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HYDRATION BEHAVIOR OF LASER DYE AEROSOLS OF MIXED COMPOSITION HAVING HIGH CRITICAL SUPERSATURATIONS

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Abstract—This study concerns aerosol particles of mixed composition. The particles contain a water insoluble core (polystyrene latex), surrounded by a water soluble shell (various fluorescent dyes). A Collison nebulizer and an electrostatic aerosol classifier are used to prepare the aerosol; its critical supersaturation spectrum is measured with a diffusion cloud chamber. Experiments were done using four different dyes (disodium fluorescein, sulforhodamine 640, sulforhodamine B and rhodamine 560 chloride) with five different polystyrene latex sphere sizes. The results indicate that a Kohler-type behavior is obeyed. This technique of putting a soluble coating onto an insoluble core is found to be a successful method for generating particles with relatively high critical supersaturations.

INTRODUCTION

The Cloud and Aerosol Sciences Laboratory at UMR is currently investigating the scavenging of dry aerosol particles (in the 0.01–0.2 μm diameter range) by water droplets during the droplets' growth and evaporation. The intended method involves simultaneous injection of two types of aerosols into the simulation chamber (SC) (White *et al.*, 1987). Type A aerosol will be NaCl with a critical supersaturation (SS_c) of about 0.3%. The SC will expand, creating a supersaturation of about 1%, and droplets will grow on these NaCl aerosol particles. The type B aerosol will be either pure laser fluorescent dye or a hybrid particle containing an inert, insoluble latex sphere and a thin layer of laser fluorescent dye. The type B aerosol will have an SS_c greater than 1% and hence will not activate and grow into droplets during the SC expansion. This will provide the scavengable aerosol particles.

The SC will oscillate through several cycles of expansion and compression causing the droplets formed on the NaCl aerosol to grow and evaporate (Hagen *et al.*, 1989a). During these growth and evaporation processes, phoretic forces will attract and repel the type B particles toward and away from the droplets.

NaCl solution droplets that have scavenged a type B particle will now be fluorescent, whereas solution drops that have not scavenged a type B particle will not be fluorescent. A specially designed optical counter called a fluorescent aerosol spectrometer (FAS) will then withdraw a small portion of the SC gas and will separately count the number of pure NaCl solution droplets and the number of fluorescent NaCl solution droplets. This will then yield valuable information about the scavenging of aerosol particles by growing/evaporating droplets.

A study of the SS_c vs diameter (D_p) for six fluorescent dyes (Hagen *et al.*, 1989b) revealed that as long as D_p is kept less than about 0.07 μm , the type B particles do not activate for a supersaturation of 1%.

In order to study the scavenging of type B particles with $D_p > 0.07 \mu\text{m}$, one must keep the particle's SS_c above 1% to avoid condensation. This can be accomplished by filling some of the volume of the particle with an insoluble substance. Here we take a polystyrene latex sphere (PSL), and then apply a thin coating of the dye such that the mass of the dye is still less than what would be found in a pure dye particle with $D_p = 0.07 \mu\text{m}$. These hybrid nuclei are relatively large and yet have a fairly high SS_c . They retain the ability to impart fluorescence to water drops that scavenge them. Other studies requiring large aerosol particles with a high SS_c can also be envisioned, of course.

APPARATUS

The experimental apparatus used was essentially the same as that described in a previous paper (Hagen *et al.*, 1989b). A short description of it will be offered here.

The task of studying the hydration properties of fluorescent dye aerosols involves the use of several pieces of apparatus. Figure 1 is a schematic of the experimental apparatus. CN is a Collision nebulizer to produce an aerosol. EAC is an electrostatic aerosol classifier to remove from the aerosol stream all particle sizes other than those with diameters in a very narrow size range centered about a mean value d_2 (the size being studied at that time). The electrostatic aerosol classifier (EAC) was developed by Liu and Pui (1974) and by Knutson and Whitby (1975) and is commercially available (Model 3071, TSI, Inc., P.O. Box 64394, St. Paul, MN 55164, U.S.A.). CFD/IT and ALGR are cloud chambers to expose the aerosol to the desired supersaturation and temperature. OPC is an optical particle counter to sense and record whether or not the aerosol activated (passed over the energy barrier and became a freely growing water droplet) under those conditions.

