Development of Partial/Non-Slagging Entrained-bed Coal Gasifier to Lower Capital Cost

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Background

Recent construction cost of IGCC

- US$3,200-3,500/$kW_e$ (US data, 2007-2008)
- In Korea's case,
  - Coal IGCC : US$3,800-4,300/$kW_e$
  - USC : less than US$2,000/$kW_e$
  - Conventional PC(Pulverized Coal) combustion-based power plant : US$1,300-1,400/$kW_e$

Slagging vs. Non-Slagging → Partial/Non-slagging

- Slagging of coal ash frequently causes operational problems in gasifier. Non-slagging gasification is much more easy to operate. But, a higher possibility in lower carbon conversion (higher entrained fines).
- In large commercial size gasifier, it would be better to obtain over 99% carbon conversion. Few percent of fines could pose a burden in disposing.
- Captured fines contain 30-60% carbon content, which suggests a possibility as a combustion fuel or other economically useful way.

Criteria/Results of Fly–ash (Fines) for Economic Usage

- Typically, the combustion fly-ash should contain less than 5 wt% remaining carbon to be useful as a cement filler.

  ⇨ However, fines from the one-stage entrained-bed coal gasifier of pilot-scale contain 30-60% remaining carbon. In this case, final fines might be applicable instead as a low-grade fuel if combustibility and other criteria are satisfactory.

- For direct use of fines, heavy metal should not leach out to contaminate underground water.

  ⇨ Gasification slags are not leaching any heavy metals. Entrained fines from a non/partial-slagging gasifier were confirmed passing environmental standards.

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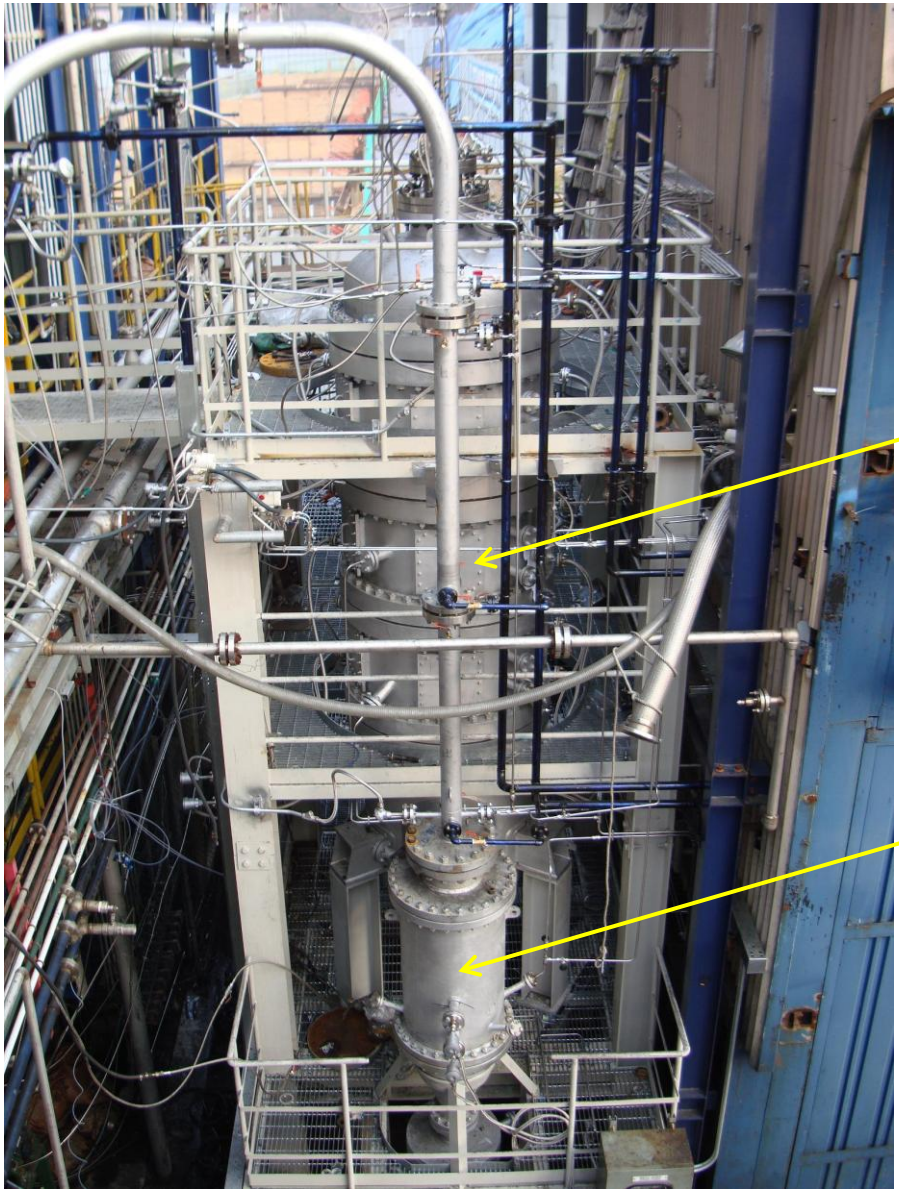
Target of Development

- **Main factors of high capital cost in entrained-bed gasifiers :**
  - Too high operation temperatures for slagging
  - Exotic, expensive, 'not-easy-to-get' metal materials
  - Too many welding points + Not in mass production
  - Safety and Control for explosive, toxic, corrosive syngas
- **Situation of slag/fly-ash usage :**
  - Before: fly-ash was dumped → Now: most combustion fly-ashes are sellable as cement filler, etc.
  - Large quantities of slag have a limited usage till now.
  - Fly-ash at 1,100-1,350^{o}C range → Solve ash leaching problem
- **Target :**
  - Gasifier of partial/non-slagging mode of entrained-bed type (operation temperature 1,100-1,350^{o}C)
  - Carbon conversion of single pass in gasifier: above 90% (92-96%)
  - Fly-ash recycling for >99% carbon conversion, or use as another profitable feedstock
  - Easy-to repair and replaceable feature
  - 200-500 TPD gasification system with spare gasifier
  - Capital cost 1/3-1/4 of current slagging entrained-bed system.
- **Limitations :**
  - Not suitable for all available coals (limited in fusibility characteristics)

Entrained-bed 2 TPD Pilot Plant of Partial/Non-Slagging Mode

Hot Syngas Metal Filtering

Syngas to High Temp. Metal Filter



Gasifier

Cyclone

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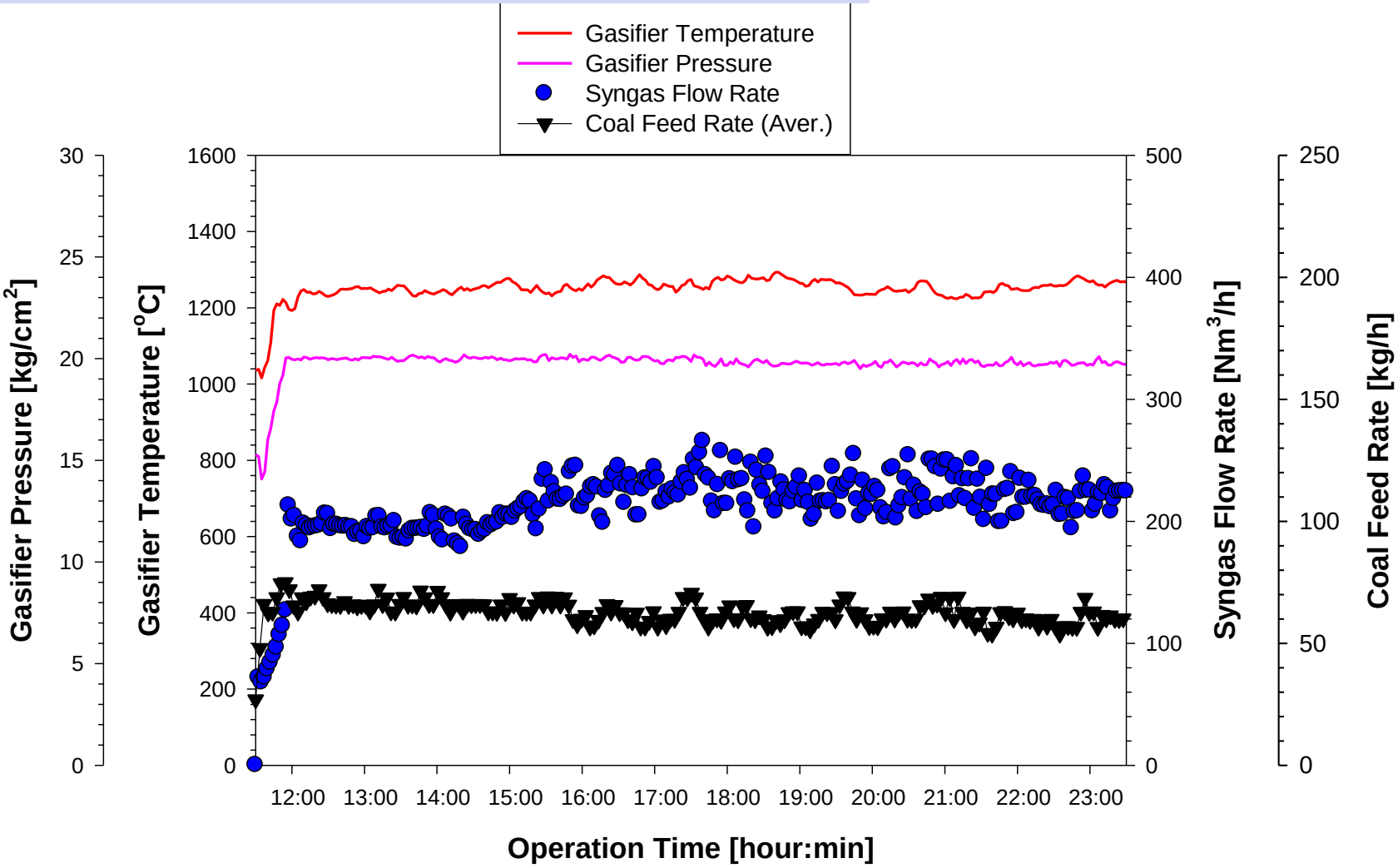
Typical Profiles of Key Operation Parameters

