Cloud Condensation Nucleus Activity of Organic Compounds — A Laboratory Study

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Abstract

Critical (or activation) diameters of water-soluble, organic aerosols were determined using laboratory-generated, single-component aerosols that were composed of succinic acid, adipic acid and glucose. Measurements of sodium chloride and ammonium sulfate aerosols were performed for comparison and method validation. Our experimental approach involved producing single component aerosol particles of a known size, and measuring the fraction of aerosol number concentrations (CN) that act as CCN at several supersaturations. The particle diameter (D_{50}) at which the CCN/CN ratio of 0.50 is reached is defined as the critical, or activation, diameter. These experimentally derived diameters are compared with the theoretical critical diameter (D_C) obtained from a modified Kohler theory.

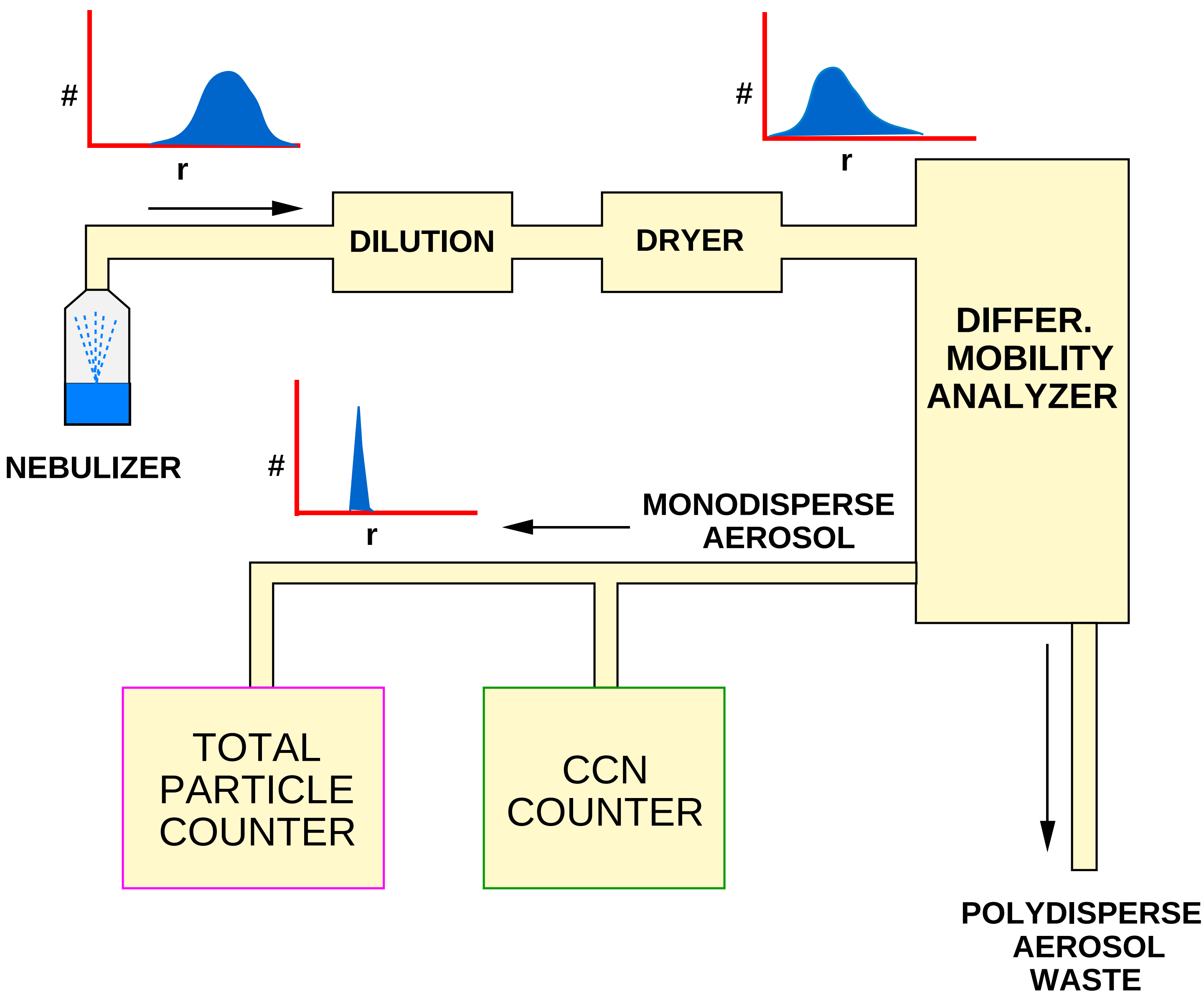
OBJECTIVE

- To demonstrate that water-soluble organic compounds are intrinsically active as cloud condensation nuclei.

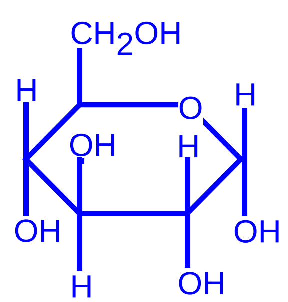
EXPERIMENTAL

- CCN activity was determined by producing a single-component aerosol of a water-soluble compound and then stepping through a series of monodisperse size cuts while simultaneously measuring the CCN concentration and the total aerosol concentration.
- The CCN concentration was measured with a DH Associates M1 CCN Counter. The total aerosol concentration was measured with a TSI 3022 CPC.
- The critical diameter was defined as the diameter at which 50% of the particles became CCN active.
- CCN activity was measured at 0.4%, 0.5%, and 0.8% supersaturation.
- The method was verified by measuring the activity of the well-characterized, inorganic salts, sodium chloride and ammonium sulfate.

Apparatus for Measuring CCN Activity



Compounds Analyzed for CCN Activity

Sodium Chloride	$NaCl$
Ammonium Sulfate	$(NH_4)_2SO_4$
Succinic Acid	$HO_2C-CH_2-CH_2-CO_2H$
Adipic Acid	$HO_2C-(CH_2)_4-CO_2H$
Glucose	

