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INTERCOMPARISON OF MEE AND NCAR ICE NUCLEUS COUNTERS AND THE CSU ISOTHERMAL CHAMBER

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ABSTRACT

Two Mee counters, an NCAR counter, and the Colorado State University isothermal chamber were compared for their ability to count ice forming nuclei in the -16° to -20° range. After several improvements were made on the Mee counters, all devices were in relatively good agreement for counting silver iodide aerosol particles generated from acetone burners and pyrotechnic flares. The Mee counter has the ability to follow rapid changes in nucleus concentration. It was not possible to operate it above -16°C. The Mee counter requires considerable operator skill and is difficult to operate on an aircraft.

1. INTRODUCTION

Widespread efforts to modify cloud systems by intentionally adding ice nuclei to the atmosphere and the many potential sources of natural and man-made nuclei require that the extent and concentrations of these particles be monitored. At present there is no clear understanding of all aspects of ice nucleus counting. Therefore, such measurements are strongly dependent upon an empirical approach which places great importance on ascertaining that the measurements are reproducible and that instrumental variables are accurately controlled.

Currently there are two ice nucleus detection devices, the NCAR and Mee counter, designed to monitor the ice nucleus content of the atmosphere in a continuous manner. This paper concerns itself with a comparison of the responses of these two devices to artificial ice nucleating aerosols detected in the CSU isothermal cloud chamber. No systematic evaluation of the basic mode of operation of the Mee counter has been carried out as for the NCAR counter (Langer, 1973). The Mee counter has recently been used in some field projects by Colorado State University (CSU) and this intercomparison will at least provide some point of reference.

The Mee counter[1] (Model 140) employs a small, continuous-flow mixing chamber in which nuclei are activated and the resulting ice crystals are detected by optical means. The NCAR counter uses a similar procedure but employs an acoustic detector to count the crystals. It also uses a larger mixing chamber, and the formation of the supercooled cloud is controlled by supplying artificially generated cloud condensation nuclei. In the Colorado State University (CSU) isothermal chamber a batch procedure is employed. The ice nuclei are introduced by a 4 ℓ syringe into a 1000 ℓ cloud chamber continuously replenished with supercooled droplets from an ultrasonic atomizer. As the ice crystals fall onto a microscope slide, they are counted periodically. This paper gives the results of an intercomparison of the three instruments in December 1975 and January 1976 conducted jointly by CSU and NCAR at the CSU Cloud Simulation and Aerosol Laboratory. The work was done with pyrotechnics and acetone burners producing silver iodide aerosols. Some background aerosol measurements were also made.

2. EXPERIMENTAL EQUIPMENT

The CSU isothermal chamber (Garvey, 1975) and NCAR ice nucleus counter (Langer, 1973) will not be described in detail, since they are well documented in the literature. The NCAR counter used in this study was a small airborne unit with a 25ℓ cloud chamber. The larger 34 ℓ groundbased units tend to give higher counts because more time is allowed for activation of ice nuclei. The airborne unit was a commercial model made by the former Bollay Associates and extensively modified to meet the systems requirements reported in the paper by Langer (1973) and blueprints covering this design are available from NCAR. It was operated at temperatures from -12 to -20°C. Operation of the NCAR counter at temperatures warmer than -12°C requires a higher humidifier temperature and lower glycol concentration or else a weak supercooled cloud would form; these changes were not made during the limited time available except for increasing the humidifier temperature from 20°C to 25°C for the -12°C runs. The counter has been operated as warm at -5°C in other studies by making these adjustments. The NCAR counter tests were all carried out at the same glycol concentration, i.e., a specific gravity of 1.065 g cm^{-3} and at a cloud condensation nucleus concentration of approximately 7000 cm^{-3} allowing for a supersaturation under 0.2% (See Langer, 1973 for LWC and dropsize data).

The Mee counter is not documented in the open literature and, furthermore, both units used in this study had to be modified* under the direction of CSU. To achieve consistent operation for an intercomparison in the laboratory one unit was, at the time of the comparisons, operated by Convergence Systems, Incorporated (CSI). The other unit belongs to Colorado State University. A

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[1]Manufactured by Mee Industries, 4939 N. Earle Street, Rosemead, CA. 91770

*The co-author, D. Garvey, should be contacted regarding these modifications. These were rather extensive but did not affect the fundamental principle of the counter.

flow diagram of the Mee counter is shown in Fig. 1. The chamber has a capacity of about 3.5 ℓ . Sample air entering the chamber from the humidifier is cooled very rapidly, and condensation takes place on most of the aerosol particles present. So the condensation process may approach that of an expansion chamber. The reference temperature for the Mee counter was taken to be that of the cooling fluid inlet which is close to the exit air temperature. The humidification chamber was kept at +26°C.

