Ash deposition formation from biomass oxyfuel combustion in a pilot-scale furnace

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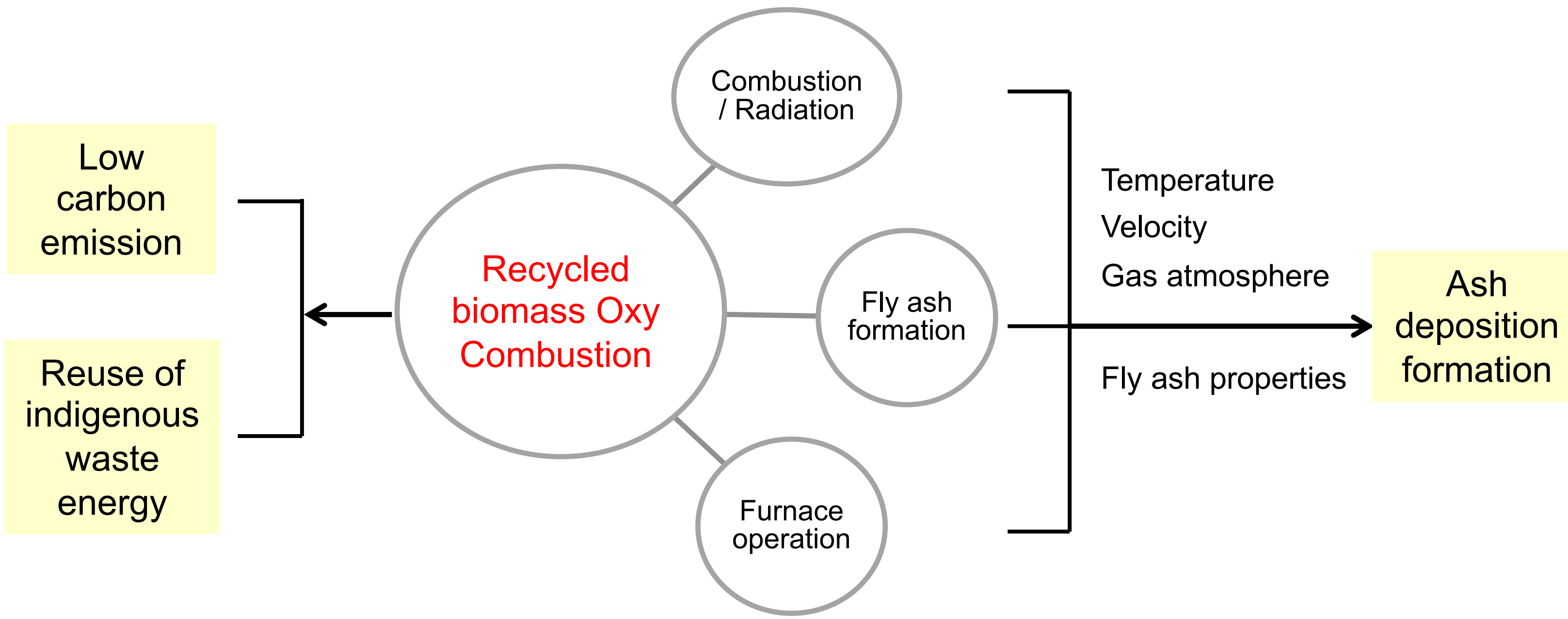
1 Introduction: Oxy → Ash deposition



How will this change affect the ash deposition formation?

