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Evaluation of different strategies to improve the efficiency of coal conversion in a 50 kW_{th} Chemical Looping Combustion unit

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CLC with coal

Oxygen Carrier: Me_xO_y

in-situ gasification CLC (iG-CLC)

Preliminary results

	FR (bubbling)	AR (bubbling)
Height bottom (m)	0.3	0.1
Diameter bottom (m)	0.05	0.1
Diameter up (m)	0.08	0.03

Preliminary results

	FR (bubbling)	AR (bubbling)
Height bottom (m)	0.3	0.1
Diameter bottom (m)	0.05	0.1
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Preliminary results

Combustion efficiency

OC: Ilmenite

0.5 kW_{th} unit

	FR (bubbling)	AR (bubbling)
Height bottom (m)	0.3	0.1
Diameter bottom (m)	0.05	0.1
Diameter up (m)	0.08	0.03

Preliminary results

➤ Combustion efficiency*:

- Volatile matter: ~70%
- Gasification products: ~90%

* Adánez et al. Prog. En Comb Sci 65 (2018) 6-66

Combustion efficiency

Management of unburnt products: OXYGEN POLISHING

The objective of this work was to evaluate the potential to increase the **CO₂ capture** and the **combustion efficiency** of the *i*G-CLC process by different strategies

- ❑ A CLC unit was built to carry out the combustion of coal
- ❑ The CO₂ capture and combustion efficiency were evaluated as a function of:
 - Operating conditions: temperature, solids inventory in the fuel reactor, solids circulation rate, power input (12.5–23.5 kW_{th})
 - Gas-solid contact in the fuel reactor
 - Using two reactors to convert the coal

Strategy to increase the CO₂ capture: CARBON STRIPPER

Strategies to decrease the oxygen demand:

➤ Enhance the gas-solid contact

(1) Fluidization: from bubbling to turbulent

(2) Modify the solids distribution in the riser

ring-type internals*

* Schmid et al. Biomass Conv. Bioref. 2 (2012) 229-244

➤ Using an oxygen carrier with higher reactivity

➤ Using a secondary fuel reactor

50 kW_{th} CLC unit

	FR	AR	CS
Height (m)	4.0	4.8	0.7
Diameter bottom (m)	0.1	0.3	0.15
Diameter up (m)	0.08	0.1	-

Combustion tests

Hot conditions in the CLC unit	160 h
Coal combustion	88 h
Tests at steady stay	34

Oxygen carriers

	Ilmenite	Tierga Fe-ore
d _p (mm)	0.1-0.3	0.1-0.2
Density (kg/m ³)	3000	3100
Active phases	Fe ₂ TiO ₅ / FeTiO ₃	Fe ₂ O ₃ /Fe ₃ O ₄
R _{OC} (%)	4.0	2.5

Solid fuels

wt.% as received	South Africa	Taldinsky
Moisture	3.5	5.8
Volatile matter	25.5	32.1
Fixed carbon	55.3	52.1
Ash	15.7	10.0
C	66.3	65.8
H	3.6	4.0
N	1.8	2.0
S	0.5	0.5
LHV (kJ/kg)	24930	26640

Relevance of the CARBON STRIPPER

Ilmenite + South African coal

- ❖ The presence of a **Carbon Stripper** in the 50 kW_{th} unit improved the CO₂ capture (although the mean residence time of solids was lower than in the 0.5 kW_{th} unit)

Relevance of the CARBON STRIPPER

Ilmenite + South African coal

❖ The higher gas velocity in Carbon Stripper led to the higher CO₂ capture efficiency

Relevance of the fluidization regime & operating conditions

Ilmenite

	CLC unit	Coal	F_{oc} (kg/s MW _{th})	ϕ
●	0.5 kW	South Africa	2.2	1.1
▲	50 kW	South Africa	2.2	1.1

Oxygen carrier
to fuel ratio

$$\phi = \frac{\text{Ox. in oxygen carrier}}{\text{Ox for coal combustion}}$$

- ❖ The oxidation of volatile matter in the 50 kW_{th} CLC unit was more efficient than in the 0.5 kW_{th} CLC unit because gas-solid reaction was improved in the riser

Relevance of the fluidization regime & operating conditions

Ilmenite

	CLC unit	Coal	F_{oc} (kg/s MW _{th})	ϕ
●	0.5 kW	South Africa	2.2	1.1
▲	50 kW	South Africa	2.2	1.1
▲	50 kW	South Africa	3.0	1.5

