Application of Chemical Looping with Spouting Fluidized Bed for Hydrogen-Rich Syngas Production from Catalytic Coal Gasification

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CLG Process Under Evaluation

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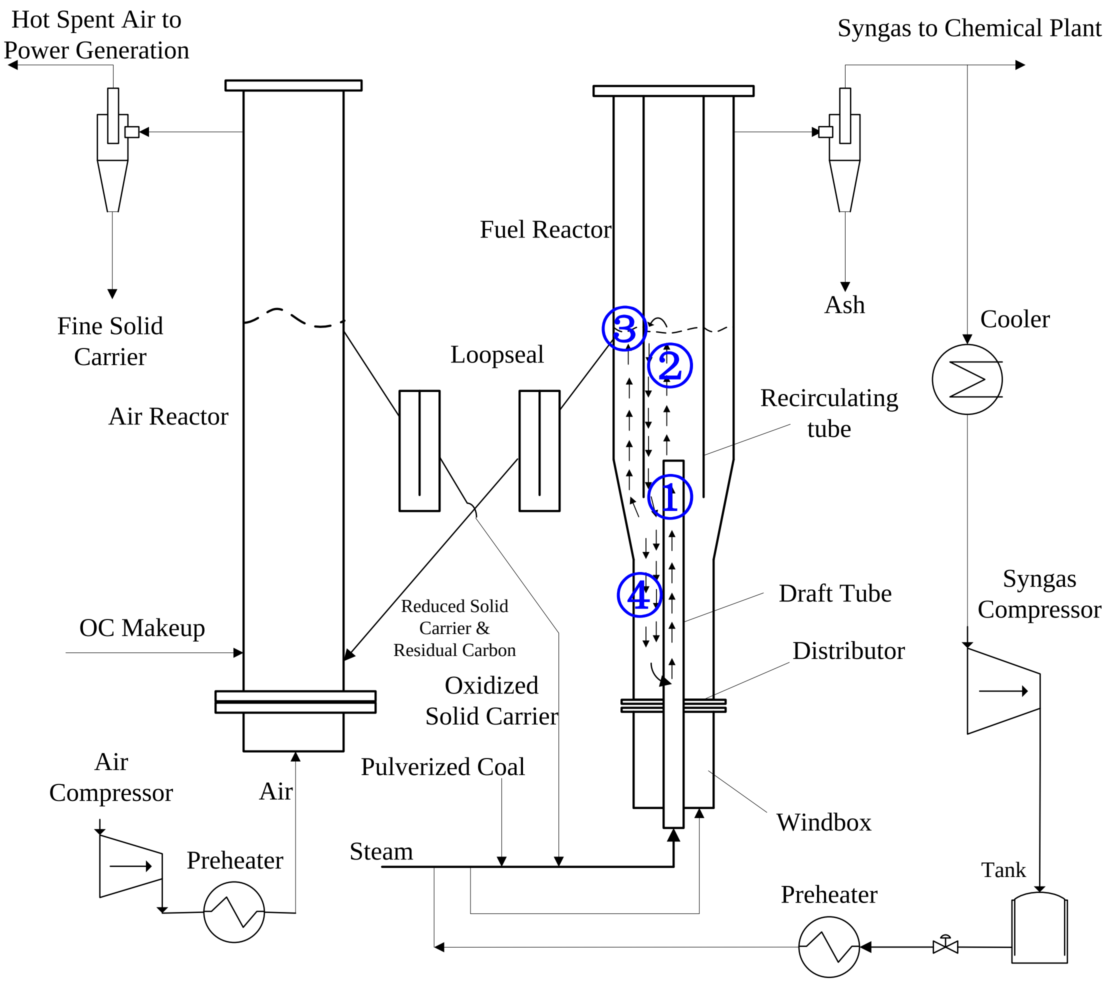

① Draft tube (>1000 °C)

fast pyrolysis, eliminate tar

② Freeboard (850-1000 °C)

catalytic gasification

③ Annular zone (650 °C)

in-situ WGS reaction

④ Moving bed: internal circulation

Advantage:

- Spouted bed → avoid agglomeration
- Low-temp. gasification
- In-situ WGS
- Multi-function OC-catalyst

Objective: Develop a catalytic coal gasification technology integrated with CL

Project Key Tasks

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- Validate the feasibility of coal gasification technology integrated with chemical looping and high-T catalytic syngas reforming to produce H_2-rich syngas √
- Design catalyst-OC structure suitable for the proposed gasification process √
- Test the spouted bed gasifier for catalytic coal gasification and in-situ syngas reforming (ongoing)
- Process design, modeling and performance evaluation at commercial scale (ongoing)

Outline

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1. Investigate OC-catalyst on Bench Fluidized Bed Reactor
2. Spouted Bed Reactor Design and Fabrication
3. Material (OC & Fuel) Preparation

