

Supporting information

Title:

Applications of ultrafine limestone sorbents for the desulfurization
process in CFB boilers

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Table S1 The XRF component analysis of limestone samples.

Parameters	LOI *	CaO	MgO	SiO ₂	Al ₂ O ₃	Na ₂ O	Fe ₂ O ₃	Others
PS-Test 1	42.89	55.79	0.21	0.38	0.20	0.16`	0.06	0.59
PS-Test 2	43.00	55.38	0.22	0.54	0.22	0.18	0.09	0.56
CS-Test1	42.76	54.25	0.36	1.04	0.77	0.12	0.29	0.35
CS-Test2/3	42.06	53.32	1.43	1.68	0.40	0.16	0.47	0.25
CS-Test4	42.45	53.43	0.89	1.15	0.54	0.16	1.02	0.28
CS-Test5	41.27	52.95	0.84	2.24	1.56	0.15	0.49	0.50
CS-Test6	41.61	52.44	2.34	2.04	0.74	0.15	0.33	0.35

* Loss on ignition

Table S2 Instrument parameters of gas analyzers used in pilot-scale and commercial-scale experiments.

Instrument	Producer	SO₂	NO	Particle matter
Optimal 7	MRU Air Instrument	± 10 ppm (<200 ppm) or 5% of the measured value (200~2000 ppm) 1% of the measured value (0~2500 mg/Nm ³)	± 2 ppm (<40 ppm) or 5% of the measured value (40~300 ppm) 1% of the measured value (0~2500 mg/Nm ³)	-
SCS-900	Beijing SDL Technology			
43i SO ₂ analyzer	Thermo Fisher Scientific	2 mg/Nm ³ (<200 mg/Nm ³)	-	-
42i NOx analyzer	Thermo Fisher Scientific	-	1.5 mg/Nm ³ (<150 mg/Nm ³)	-
Model 5030i	Thermo Fisher Scientific	-	-	±5 µg/Nm ³ (0~10 mg/Nm ³)
PA200	Chongqing Chuanyi	10 mg/Nm ³	-	-
MGA5+	MRU Air Instrument	1 ppm (<200 ppm)	1 ppm (<250 ppm)	-

Table S3 The proximate and ultimate analyses of coals used in pilot-scale test

Parameter	LHV_{ar} (MJ/kg)	$M_{ar}(\%)$	$A_{ar}(\%)$	$V_{daf}(\%)$	$C_{ar}(\%)$	$H_{ar}(\%)$	$O_{ar}(\%)$	$N_{ar}(\%)$	$S_{ar}(\%)$
Value	17.69	3.75	45.74	12.82	43.28	2.74	7.02	0.58	1.28

Table S4 The proximate and ultimate analyses of coals used in CS-Test1/2

Parameter	LHV_{ar} (MJ/kg)	$M_{ar}(\%)$	$A_{ar}(\%)$	$V_{daf}(\%)$	$C_{ar}(\%)$	$H_{ar}(\%)$	$O_{ar}(\%)$	$N_{ar}(\%)$	$S_{ar}(\%)$
Test1	20.67	7.35	29.26	16.23	53.43	1.95	5.54	0.83	1.66
Test2	14.33	4.00	47.26	18.30	36.22	2.61	7.09	0.75	2.08

Table S5 The proximate and ultimate analyses of coals used in CS-Test3

Parameter	LHV_{ar} (MJ/kg)	$M_{ar}(\%)$	$A_{ar}(\%)$	$V_{daf}(\%)$	$C_{ar}(\%)$	$H_{ar}(\%)$	$O_{ar}(\%)$	$N_{ar}(\%)$	$S_{ar}(\%)$
Average value	14.24	5.75	46.32	18.81	35.45	2.55	6.94	0.73	2.26
Number	1	2	3	4	5	6	7	8	9
$S_{ar} (\%)$	2.26	2.14	2.32	2.32	1.84	2.06	2.74	2.24	2.22
LHV_{ar} (MJ/kg)	11.88	14.57	13.06	12.49	17.20	15.59	11.95	13.25	13.44
								10	11
								12.18	2.14
								12.02	2.62
								13.41	

