Supporting Information for

Particle Formation and Growth from Oxalic Acid, Methanesulfonic Acid, Trimethylamine and Water: A Combined Experimental and Theoretical Study

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1. Tables of all experimental conditions and a summary of results

Tables of all experiments separated by the last species added to the reactor whose effect on particle formation was tested.

Table S1 Experiments with and without methanesulfonic acid (MSA)

Expt.	Ring #1	Ring #2[a]	Spoke #1[b]	Spoke #2 [b]	Degree of Particle Formation Enhancement due to Addition of MSA
humid conditions[c]					
1a	30% RH	17 ppb OxA	dry air	4 ppb TMA[d]	base case
1b	30% RH	17 ppb OxA	2.3 ppb MSA	**4 ppb TMA**	+ + +
2a	29% RH	17 ppb OxA	dry air	1 ppb TMA	base case
2b	29% RH	17 ppb OxA	1.2 ppb MSA	1 ppb TMA	+ + + [e]
3a	30% RH	17 ppb OxA	dry air	0.2 ppb TMA	base case
3b	30% RH	17 ppb OxA	0.3 ppb MSA	0.2 ppb TMA	+ + +
dry conditions					
4a	dry air	17 ppb OxA	dry air	2.7 ppb TMA	base case
4b	dry air	17 ppb OxA	**5 ppb MSA**	2.7 ppb TMA	+ + +
5a	dry air	17 ppb OxA	dry air	4 ppb TMA	base case
5b	dry air	17 ppb OxA	2.2 ppb MSA	**4 ppb TMA**	+ + +
6a	dry air	17 ppb OxA	dry air	3.5 ppb TMA	base case
6b	dry air	17 ppb OxA	4 ppb MSA	3.5 ppb TMA	+ + +

Note: Only dry air was added through ring #3 and spoke #3.

[a] The oxalic acid concentration, calculated from its vapor pressure at 303 K,[1] takes into account dilution in the flow reactor. This represents the maximum concentration achieved in the reaction.

[b] MSA and TMA concentrations are measured prior to their entrance to the reactor. These values account for dilution in the reactor, and are in bold-face font when in excess. These represent the maximum concentrations achieved in the reaction.

[c] Blue highlight indicates experiment was done in the presence of water vapor.

[d] 1 ppb = 2.48×10^{10} cm^{-3} at 1 atm and 294 K

[e] An enhancement of + + + represents > 10 times more particles due to the added MSA.

Table S2 Experiments with and without oxalic acid (OxA)

Expt.	Ring #1	Ring #2[a]	Spoke #1[b]	Spoke #2[b]	Degree of Particle Formation Enhancement due to Addition of OxA	Particle growth?
humid conditions[c]						
7a	20% RH	dry air	**5.3 ppb MSA**[d]	2.6 ppb TMA	base case	base case
7b	20% RH	17 ppb OxA	**5.3 ppb MSA**	2.6 ppb TMA	no change[e]	X[f]
8a	20% RH	dry air	**5.5 ppb MSA**	2.6 ppb TMA	base case	base case
8b	20% RH	17 ppb OxA	**5.5 ppb MSA**	2.6 ppb TMA	no change	X
9a	30% RH	dry air	**5 ppb MSA**	2.7 ppb TMA	base case	base case
9b	30% RH	17 ppb OxA	**5 ppb MSA**	2.7 ppb TMA	no change	X
10a	30% RH	dry air	**5 ppb MSA**	2.7 ppb TMA	base case	base case
10b	30% RH	17 ppb OxA	**5 ppb MSA**	2.7 ppb TMA	no change	X
11a	30% RH	dry air	2.1 ppb MSA	**4 ppb TMA**	base case	base case
11b	30% RH	17 ppb OxA	2.1 ppb MSA	**4 ppb TMA**	no change	†[g]
12a	30% RH	dry air	2.1 ppb MSA	**4 ppb TMA**	base case	base case
12b	30% RH	17 ppb OxA	2.1 ppb MSA	**4 ppb TMA**	no change	X
13a	30% RH	dry air	4.2 ppb MSA	**6 ppb TMA**	base case	base case
13b	30% RH	17 ppb OxA	4.2 ppb MSA	**6 ppb TMA**	no change	X
14a	30% RH	dry air	1.3 ppb MSA	**5 ppb TMA**	base case	base case
14b	30% RH	17 ppb OxA	1.3 ppb MSA	**5 ppb TMA**	no change	X
15a	15% RH	dry air	4.4 ppb MSA	3.2 ppb TMA	base case	base case
15b	15% RH	17 ppb OxA	4.4 ppb MSA	3.2 ppb TMA	no change	X
16a	15% RH	dry air	4 ppb MSA	3.5 ppb TMA	base case	base case
16b	15% RH	17 ppb OxA	4 ppb MSA	3.5 ppb TMA	no change	X