Catalytic Function for In-situ WGS

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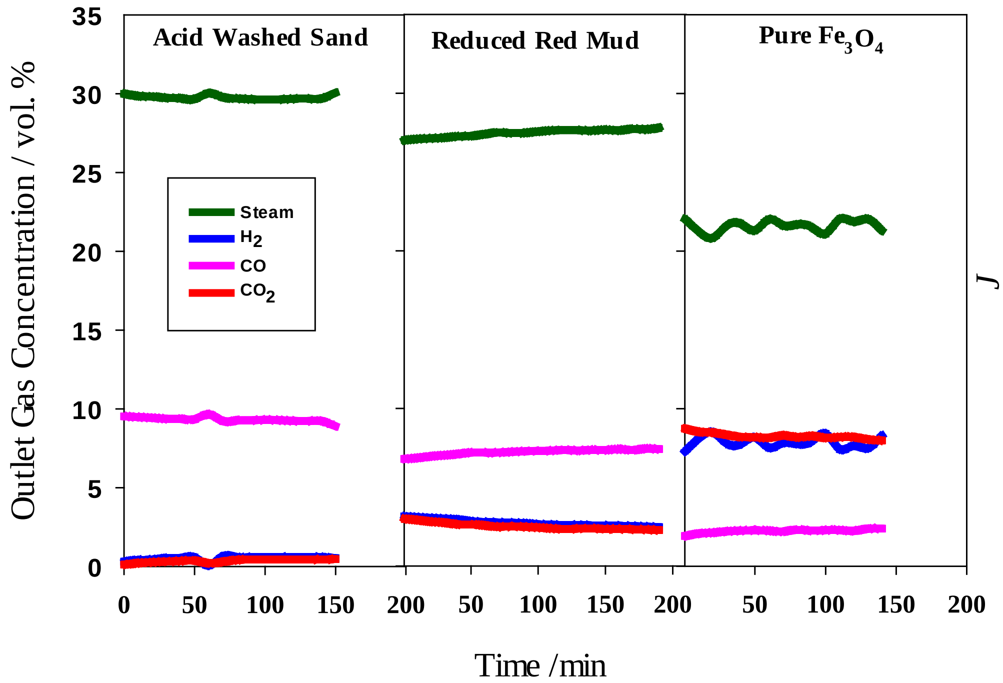

