Electronic Supplementary Material

Enhancing cyclone separator performance via computational fluid dynamics and intelligent optimization: synergizing design of experiments, machine learning, and multi-objective genetic algorithms

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Table S1 The geometrical factor ratios of Stairmand design.

Parameters	S/D	A/D	B/D	D_x/D	h_c/D	B_c/D	h/D
Values	0.5	0.5	0.5	0.5	2.5	0.375	1.5

Table S2 The coefficients of Oka erosion model

Coefficients	L	n_1	n_2	k_1	k_2	k_3	H_v	d'(μm)	$V'(m \cdot s^{-1})$
Value	65	0.77	1.36	-0.12	2.35	0.19	1.83	3.26	104

Table S3 The simulation parameters

Simulation Parameter	Values(Units)
Gas inlet velocity	$28(m \cdot s^{-1})$
Particle inlet velocity	$8(m \cdot s^{-1})$
Total flow rate of particles	$10^{-10}(kg \cdot s^{-1})$
Operating pressure	101325(Pa)
Operating temperature	288.15(K)

Table S4 The numerical simulation results of 32 different structures of cyclone separators.

	S/D	A/D	B/D	D_X/D	B_C/D	h/D	v/D	ER (10^{-5} kg·s^{-1})	ΔP (Pa)	EF (%)
1	0.35	0.59	0.26	0.35	0.3	2.2	24	27.67	3547.37	81.98
2	0.65	0.41	0.14	0.65	0.3	2.2	32	19.86	3564.52	84.54
3	0.35	0.41	0.14	0.35	0.45	2.2	24	8.39	1509.03	90.00
4	0.35	0.59	0.14	0.35	0.3	0.8	24	9.15	2405.98	63.1
5	0.65	0.41	0.14	0.35	0.3	0.8	24	9.47	1406.53	85.57

6	0.65	0.59	0.26	0.65	0.3	2.2	24	6.10	813.40	65.58
7	0.65	0.59	0.26	0.35	0.3	0.8	32	23.29	1996.01	90.46
8	0.35	0.41	0.26	0.35	0.45	0.8	24	4.74	2013.43	89.54
9	0.65	0.41	0.14	0.35	0.45	0.8	32	5.48	2238.32	77.41
10	0.35	0.41	0.26	0.65	0.45	2.2	32	7.14	839.86	69.38
11	0.65	0.59	0.14	0.35	0.45	2.2	24	6.45	1839.06	81.38
12	0.65	0.59	0.26	0.65	0.45	2.2	32	10.70	1568.57	66.82
13	0.65	0.59	0.26	0.35	0.45	0.8	24	12.49	4128.31	60.73
14	0.65	0.59	0.14	0.65	0.45	0.8	32	0.753	215.96	72.50
15	0.65	0.59	0.14	0.35	0.3	2.2	32	19.70	4253.33	67.35
16	0.35	0.41	0.26	0.65	0.3	2.2	24	2.95	553.04	63.89
17	0.35	0.59	0.14	0.65	0.3	2.2	32	8.34	875.25	64.00
18	0.35	0.41	0.14	0.65	0.3	0.8	24	0.63	345.96	82.77
19	0.65	0.41	0.26	0.35	0.45	2.2	32	20.37	4140.07	86.29
20	0.35	0.41	0.14	0.65	0.45	0.8	32	5.70	667.69	74.97
21	0.65	0.41	0.26	0.35	0.3	2.2	24	9.13	2723.10	79.49
22	0.65	0.41	0.14	0.65	0.45	2.2	24	1.79	312.64	77.45
23	0.35	0.59	0.26	0.65	0.3	0.8	32	7.98	1438.71	56.94
24	0.35	0.41	0.14	0.35	0.3	2.2	32	14.97	2384.14	87.26
25	0.35	0.59	0.14	0.65	0.45	2.2	24	2.79	453.68	80.36
26	0.65	0.59	0.14	0.65	0.3	0.8	24	2.78	520.83	67.76
27	0.35	0.59	0.14	0.35	0.45	0.8	32	15.22	3355.25	87.47
28	0.35	0.59	0.26	0.65	0.45	0.8	24	3.14	846.45	60.45
29	0.65	0.41	0.26	0.65	0.3	0.8	32	7.08	880.38	71.39
30	0.35	0.59	0.26	0.35	0.45	2.2	32	22.42	5229.95	83.81
31	0.35	0.41	0.26	0.35	0.3	0.8	32	17.73	6033.35	39.73
32	0.65	0.41	0.26	0.65	0.45	0.8	24	2.26	624.71	64.10

Table S5 The list of comprehensive Z-score evaluation metrics.