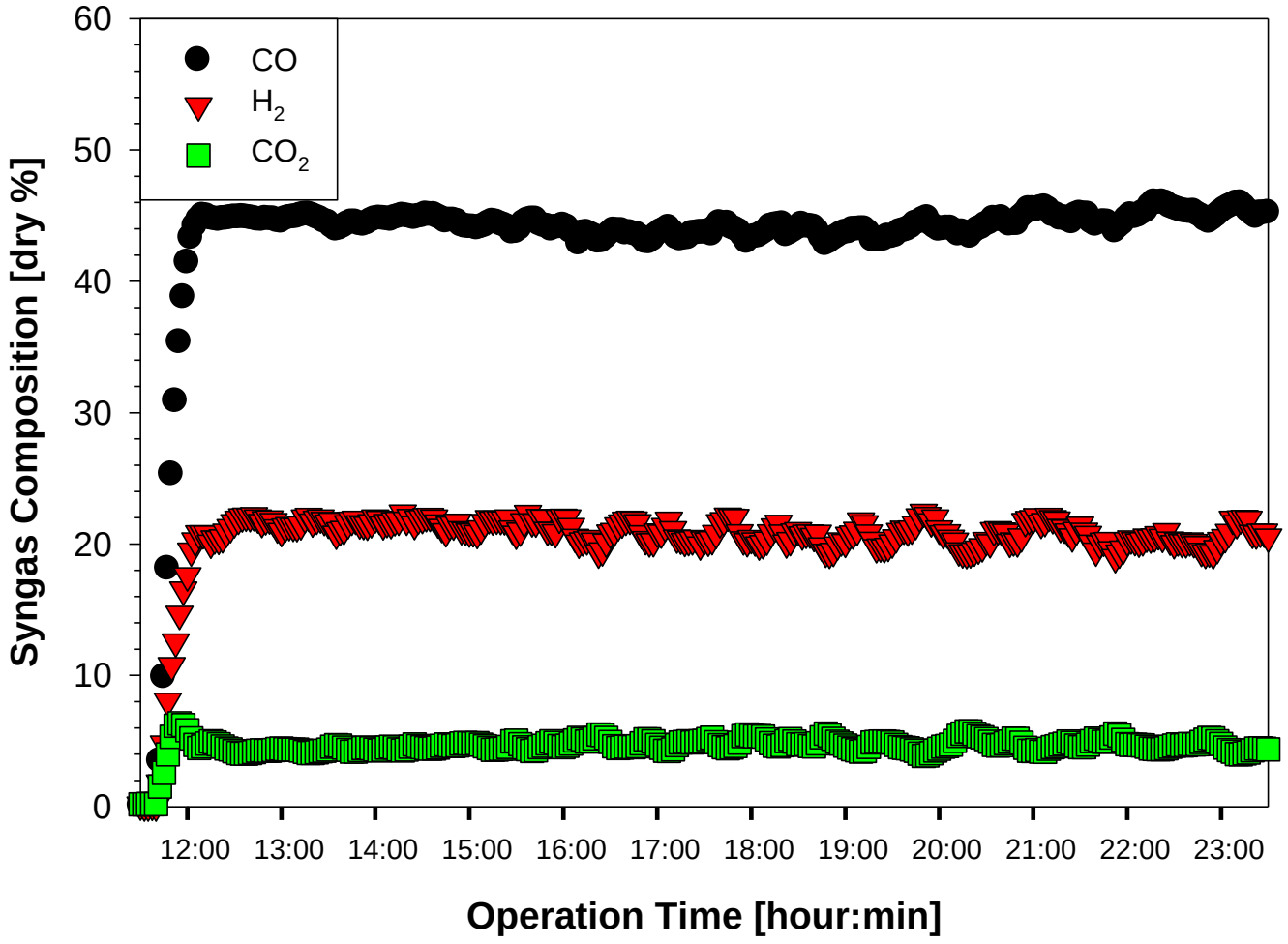
Indonesian ABK coal, Gasifier Temperature: *ca.* 1,250°C



Source: Y. Yun et. al., "Performance Comparison of Non-slagging Entrained-bed Gasifier with Different Ash Melting Temperature Coals," Fifth International Conference on Clean Coal Technologies, CCT2011.

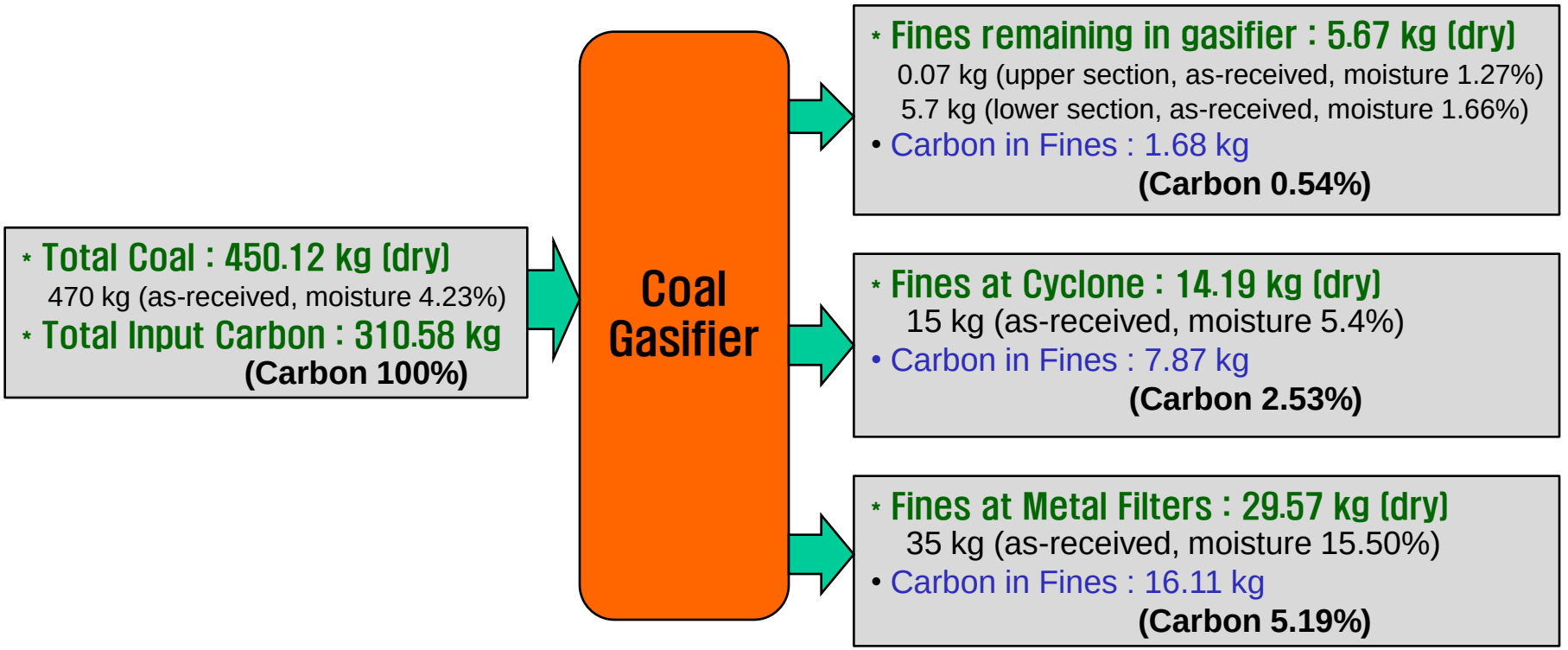
Typical Syngas Composition from 2 TPD Pilot Gasifier

Indonesian ABK coal, Gasifier Temperature: *ca.* 1,250°C



Source: Y. Yun et. al., "Performance Comparison of Non-slagging Entrained-bed Gasifier with Different Ash Melting Temperature Coals," Fifth International Conference on Clean Coal Technologies, CCT2011.