1 Introduction: Literature findings and purposes

	Furnace and fuel	Findings
Fryda et al. [1,2]	Lab scale pulverized coal combustor; Russian and South African coals, Lignite; co-firing,	Oxy30, higher deposition rate (20%-110%), 1300 and 900 K; Mainly due to flue gas properties, flow conditions, and particle sizes, rather than the ash chemistry.
Yu et al. [3]	100 kW down-fired combustor; US coals,	Oxy 27 and Oxy 32, higher deposition rate (visual observation); 1300-1400 K; Mainly due to lower gas velocity; no obvious difference in ash chemistry and size distribution.
Li et al. [4]	25 kW down-fired combustor; Chinese bituminous coal.	Oxy 30, lower deposition rate (10%-50%); 1150 K; Mainly due to lower gas velocity and slightly coarser particle size; no obvious difference in ash chemistry.
Jurado et al. [5]	100 kW pulverised fuel combustor; El Cerrejon (EC) coal and cereal co-firing.	Flue gas recirculation, Oxy 27–35%, similar deposition formation (visual observation); Radiant zone;
Brink et al. [6]	300 kW pilot scale combustor; South African coal	Wet flue gas recirculation, similar deposition formation (deposit composition and SEM images); about 1500K;

Very different conclusions? What to expect for a new fuel in a new combustion environment?

1 Introduction: Literature findings and purposes

Experimental work

- Coal vs biomass.
- Biomass air vs Biomass Oxy.

⇩

✓ Overall ash deposition behaviour

Modelling analysis

- Build the new ash deposition models.
- Validate the models with experimental data.
- Investigate the detailed particle deposition behaviour.
- Predict the effect of the oxy condition.
- Predict the effect of the flue gas velocity.

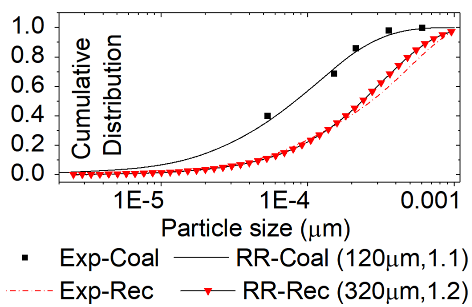
⇩

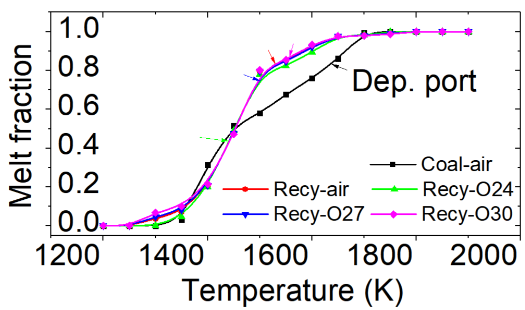
✓ Particle based deposition behaviour.
✓ Fuel property-furnace operation condition interaction.
✓ Predictions in the new environments.

2 Experimental data: fuel properties and the PACT facilities

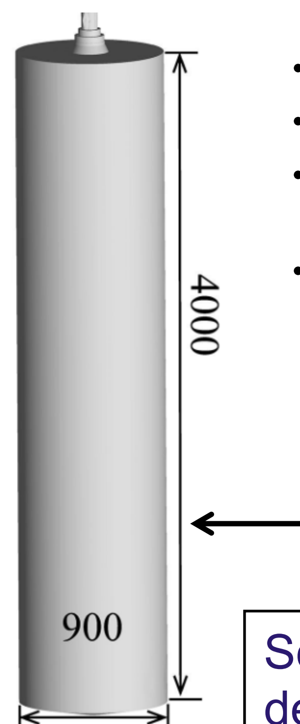
Fuel properties (El Cerrejon coal and Recycled wood)

Combustion furnace and deposition measurements.

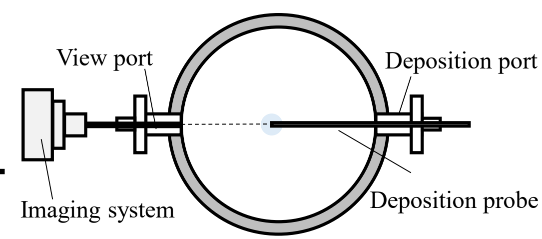




	Coal	REC	AR	Coal	REC
SiO_2	39.9	44.4	Moist.	7.63	5.8
Al_2O_3	16.6	5.8	Vol.	35.5	73.9
Fe_2O_3	10.8	7.6	FC	54.0	17.1
CaO	14.4	29.5	Ash	2.9	3.2
MgO	1.9	4.1	GCV (kJ/kg)	28.7	18.4
K_2O	1.6	2.6	DAF	Coal	REC
Na_2O	1.9	1.5	C	80.9	51.9
TiO_2	0.6	0.9	H	5.12	6.0
P_2O_5	0.8	0.6	N	1.65	0.4
SO_3	11.4	3.0	O	11.8	41.7



