



ECIC 2024

9th ECIC

European Coke and Ironmaking Congress

COAL, COKE, BIOCOAL, BIOCOKE, BIOCHAR AND IRON REDUCTION

Bardolino . Italy . 16-18 October 2024

PRODUCTION OF HOT HYDROGEN-RICH SYNGAS IN INTEGRATED PLANTS FOR EFFICIENT INJECTION IN THE BLAST FURNACE AND CO2 MITIGATION

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Production of hot hydrogen-rich syngas in integrated plants for efficient injection in the blast furnace and CO2 mitigation.

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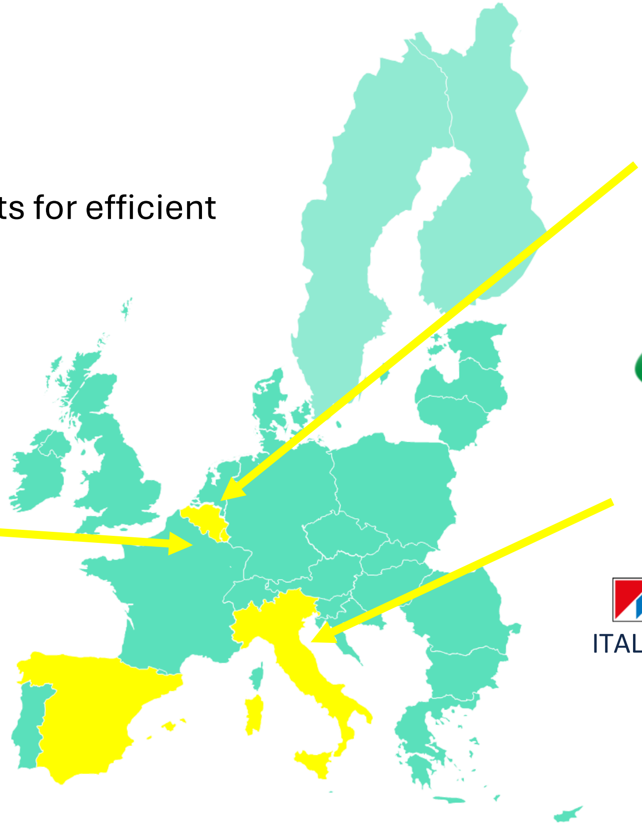
PAUL WURTH SMS group



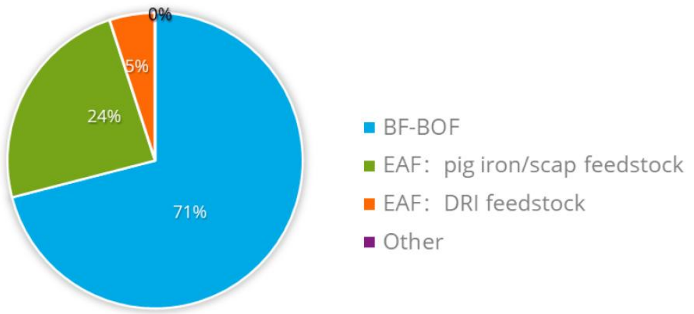
PAUL WURTH SMS group

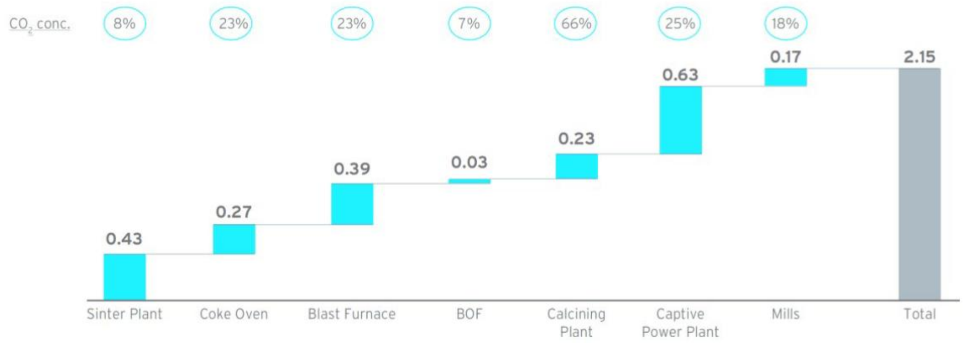
ITALY – Third party

ArcelorMittal

This work was carried out with support from the European Union's Research Fund for Coal and Steel (RFCS) research program under the ongoing project: Production of hot hydrogen-rich syngas in integrated plants for efficient injection in the blast furnace and CO2 mitigation – ProSynteg - GA number: 101057965.