House compressed air drove the nebulizer, which was a Fluid Atomization Aerosol Generator (Model 7300, Environmental Research Corp., St. Paul, MN). This is a three jet, stainless steel Collision type (May, 1973) atomizer.

It is essential that the aerosol particles be nearly dry when they pass through the EAC in order that their diameter (d_2) be accurately known. Thus the diffusion dryers (DD) are present in order to reduce the relative humidity to about 20%.

The continuous flow diffusion/isothermal chamber (CFD/IT) is a dual mode thermal diffusion cloud chamber capable of measuring SS_c values from 0.013 to 9.0% (Alofs, 1978; Alofs *et al.*, 1979; Alofs and Trueblood, 1981; Hagen *et al.*, 1989b). In the present study it was used only in the CFD mode. The CFD features two parallel plates separated by about 8 mm, with wet filter paper on the two plates. Filtered air flows down between the plates and a very small flow of the test aerosol is metered in, halfway between the plates. A temperature difference is maintained between the two plates and the diffusion of heat and vapor from the hot to the cold plate leads to a supersaturation in the region between the plates, with a maximum approximately midway between them. If the applied supersaturation SS_{crd} exceeds the critical supersaturation SS_c of the test aerosol, then the aerosol particles form droplets large enough to be detected by the OPC. The alternating gradient (ALGR) chamber

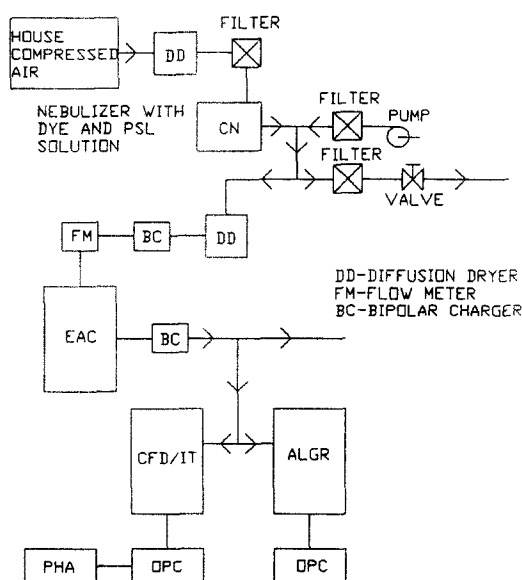


Fig. 1. Apparatus block diagram.

exposes the test aerosol to a high supersaturation (Hoppel *et al.*, 1979, 1980) and was used to normalize the concentration measured by the CFD, thus removing any fluctuation of the CN output with time.

The present experiment departs from the procedure of Hagen *et al.* (1989b) in that several drops of monodispersed polystyrene latex (PSL) sphere solution were added to the dye solution in the CN. To avoid doublets, i.e. those having two or more PSL spheres per atomized droplet, May (1973) recommends keeping the concentration of spheres less than 10^9 cm^{-3} of nebulizer solution.

The atomized drops therefore contain water (the solvent), the laser dye, an insoluble PSL sphere, and a small amount of unknown (proprietary) electrolyte, the function of which is to prevent coagulation in the original PSL solution. When the water evaporates, an insoluble PSL sphere coated with a thin layer of laser dye (and a very small amount of the proprietary electrolyte) remains as the airborne aerosol particle. Some of the atomized drops do not contain even one insoluble sphere. These drops give rise then to a pure dye particle presenting a special problem that will be discussed later.

THEORY

The droplet size spectrum produced by the CN is somewhat polydisperse. Small droplets will therefore contain a small amount of dye and the layer of dye left on the PSL sphere will be thin. Large droplets will contain a larger amount of dye and the layer of dye left on the PSL sphere will be thicker. Except for the few pure dye particles mentioned above, and the rare particles containing more than one PSL sphere, the aerosol particles entering the EAC contain one PSL sphere and a differing amount of dye. Since the latex spheres are spherical and the layer of dye is thin, the hybrid particles are very likely to also be quite spherical.

Imagine, therefore, an insoluble PSL sphere of diameter d_1 with a thin coating (concentric spherical shell) of soluble laser fluorescent dye such that the outside diameter of this mixed or hybrid particle is d_2 . The PSL sphere is insoluble and the layer of dye is soluble, but only the mass of the laser dye is effective in causing a droplet to grow on this mixed particle.