3. EXPERIMENTAL PROCEDURES

Figure 2 shows the general layout of the equipment used during the tests. The pyrotechnic flares (WM-105) were burned above the wind tunnel fan while the acetone burners were operated below the fan. At a distance of 7 m above the point where the flares were burned a sample of the nuclei was taken with a 4 ℓ syringe and diluted appropriately with clean, dry air. The sample was taken to a 770 ℓ storage tank, into which part was injected; the remaining sample was injected into the CSU isothermal chamber for ice crystal counting. The tank served as the nucleus supply for the portable counters tested and as the reference volume to which the ice crystal counts in the isothermal chamber were related.

The following tests were selected for this study:

a. The Mee counter operated by CSI was first tested in detail against the CSU isothermal chamber using aerosols produced by WM-105 calibration pyrotechnics. The comparison was carried out at three different temperatures.

b. Next, tests were made to compare the two Mee counters directly. As before, simultaneous samples were pulled from the tank. The comparisons were done with WM-105 calibration pyrotechnics and also with a burner using a 2% AgI-NaI solution. Because the threshold setting for the Mee counters is somewhat arbitrary, the CSU instrument was first adjusted so that the background at -20°C was comparable to the CSI Mee unit as a reference.

c. In a series of tests the CSI Mee counter was compared with the airborne NCAR ice nucleus counter. This was done with three different AgI aerosols, those obtained from WM-105 calibration pyrotechnics and those produced by burning acetone solutions of 2% AgI-NH_4I and 2% AgI-NaI. An acoustic sensor attached at the base of the isothermal chamber was used to estimate the concentration of ice crystals forming in it. Samples were pulled from the tank simultaneously by both the Mee counter and the NCAR counter, generally for about 5 minutes. Periodically the two counters sampled the room air to obtain comparisons at lower ice nucleus concentrations.

d. To compare the response of the NCAR counter and the Mee counter against pulses of nuclei, a series of tests were carried out in

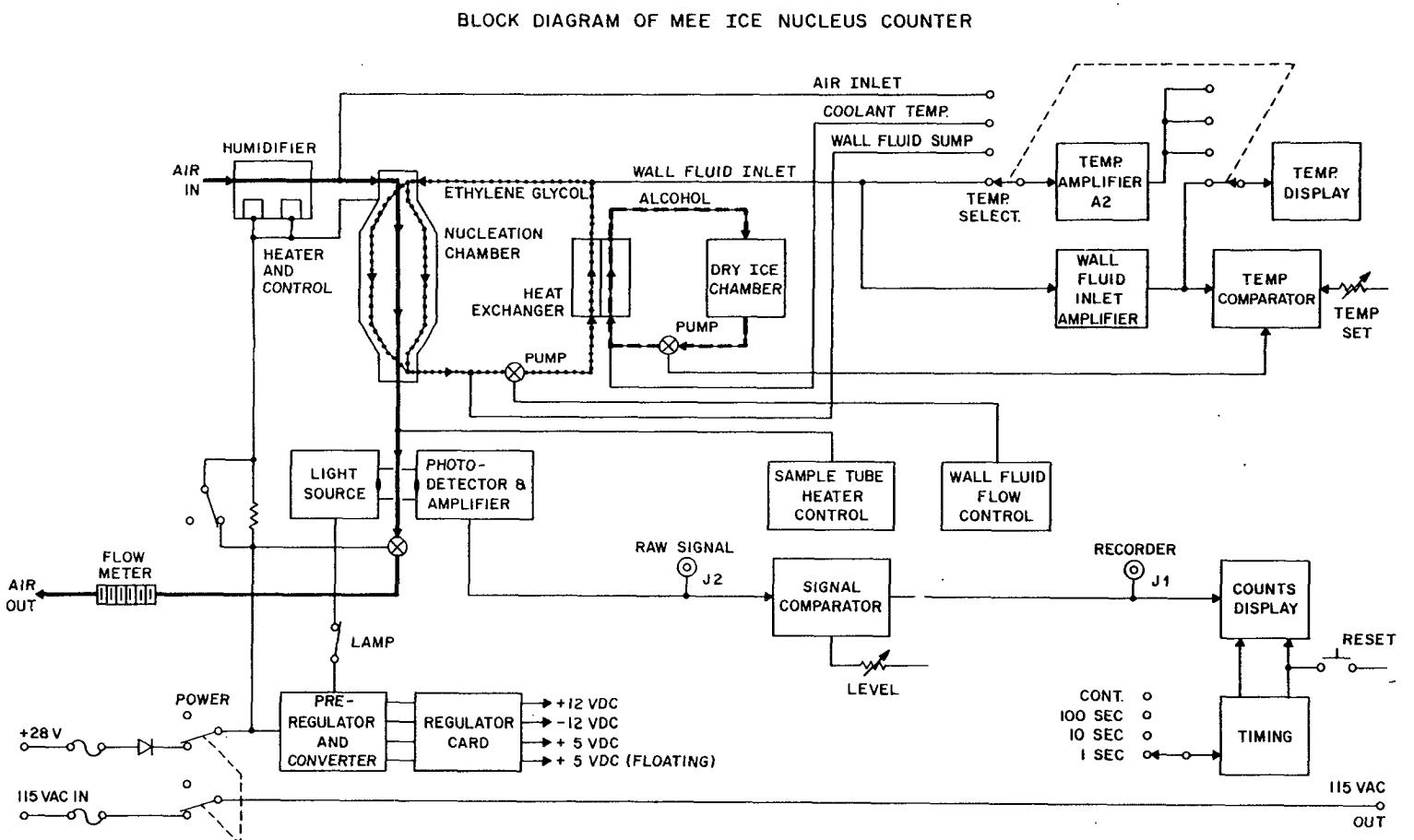
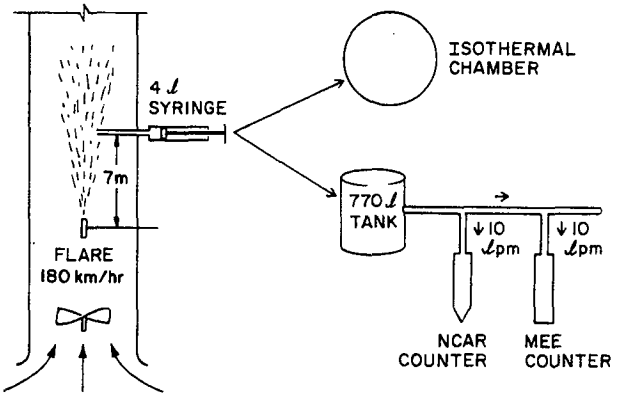