Material Balance (Down-flow / Non-Slagging, ABK coal)



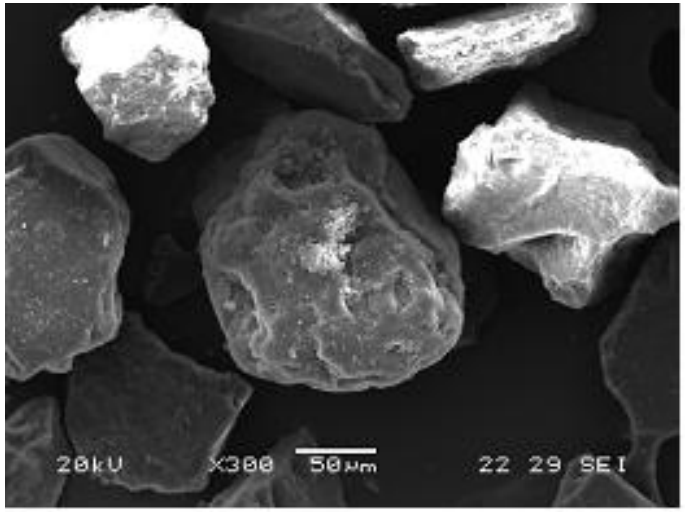
Carbon Conversion (one-pass) : 91.74%
Fines % of Input Coal : 10.98%

→ will increase with cyclic recycling

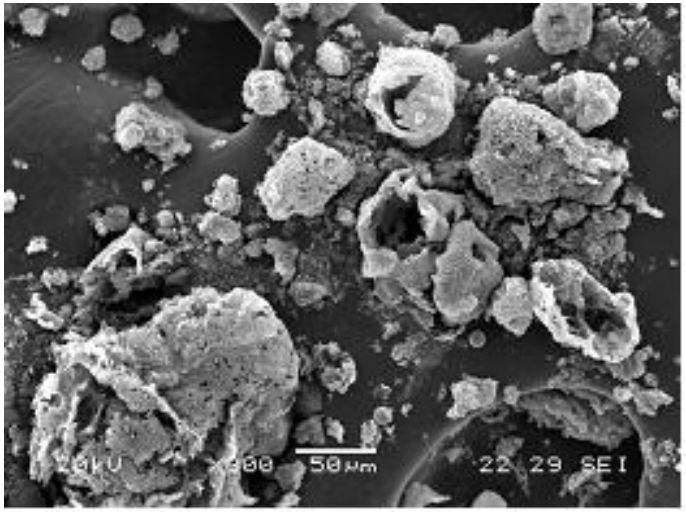
Comparison of Raw Coal and Fines Captured by Metal Filters (Down-flow / Non-Slagging)

Raw KPC Coal

Captured Fines by Metal Filters



Raw KPC Coal (SEM, x300)



Captured Fines (SEM, x300)

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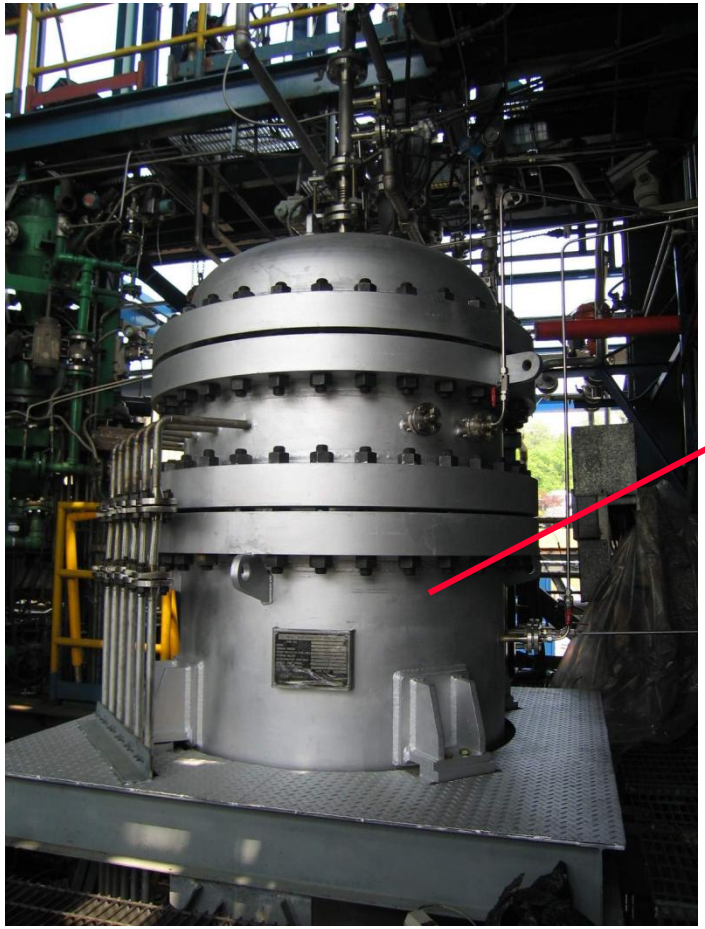
Metal Filters after Gasification Test (ABK Coal)

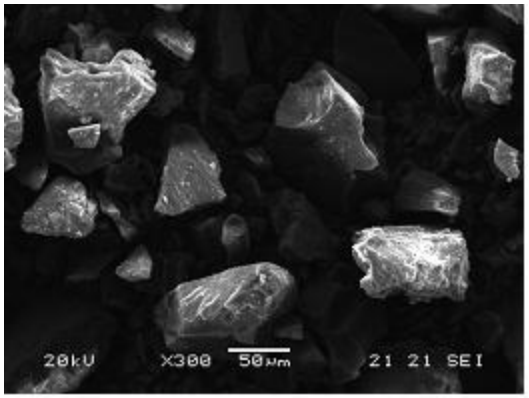


(High Temp. Metal Filter System)

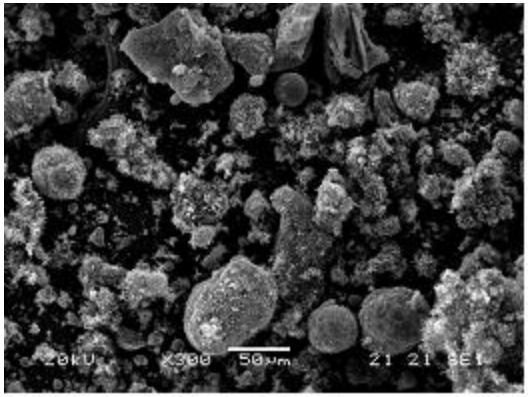
Changes of Particles through Gasifier–Filters

(ABK coal, x300 magnification)

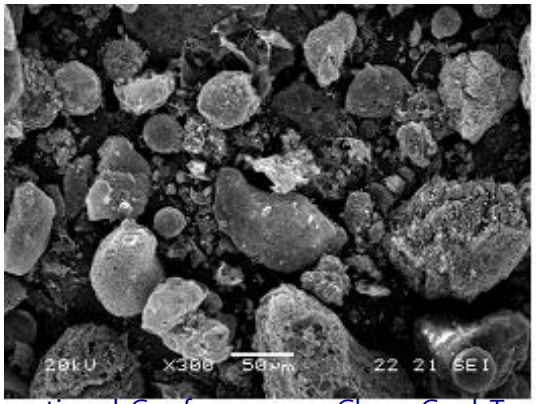
Raw ABK Coal



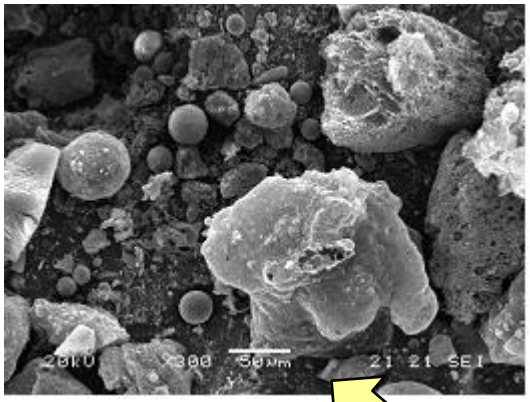
Gasifier
– Upper section



Gasifier
– Lower section

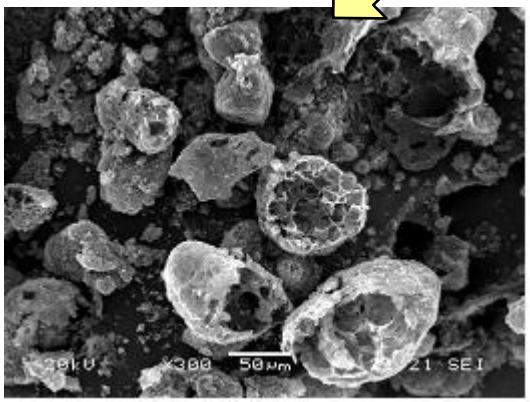


Cyclone



Main Target for Usage

Metal Filters



Source: Y. Yun et. al., Fifth International Conference on Clean Coal Technologies, CCT2011.