If removed from the insoluble PSL sphere and molded into a sphere on its own, the layer of dye would form a sphere with diameter

$$d_{\text{eff}} = (d_2^3 - d_1^3)^{1/3}. \quad (1)$$

The value of d_1 is supplied by the PSL sphere manufacturer, whereas the value of d_2 is determined by the EAC setting. The value of d_{eff} is then computed from equation (1).

Several different approaches to the theory describing a mixed particle's critical supersaturation can be employed here. In method I the critical supersaturation $SS_{c,m1}$ is arrived at by simply ignoring the presence of the insoluble part of the nucleus. Pruppacher and Klett (1978) provide the standard Kohler expression for the equilibrium supersaturation, SS , surrounding a solution droplet of radius a :

$$SS = \left[\left(1 + \frac{A}{a} - \frac{B}{a^3} \right) - 1 \right] \times 100\%. \quad (2)$$

Here

$$A = \frac{2M_w\sigma}{RT\rho_w}, \quad (3)$$

where M_w is the molecular weight of water, σ is the surface tension of water against air, R is the universal gas constant, T is the absolute temperature and ρ_w is the density of liquid water. Likewise

$$B = \frac{2.251\rho_s v\phi_s}{M_s} d_{\text{eff}}^3, \quad (4)$$

where ρ_s is the density of the soluble portion of the nucleus, v is the number of ions into which the soluble constituent dissociates, ϕ_s is the osmotic coefficient of the soluble portion and M_s is the molecular weight of the soluble portion.

For a particular experiment in the present paper, equation (1) was solved for d_{eff} . This was needed to calculate B in equation (4). Also needed for B is the value for $\rho_s v \phi_s$. The measured critical supersaturation was plotted vs particle diameter (log-log plot) for pure dye particles. The value of $\rho_s v \phi_s$ was taken from the intercept of this plot. The theory behind this determination of $\rho_s v \phi_s$ is given in Hagen *et al.* (1989b).

Equation (2) for the particle's equilibrium supersaturation ratio as a function of size, was differentiated with respect to radius, set to zero, and solved analytically for $a = a_c$, the critical drop radius. This value was then inserted into equation (2) and the $SS_{c,m1}$ computed.

In Method II, the critical supersaturation $SS_{c,m2}$ is arrived at by taking the presence of the insoluble portion of the nucleus into consideration, as is done by Pruppacher and Klett (1978):

$$SS = \left[\left(1 + \frac{A}{a} - \frac{B}{a^3 - r_i^3} \right) - 1 \right] \times 100\%, \quad (5)$$

where r_i denotes the radius of the insoluble core. This approach assumes the insoluble particle: (1) does not take up any water by itself; (2) does not adsorb any of the salt ions; and (3) is completely submerged in the solution droplet.

The values of d_{eff} and $\rho_s v \phi_s$ are obtained as in Method I. The r_i in equation (5) is the radius of the insoluble portion of the hybrid nucleus and clearly this is $d_1/2$, where d_1 is the diameter of the PSL sphere. Equation (5) is differentiated, solved numerically for $a = a_c$, and this value is inserted into equation (5), yielding $SS_{c,m2}$.

RESULTS

A series of experiments was conducted to measure the critical supersaturation for assorted mixed aerosols. These were composed of an inert core coated with various laser dyes of controlled thicknesses. Commercial monodisperse polystyrene latex (PSL) spheres were used for the inert cores.

Figure 2 shows the results of a supersaturation sweep with the CFD/IT on an aerosol generated by mixing a few drops of PSL2 sphere solution ($d_1 = 0.277 \mu\text{m}$, unspecified σ ,

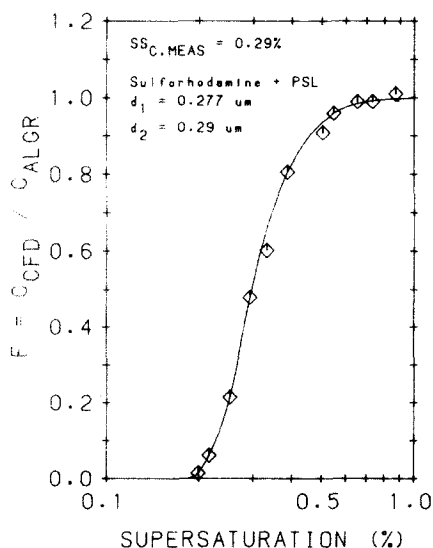


Fig. 2. Fraction of $0.29 \mu\text{m}$ diameter aerosol (sulforhodamine and PSL) particles activated at supersaturation SS . $C_{\text{CFD}} / C_{\text{ALGR}}$ denotes the aerosol concentration measured by the CFD (ALGR) cloud chamber.