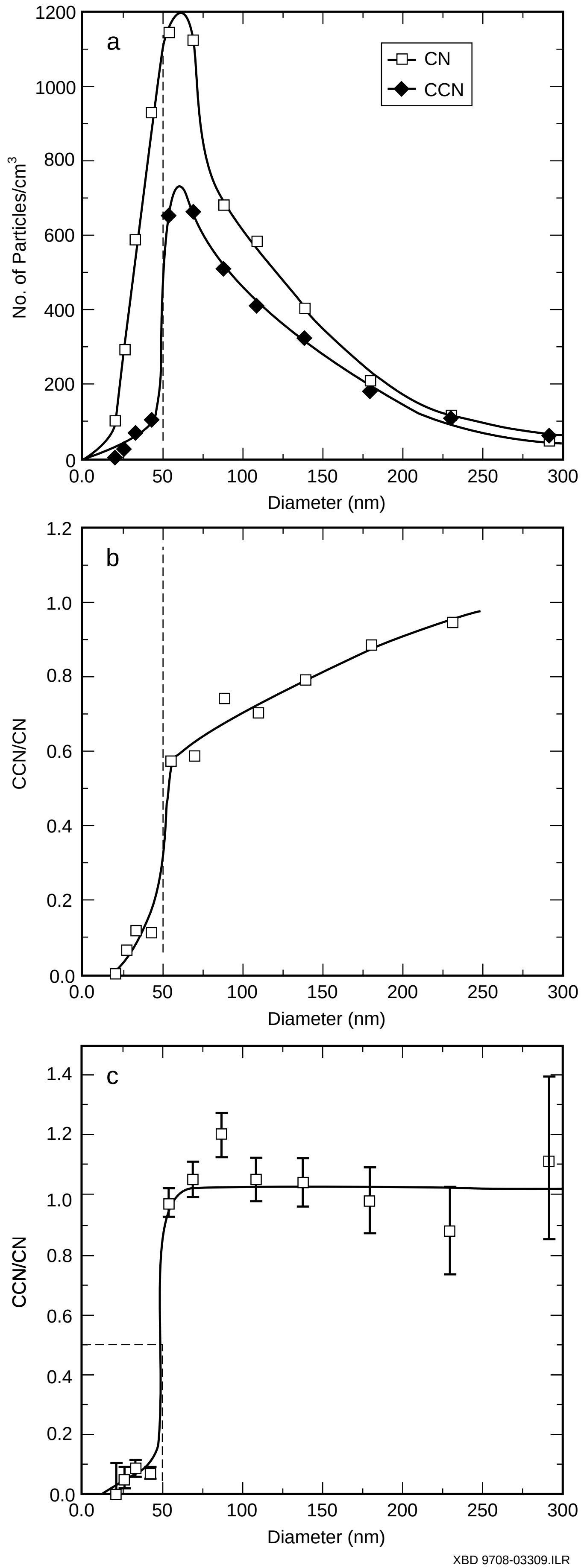


Fig 2. (a) Number concentrations of CN and CCN (at 0.4% supersaturation) for ammonium sulfate as a function of particle diameter. (b) CCN/CN ratio vs. particle diameter or the activation curve