Table S6 The proximate and ultimate analyses of coals used in CS-Test4

Parameter	LHV_{ar} (MJ/kg)	$M_{ar}(\%)$	$A_{ar}(\%)$	$V_{daf}(\%)$	$C_{ar}(\%)$	$H_{ar}(\%)$	$O_{ar}(\%)$	$N_{ar}(\%)$	$S_{ar}(\%)$
Average value	13.59	3.80	47.69	18.30	34.84	2.36	8.62	0.63	2.02
Number	1		2		3		4		5
$S_{ar} (\%)$	2.05		1.80		2.00		2.25		1.99
LHV_{ar} (MJ/kg)	13.52		14.73		11.93		15.52		12.68

Table S7 The proximate and ultimate analyses of coals used in CS-Test5/6

Name	LHV _{ar} (MJ/kg)	Proximate analysis				Ultimate analysis			
		M _{ar} (%)	V _{daf} (%)	A _{ar} (%)	C _{ar} (%)	H _{ar} (%)	O _{ar} (%)	N _{ar} (%)	S _{ar} (%)
Ultrafine	16.56	11.80	25.48	34.79	42.95	1.67	7.06	0.70	1.03
Coarse	16.67	11.50	25.25	34.61	43.26	1.70	7.14	0.73	1.06

Table S8 Comparison of costs for using the ultrafine limestone and coarse limestone in the 90t/h CFB boiler (CS-Test 2/3)

Coarse limestone			Ultrafine limestone		
Crude limestone	50.00	yuan/ton	Ultrafine limestone	140.00	yuan/ton
Production cost of coarse limestone	15.00	yuan/ton	Ca/S	2.00	-
Ca/S	2.50	-	Limestone feeding	3.00	ton/h
Limestone feeding	3.75	ton/h	Annual service hours	5000	h/a
Annual service hours	5000	h/a	Operation cost	2.10	million/a
Operation cost	1.22	million/a	Total cost	2.10	million/a
Investment cost	3.00	million			
Matainance cost (5%)	0.15	million/a			
Total cost	1.37	million/a	Cost recovery	4.10	a

(Unit: RMB)

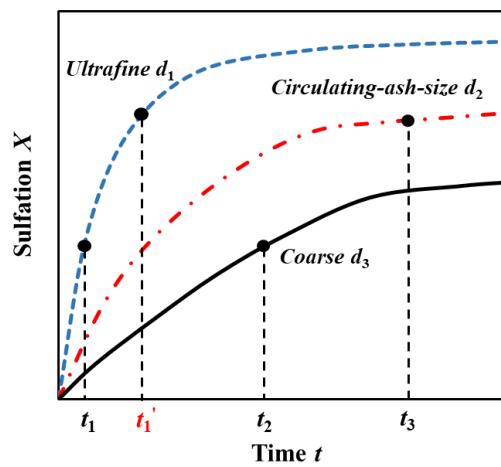


Figure S1 Schematics of the optimal particle size after comprehensive consideration of the chemical reaction rate and particle residence time