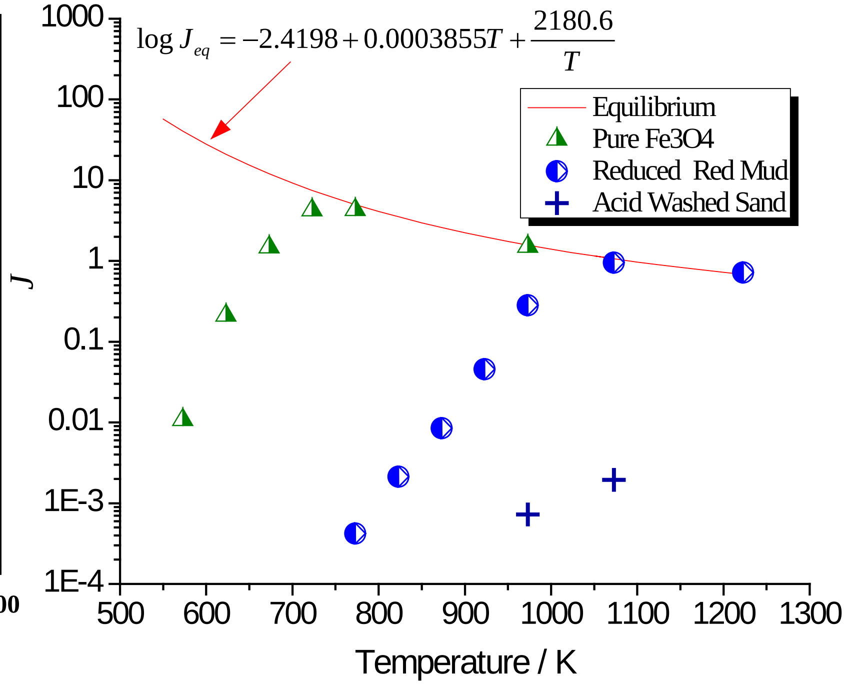

Gas residence time: 6s (973 K)
Inlet gas: 10% CO + 30% Steam

OC/Fuel Ratio

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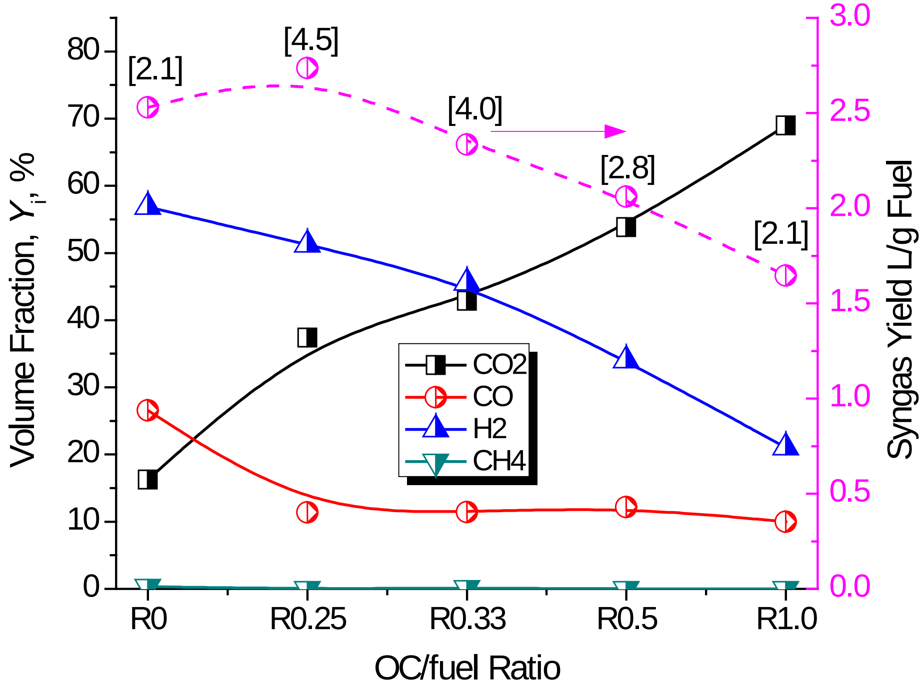
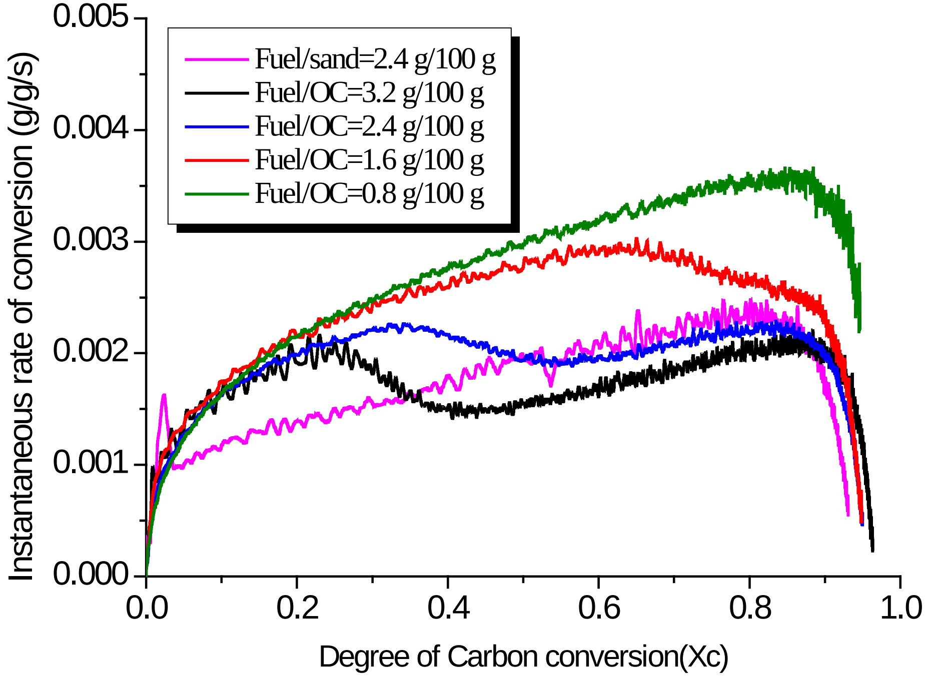
Gas Composition