derived from uncorrected data. (c) Activation curve obtained with corrections described in text.

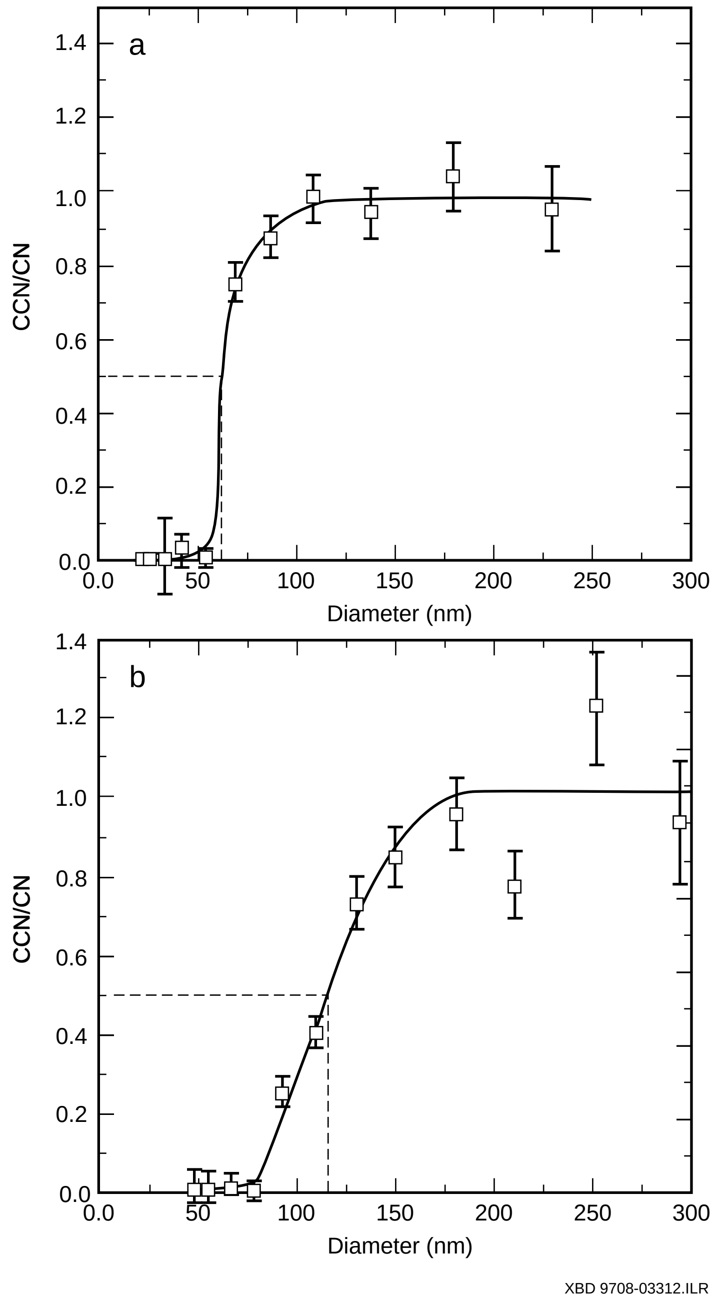


Fig. 3. Activation curves for succinic acid (a) and adipic acid (b) measured at 0.5% supersaturation.

