waste acceptance criteria
WACC	Weighted average cost of capital
WB	Wind box
WCP	Water cooled panels
WE	Working electrode
WFD	Water framework directive
WFGD	Wet flue gas desulfurization
WGSR	Water gas shift reaction

WHRS	Waste heat recovery system
WISCO	Wuhan Iron and Steel Company
WL	Wind leg
WP	Wood pellets
WPI	Waste plastic injection
WRZ	Wüstite reserve zone
WTCR	Wet-type top-gas cleaning and recovery
YSZ	Yttria stabilized zirconia
ZR	Zero reformer

List of Figures