Interfacial Dynamics Co., P.O. Box 40306, Portland, OR 97240, U.S.A.) and about 5 mg of sulforhodamine 640 (Exciton Chemical Co., P.O. Box 31126, Overlook Station, Dayton, OH 45431, U.S.A.) in the CN jar which contains 250 cm³ of doubly distilled water. The EAC was set to extract particles with an outside diameter of $d_2 = 0.29 \mu\text{m}$. Thus $d_{\text{eff}} = 0.164 \mu\text{m}$ and from Fig. 2 the value of SS at $F = 0.5$ is 0.29%; hence the measured value of critical supersaturation, $SS_{c,\text{meas}}$, is 0.29%.

Table 1 compares the critical supersaturations obtained from Method I and Method II with the measured value, $SS_{c,\text{meas}}$. The $SS_{c,m1}$ and $SS_{c,\text{meas}}$ values are found to differ by an average of 8% with a 7% standard deviation around this average. The $SS_{c,m2}$ and $SS_{c,\text{meas}}$ values differ by an average of 10% with a standard deviation of 4%. Also shown in the table are the critical droplet radii $a_{c,m1}$ and $a_{c,m2}$, computed by Methods I and II, respectively.

Since Method I ignores the presence of the PSL and Method II takes its presence into account, $SS_{c,m2}$ is expected to better represent the true value. Although $SS_{c,\text{meas}}$ was typically the highest value, $SS_{c,m1}$ next highest, and $SS_{c,m2}$ lowest, $SS_{c,\text{meas}}$ and $SS_{c,m2}$ were still within 10% of each other in two of the three cases. Alofs and Trueblood (1981) demonstrated that the CFD's precision is about 10%. Since the Method II analysis, which does include the presence of the PSL sphere, does a satisfactory job of fitting the data, we recommend adopting this method. Another aspect of the Method II analysis is the assumption that the PSL spheres are inert. The amount of soluble material they contribute to the hybrid particle must be small compared to that contributed by the laser dye coating. This is equivalent to the condition that the SS_c of the PSL alone is high relative to the SS_c of the hybrid particle.

A control experiment was performed to test the critical supersaturation of the PSL alone. The solution in the CN contained just the few drops of the $0.277 \mu\text{m}$ PSL. The particles generated by the CN, DD, and EAC were then composed of just dry PSL, a small amount of the proprietary electrolyte which is carried along, and whatever soluble impurities may have entered along with the distilled water. The critical supersaturation of the $0.277 \mu\text{m}$ PSL was then found to be $SS_{c,\text{meas}} = 1.1\%$. Note that the $SS_{c,\text{meas}}$ values of the hybrid nuclei in Table 1 are well below this, being in the 0.150–0.290% range. Thus the $0.277 \mu\text{m}$ PSL can justifiably be considered as an insoluble, inert core.

Figure 3 shows the results of mixing a few drops of PSL1 sphere solution ($d_1 = 0.109 \mu\text{m}$, std. dev. = $0.0027 \mu\text{m}$, Lot No. 7N3B, Dow Diagnostics, Indianapolis, IN 46206, U.S.A.) and about 10 mg of disodium fluorescein, commonly called uranine (Fisher Scientific Co., P.O. Box 14989, St. Louis, MO 63178-4989, U.S.A.) in the CN jar. The EAC was set to extract particles with outside diameter of $d_2 = 0.13 \mu\text{m}$. Thus $d_{\text{eff}} = 0.096 \mu\text{m}$ and from Fig. 3 of the present study one sees that $SS_{c,\text{meas}} = 0.347\%$. Table 2 compares the various SS_c values for this set of experiments. The $SS_{c,m1}$ and $SS_{c,\text{meas}}$ values are found to differ by an average of 1% with a 1% standard deviation. $SS_{c,m2}$ and $SS_{c,\text{meas}}$ differ by an average of 2% with a 2% standard deviation.