	ER (10^{-5}kg/s)	ΔP (Pa)	EF (%)	$Z_{composite}$ score
1	4.81	997.31	79.36	-0.52
2	4.67	1016.03	79.67	-1.06
3	4.64	1030.17	79.99	-1.37
4	4.71	1036.85	80.19	-1.33
5	4.97	1019.46	80.58	-1.28
6	4.94	1027.39	80.74	-1.42
7	4.63	1081.90	81.20	-2.11
8	5.13	1041.77	81.29	-1.35
9	4.85	1065.18	81.38	-1.85
10	5.09	1062.73	81.50	-1.41
11	4.85	1100.43	81.67	-1.77
12	5.58	1066.41	81.82	-0.71
13	5.12	1085.46	81.87	-1.43

14	5.41	1090.10	82.37	-1.17
15	5.51	1086.07	82.39	-1.05
16	5.83	1090.22	82.63	-0.71
17	5.21	1123.93	82.68	-1.47
18	5.83	1110.59	82.83	-0.65
19	5.77	1120.32	82.84	-0.67
20	5.42	1153.80	82.99	-1.03
21	6.18	1124.89	83.30	-0.46
22	6.20	1133.54	83.45	-0.45
23	6.25	1141.73	83.66	-0.44
24	5.98	1153.59	83.73	-0.61
25	6.17	1162.66	83.91	-0.45
26	6.21	1168.38	84.30	-0.52
27	6.34	1179.54	84.37	-0.39
28	6.05	1187.50	84.58	-0.60
29	5.96	1208.66	84.66	-0.59
30	6.03	1203.81	84.88	-0.59
31	6.32	1213.79	85.04	-0.36
32	6.33	1242.73	85.45	-0.27
33	6.61	1228.30	85.61	-0.24
34	7.15	1305.79	86.74	-0.04
35	7.08	1344.76	86.81	0.04
36	7.31	1371.94	86.82	-0.13
37	6.95	1397.12	86.84	0.04
38	6.98	1389.23	86.93	0.07
39	7.57	1401.78	87.09	-0.36
40	7.03	1406.95	87.13	0.07
41	7.14	1456.29	87.17	-0.13
42	7.05	1486.72	87.20	-0.21
43	7.21	1441.13	87.43	-0.03
44	7.26	1418.93	87.69	0.10
45	7.25	1458.09	87.81	0.03
46	7.21	1491.34	87.81	-0.10
47	7.32	1433.46	87.95	0.12
48	7.41	1527.64	87.99	-0.40
49	7.52	1479.10	88.09	-0.19
50	7.96	1495.27	88.17	-0.85
51	7.62	1503.84	88.18	-0.38
52	8.01	1492.09	88.24	-0.88
53	7.57	1514.48	88.33	-0.31
54	7.43	1534.01	88.47	-0.21
55	7.46	1549.11	88.56	-0.30
56	7.81	1555.94	88.61	-0.76
57	7.64	1567.05	88.75	-0.52

58	8.12	1560.55	88.77	-1.22
59	7.72	1583.14	88.82	-0.72
60	8.33	1568.05	88.90	-1.63
61	7.76	1613.59	89.03	-0.91
62	8.24	1645.02	89.20	-1.95
63	8.36	1631.83	89.30	-2.00
64	7.86	1668.97	89.34	-1.43
65	7.91	1745.94	89.41	-2.45
66	8.44	1679.09	89.46	-2.60
67	8.52	1694.88	89.53	-2.92
68	8.64	1693.13	89.65	-3.10
69	8.74	1731.11	89.66	-3.88
70	8.50	1828.46	90.17	-4.30
71	8.88	1886.99	90.30	-6.26