- Probe location: 2.8 m.
- Uncooled ceramic probe;
- 37 mm OD and 150 mm Length.
- Thermal input: 200 kW.



Schematic diagram of ash deposition measurement.

2 Models: Ash deposition models

3D CFD simulation of combustion (turbulence, combustion, and radiation)

→ Flow field, gas composition, temperature and ash flux. →

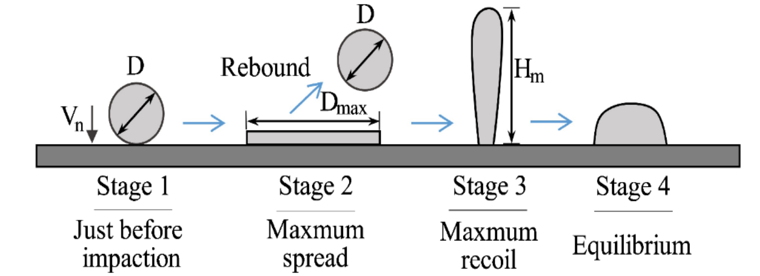
2D CFD case for deposition.

Inertia impaction | Particle sticking model based on excess energy [7]

Particle ash deposition →

- Overall deposition
- Particle impaction
- Particle sticking

Schematic diagram of ash deposition prediction



Kinetic energy + Surface energy → Maximum surface energy → Surface energy + potential energy → Surface energy + Kinetic energy

$$d_m = 1 + 0.259 * We^{0.317}$$

$$E^* = \frac{1}{4} d_m^2 (1 - cos\theta) + \frac{2}{3d_m} - 0.00536 * d_m{}^{4.70} * (1 - cos\theta)^{0.591} - 1$$

For $E^* \leq 0$, the sticking efficiency, E_{stick}, equals to unity.

$$E_{stick} = \exp(a * E^*), \text{ if } E^* > 0$$

$$E^*_{stick} = \exp[-9.21 * E^* (1 - f_{melt})], \text{ if } E^* > 0$$

Details of the sticking model: Yang, X., et al. "Prediction of particle sticking efficiency for fly ash deposition at high temperatures." *Proceedings of the Combustion Institute* (2018).

3 Results: Experimental results of ash deposition

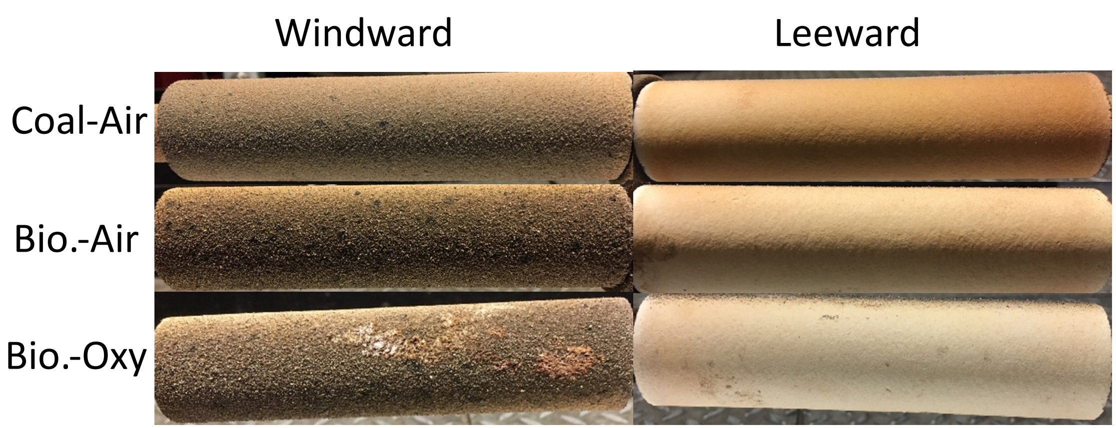
g/(m²*hr)	Exp.	Predictions
Coal-air	6.92	7.50
Recy-air	24.22	30.56
Recy-o27	22.49	24.22