Analysis Data of Raw Coal / Fines
(Down-flow / Non/Partial-Slagging)

Sampling Point		Raw Feeding Coal	Gasifier		Cyclone	Metal Filters
			Upper section	Lower section		
Proximate Analysis (dry basis, wt.%)	Volatiles	43.36	2.04	1.35	3.16	4.37
	Ash	7.42	35.47	70.13	42.92	42.44
	Fixed Carbon	49.22	62.49	28.52	53.92	53.19
Ultimate Analysis (dry basis, wt.%)	C	69.00	62.70	29.15	55.43	54.47
	H	5.02	0.30	0.21	0.35	0.62
	N	1.34	0.34	0.06	0.39	0.15
	S	0.48	0.44	0.45	0.90	1.10
	O (by-difference)	16.74	0.75	0.00	0.00	1.23
	Ash	7.42	35.47	70.13	42.92	42.44
Heating Value (dry basis, kcal/kg)		6325.5	4984.3	1475.8	4642.8	4237.2

- Raw coal : Indonesian ABK subbituminous coal

Source: Y. Yun et. al., "Performance Comparison of Non-slagging Entrained-bed Gasifier with Different Ash Melting Temperature Coals," Fifth International Conference on Clean Coal Technologies, CCT2011.

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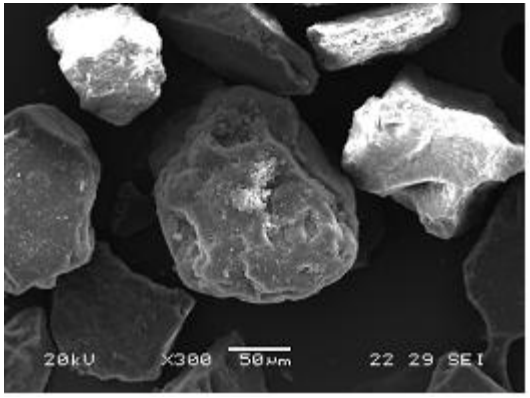
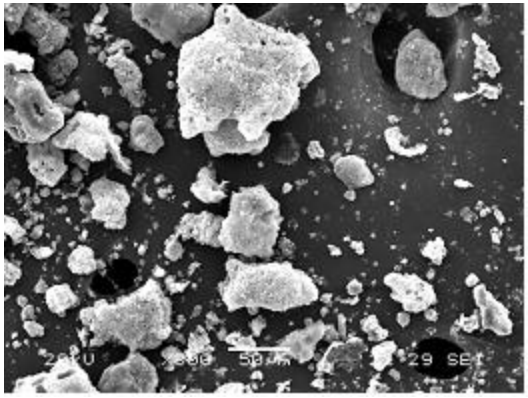
Changes of Particles through Gasifier–Filters

(Indonesian KPC subbituminous coal case)

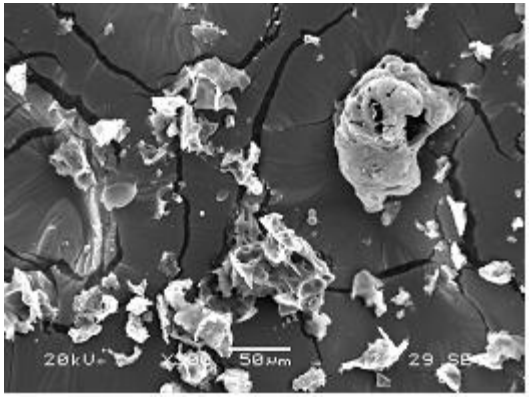
Raw KPC Coal (x300)



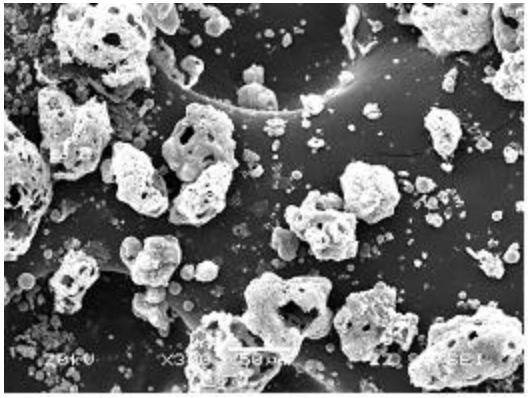
Inside of Gas Cooler (x300)



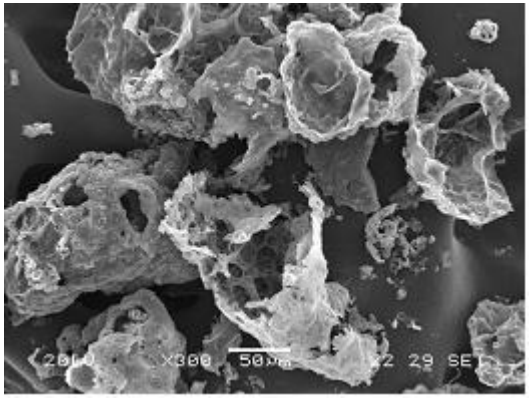
Lower part of Gasifier (x300)



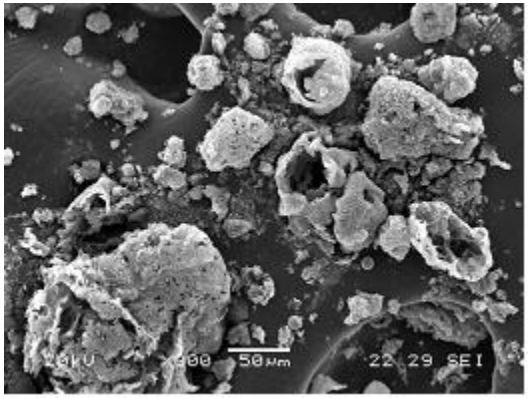
Inlet pipe for Filters (x300)



Gasifier outlet (x300)



Filter hopper (x300)



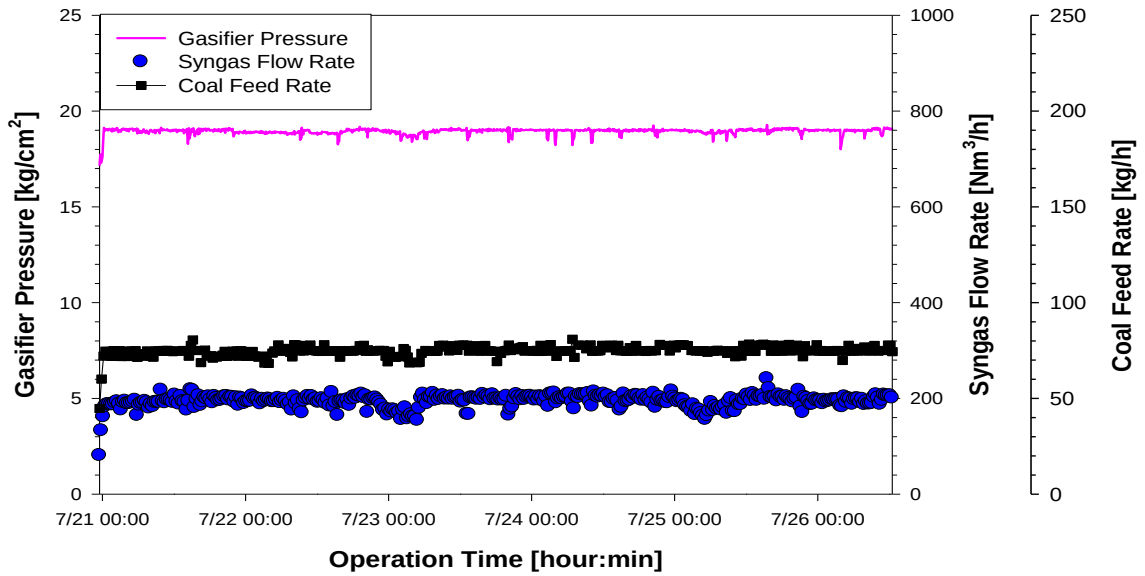
Proximate Analysis of Solid Samples (KPU Coal1211-5)

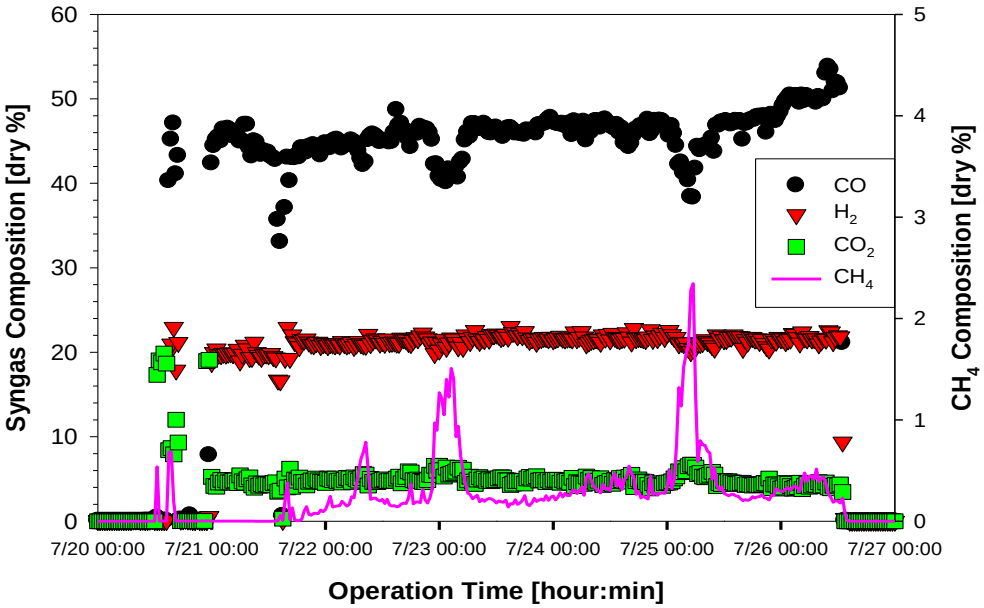
(Dry basis, unit: wt.%)