INTRODUCTION





70% of the world steel production is based on Blast Furnace – Basic Oxygen Furnace (BF-BOF) route, that has a strong impact on the CO_2 production.

1 tonne of crude steel → **2,15** tonnes of CO_2

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INTRODUCTION

The replacement of carbon with H2 as a reducing agent is expected to decrease CO2 emission.

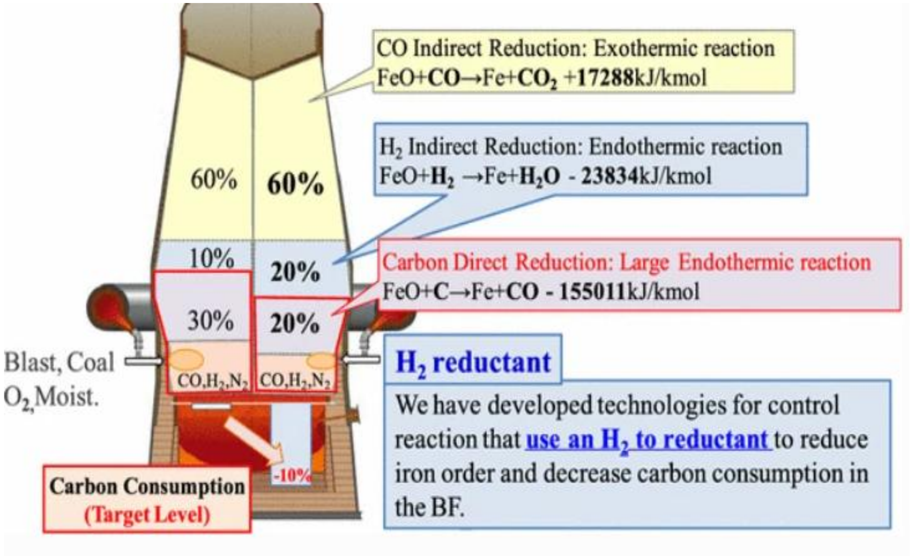
Contrariwise the utilization of H2 in BF deteriorates the process operation from the following issues:

1) H2 requires more energy to compensate the endothermic reaction heats.

Fe2O3 + 3H2 → 2Fe + 3H2O is 100 kJ (endoth.)

Fe2O3 + 3CO → 2Fe + 3CO2 is –23.5 kJ (exoth.).

2) Coke layer is thinned when the reducing agent is replaced by H2 . (C + H2O → CO + H2) (endoth.)



INTRODUCTION

Main possible pathways to reduce CO2 emissions:

1. Utilization of Electric Arc Furnace (**EAF**) technology:
   I. limitations on the availability of scrap metal;
   II. limitations on the production of certain steel grades that require high purity.
2. Optimization of the BF-BOF process route:
   I. improving the efficiency and effectiveness of the BF process for the steel production.

Process Integration (PI) is one of the main pathway dedicated to the process modifications of conventional steel plants processes.

- Gas injection in the BF has a potential of 15-20% total mitigation.

	Mitigation potential (% of average BF/BOF plant)
Use of biomass and spent-C streams at the BF	20-25%
Gas injection in the BF (including the energy required for preparing the gas)	15-20%
Use of some biomass and spent-C streams at the coke plant	5%
Actions at the Sinter plant	5%
Operation of heating applications using low-C fuel gas	5%
CCUS on steel plant gases	40%
	90-100%

PROBLEM ADDRESSED BY PROSYNTEG

In integrated steel plants **coke breeze** is used as a solid fuel in the ore/mineral mix of the sinter strand(s) but in the next future, due to **high environmental impact** of the sinter production, various steelmaking will be forced to close the sinter plants with the necessity to find an **alternative** of coke breeze **utilization**.

MAIN OBJECTIVES

Utilization of the coke breeze calorific value to produce hot H2-rich syngas from dry-reforming of coke oven gas.

PROSYNTEG MAIN TASKS

1. Material characterisation and small scale tests
2. Process modelling
3. Pilot tests campaigns and data collection
4. Impact evaluation on industrial scale economic feasibility of the process

PROJECT CONCEPT

By combining COG with hot CO2, it is possible to thermally reform the methane (and higher hydrocarbons) contained in the COG according to the dry reforming reaction.