Again, $SS_{c,\text{meas}}$ is typically the highest value, $SS_{c,m1}$ next highest, and $SS_{c,m2}$ lowest. Even so, $SS_{c,\text{meas}}$ and $SS_{c,m2}$ are within 3% of each other in all cases. This implies that Method M1 may be somewhat better than Method M2, but both satisfactorily fit the data, and one cannot conclude that either method is clearly superior.

Another control experiment was performed in which only the $0.109 \mu\text{m}$ PSL solution was added to the distilled water in the CN. The measured critical supersaturation of the PSL

Table 1. Results for PSL spheres ($d_1 = 0.277 \mu\text{m}$) coated with varying thicknesses of sulforhodamine 640

Exper. no.	d_2 (μm)	d_{eff} (μm)	$SS_{c,m1}$ (%)	$SS_{c,m2}$ (%)	$SS_{c,\text{meas}}$ (%)	$a_{c,m1}$ (μm)	$a_{c,m2}$ (μm)
1023A	0.295	0.164	0.287	0.270	0.290	0.260	0.291
1023B	0.310	0.204	0.207	0.202	0.222	0.360	0.379
1024	0.320	0.226	0.178	0.175	0.150	0.420	0.434

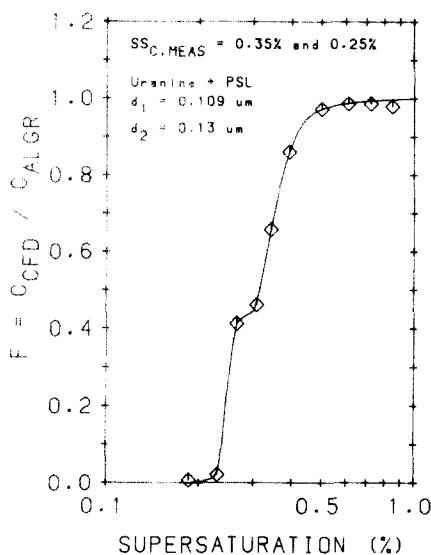


Fig. 3. Fraction of 0.13 μm diameter aerosol (disodium fluorescein and PSL) particles activated at supersaturation SS . C_{CFD}/C_{ALGR} denotes the aerosol concentration measured by the CFD (ALGR) cloud chamber.

Table 2. Results for PSL spheres ($d_1 = 0.109 \mu\text{m}$) coated with varying thicknesses of disodium fluorescein

Exper. no.	d_2 (μm)	d_{eff} (μm)	$SS_{c,m1}$ (%)	$SS_{c,m2}$ (%)	$SS_{c,\text{meas}}$ (%)	$a_{c,m1}$ (μm)	$a_{c,m2}$ (μm)
110	0.120	0.076	0.493	0.483	0.500	0.151	0.158
109A	0.130	0.096	0.347	0.345	0.347	0.215	0.218
109B	0.150	0.128	0.226	0.225	0.230	0.331	0.333

was then found to be $SS_{c,\text{meas}} = 1.25\%$. Note that the $SS_{c,\text{meas}}$ values of the hybrid nuclei in Table 2 are well below this, being in the 0.230 to 0.500% range. Thus the 0.109 μm PSL can justifiably be considered as an insoluble, inert core.

A third series of experiments was done using a few drops of PSL3 sphere solution ($d_1 = 0.173 \mu\text{m}$, std. dev. = 0.0054 μm , Lot No. 11930, Duke Scientific Corp., P.O. Box 50005, Palo Alto, CA 94303, U.S.A.) and about 10 mg of sulforhodamine B (Eastman Kodak Co., Rochester, NY 14650, U.S.A.). Table 3 shows that the $SS_{c,m1}$ and $SS_{c,\text{meas}}$ differ by an average of 4% with a 4% standard deviation. $SS_{c,m2}$ and $SS_{c,\text{meas}}$ differ by an average of 7% with standard deviation 2%. Hence although Method I gives a somewhat better fit to the observed critical supersaturations, the relative error for both methods is less than the resolution of the CFD/IT. The control experiment, in which only the few drops of 0.173 μm PSL solution were added to the distilled water, gave a $SS_{c,\text{meas}} = 0.90\%$. Again the PSL can be considered as an insoluble, inert core.