Item / Sample	Operating Condition	V.M.	F.C.	Ash	Combustibles : Ash (wt.%)
① KPU Coal		38.02	49.66	12.32	**87.68 : 12.32**
② Gasifier Top	1150 ~ 1250℃ 19.8~20.2 kg/cm^2	2.98	5.37	91.65	**8.35 : 91.65**
③ Cyclone		**5.44**	**19.90**	**74.66**	**25.34 : 74.66**
④ Filtered Ash		**1.91**	**45.91**	**52.18**	**47.82 : 52.18**
⑤ Final Gas Filtering in Quencher		0.72	0.42	98.86	**1.14 : 98.86**
⑥ Slag		0.08	**N.D.***	99.92	**0.08 : 99.92**
⑦ Ash in water quencher		1.20	6.43	92.37	**7.63 : 92.37**

* N.D. : not detected (<0.01)

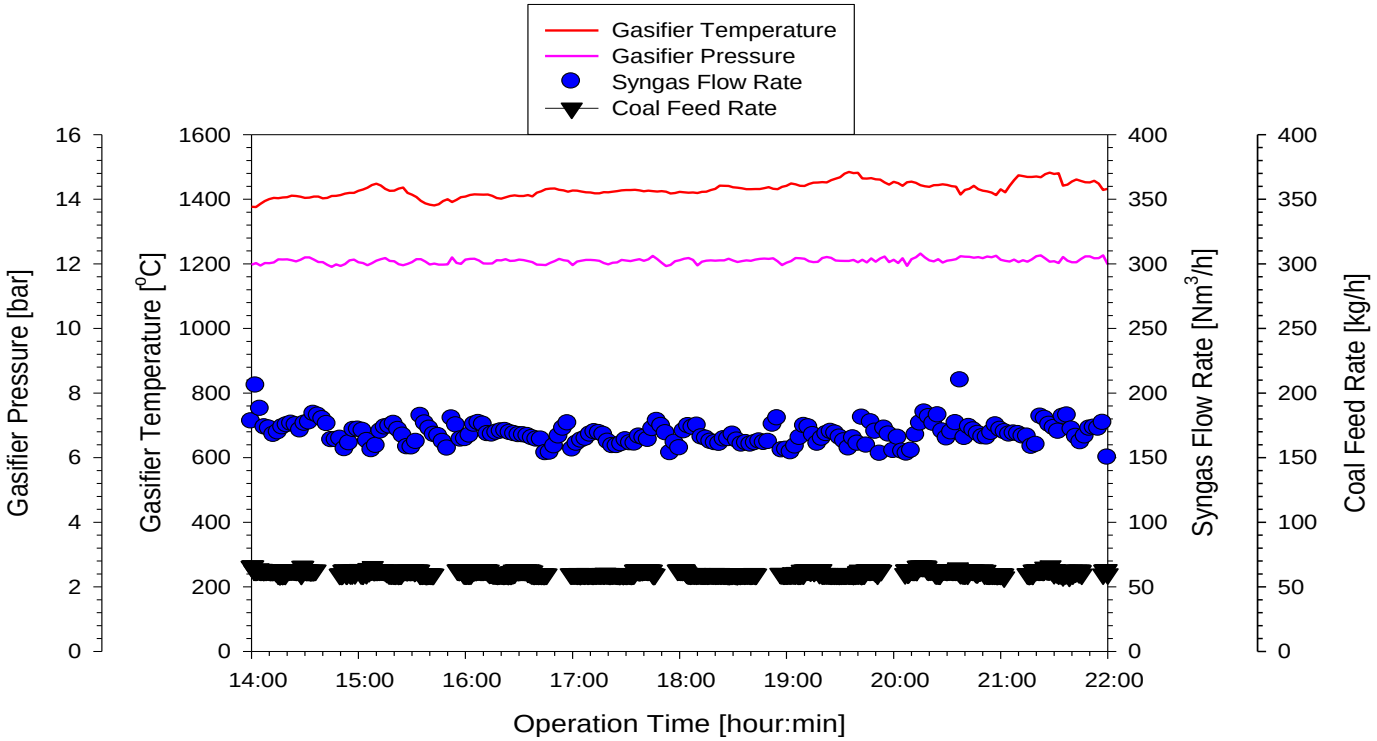
Test with LG Mixed Subbituminous Coal ('11)

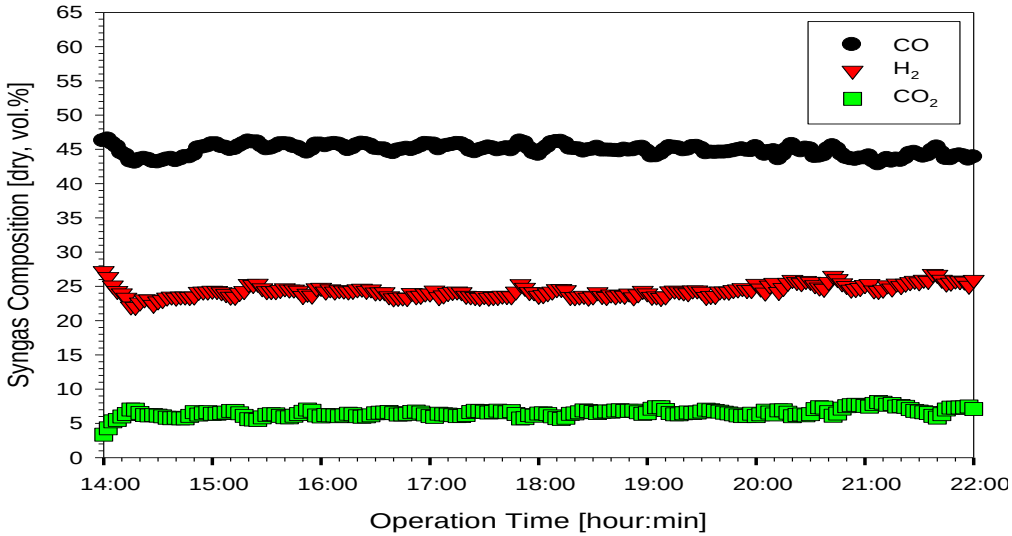




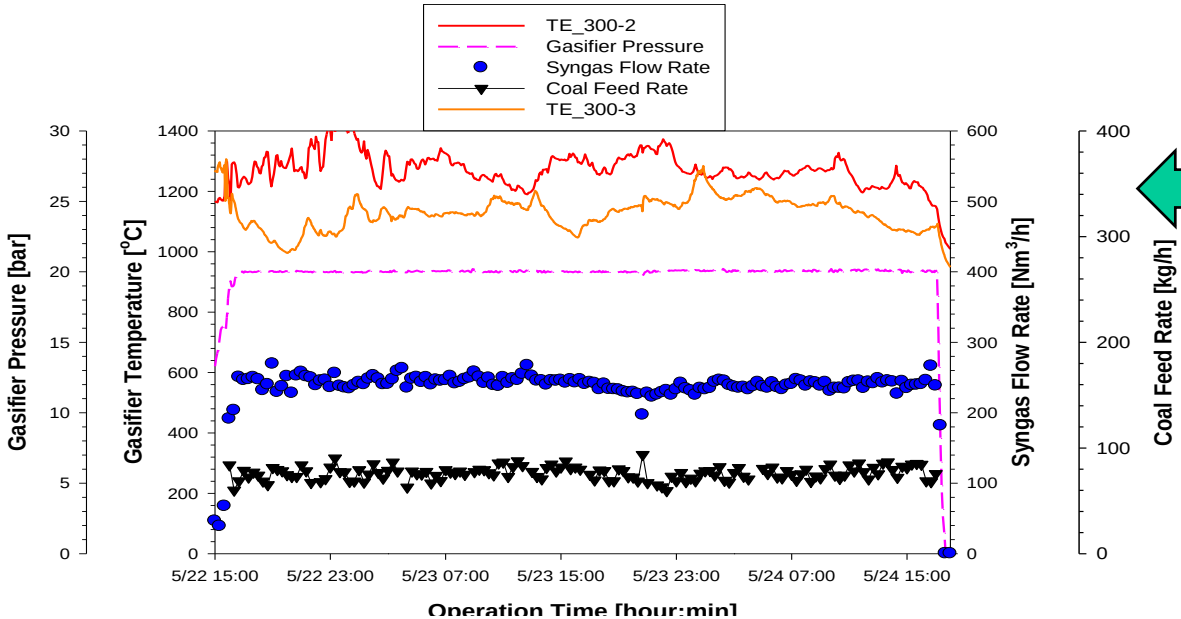
Testing Temperature vs. CH_4 concentration