COG

	CH_4	C_2H_6	C_2H_4	C_6H_6	O_2	H_2	H_2O	CO	CO_2	N_2
%	22.6	0.8	1.7	1.2	0.4	45.6	1.6	4.8	2.5	18.8

Coke breeze + O2 →

Combustion reactor

C+O2

T~3200 °C

P = 4-6 bar

CO2 + heat →

Reforming reactor

CH4 + CO2 ➔ 2 CO +2 H2 ΔH (1000°C) = +258,9 kJ/mol

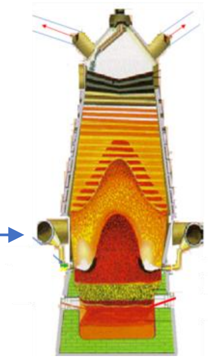
- T~2075 °C

P = 4-6 bar

Flue gas →

	%
H_2	43
CO	32.5
H_2O	6
CH_4	5
CO_2	2
Other	11.6

Syngas injection →



Reduction of Coke rate and CO2 emissions.

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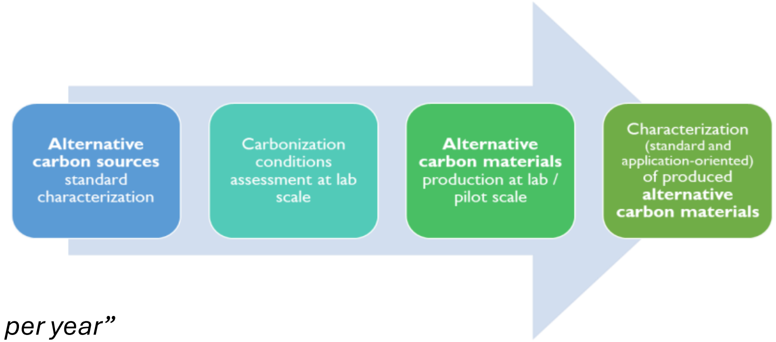
CHARACTERIZATION OF ALTERNATIVE CARBON MATERIALS AND COKE BREEZE

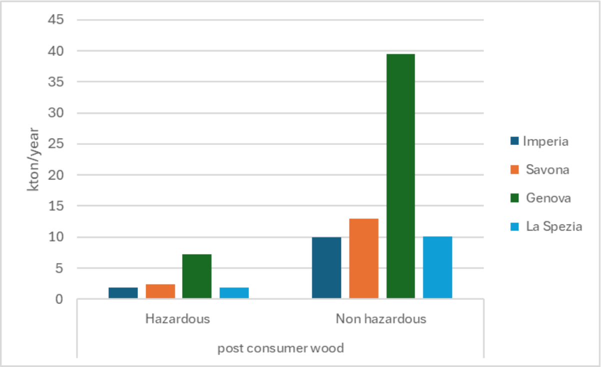
Selection of alternative C-sources (ACS)

1. Recovered post-consumer wood (B-wood)
2. Spent activated carbon (SAC) (industry residue)
3. Natural wood waste from coppice woodland forestry (WW)



"Recovered post-consumer wood (B-wood) is available in Italy at a level of 2 million tons per year"



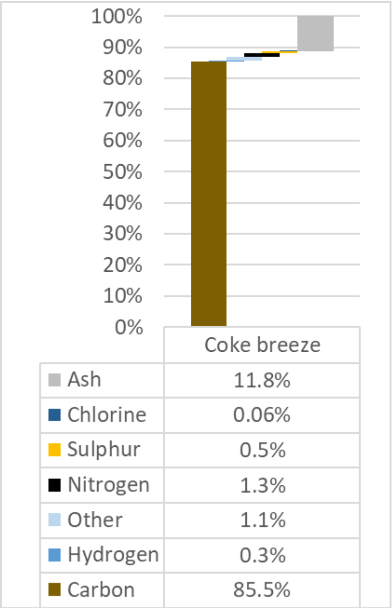



Sources:
- FAO STAT 2024
- http://atlantebiomasse.brindisi.enea.it/atlantebiomasse/mappe.html