The fourth series of experiments was done using a few drops of PSL4 sphere solution ($d_1 = 0.202 \mu\text{m}$, std. dev. = 0.0141 μm , Lot No. 9754, Duke Scientific Corp.) and about 10 mg of rhodamine 560 chloride (Exciton Chemical Co.). Table 4 compares the different SS_c values. Here both $SS_{c,m1}$ and $SS_{c,m2}$ differ from $SS_{c,\text{meas}}$ by an average of 11% with a 4% standard deviation. The control experiment using only the PSL spheres gave a value of 0.40%. This is considerably lower than the SS_c for the other PSL spheres. The measured and predicted SS_c values were still fairly close, however.

The fifth series of experiments were performed using a few drops of PSL5 sphere solution ($d_1 = 0.04 \mu\text{m}$, std. dev. = 0.0018 μm , Lot No. 12301, Duke Scientific Corp.) and about 10 mg of disodium fluorescein (Exciton Chemical Co.). Table 5 lists the various SS_c values. Here again both $SS_{c,m1}$ and $SS_{c,m2}$ differ from $SS_{c,\text{meas}}$ by an average of 8% with a 7% standard

Table 3. Results for PSL spheres ($d_1=0.173 \mu\text{m}$) coated with varying thicknesses of sulforhodamine B

Exper. no.	d_2 (μm)	d_{eff} (μm)	$SS_{c,m1}$ (%)	$SS_{c,m2}$ (%)	$SS_{c,\text{meas}}$ (%)	$a_{c,m1}$ (μm)	$a_{c,m2}$ (μm)
0103	0.20	0.141	0.352	0.341	0.364	0.212	0.225
0106	0.215	0.168	0.272	0.268	0.300	0.274	0.283
0107	0.190	0.119	0.46	0.432	0.453	0.162	0.182
0108	0.190	0.119	0.46	0.432	0.46	0.162	0.182
0109a	0.185	0.105	0.56	0.508	0.549	0.133	0.159
0109b	0.220	0.176	0.25	0.247	0.231	0.299	0.306

Table 4. Results for PSL spheres ($d_1=0.202 \mu\text{m}$) coated with varying thicknesses of rhodamine 560 chloride

Exper. no.	d_2 (μm)	d_{eff} (μm)	$SS_{c,m1}$ (%)	$SS_{c,m2}$ (%)	$SS_{c,\text{meas}}$ (%)	$a_{c,m1}$ (μm)	$a_{c,m2}$ (μm)
0114	0.25	0.195	0.135	0.134	0.124	0.553	0.556
0115	0.25	0.195	0.135	0.134	0.149	0.553	0.556
0116	0.26	0.21	0.12	0.120	0.138	0.622	0.625

Table 5. Results for PSL spheres ($d_1=0.04 \mu\text{m}$) coated with varying thicknesses of disodium fluorescein

Exper. no.	d_2 (μm)	d_{eff} (μm)	$SS_{c,m1}$ (%)	$SS_{c,m2}$ (%)	$SS_{c,\text{meas}}$ (%)	$a_{c,m1}$ (μm)	$a_{c,m2}$ (μm)
0116	0.06	0.0534	0.83	0.826	0.84	0.090	0.091
0117	0.09	0.0873	0.375	0.375	0.431	0.199	0.199
0117	0.08	0.0765	0.475	0.474	0.507	0.157	0.157

deviation. The control experiment using only the PSL spheres gave a value of $SS_{c,\text{meas}} = 1.7\%$. As with the first three PSL spheres, this $SS_{c,\text{meas}}$ is considerably higher than that measured for the hybrid particles and so the PSL can clearly be considered as insoluble, inert cores. Moreover, one can conclude from Tables 1–5 that the hybrid nuclei obey a Kohler type behavior within about 10%.

Figure 3 shows a secondary shoulder at $F=0.45$. The value of SS at $F=0.45/2$ is 0.25%. This secondary shoulder can be attributed to aerosol particles that are pure disodium fluorescein (or uranine), i.e. particles of dye coming from water droplets exiting the CN jet that contained no PSL sphere. Under this assumption, $d_2 = d_{\text{eff}}$ and $SS_{c,m1} = 0.22\%$. This is close to $SS_{c,\text{meas}} = 0.25\%$ as indicated by the secondary shoulder. Figure 4 shows a similar secondary shoulder for $d_1 = 0.109 \mu\text{m}$, disodium fluorescein, and $d_2 = 0.12 \mu\text{m}$.