Test with KPU Subbituminous Coal ('12)

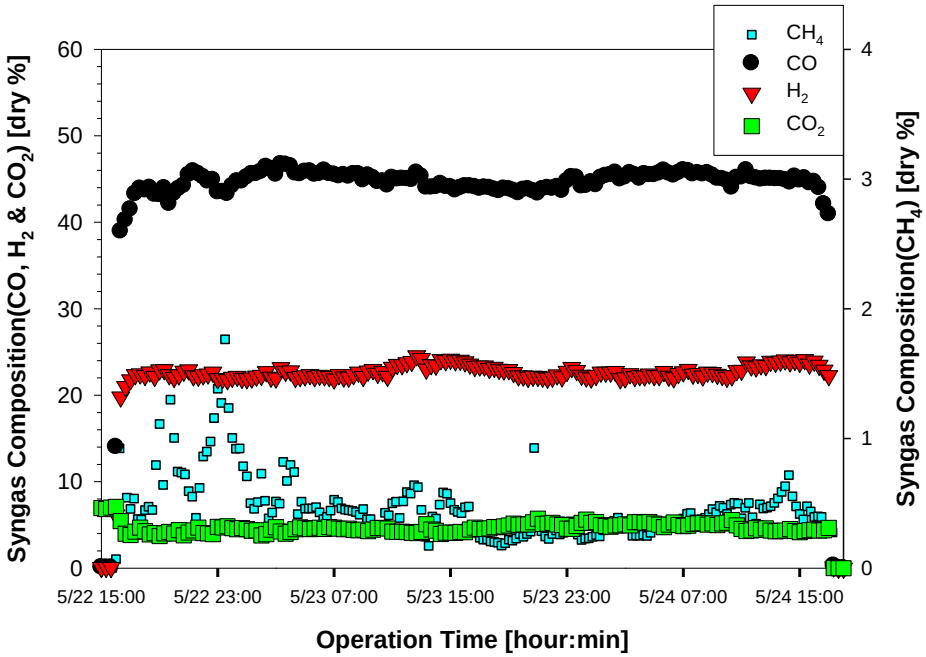




Operation Profiles in KPU Coal Gasification Test ('13/05)



Actual gasifier inside temperature measuring



Testing Temperature vs. CH_4 concentration

Variation of Coal Properties with Import Time

	Date	Coal1211-5 (2012.11)	Coal1303-1 (2013.03)	Coal1305-2 (2013.05)
	Coal	KPU(Indonesia)		
	Rank	Subbituminous		
Proximate Analysis (as-received basis, wt.%)	I.M.	4.29	7.01	4.69
	V.M.	36.39	39.65	41.99
	F.C.	47.53	45.67	46.21
	Ash	11.79	7.67	7.11
Ultimate Analysis (dry basis, wt.%)	C	70.5	68.5	68.70
	H	4.5	5.01	4.99
	N	1.36	1.27	1.21
	S	0.46	0.32	0.20
	Cl	N.D.*		
Calorific Value (HHV, dry basis)	kcal/kg	6,196	6,413	6,334

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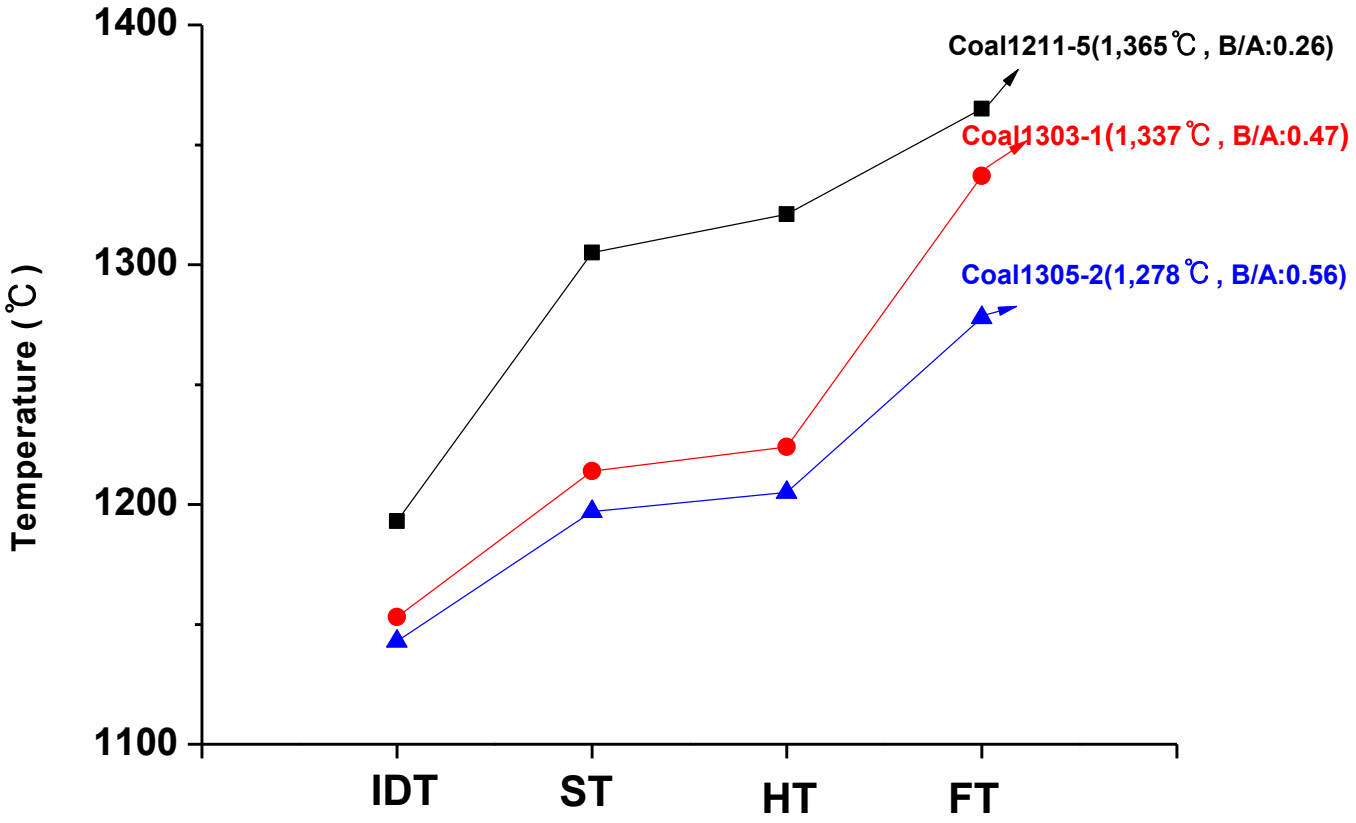
Fusibility Behavior of KPU Coal Ashes

KPU Coal1211-5 Ash (2012.11) (B/A=0.26)					
	Initial	IDT	ST	HT	FT
Temp(℃)	20	1,193	1,305	1,321	1,365
KPU Coal1303-1 Ash (2013.03) (B/A=0.47)					
	Initial	IDT	ST	HT	FT
Temp(℃)	20	1,153	1,214	1,224	1,337
KPU Coal1305-2 Ash (2013.05) (B/A=0.56)					
	Initial	IDT	ST	HT	FT
Temp.(℃)	20	1,143	1,197	1,205	1,278

Fusibility Behavior of KPU Coal Ashes

(at Oxidizing Atmosphere)



*** IDT:Initial Deformation Temperature , ST: Spherical Temperature, HT: Hemispherical Temperature, FT: Fluid Temperature**

- Partial slagging mode gasifier is sensitive to coal variation in fusibility, which needs additional design and operational aspects.