17a	29% RH	dry air	3.9 ppb MSA	3.7 ppb TMA	base case	base case
17b	29% RH	17 ppb OxA	3.9 ppb MSA	3.7 ppb TMA	no change	n/a [h]
18a	30% RH	dry air	3.1 ppb MSA	3.5 ppb TMA	base case	base case
18b	30% RH	17 ppb OxA	3.1 ppb MSA	3.5 ppb TMA	no change	X
19a	30% RH	dry air	3.2 ppb MSA	3.5 ppb TMA	base case	base case
19b	30% RH	17 ppb OxA	3.2 ppb MSA	3.5 ppb TMA	no change	X
20a	30% RH	dry air	3.6 ppb MSA	3.5 ppb TMA	base case	base case
20b	30% RH	34 ppb OxA	3.6 ppb MSA	3.5 ppb TMA	no change	X
21a	30% RH	dry air	3.4 ppb MSA	3.3 ppb TMA	base case	base case
21b	30% RH	34 ppb OxA	3.4 ppb MSA	3.3 ppb TMA	no change	X
22a	30% RH	dry air	3.1 ppb MSA	3.2 ppb TMA	base case	base case
22b	30% RH	34 ppb OxA	3.1 ppb MSA	3.2 ppb TMA	no change	X
23a	50% RH	dry air	3.7 ppb MSA	3.5 ppb TMA	base case	base case
23b	50% RH	17 ppb OxA	3.7 ppb MSA	3.5 ppb TMA	no change	X
24a	50% RH	dry air	2.7 ppb MSA	3.7 ppb TMA	base case	base case
24b	50% RH	17 ppb OxA	2.7 ppb MSA	3.7 ppb TMA	no change	X
dry conditions						
25a	dry air	dry air	**3.8 ppb MSA**	2.5 ppb TMA	base case	base case
25b	dry air	17 ppb OxA	**3.8 ppb MSA**	2.5 ppb TMA	no change	✓ [i]
26a	dry air	dry air	**4.7 ppb MSA**	2.5 ppb TMA	base case	base case
26b	dry air	17 ppb OxA	**4.7 ppb MSA**	2.5 ppb TMA	no change	✓
27a	dry air	dry air	**5.5 ppb MSA**	3.7 ppb TMA	base case	base case
27b	dry air	17 ppb OxA	**5.5 ppb MSA**	3.7 ppb TMA	no change	n/a
28a	dry air	dry air	**5 ppb MSA**	2.7 ppb TMA	base case	base case
28b	dry air	17 ppb OxA	**5 ppb MSA**	2.7 ppb TMA	no change	✓
29a	dry air	dry air	**5.3 ppb MSA**	2.7 ppb TMA	base case	base case

29b	dry air	17 ppb OxA	**5.3 ppb MSA**	2.7 ppb TMA	no change	✓
30a	dry air	dry air	4.6 ppb MSA	**9 ppb TMA**	base case	base case
30b	dry air	17 ppb OxA	4.6 ppb MSA	**9 ppb TMA**	+ [j] (3 times more)	n/a
31a	dry air	dry air	2.1 ppb MSA	**4 ppb TMA**	base case	base case
31b	dry air	17 ppb OxA	2.1 ppb MSA	**4 ppb TMA**	no change	✓
32a	dry air	dry air	2.2 ppb MSA	**4 ppb TMA**	base case	base case
32b	dry air	17 ppb OxA	2.2 ppb MSA	**4 ppb TMA**	no change	✓
33a	dry air	dry air	3.5 ppb MSA	3.6 ppb TMA	base case	base case
33b	dry air	17 ppb OxA	3.5 ppb MSA	3.6 ppb TMA	no change	✓
34a	dry air	dry air	3.6 ppb MSA	3.5 ppb TMA	base case	base case
34b	dry air	17 ppb OxA	3.6 ppb MSA	3.5 ppb TMA	no change	✓
35a	dry air	dry air	3.2 ppb MSA	3.5 ppb TMA	base case	base case
35b	dry air	17 ppb OxA	3.2 ppb MSA	3.5 ppb TMA	no change	✓
36a	dry air	dry air	3.8 ppb MSA	3.5 ppb TMA	base case	base case
36b	dry air	17 ppb OxA	3.8 ppb MSA	3.5 ppb TMA	no change	✓
37a	dry air	dry air	3.7 ppb MSA	3.7 ppb TMA	base case	base case
37b	dry air	17 ppb OxA	3.7 ppb MSA	3.7 ppb TMA	no change	✓
38a	dry air	dry air	3.4 ppb MSA	3.5 ppb TMA	base case	base case
38b	dry air	34 ppb OxA	3.4 ppb MSA	3.5 ppb TMA	no change	✓
39a	dry air	dry air	3.5 ppb MSA	3.2 ppb TMA	base case	base case
39b	dry air	34 ppb OxA	3.5 ppb MSA	3.2 ppb TMA	no change	✓