The fact that two of the three F vs SS_{efd} plots show this secondary shoulder is a little misleading. In fact only four of the 18 F vs SS_{efd} had a secondary shoulder. By careful adjustment of the amount of PSL sphere solution, one could no doubt minimize the fraction of Collision nebulizer droplets that contain only fluorescent dye and no PSL sphere while avoiding doublets. No attempt to do this was made in this study.

The plots having the secondary shoulder are intentionally shown (rather than the plots without the secondary shoulder) to illustrate the high sensitivity of the method to the behavior of the aerosol. Not only can the primary shoulders be predicted and explained, but so can the secondary shoulders.

Furthermore we have here a method of generating a two component aerosol (where the two components have distinctly different SS_c values) from a single CN-EAC combination. By properly choosing the dye, the PSL sphere size, and the overall diameter d_2 , one could produce a wide variety of two component aerosols having tailor made SS_c values from a single CN-EAC combination.

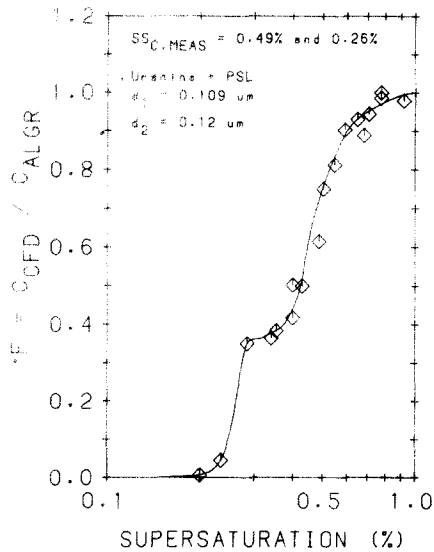


Fig. 4. Fraction of $0.12 \mu\text{m}$ diameter aerosol (disodium fluorescein and PSL) particles activated at supersaturation SS_c . C_{CFD} (C_{ALGR}) denotes the aerosol concentration measured by the CFD (ALGR) cloud chamber.

CONCLUSION

This investigation involved measuring the critical supersaturation SS_c of mixed or hybrid nuclei [composed of an insoluble polystyrene latex (PSL) sphere and an outer layer of soluble laser dye] as a function of the overall diameter of the mixed nuclei. For a given set of experiments the diameter of the PSL sphere was held constant and the amount of dye in the outer layer was the variable. If one imagines removing this outer layer of soluble dye from the inner insoluble PSL particle and forming the dye into a sphere on its own, then the resulting sphere of dye has a diameter d_{eff} . Using previous results (Hagen *et al.*, 1989b) and two theoretical methods, one can arrive at two predicted critical supersaturations, $SS_{c,m1}$ and $SS_{c,m2}$. The method yielding $SS_{c,m1}$ ignored the presence of the insoluble polystyrene latex sphere. The method yielding $SS_{c,m2}$ took into account the presence of the insoluble polystyrene latex sphere. Both methods are based on the Kohler theory. Eighteen experiments were performed to obtain the measured value of the critical supersaturation ($SS_{c,meas}$) of these mixed nuclei. The $SS_{c,m1}$ and $SS_{c,meas}$ differed by an average of 6.0% with a standard deviation of 4.5%. The $SS_{c,m2}$ and $SS_{c,meas}$ differed by an average of 7.7% with standard deviation of 3.4%. Since the resolution of the CFD/IT has been shown to be about 10% (Alofs and Trueblood, 1981) the present results show that both Method I and Method II agree with the experimental results within the resolution of the CFD/IT.

The original goal of this study was to generate particles that have a high critical supersaturation for their size. We explored the idea of embedding an insoluble particle (a polystyrene latex sphere) in a dye particle, which already has a high SS_c relative to a particle of equal diameter made from NaCl or $(\text{NH}_4)_2\text{SO}_4$. This technique was found to be successful. Thus for a fixed dye mass, one can increase the particle's SS_c by embedding an insoluble particle into it.

Furthermore we have shown that the Kohler theory satisfactorily describes the hydration behavior of binary mixed nuclei where one of the two constituent substances is insoluble.

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