Number in brackets : H_2/CO ratio

Fuel Conversion Rate



RM 100 g, Char 0.8-3.2 g
950 °C, 50 vol.% WV

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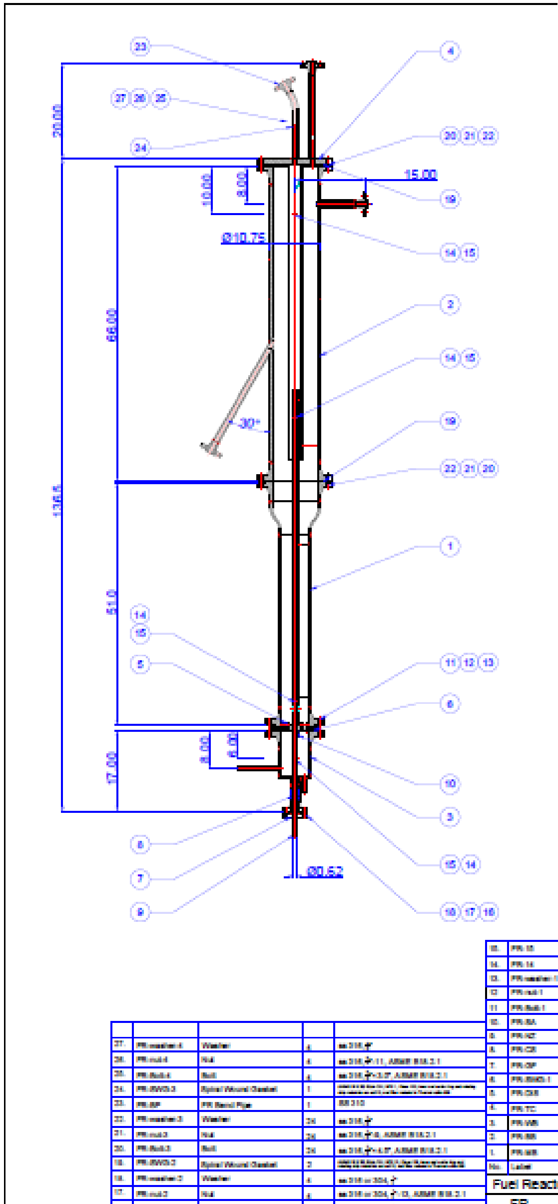
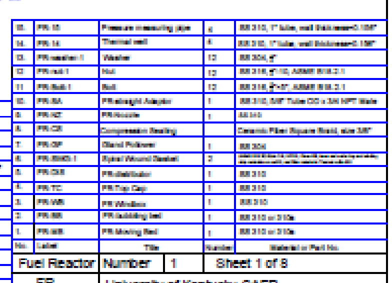
Spouted Bed Reactor Design