Note: Only dry air was added through ring #3 and spoke #3.

[a] The oxalic acid concentration, calculated from its vapor pressure at 303 K,[1] takes into account dilution in the flow reactor. This represents the maximum concentration achieved in the reaction.

[b] MSA and TMA concentrations are measured prior to their entrance to the reactor. These values account for dilution in the reactor, and are in bold-face font when in excess. These represent the maximum concentrations achieved in the reaction.

[c] Blue highlight indicates experiment was done in the presence of water vapor.

[d] 1 ppb = 2.48×10^{10} cm^{-3} at 1 atm and 294 K

[e] The designation, "no change" indicates $\leq$ 2 times more particles were observed due to the added OxA.

[f] An "X" means particle growth compared to the base case was not observed.

[g] The "†" indicates that particle growth was observed only once out of four experiments performed under similar conditions. In most cases no particle growth was observed under humid conditions with excess TMA.

[h] "n/a" means the reaction was not measured with the SMPS.

[i] A "✓" means particle growth compared to the base case was observed.

[j] An enhancement of + represents $>$ 2 times more but $\leq$ 4 times more particles due to the added OxA.

Table S3 Experiments with and without water vapor

Expt.	Ring #1	Ring #2[a]	Spoke #1[b]	Spoke #2[b]	Degree of Particle Formation Enhancement due to Addition of H_2O	Particle growth?
40a	dry air	dry air	**5 ppb MSA**[c]	2.7 ppb TMA	base case	base case
40b[d]	30% RH	dry air	**5 ppb MSA**	2.7 ppb TMA	+ + [e]	✓ [f]
41a	dry air	dry air	**5 ppb MSA**	2.7 ppb TMA	base case	base case
41b	30% RH	dry air	**5 ppb MSA**	2.7 ppb TMA	+ [g]	✓
42a	dry air	dry air	2.1 ppb MSA	**4 ppb TMA**	base case	base case
42b	30% RH	dry air	2.1 ppb MSA	**4 ppb TMA**	+ + + [h]	✓
43a	dry air	dry air	2.1 ppb MSA	**4 ppb TMA**	base case	base case
43b	30% RH	dry air	2.1 ppb MSA	**4 ppb TMA**	+ + (9 times more)	✓
44a	dry air	dry air	1.3 ppb MSA	**5 ppb TMA**	base case	base case
44b	30% RH	dry air	1.3 ppb MSA	**5 ppb TMA**	+ + +	✓
45a	dry air	dry air	4.4 ppb MSA	3.2 ppb TMA	base case	base case
45b	15% RH	dry air	4.4 ppb MSA	3.2 ppb TMA	+	✓
46a	dry air	dry air	4 ppb MSA	3.5 ppb TMA	base case	base case
46b	15% RH	dry air	4 ppb MSA	3.5 ppb TMA	+	✓
47a	dry air	dry air	3.9 ppb MSA	3.7 ppb TMA	base case	base case
47b	29% RH	dry air	3.9 ppb MSA	3.7 ppb TMA	+ +	n/a [i]
48a	dry air	dry air	3.1 ppb MSA	3.5 ppb TMA	base case	base case
48b	30% RH	dry air	3.1 ppb MSA	3.5 ppb TMA	+ + +	✓
49a	dry air	dry air	3.2 ppb MSA	3.5 ppb TMA	base case	base case
49b	30% RH	dry air	3.2 ppb MSA	3.5 ppb TMA	+ +	✓
50a	dry air	dry air	3.6 ppb MSA	3.5 ppb TMA	base case	base case
50b	30% RH	dry air	3.6 ppb MSA	3.5 ppb TMA	+ + +	✓
51a	dry air	dry air	3.4 ppb MSA	3.3 ppb TMA	base case	base case
51b	30% RH	dry air	3.4 ppb MSA	3.3 ppb TMA	+ +	✓