- ❖ The oxygen demand could be decreased by increasing:
 - The solids inventory in the fuel reactor (kg/MW_{th})
 - The oxygen carrier to fuel ratio (ϕ)

$\phi = 1.5$ and ~ 700 kg/MW_{th}
 $\Omega_T = 5\%$

Relevance of the fluidization regime & operating conditions

Ilmenite

	CLC unit	Coal	F_{oc} (kg/s MW _{th})	ϕ
●	0.5 kW	South Africa	2.2	1.1
▲	50 kW	South Africa	2.2	1.1
▲	50 kW	South Africa	3.0	1.5
■	50 kW	Taldinsky	2.5	1.3

- ❖ Taldinsky coal has a higher fraction of volatile matter (38.1% daf) compared to coal from South Africa (31.6% daf)

Improvement of the gas-solid contact (ring-type internals)

FUEL REACTOR

The rings were wedge-shaped designed, with the **opening section being the 60%** of the reactor cross-section

Results: combustion efficiency

Improvement of the gas-solid contact (ring-type internals)

Ilmenite + Taldinsky coal

Main unburnt compounds

- ❖ The presence of the ring-type internals decreased the Oxygen Demand, i.e. improved the combustion efficiency
- ❖ Both volatile matter and gasification products were better oxidised

Using a more reactive oxygen carrier: Tierga iron ore

- ❖ With equal circulation of solids, lower values of Oxygen demand were achieved, even with less solids of Fe-ore than with ilmenite

Results: combustion efficiency

Using a secondary fuel reactor: coal feed to the carbon stripper

Using a secondary fuel reactor: coal feed to the carbon stripper

- ❖ The feeding of coal to the carbon stripper produced a decrease of 25% in the Oxygen demand compared to usual operation (i.e. coal feeding to the fuel reactor)

Overview on the improvement of the Oxygen Demand

(I) Optimizing operating conditions

- Oxygen carrier: ILMENITE
- Coal: South African

	Solids in FR (kg/MW _{th})	Circulation (kg/sMW _{th})
Il-1	466	2.2
Il-2	481	3.1
Il-3	722	3.1

Overview on the improvement of the Oxygen Demand

(1) Optimizing operating conditions

(2) Internals in FR

- Oxygen carrier: ILMENITE
- Coal: Taldinsky

INTERNALS	
II-4	NO
II-5	YES

Overview on the improvement of the Oxygen Demand

(1) Optimizing operating conditions

(2) Internals in FR

(3) Oxygen carrier reactivity

- Oxygen carrier: ILMENITE & Fe-ore
- Coal: South African

	Solids in FR (kg/MW _{th})	Circulation (kg/sMW _{th})
Il-1	466	2.2
Fe-1	485	2.2

Overview on the improvement of the Oxygen Demand

(1) Optimizing operating conditions

(2) Internals in FR

(3) Oxygen carrier reactivity

(4) Coal feedind point (FR or CS)

➤ Oxygen carrier: TIERGA Fe-ore

➤ Coal: South African

COAL FEED	
Fe-1	Fuel Reactor
Fe-2	Carbon Stripper

Overview on the improvement of the Oxygen Demand

(1) Optimizing operating conditions

(2) Internals in FR

(3) Oxygen carrier reactivity

(4) Coal feedind point (FR or CS)

(5) Operating conditions

- Oxygen carrier: TIERGA Fe-ore
- Coal: South African

	Solids in FR (kg/MW _{th})	Circulation (kg/sMW _{th})
Fe-1	485	2.2
Fe-3	525	3.6
Fe-4	465	4.9

- ❖ iG-CLC process allows coal combustion with high CO₂ capture rates when a carbon separation system was included
- ❖ Oxygen demand could be decreased by:
 - Optimizing the operating conditions (-25%)
 - Using more reactive oxygen carriers (-30% Fe-ore vs. ilmenite)
 - Design considerations:
 - Fuel reactor being a circulating fluidised bed (at least -40%)
 - Implementing ring-type internals in the fuel reactor (-25%)
 - Feeding coal to the Carbon Stripper (-25%)
- ❖ The oxygen demand was as low as 4 % with 465 kg/MW_{th} of solids in the fuel reactor and specific solids circulation of 5 kg/s per MW_{th}
- ❖ Further decrease of the oxygen demand would be possible by combining different options

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