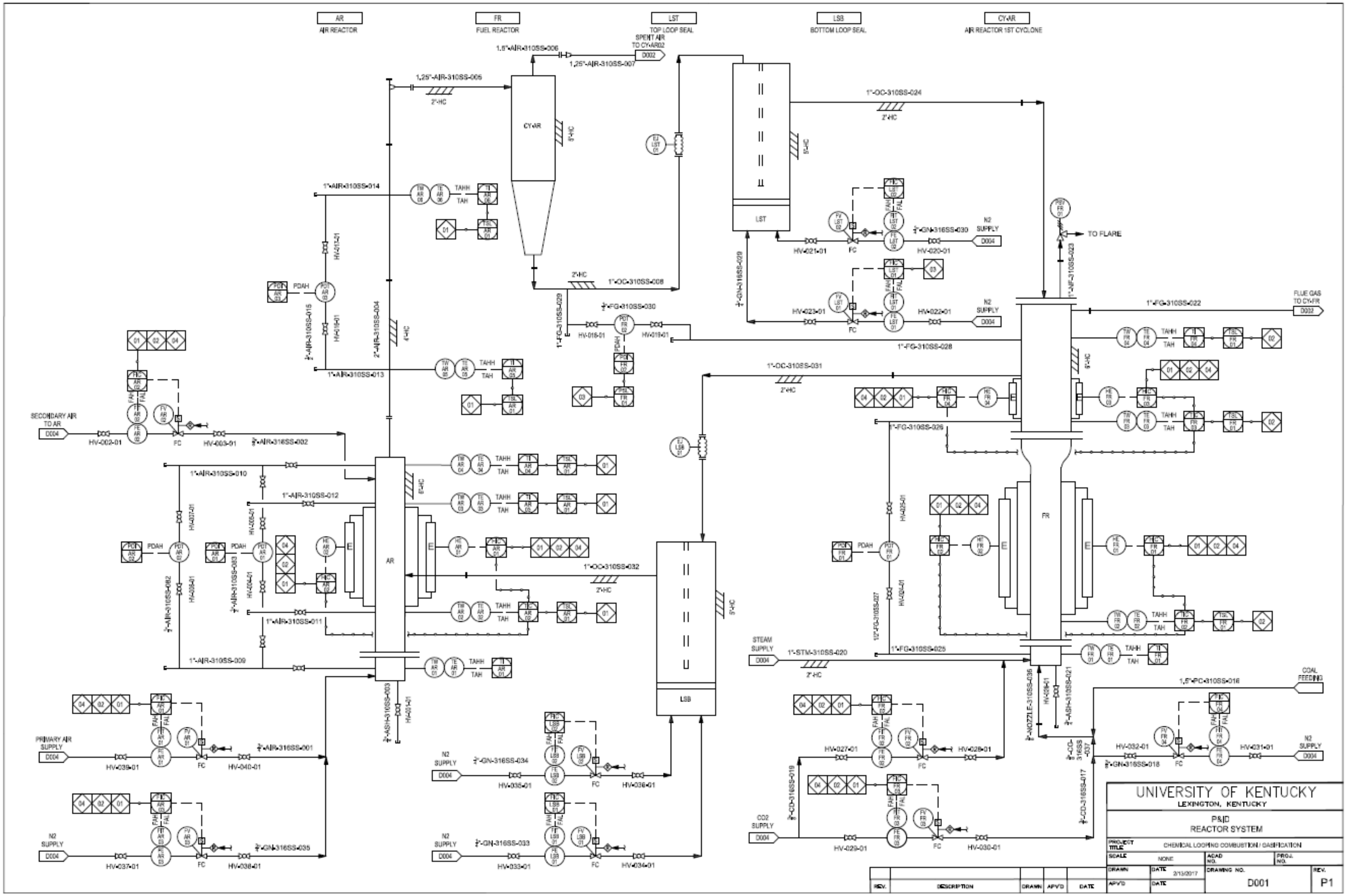


Material		SS 310	
Working Medium		Red mud/Ilmenite/Coal	H2O/CO2/CO/H2
Properties		Solid particle~350 um	Flammable gas
Inlet Temperature	°C (°F)	980-1,000 (1795-1832)	300-500 (572-932)
Operation Regime		Fluidized Bed	
Design Pressure	Mpa (psi)	0.11 (16 psi)	
Metal Temperature	°C (°F)	970 (1778)	
Erosion/corrosion allowance	mm (inch)	1.0 (0.04)	
Expansion (Max.)	mm (inch)	Vertical: 63.5 (2.5); horizontal: 19 (0.75)	
Unit Weight	kg (lb)	150 (330)	
Solid Inventory	kg (lb)	80 (176)	

OC-catalyst		
Fe_2O_3 content	wt.%	42.49
$SiO_2 + Al_2O_3 + TiO_2$	wt.%	57.51
Particle Size	μm	350
Particle Density	kg/m^3	3529
Bulk Density	kg/m^3	1875
Heat Capacity-oxidized	kJ/kg·K	1.5
Heat Capacity- Reduced	kJ/kg·K	1.07
Sphericity		0.86

Coal: 6-8 kg/h
PRB Sub-bituminous

P & ID - Reactor System



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Fuel and OC Preparation

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Fuel

- PRB coal (420 kg)
- Active carbon (200 kg)

	Proximate Analysis (%, as received)				Ultimate Analysis (%)					Heat Value (BTU/lb)
	FC	VM	M	A	C	H	O	N	S	
PRB coal	38.09	33.58	23.74	4.59	55	6.47	33.2	0.56	0.18	9238
Active Carbon	89.81	5.57	3.79	0.83	93.15	0.97	4.63	0.33	0.09	13531

Oxygen Carrier

- Red mud (300 kg)
- Ilmenite (850 kg)

	Fe_2O_3	FeO	Al_2O_3	SiO_2	TiO_2	MgO	CaO	Na_2O
Red mud	43.7	-	23.4	11.8	7.7	-	5.5	6.4
Ilmenite	27.2	29.9	0.8	0.8	37.6	2.7	0.2	-

Large-scale OC Fabrication Challenge

Lab-scale Methods

- OC: $100K/ton quoted by JMP Laboratories Inc.
- Coal: $50/ton
- Lose competitiveness