52a	dry air	dry air	3.1 ppb MSA	3.2 ppb TMA	base case	base case
52b	30% RH	dry air	3.1 ppb MSA	3.2 ppb TMA	+ +	✓
53a	dry air	dry air	2.9 ppb MSA	3.2 ppb TMA	base case	base case
53b	30% RH	dry air	2.9 ppb MSA	3.2 ppb TMA	+ +	✓
54a	dry air	dry air	3.7 ppb MSA	3.5 ppb TMA	base case	base case
54b	50% RH	dry air	3.7 ppb MSA	3.5 ppb TMA	+ + +	✓
55a	dry air	dry air	2.7 ppb MSA	3.7 ppb TMA	base case	base case
55b	50% RH	dry air	2.7 ppb MSA	3.7 ppb TMA	+ + +	✓
56a	dry air	17 ppb OxA	3.8 ppb MSA	3.5 ppb TMA	base case	base case
56b	15% RH	17 ppb OxA	3.8 ppb MSA	3.5 ppb TMA	+	X [j]
57a	dry air	17 ppb OxA	3.7 ppb MSA	3.7 ppb TMA	base case	base case
57b	15% RH	17 ppb OxA	3.7 ppb MSA	3.7 ppb TMA	no change	X
58a	dry air	17 ppb OxA	**5.5 ppb MSA**	3.7 ppb TMA	base case	base case
58b	29% RH	17 ppb OxA	**5 ppb MSA**	3.7 ppb TMA	+ +	n/a
59a	dry air	17 ppb OxA	**5 ppb MSA**	2.7 ppb TMA	base case	base case
59b	30% RH	17 ppb OxA	**5 ppb MSA**	2.7 ppb TMA	+ +	✓
60a	dry air	17 ppb OxA	**5.3 ppb MSA**	2.7 ppb TMA	base case	base case
60b	30% RH	17 ppb OxA	**5.3 ppb MSA**	2.7 ppb TMA	+ +	✓
61a	dry air	17 ppb OxA	2.2 ppb MSA	**4 ppb TMA**	base case	base case
61b	27% RH	17 ppb OxA	2.2 ppb MSA	**4 ppb TMA**	+ +	n/a
62a	dry air	17 ppb OxA	4.6 ppb MSA	**9 ppb TMA**	base case	base case
62b	28% RH	17 ppb OxA	4.6 ppb MSA	**9 ppb TMA**	+ +	n/a
63a	dry air	17 ppb OxA	2.1 ppb MSA	**4 ppb TMA**	base case	base case
63b	30% RH	17 ppb OxA	2.1 ppb MSA	**4 ppb TMA**	+ +	X