Table S6 Comparison results of calculated pressure drop, efficiency and erosion rate by CFD and NSGA-II

	ΔP (Pa)	EF (%)	ER (10^{-5}kg·s^{-1})
CFD	1428	85.57	7.47
NSGA-II	1443	87.95	7.32

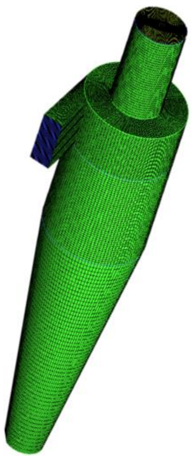

Fig.S1 Computation grids for the cyclone simulation

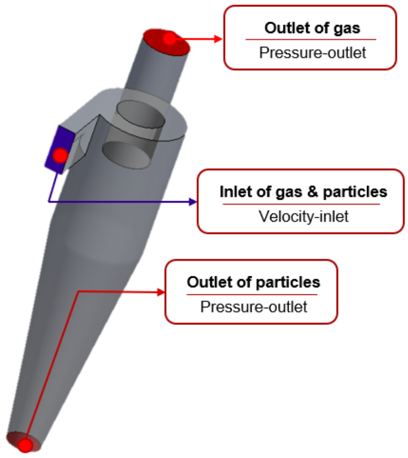

Fig.S2 Boundary conditions

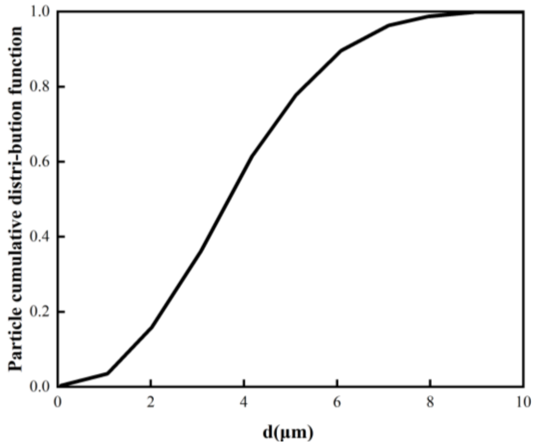

Fig.S3 Particle cumulative distribution function curve.

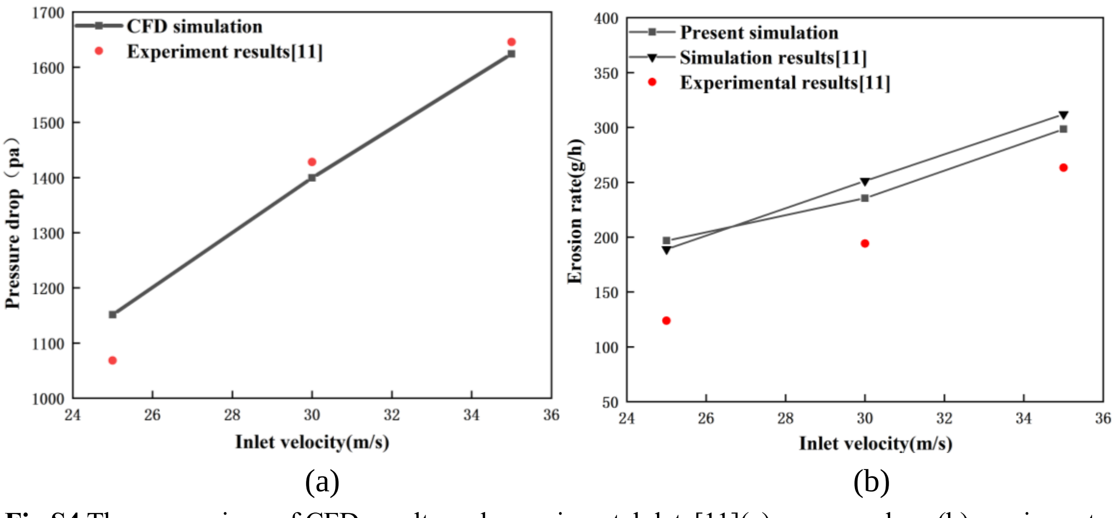

Fig.S4 The comparison of CFD results and experimental data[11](a) pressure drop (b) erosion rate