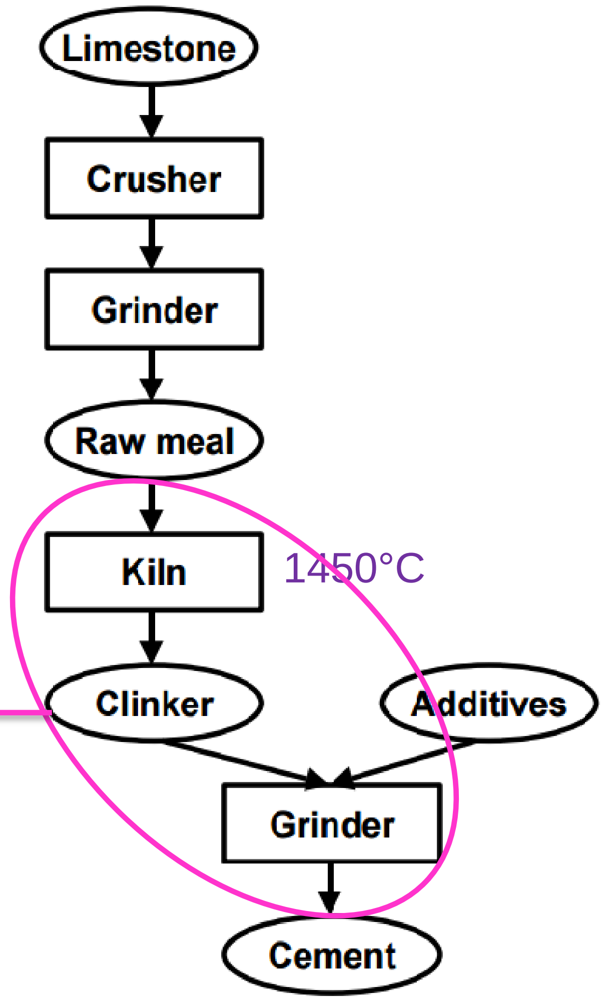
Reduce large-scale production cost

How?

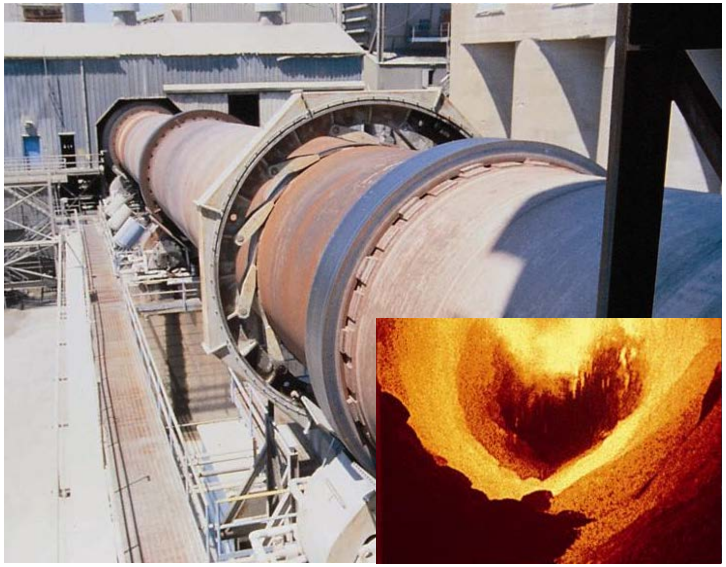
Cement: $85-100 / ton

http://www.nasdaq.com/article/cement-makers-find-right-mix-for-pricing-power-cm488965

Can Cement Production be Applied?



Applicable to OC production



Industrial case study: the cement industry. KEMA Inc. 2005. http://www.calmac.org/publications/industrialcementfinalkema.pdf

Large-scale OC Production – Our Approach

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Raw Material → Fire in Kiln → Clinker → Crush Sieve → OC Product

Calcine Temp. in Rotary Kiln

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1200 °C	1250 °C	1300 °C
		
×	√	√

	1200 °C	1250 °C	1300 °C
Strength (N)	1.60	2.76	3.10
Bulk Density (kg/m^3)	-	1493.4	1719.6