Figure 1. Flow diagram for Mee Counter



SCHEMATIC OF EXPERIMENTAL EQUIPMENT

Figure 2. Schematic of experimental equipment

which a small volume of aerosol from a syringe was quickly injected into the sampling line leading to both ice nucleus counters. The injection period lasted less than 5 s. The speed of response and the resolution are of particular interest for measuring plumes from the aircraft.

4. RESULTS AND DISCUSSION

a. CSI Mee counter comparison with CSU's isothermal chamber. The results of this comparison are given in Fig. 3. Two features of the resulting temperature spectra deserve comment. The first is that at a temperature below -16°C the Mee counter, in its present configuration, counts on the order of 10% of the total number of ice nuclei active in the isothermal chamber. This is a reasonable percentage since the activation time in the Mee counter is very short, i.e., at best 20s, compared to up to 60 min in the isothermal chamber. Moreover, some crystals fall within the cloud droplet noise and cannot be detected. The second point is that at temperatures above -16°C the efficiency of the Mee counter falls off drastically. It is presumed that this is primarily due to insufficient cloud formation; either there is a problem in properly humidifying the sample air or the glycol used is too dry and absorbs too much of the water vapor at the warmer temperatures. The points in Fig. 3 show good reproducibility for different measurements.

b. Comparison of the CSI and CSU Mee ice nucleus counters. The results of this intercomparison are shown in Fig. 4. Agreement was generally within a factor of two, with the CSI instrument counting more nuclei in all cases but one. There was some indication that the CSU unit may have had some humidification problems for a few tests.

c. CSI Mee counter versus NCAR counter. The data are summarized in Table 1. Again note that the temperature for the Mee instrument is the temperature of the cooling fluid (glycol) that is also used to prevent frosting of the wall. In general, the two instruments agreed in a reproducible manner and the NCAR instrument counted from 1.5 to 5 times higher than the Mee instrument. The agreement is particularly good for the AgI-NH_4I aerosols, with counts within a factor of three in all cases but two. The ratio of the NCAR counts to the Mee counts is largest at the warmest temperature. It was pointed out above that cloud formation in the Mee counter is inadequate at warmer temperatures. The humidifier temperature was adjusted for the NCAR ice nucleus counter for warmer temperatures, but no adjustment was made on the Mee unit. In some of the tests the concentration of nuclei in the storage tank was so high that the Mee counter reached saturation. This occurred at about 10,000 nuclei/ℓ for the Mee chamber. The NCAR counter has similar limitations. However, the saturation limit is not quite as low for the NCAR counter because a considerable number of ice crystals settle out on the bottom of the cloud chamber. Based on past calibrations the electronic count can be adjusted to take this effect into account.