a) For all cases, the deposits are mainly formed at the windward section and the leeward section of the probe is clean.

b) Recycled > coal.

c) For Recy., Air slightly > Oxy27.

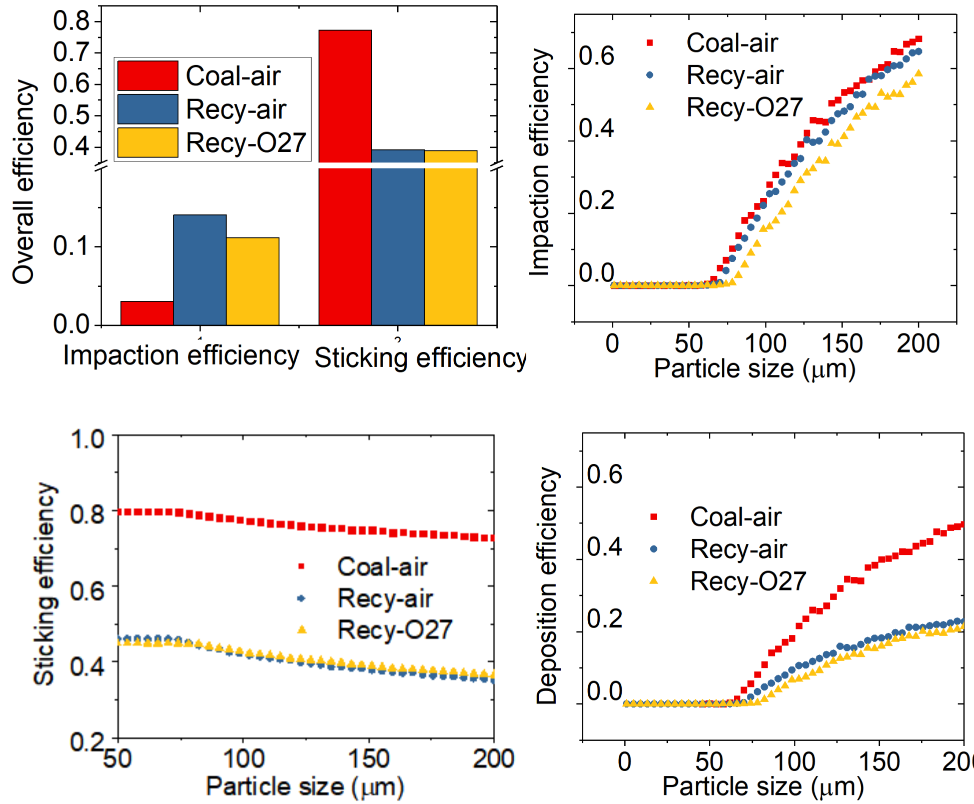
d) Predictions are close to measurements.



Images of ash deposits formed on the uncooled probes.

3 Results: Predicted particle size based deposition behaviour

g/(m²*hr)	Exp.	Predictions
Coal-air	6.92	7.50
Recy-air	24.22	30.56
Recy-o27	22.49	24.22



(1) Overall impaction and sticking behaviour; (2-4) Particle size based impaction, sticking and deposition behaviour.

Overall impaction and sticking:

a) For impaction efficiency, biomass >coal
b) For sticking efficiency, coal > biomass
c) For impaction efficiency, bio-Air > bio-Oxy27.
d) For sticking efficiency, bio-Air ≈ bio-Oxy27.