CHARACTERIZATION OF ALTERNATIVE CARBON MATERIALS AND COKE BREEZE

Complete characterization of the coke breeze and ACS

Value	Unit	Coke breeze	SAC used in gas cleaning	Waste Wood (WW)	B-wood
Bulk Density					
Bulk density	Kg/m3	854	663	241	152
Proximate analysis					
Volatile matter	% (db)	2,2	12,2	81,4	75,7
Ash	%(db)	11,8	12,0	2,1	3,6
Fixed carbon	%(db)	86,0	75,8	16,5	20,7
Ultimate analysis					
Carbon	% (db)	96,2	93,6	48,8	49,5
Hydrogen	% (db)	0,3	2,5	6,2	5,9
Nitrogen	% (db)	1,5	0,6	0,3	3,0
Sulphur	% (db)	0,8	1,8	0,0	0,0
Oxygen	% (db)	1,2	1,5	44,7	41,6



- **WW and B-wood**: High volatile matter → High steam proportion
- **High-temp pyrolysis** of the three ACS materials reduces volatile matter to 2%

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PREPARATION OF THE SITE FOR THE EXPERIMENTAL TRIALS

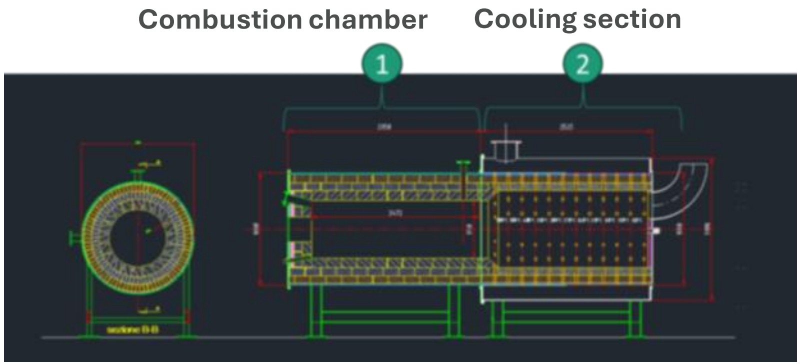
Combustion chamber and injection system design

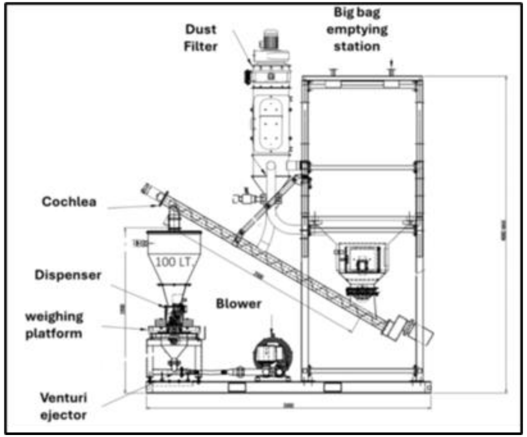
Some characteristics of the combustion chamber.

- Thermal potential: 1000 kWt
- Internal diameter: 1000 mm
- Internal length: 3500 mm
- Flue gas outlet T: 1600 °C

The system will be equipped with:

- an auxiliary heating system
- fuel and oxygen flow rate monitoring
- temperature monitoring system





REFORMING MODEL

Model description

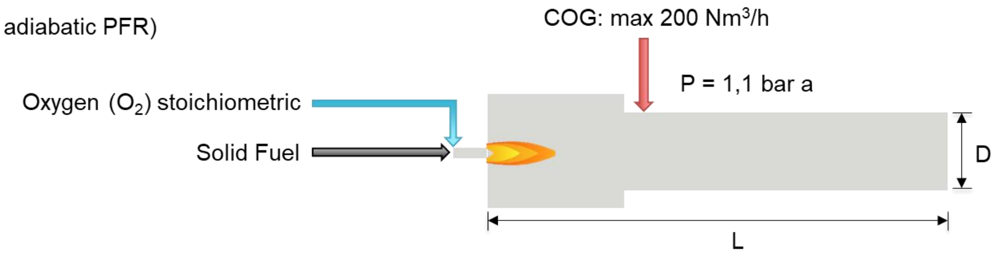
	CH_4	C_2H_6	C_2H_4	C_6H_6	O_2	H_2	H_2O	CO	CO_2	N_2
%	22,6	0,8	1,7	1,2	0,4	45,6	1,6	4,8	2,5	18,8

Simulation:
Flame (CSTR) + Reformer (1D adiabatic PFR)