For the pulse test the Mee counter is superior to the NCAR instrument. The 5 s pulse spreads out over about a 1 min interval in the Mee counter while it takes 5 min to decay in the NCAR counter. Both instruments

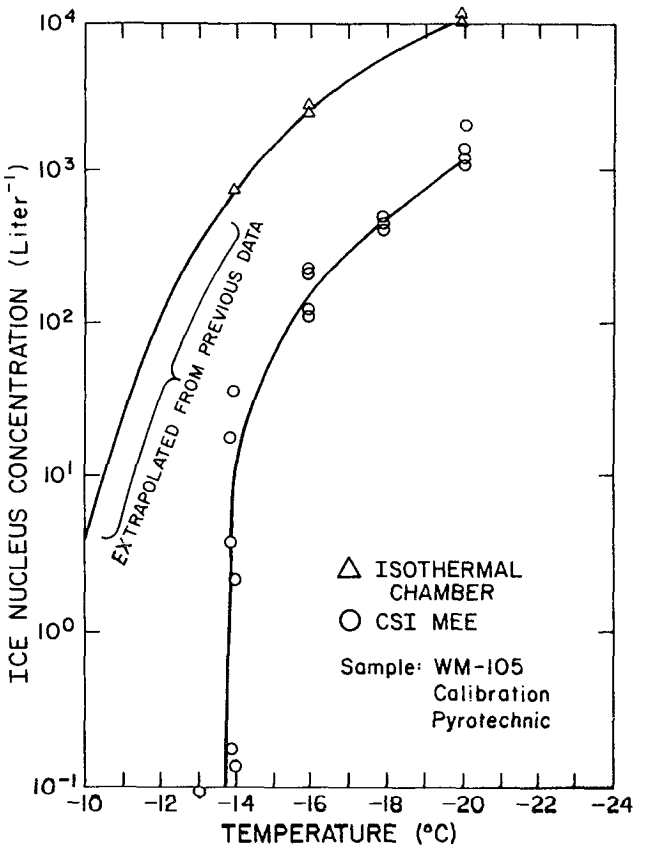


Figure 3. Comparison of CSU isothermal chamber and CSI Mee counter with pyrotechnics.

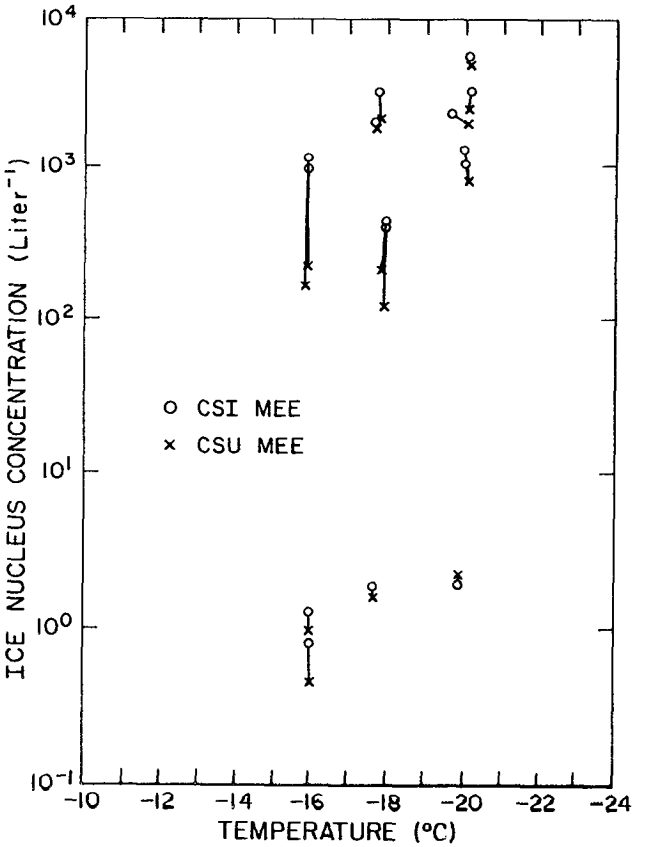


Figure 4. Comparison of CSI and CSU Mee counters with pyrotechnics and acetone burners.