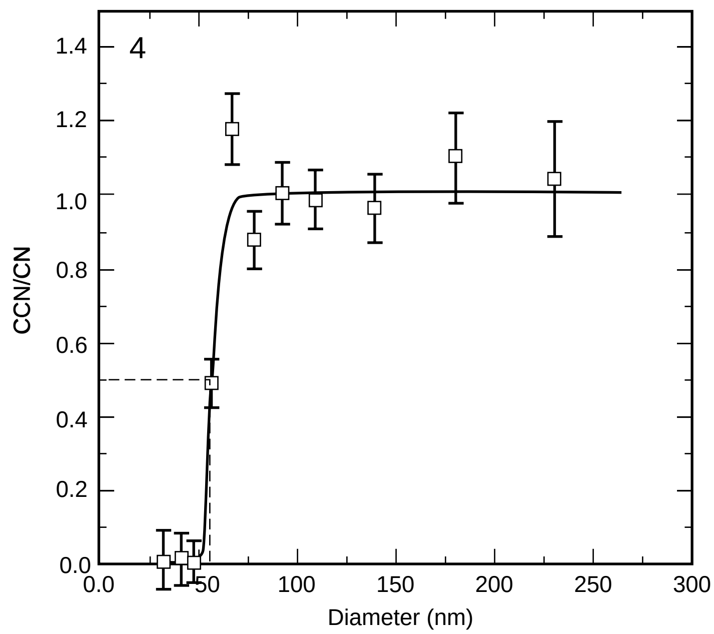


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Fig. 4. Activation curve for glucose measured at 0.5% supersaturation.

Modified Kohler Theory

(Fitzgerald and Hoppel, 1984)

$$S = \frac{e'}{e_s} = 1 + \frac{A}{r} - \frac{B r_o^3}{r^3} \qquad (1)$$

where

$$A = \frac{2 \sigma M_w}{\rho_w R_v T r} \qquad B = \frac{i \varepsilon \rho_s M_w}{\rho_w M_s}$$

Finding the maximum S with respect to r yields:

$$S_c = \frac{(4A^3)^{\frac{1}{2}}}{27 B} r_o^{-\frac{3}{2}} \qquad (2)$$

S - supersaturation
e’ - equilibrium vapor pressure over curved surface of solution droplet
e_s - equilibrium vapor pressure over a flat surface of pure water
σ - surface tension
M_w - molecular weight of water
M_s - molecular weight of solute
ρ_w - density of water
ρ_s - density of solute
R_v - gas constant for water vapor
T - temperature
r - radius of droplet
r_o - radius of dry particle
i - van’t Hoff factor
ε - fraction of dry particle that is soluble

Measured and Theoretical Activation Diameters

Compound	Solubility (M)	Supersaturation (%)	Activation Diameter Theor. (nm)	Activation Diameter Exp. (nm)
NaCl	6.1	0.4	41	40
		0.5	35	31
		0.8	26	*ND*
$(NH_4)_2SO_4$	5.7	0.4	50	51
		0.5	43	41
		0.8	31	30
Succinic Acid	0.65	0.4	71	82
		0.5	64	64
		0.8	45	41
Adipic Acid	0.10	0.4	80	148
		0.5	69	116
		0.8	51	*ND*
Glucose	5.7	0.4	83	74
		0.5	71	57
		0.8	52	41

ND -- no data

CONCLUSIONS

- Water-soluble, organic compounds can behave as CCN and show activity that is similar to ammonium sulfate.

- The CCN activity of organic compounds appears to correlatewith the compound's solubility.

- Modified Kohler theory predicts CCN activity for very soluble compounds, but deviates when used to predict less soluble compounds (<0.5 M saturated concentration)