Coke breeze

	C	H	N	O	Cl
%	84,8	0,3	1,2	1,1	0,06

	Moisture	Volatile matter	Ash	Fixed carbon
%	0,8	2,2	11,7	85,3



Flame evaluation: termodynamic equilibrium, semiempirical data
Reformer evaluation: kinetic calculation, geometrical data
Kinetic scheme: Polimi 50

Constraints:

- ✓ $CH_4 < 5\%$
- ✓ $H_2O < 7\%$
- ✓ T < 1100-1300 °C
- ✓ $\frac{CO+H_2}{CO_2+H_2O} > 7$
- ✓ Soot: as low as possible

REFORMING MODEL

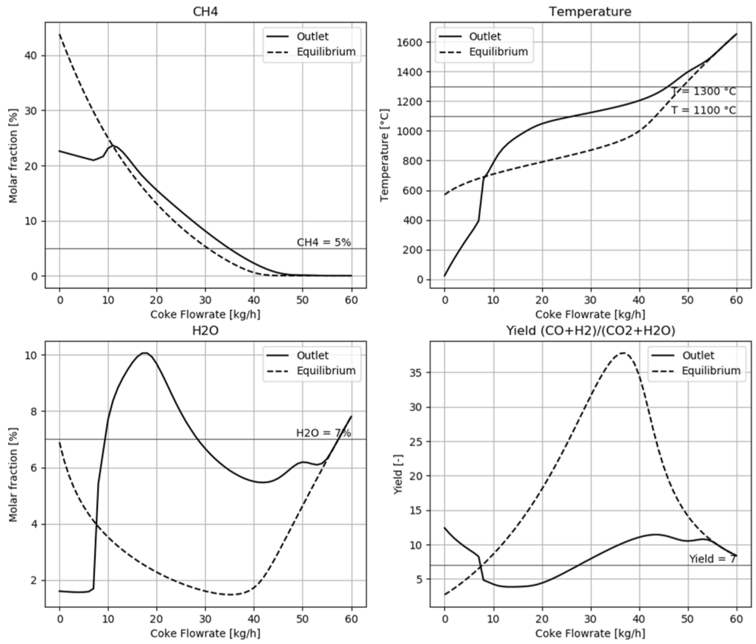
Main model parameters

- Fuel: coke breeze
- O_2: stoichiometric
- COG: 200 Nm^3/h

Results

- Feasible flowrate: between 35 and 46 kg/h
- Lower limits due to methane fraction
- Upper limit due to temperature

COG Nov-2023				
Fcoke (kg/h)	CH4 (% vol)	H2O (% vol)	Tout (°C)	Yield (-)
30	8,10	6,66	1123	7,92
31	7,43	6,48	1130	8,29
32	6,76	6,31	1136	8,65
33	6,12	6,16	1144	9,01
34	5,50	6,02	1151	9,36
35	4,89	5,89	1158	9,69
36	4,32	5,79	1166	10,01
37	3,76	5,69	1175	10,31
38	3,23	5,61	1183	10,59
39	2,73	5,55	1193	10,84
40	2,26	5,50	1204	11,06
41	1,82	5,47	1215	11,24
42	1,43	5,46	1228	11,37
43	1,07	5,48	1242	11,44
44	0,76	5,53	1259	11,43
45	0,52	5,61	1278	11,34
46	0,33	5,73	1300	11,18
47	0,21	5,87	1324	10,96
48	0,14	6,02	1349	10,74
49	0,11	6,14	1374	10,57
50	0,09	6,19	1397	10,51