Particle size based impaction, sticking and deposition:

- For the pilot-scale furnace, deposition formation favours coarse particles.

3 Results: Effect of Oxy conditions (numerical results)

	Temperature, K	Velocity, m/s
air	1531	0.47
O24	1440	0.54
O27	1497	0.36
O30	1563	0.33

	deposition rate g/(m²*hr)	impaction efficiency	sticking efficiency	deposition efficiency
air	30.56	0.14	0.39	0.055
O24	27.68	0.18	0.27	0.05
O27	24.22	0.11	0.39	0.043
O30	23.07	0.1	0.42	0.041

Oxy effect:

a) Change in velocity and temperature.
b) Affect particle impaction and sticking behaviour.

Air vs Oxy

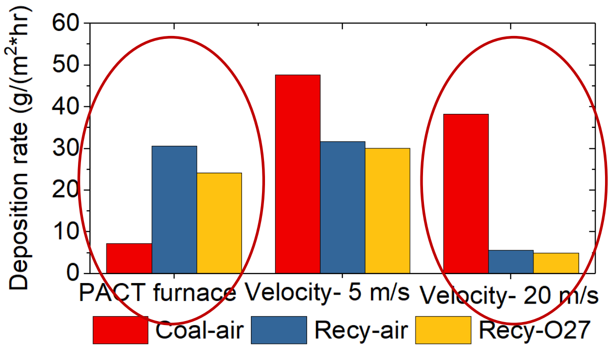
a) For deposition rate, Air slightly > Oxy.

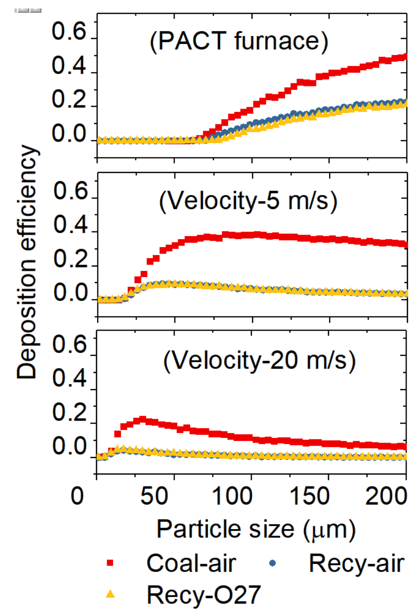
Oxy 24, 27 and 30

a) Oxy↑, deposition rate slightly↓.
b) Overall effect of impaction and sticking.

3 Results: Effect of flue gas velocity(numerical results)

Full-scale boiler condition?





Effect on deposition rate:

a) The difference between air and oxy27 is small, although air slightly > oxy27.

b) Interestingly, with increasing the flue gas velocity, Coal > biomass, different from the PACT results.

Effect on the particle size based deposition efficiency:

a) Very different selective deposition behaviour.

b) PACT furnace, low furnace velocity, deposition favours the coarse particles. This makes biomass to have a higher overall deposition efficiency than the coal.

c) With velocity ↑, deposition gradually favours medium to small particle. This can make the coal to have a much higher deposition rate than biomass.

4 Conclusions

i. In the pilot-scale furnace, Recy. > Coal and Recy.-Air slightly > Recy.-Oxy 27.

ii. An ash deposition model has been developed and validated.

iii. By using the model, deposition efficiency of coal >biomass with same size. However, in pilot-scale furnace, low velocity conditions favour coarse particle deposition. In addition, the recycled wood has a much higher ash concentration. Both make the biomass have a higher deposition rate than coal.

iv. Change in the oxy condition can affect the velocity and temperature, which affects the deposition formation.

v. The transfer of the deposition observations in the pilot-scale furnace to full-scale boiler should be performed very cautious. Furnace velocity condition has a significant effect.

Acknowledgments

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Many thanks for your kind attention.

Reference

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