64a	dry air	17 ppb OxA	2.2 ppb MSA	**4 ppb TMA**	base case	base case
64b	30% RH	17 ppb OxA	2.2 ppb MSA	**4 ppb TMA**	+ +	X
65a	dry air	17 ppb OxA	2 ppb MSA	2 ppb TMA	base case	base case
65b	30% RH	17 ppb OxA	2 ppb MSA	2 ppb TMA	+ +	n/a
66a	dry air	17 ppb OxA	3.5 ppb MSA	3.6 ppb TMA	base case	base case
66b	30% RH	17 ppb OxA	3.5 ppb MSA	3.6 ppb TMA	+ +	X
67a	dry air	17 ppb OxA	4 ppb MSA	3.5 ppb TMA	base case	base case
67b	30% RH	17 ppb OxA	4 ppb MSA	3.5 ppb TMA	+ +	X
68a	dry air	17 ppb OxA	3.6 ppb MSA	3.5 ppb TMA	base case	base case
68b	30% RH	17 ppb OxA	3.6 ppb MSA	3.5 ppb TMA	+ +	X
69a	dry air	17 ppb OxA	3.2 ppb MSA	3.5 ppb TMA	base case	base case
69b	30% RH	17 ppb OxA	3.2 ppb MSA	3.5 ppb TMA	+ +	X
70a	dry air	17 ppb OxA	3.8 ppb MSA	3.5 ppb TMA	base case	base case
70b	30% RH	17 ppb OxA	3.8 ppb MSA	3.5 ppb TMA	+ +	X
71a	dry air	17 ppb OxA	3.7 ppb MSA	3.7 ppb TMA	base case	base case
71b	30% RH	17 ppb OxA	3.7 ppb MSA	3.7 ppb TMA	+	X
72a	dry air	34 ppb OxA	3.4 ppb MSA	3.5 ppb TMA	base case	base case
72b	30% RH	34 ppb OxA	3.4 ppb MSA	3.5 ppb TMA	+ + (6 times more)	X
73a	dry air	34 ppb OxA	3.5 ppb MSA	3.2 ppb TMA	base case	base case
73b	30% RH	34 ppb OxA	3.5 ppb MSA	3.2 ppb TMA	+ (4 times more)	X
74a	dry air	17 ppb OxA	3.8 ppb MSA	3.5 ppb TMA	base case	base case
74b	50% RH	17 ppb OxA	3.8 ppb MSA	3.5 ppb TMA	+ + +	X
75a	dry air	17 ppb OxA	3.7 ppb MSA	3.7 ppb TMA	base case	base case

75b	50% RH	17 ppb OxA	3.7 ppb MSA	3.7 ppb TMA	+ + (9 times more)	X

Note: Only dry air was added through ring #3 and spoke #3.

[a] The oxalic acid concentration, calculated from its vapor pressure at 303 K,[1] takes into account dilution in the flow reactor. This represents the maximum concentration achieved in the reaction.

[b] MSA and TMA concentrations are measured prior to their entrance to the reactor. These values account for dilution in the reactor, and are in bold-face font when in excess. These represent the maximum concentrations achieved in the reaction.

[c] 1 ppb = 2.48×10^{10} cm^{-3} at 1 atm and 294 K

[d] Blue highlight indicates experiment was done in the presence of water vapor.

[e] An enhancement of + + represents $>$ 4 times more but $\leq$ 10 times more particles due to the added H_2O.

[f] A "✓" means particle growth compared to the base case was observed.

[g] An enhancement of + represents $>$ 2 times more but $\leq$ 4 times more particles due to the added H_2O.

[h] An enhancement of + + + represents > 10 times more particles due to the added H_2O.

[i] "n/a" means the reaction was not measured with the SMPS.

[j] An "X" means particle growth compared to the base case was not observed.

Table S4 Control experiments

Exp.	Ring #1	Ring #2[a]	Spoke #1	Spoke #2[b]	Results
76[c]	50% RH	dry air	dry air	dry air	<1000 particles
77	29% RH	17 ppb OxA	dry air	dry air	<100 particles
78	23% RH	17 ppb OxA	dry air	9 ppb TMA	<100 particles
79	30% RH	17 ppb OxA	dry air	0 – 9 ppb TMA	<100 particles
80	30% RH	17 ppb OxA	dry air	0.2 ppb TMA	<100 particles
81	30% RH	17 ppb OxA	dry air	4 ppb TMA	<100 particles
82	50% RH	17 ppb OxA	dry air	4 ppb TMA	<2000 particles
83	dry air	17 ppb OxA	dry air	0 – 9 ppb TMA	no particles
84	dry air	17 ppb OxA	dry air	0.2 ppb TMA	no particles
85	dry air	17 ppb OxA	dry air	4 ppb TMA	no particles
86	dry air	17 ppb OxA	dry air	4 ppb TMA	no particles
87	dry air	17 ppb OxA	dry air	9 ppb TMA	no particles

Note: Only dry air was added through ring #3 and spoke #3.

[a] The oxalic acid concentration, calculated from its vapor pressure at 303 K,[1] takes into account dilution in the flow reactor. This represents the maximum concentration achieved in the reaction.

[b] TMA concentrations are measured prior to their entrance to the reactor. These values account for dilution in the reactor. These represent the maximum concentrations achieved in the reaction.

[c] Experiment done on a dirty/used aerosol reactor, particles likely formed from degassing of reactants. No particles are formed with water vapor on a clean aerosol reactor.

References

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