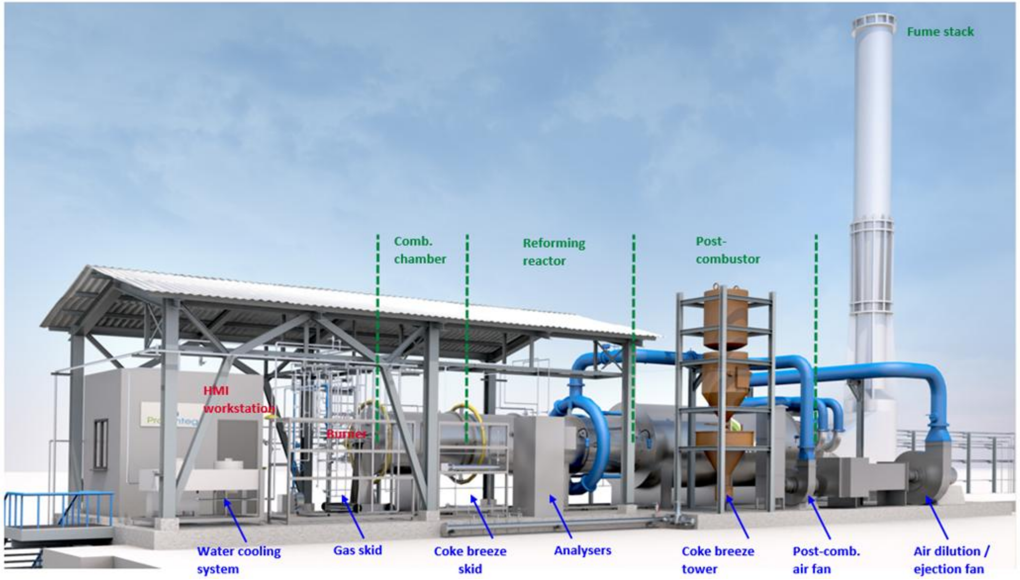
DETAILED ENGINEERING AND ADAPTATION OF THE PILOT PLANT

The pilot plant consists of the following main components.

- Combustion chamber equipped with the oxy-burner (solid fuel burner)
- Reforming reactor
- Post-combustion chamber
- Coke-breeze injection system

Main characteristics

- Production of 500 Nm3/h of reformed gas at T > 1000 °C
- COG feed (200 Nm3/h max)
- Coke breeze feed (90 kg/h max)
- Oxygen feed (190 Nm3/h max)

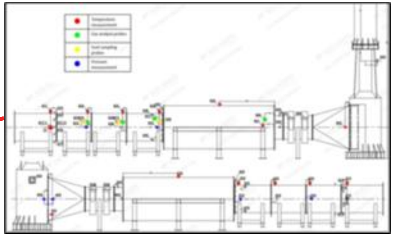


DETAILED ENGINEERING AND ADAPTATION OF THE PILOT PLANT

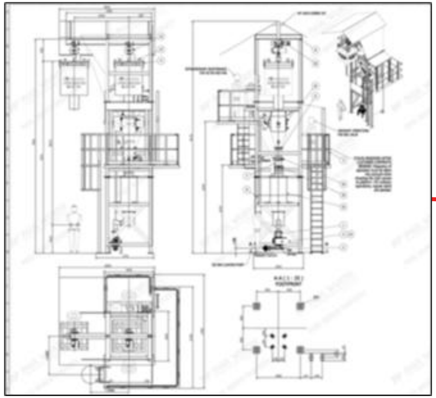
Replacement of the core "tar" equipment with the "coke breeze" equipment

- Technical specification of the **oxy-coke breeze burner** has been defined:
    - Coke breeze composition
    - LHV: about 33405 kJ/kg
    - Nominal capacity: 90 kg/h
    - Comburent: pure oxygen

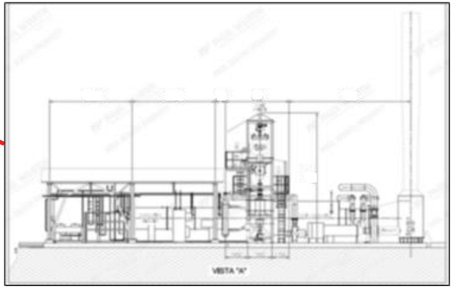
Position of T monitoring system



Coke breeze injection system



Design of new plant layout



CONCLUSIONS

1. B-wood, SAC and Natural wood waste from forestry have been selected as alternative carbon sources (ACS).
   - The criteria for the ACS selection based on:
     - proportion of carbon;
     - the availability of the resource.
2. The design of the combustion chamber and the solid fuel injection system has been completed.
3. The results of the model show that to produce a syngas that can be directly injected in the BF the desired working point for the coke breeze flow rate must be in the range of 35-46 kg/h.
4. The detailed engineering of the adaptation of the pilot plant has been carried out.
   - The pilot plant will have the following characteristics:
     - Production of 500 Nm3/h of reformed gas
     - Gaseous feed: COG or NG
     - Solid circular C feed: coke breeze
     - Oxygen feed

AKNOWLEDGMENTS

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THANK YOU FOR YOUR ATTENTION!

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