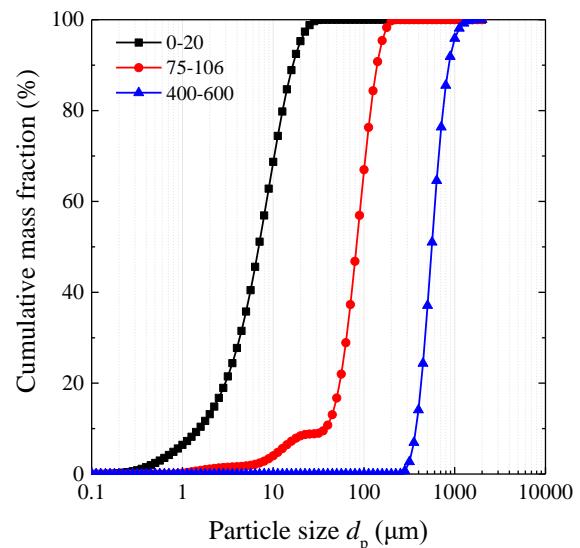
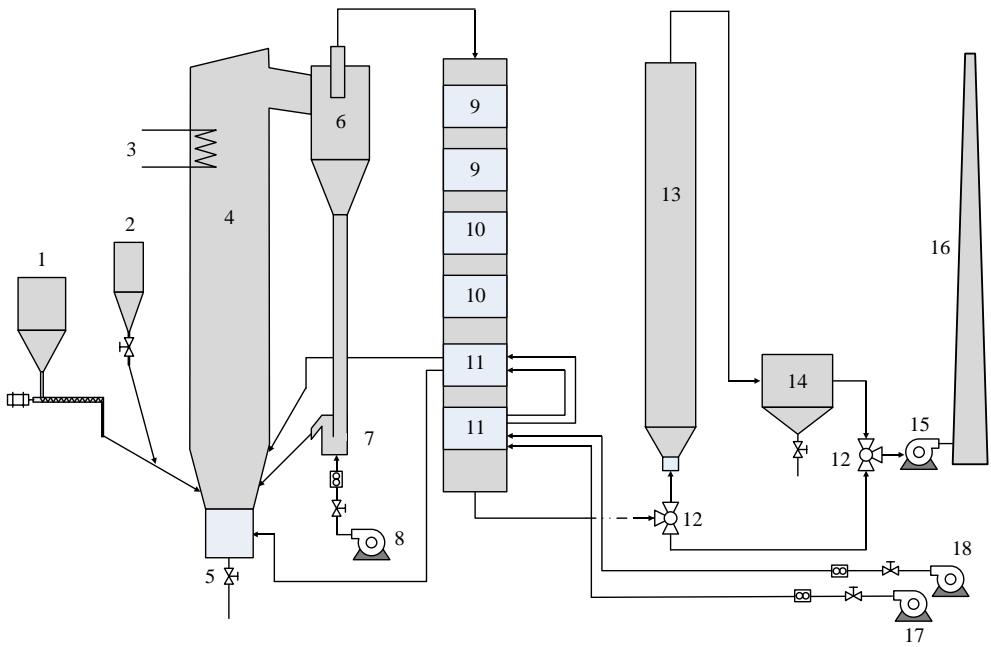


Figure S2 Particle size distribution of limestone used in LC-TGA



1. Coal bunker; 2. Limestone silo; 3. Inserted cooling tube; 4. Furnace; 5. Discharging port; 6. cyclone;
 7. Loop seal; 8. Aeration fan. ; 9. Primary economizer; 10. Secondary economizer; 11. Air preheater;
 12. Bypass valve; 13. Semi-dry FGD; 14. Bag filter; 15. Induced fan; 16. Chimney; 17. Primary air
 draft fan; 18. Secondary air draft fan

Figure S3 The schematic diagram of the 3MW_{th} pilot-scale CFB boiler

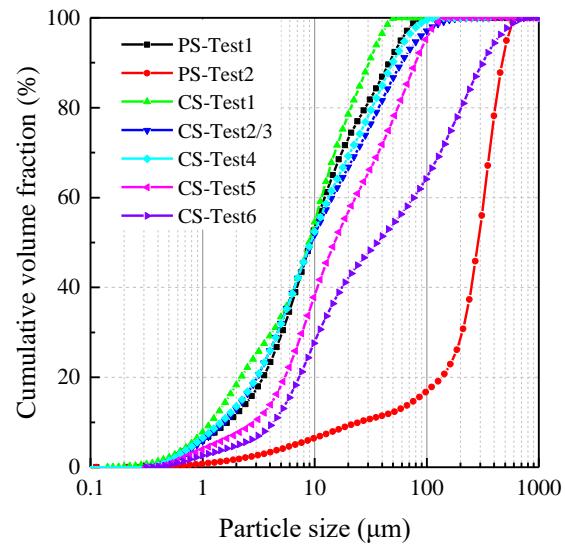


Figure S4 Particle size distribution of limestone used in the pilot-scale (PS) and commercial-scale (CS) CFB boilers.