Crystal Phase Formation

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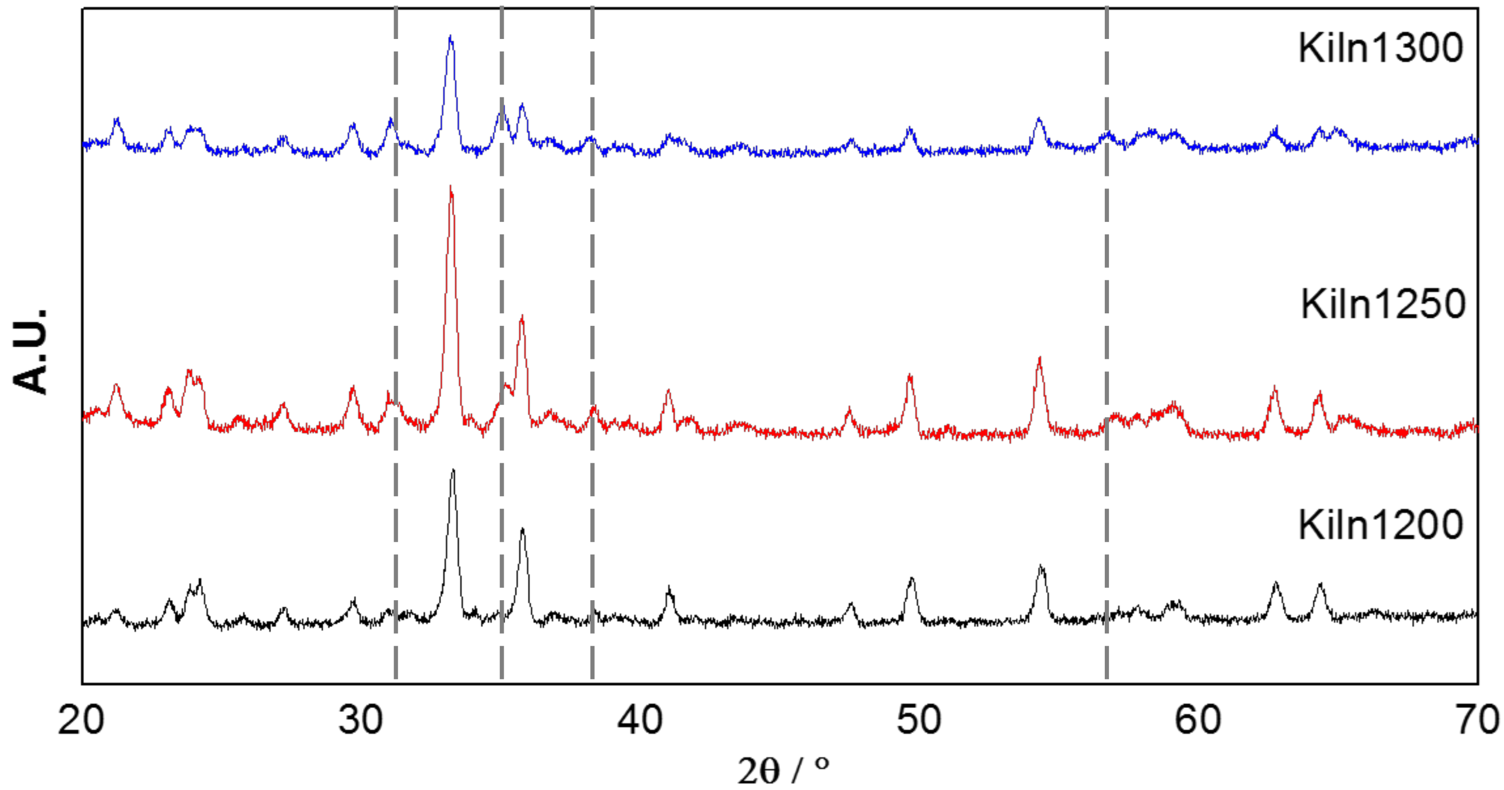


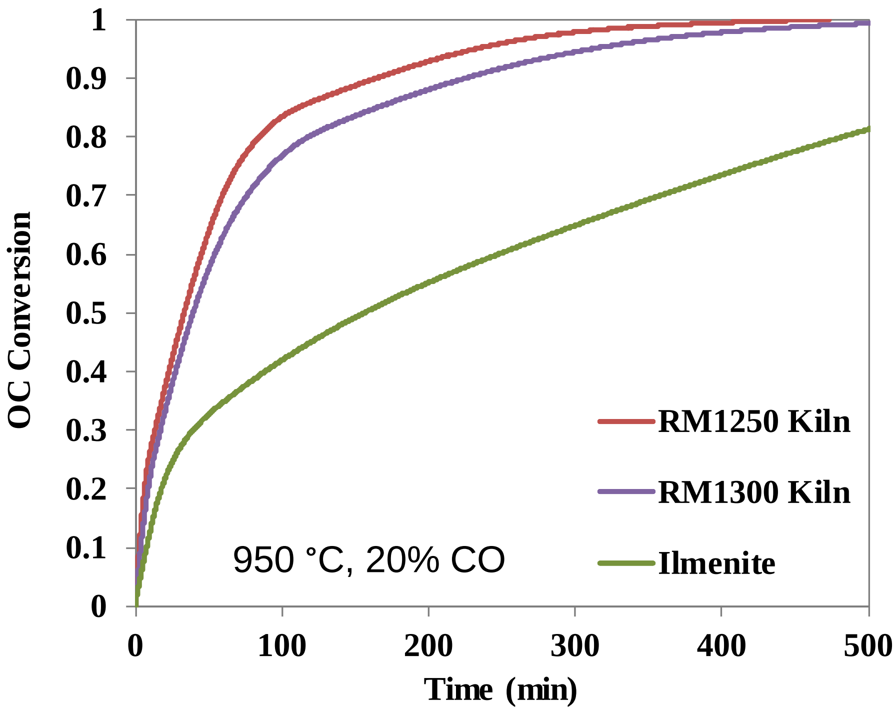
1200 °C	1250 °C	1300 °C
Fe_2O_3	Fe_2O_3	Fe_2O_3
Al_2O_3	$FeAl_2O_4$	$FeAl_2O_4$
SiO_2	$Fe_3(Al_{0.2}Fe_{1.8})(SiO_4)_3$	$Fe_3Al_2(SiO_4)_3$