Ultimate Analyses of Solid Samples after Gasification

(KPU Coal1305-2)

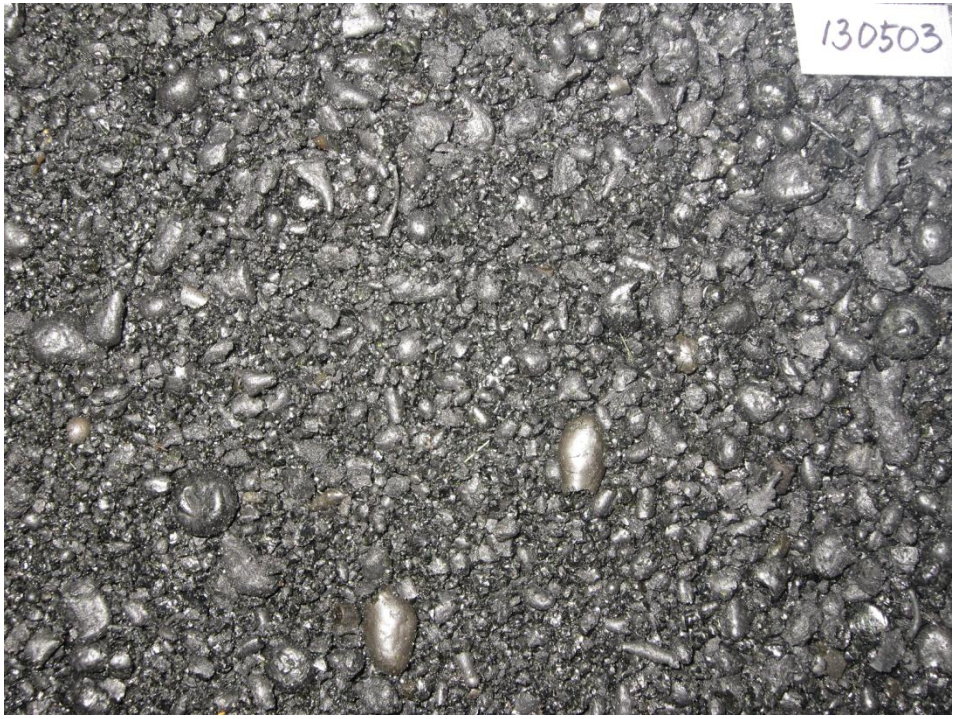
(dry basis, unit: wt.%)

Item / Sample	Operating Condition	C	H	N	S	Cl
① KPU Coal		68.70	4.99	1.21	0.20	
② Gasifier Top	1200 ~ 1400℃ 19.7~20.4 kg/cm^2	20.67	N.D.*	0.03	1.85	
③ Cyclone		26.92	0.08	0.19	1.04	
④ Filtered Ash		44.20	N.D.*	0.18	0.84	
⑤ Ash in quench water		1.84	N.D.*	N.D.*	0.03	
⑥ Slag		0.57	N.D.*	N.D.*	0.02	
⑦ Ash in water quencher		1.99	N.D.*	N.D.*	0.05	

* N.D. : not detected (<0.01)

Slag from KPU Coal Gasification Test ('13/05)

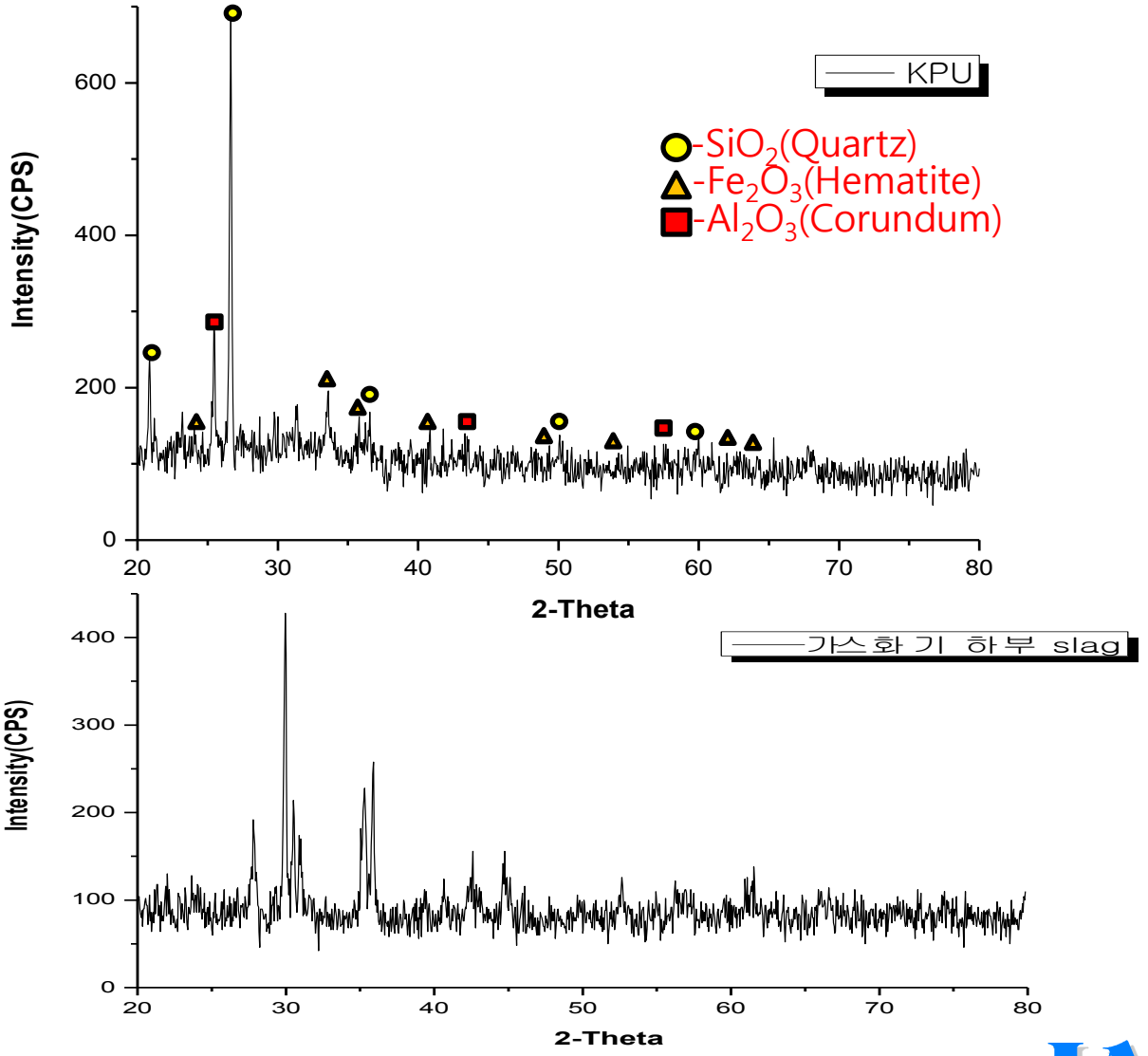
- Slag amount is less than 10% of feed-coal ash.



(Unit : cm)

XRD Analysis of KPU Coal1305-2 Ash and Slag ('13/05)

< XRD >



Heavy Metal Content & Leaching of Coal / Fines

(Down-flow / Partial/Non-Slagging)

Heavy Metal	Content of Heavy Metal (mg/kg)					Leaching of Heavy Metal (mg/L)				
	Pulverized Raw Coal (ABK)	Gasifier-Upper	Gasifier-Lower	Cyclone	Metal Filters	Pulverized Raw Coal (ABK)	Gasifier-Upper	Gasifier-Lower	Cyclone	Metal Filters
Hg	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pb	n.d.	n.d.	n.d.	n.d.	11.9	n.d.	n.d.	n.d.	n.d.	n.d.
Cd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	n.d.	72.61	411.27	178.2	945.86	n.d.	n.d.	n.d.	n.d.	n.d.
Cu	n.d.	10.76	33.34	22.33	28.54	n.d.	n.d.	n.d.	n.d.	n.d.
Fe	5172.97	23073.16	39992.1	28983.48	29755.9	0.47	n.d.	n.d.	n.d.	n.d.
Al	2956.23	6924.81	6557.13	10413.99	2860.7	**1**	0.62	n.d.	**10.98**	0.05
Zn	0.87	14.38	9.54	3.8	76.57	n.d.	n.d.	n.d.	n.d.	n.d.
As	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ti	205.5	1095.78	2183.78	1414.42	1473.09	n.d.	n.d.	n.d.	n.d.	n.d.
Ba	104.89	409.22	692.98	587.81	566.01	0.02	0.14	0.09	0.63	0.08
K	273.12	1430.34	2973.87	1943.68	2011.23	1.41	1.42	0.92	1.89	4.03
Ca	4108.1	6499.76	8883.22	15224.18	6910.11	**8.18**	116.63	24.95	**73.38**	**59.21**
Na	410.59	1694.77	3594.83	2608	2910.28	24.08	17.13	3.16	5.58	10.5
Mg	318.01	298.49	489.47	974.67	377.25	**5.96**	0.06	0.16	0.22	**12.09**
Cr^{+6}	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.006	0.007
CN^-	n.d.	0.008	0.004	0.013	n.d.	n.d.	0.021	0.006	0.005	0.034

(n.d. : not detected)

Source: Y. Yun et. al., "Performance Comparison of Non-slagging Entrained-bed Gasifier with Different Ash Melting Temperature Coals," Fifth International Conference on Clean Coal Technologies, CCT2011.