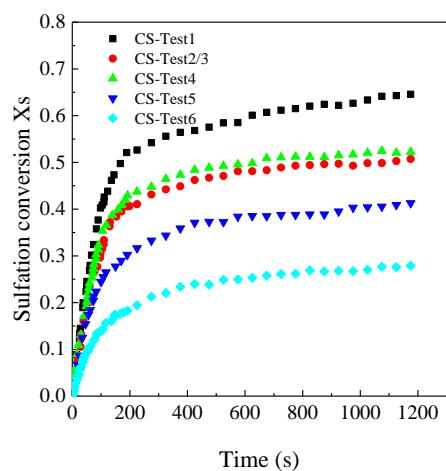


Figure S5 The sulfation reactivity of limestones used in commercial-scale tests (850 °C, 1000 ppm SO₂)

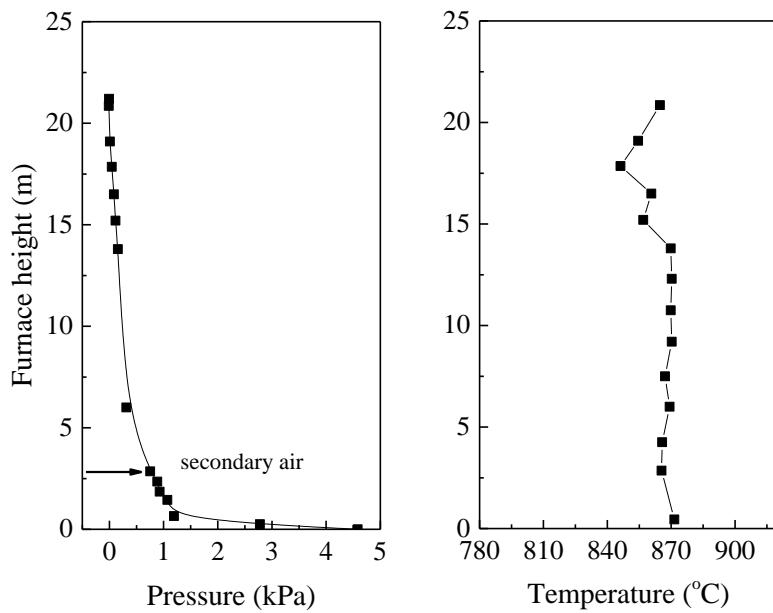


Figure S6 Pressure and temperature distribution in the pilot-scale CFB boiler

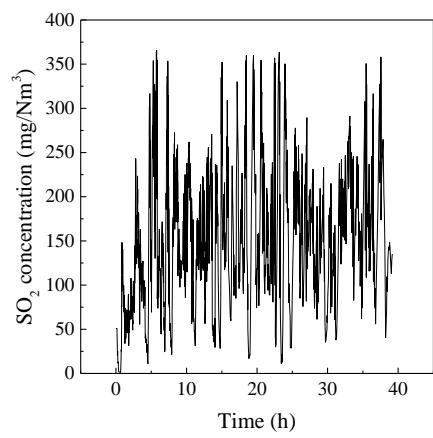


Figure S7 Time variation of SO₂ emission concentration in CS-Test4 (low boiler load)

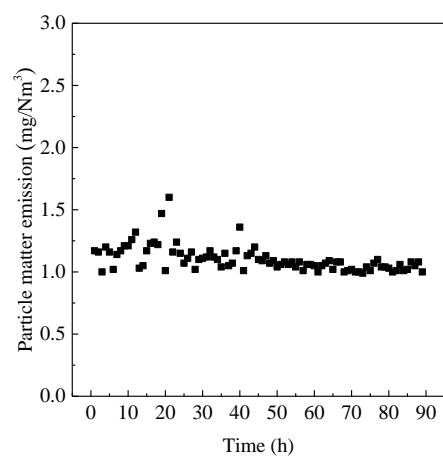


Figure S8 Particle matter emission at the chimney outlet