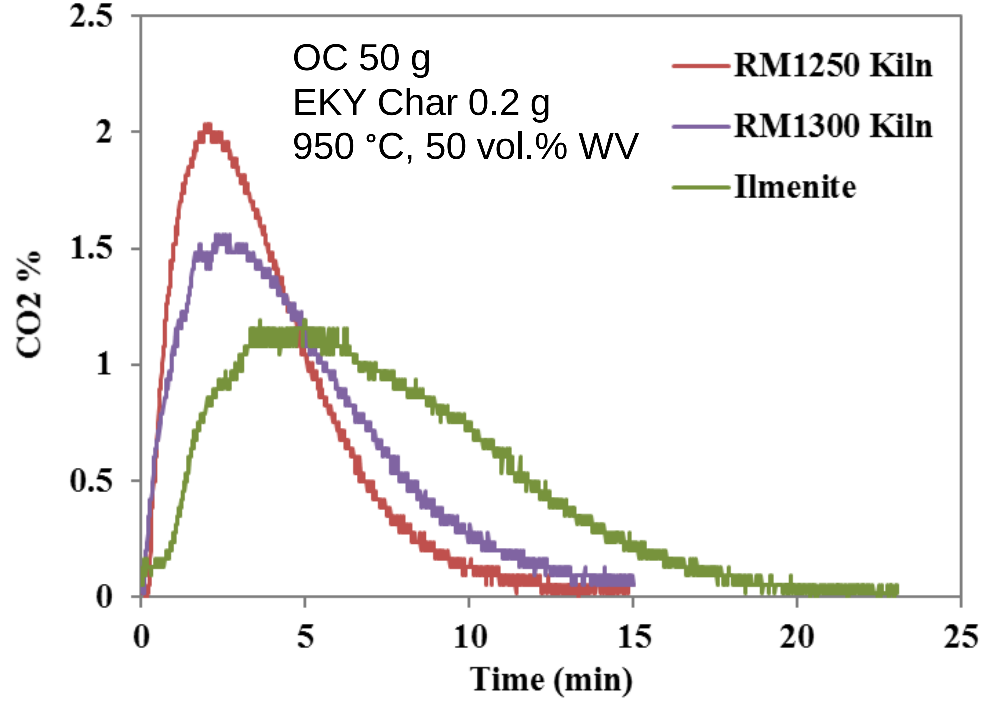
Almandine

Very hard
Dark red
Melting point: 1250 °C

http://oregon-resources.com/wp-content/uploads/2011/04/ORC_Garnet_MSDS.pdf

Reactivity with CO and Char





Kiln Temp: 1250 °C

Cost Estimation

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Process step	OPC	RM OC
Energy Consumption (kWh/ton)		
Crushing	0.9	-
Raw meal grinding	19.2	-
Kiln energy	1443	1240
Finish grinding	46.3	200
Blending	0.9	-
Total energy	1510.2	1440
Fabrication Cost		
Average electricity price in U.S. ($/kWh)	0.12	
Yield during crushing	100%	50%
Cost ($/ton)	181	346

Alexander J. Moseson, Dana E. Moseson b, Michel W. Barsoum. High volume limestone alkali-activated cement developed by design of experiment. Cement & Concrete Composites 34 (2012) 328–336.

Project Key Progress

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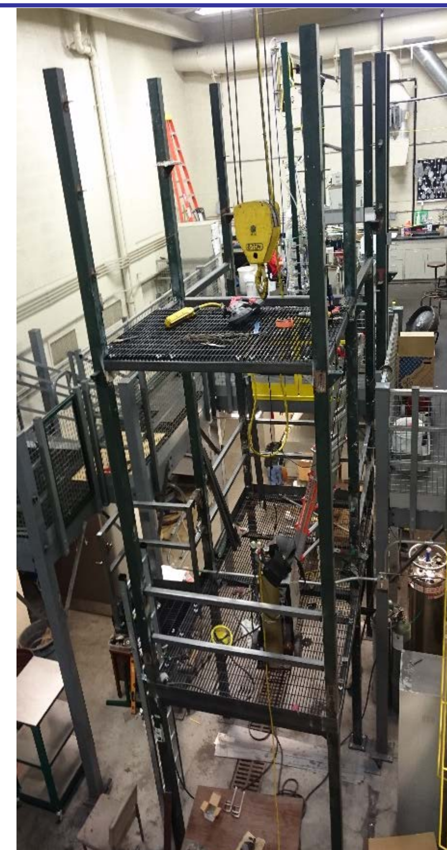
Verified the feasibility of RM in CLG and proved its multi function as OC-catalyst

Completed reactor design and ready for fabrication

Developed large-scale, cost-effective OC production technique with rotary kiln



Future Work

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- Installation of the spouted bed facility
  - ✓ Ongoing
- Demonstration of spouted bed reactor and performance evaluation of gasifier
  - ✓ Red mud / ilmenite OC
  - ✓ Performance evaluation of gasifier
- Process modeling and performance evaluation

Acknowledgement

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