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XRF Analysis on Coal/Fines (Down-flow / Partial-Slagging)

Sample / Composition (wt.%)	Raw Pulverized Coal	Gasifier		Cyclone	Metal Filters
		Upper section	Lower section		
SiO_2	38.04	45.24	43.05	38.92	41.75
Al_2O_3	29.03	29.46	28.52	28.14	28.05
TiO_2	0.321	0.348	0.375	0.358	0.367
P_2O_5	-	0.008	0.35	0.34	0.239
Fe_2O_3	3.567	4.184	4.675	4.341	4.768
CaO	6.379	5.794	7.322	7.199	7.418
MgO	5.23	5.020	5.43	5.62	5.44
Na_2O	1.75	1.66	1.86	2.15	2.34
K_2O	0.86	0.965	1.25	1.02	1.14
SO_3	14.74	7.28	7.04	11.85	8.24
MnO	0.032	0.035	0.038	0.034	0.04
CuO	0.004	0.004	0.006	0.006	0.006
Cl	0.010	-	-	-	-
BaO	0.091	0.085	0.103	0.099	0.118
ZnO	0.005	0.003	0.003	0.003	0.013

EDX Analysis on Coal/Fines

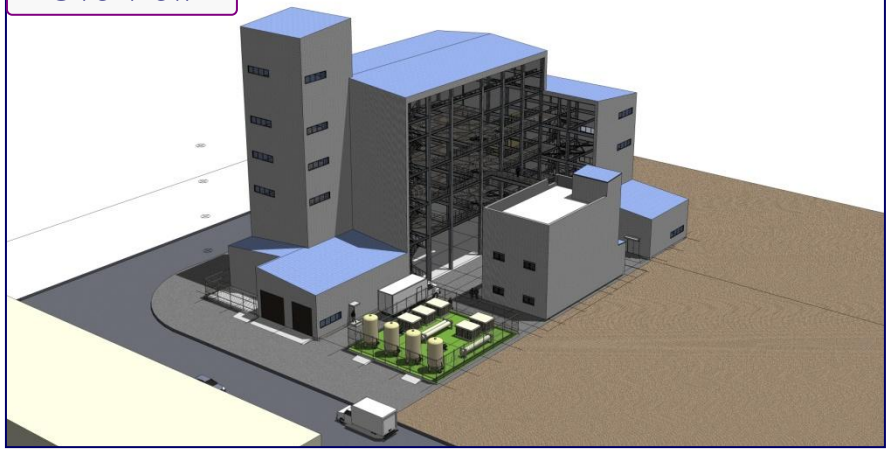
Element	ABK Raw Coal	Gasifier		Cyclone	Metal Filters
		Upper section	Lower section		
O	77.26	42.9	42.85	44.43	40.01
Mg	-	2.46	1.3	1.87	2.42
Al	5.13	10.19	10.33	11.04	10.52
Si	5.73	18.02	20.73	16.96	19.36
S	1.79	2.74	2.16	3.67	4.99
K	-	-	1.72	-	1.5
Ca	4.25	10.4	7.13	9.96	9.75
Cr	-	-	-	-	-
Fe	5.82	10.03	9.41	6.61	9.35
Cu	-	3.26	2.65	2.97	2.09
Zn	-	-	1.71	2.49	-
Total	100	100	100	100	100

- Analyzed based on the 100 magnification SEM pictures

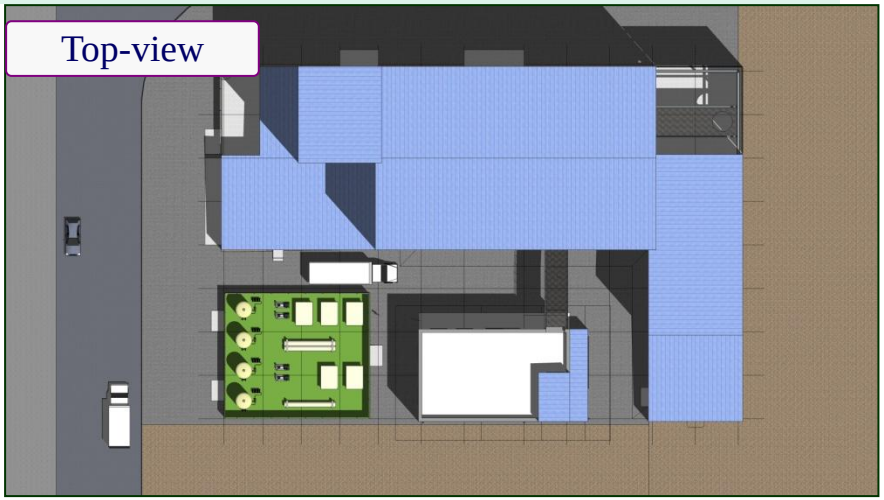
View of 20 TPD Coal Gasification Test-bed

- Schedule to complete the construction by fall, 2014.
- Will support KOWEPO Taean 300 MW IGCC Demo Project.
- Will be used as a test-bed for testing syngas-related experiments.

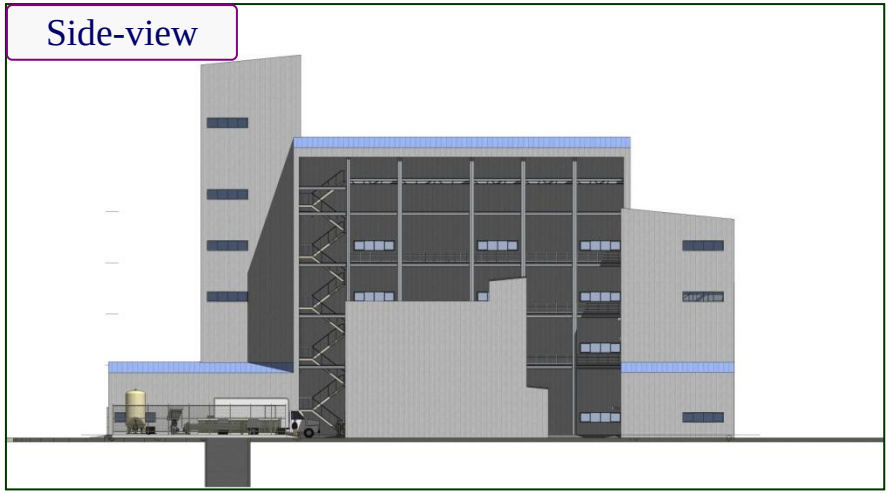
Overview



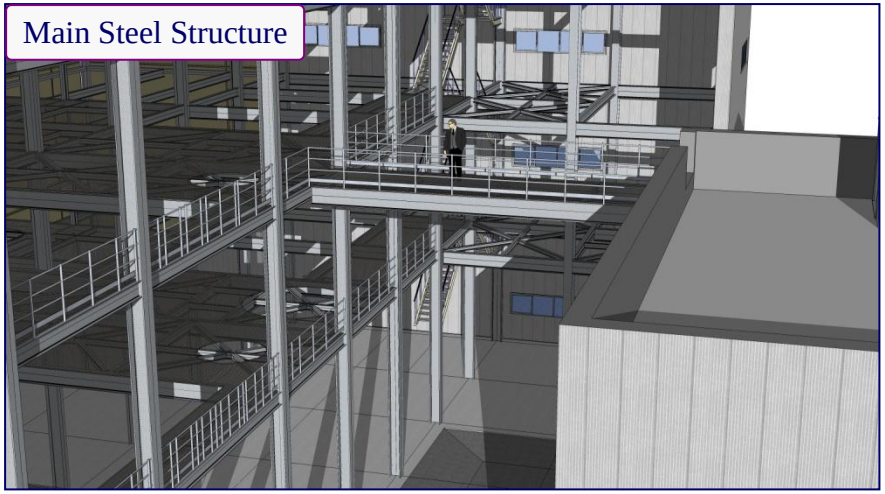
Top-view



Side-view



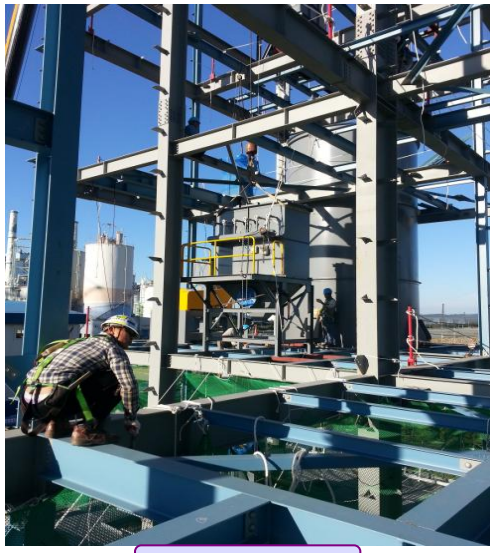
Main Steel Structure



20 TPD Coal Gasification Test-bed (2013/08)

Coal Treatment Area

Raymond Mill



PC-Bin

Coal Hopper

Cyclone

Status of 20 TPD Test-bed Site (2013/10/09)

Conclusions

- Carbon content of captured fines in partial/non-slagging entrained-bed gasifier showed 30-60%, with carbon conversion of over 90% in a single-pass through the gasifier.
- Captured fines contain a heating content of 4,200-4,600 kcal/kg, which is higher than the heating value of low-grade coals. Technically, captured fines can be utilized as a combustion fuel.
- Captured fines do not present the possibility of heavy metal leaching according to the current regulation, as confirmed by leaching tests.
- To compete with USC and other technologies, much cheaper versions of entrained-bed gasification system appear to be essential.
- The 20 ton/day scaled-up system will provide more practical data in developing partial/non-slagging entrained-bed gasifier.

Thank you for your attention.

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