Table 1

MEE-NCAR Ice Nucleus Counter Comparison

Nuclei Source	Temp. °C	Nuclei/ℓ NCAR	Nuclei/ℓ MEE(CSI)	Ratio NCAR/MEE	Comments
Building Air	-20	7.5	2.4	3.1	
Building Air plus Flare	-16	90	36	2.5	
	-17.5	822	480	1.7	
	-20	1820	750	2.4	
	-22	4160	960	4.3	Isothermal chamber gave 38,000 nuclei/ℓ at -20°C.
Flare in Tank	-16	360	54	6.7	
	-17	1130	1080	1.1	
	-20	12000	1980	6.1	
	-21	27000	1920	14	
	-22	38200	2730	14	
Building Air	-20	0.5	0.3	1.8	
	-20	0.5	0.8	0.6	
	-20	2.0	0.9	2.2	
AgI-NH_4I in Building	-14	45	0.08	560	
	-16	30	25	1.2	
	-18	261	132	2.0	
	-20	40	25	1.6	
	-20	760	450	1.7	
	-22	60	30.4	2.0	
AgI-NH_4I in Tank	-14	590	6.3	94	Isothermal chamber gave 2200 nuclei/ℓ at -18°C.
	-16	645	600	1.1	
	-18	3530	1320	2.7	
	-20	3530	1260	2.8	
	-20	7500	3300	2.3	
	-23	4620	1650	2.8	
Building Air	-20	4	3.8	1.0	
	-20	5	2.6	1.9	
AgI-NaI in Building	-12	10	0.05	200	
	-14	205	35.5	5.8	
	-16	1130	210	5.4	
	-18	880	450	2.0	
	-20	400	600	.7	
AgI-NaI in Tank	-12	310	0.36	8600	
	-13	1820	480	3.8	Isothermal chamber gave 79,000 nuclei/ℓ at -16°C.

initially respond to this pulse of nuclei within 15-20 s, but the NCAR counter, with its larger mixing chamber, has a considerably longer holdup time because of recirculation of the aerosol particles in the chamber. This might be eliminated by reducing the size of the cloud chamber of the NCAR counter. Table 2 shows typical comparisons for the pulse tests.

5. CONCLUSIONS

The two modified Mee counters as operated in the CSU laboratory gave consistent results and compared well with the NCAR counter and the CSU isothermal chamber at temperatures of -16 C and below. This conclusion holds true for the various AgI smokes tested. The counts on room air should not be considered indicative of the performance of the instruments with natural ice nuclei because the whole building in which these tests were carried out was contaminated with silver iodide. Further tests should be performed with natural nuclei, which may activate differently. The Mee counter shows superior performance for short puffs of silver iodide. The counts from a pulse decayed much faster in the Mee device and so a sharper definition of rapid changes in ice nucleus concentrations could be obtained in the field with this instrument. The NCAR counter had a five times longer decay. The initial response time to a puff of nuclei was about the same for both units.

However, before the Mee counter is employed in aircraft operations, a number of practical problems should be considered. First, the electronic counting system supplied with the instrument generally requires rebuilding. Even then, the threshold setting will depend on aircraft noise levels, and some crystal signals will fall below this level. Secondly, some of the mechanical components have engineering shortcomings; e.g., the joints of the plastic chamber tend to crack under thermal stress, the glycol and water pumps are unreliable, and the alcohol pump control is off-on rather than proportional. Thirdly, optimum glycol density for different temperatures and operations has yet to be established. All these problems are compounded if the instrument is operated on an aircraft. By comparison, the NCAR counter has been operated in the field and laboratory for fifteen years and has been flown for several hundred hours and many problems of this nature have already been addressed.

Another unknown is the effect of altitude on the operation of the Mee counter. The unit does not have a source of cloud condensation nuclei (CCN), which diminish rapidly with altitude and remoteness from cities and industry. The lack of CCN leads to a high supersaturation with the rapid cooling in the cloud chamber. Nucleation by condensation-freezing is then favored. In contrast, the NCAR counter maintains a constant CCN concentration and contact nucleation is favored. This leaves a rather important question unresolved.

Table 2

MEE-NCAR Ice Nucleus Counter Comparison with
Nuclei Pulses of 10-15 sec. Duration

		Total Nucleus Count			
Nuclei Source	Temp. °C	NCAR	MEE(CSI)	NCAR/MEE	Comments
AgI-NH_4I in tank	-21	2600	1500	1.7	MEE Counter decay
	-21	2600	1535	1.7	1 min
	-21	2800	1890	1.5	NCAR Counter decay
	-21	2800	1770	1.6	5 min

ACKNOWLEDGEMENTS

Part of this research was supported by the Bureau of Reclamation, and the continuing interest of Drs. A. Kahan, B. Silverman, and A. B. Super of the Bureau is appreciated.

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