

# A novel catalyst of warm-cloud seeding to enhance precipitation

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**Abstract.** Water is necessary for sustaining human life. In many regions of the world, traditional water sources cannot meet increasing water demands. Warm-cloud seeding is an efficient way to augment water supplies. In this paper, we explore two new hygroscopicity catalysts: Poly acrylamide (PAM) and Sodium polyacrylate (PAAS). We designed a series of experiments to investigate the effects of these catalysts together with common catalyst salt powder (NaCl). The experiment was held in a cloud chamber built in our laboratory. The results show that: 1) Catalysed by NaCl, a dose of  $0.91\text{g/m}^3$  can obtain the best precipitation efficiency and enhancement rate at 70.8% and 142%, respectively; 2) A  $1.36\text{g/m}^3$  dose catalysed by PAM and PAAS exhibits optimal performance at 76.7% and 70.4% precipitation efficiency, respectively; 3) Under the same conditions, PAM shows better catalytic effects than NaCl does.

## 1. Introduction

Water is one of the most basic necessities for human life. In many regions of the world, traditional water cannot meet increasing water demands [1]. Warm-cloud seeding can efficiently augment water supplies. Cotton and Pielke [2] reasoned that the Collision-Coalescence Process (CCP) is the most effective warm cloud precipitation process. This concept has been previously used in programs in the United States and other countries [2-4], and now is still widely used in India and Southeast Asian countries [5].

Hygroscopic salt like NaCl and  $\text{CaCl}_2$  was used in most of these experiments. Many researchers have performed experimental and theoretical studies on cloud microstructures modified by NaCl and  $\text{CaCl}_2$ . Drofa [6] studied experimental and theoretical NaCl cloud microstructure modifications in a large cloud chamber. Drofa found that seeding at low salt powder consumption rates could initiate



precipitation from otherwise non-precipitating warm convective clouds, mainly by adding large cloud drops to the distribution tail.

The disadvantages of this approach are that it requires large salt quantities, and salt dispersion can corrode soil and spreading tools. Poly acrylamide (PAM) and Sodium polyacrylate (PAAS) are super absorbent resins, which contain strong hydrophilic groups and a three-dimensional network structures. They can absorb the water as hundreds of times of the weight as their own, there is no wonder that they are significantly more hygroscopic than NaCl. Moreover, they are not corrosive to soil. Therefore, PAM and PAAS may be preferable to NaCl for warm-cloud precipitation.

## 2. Experimental Procedure

### 2.1. Processing of catalyst

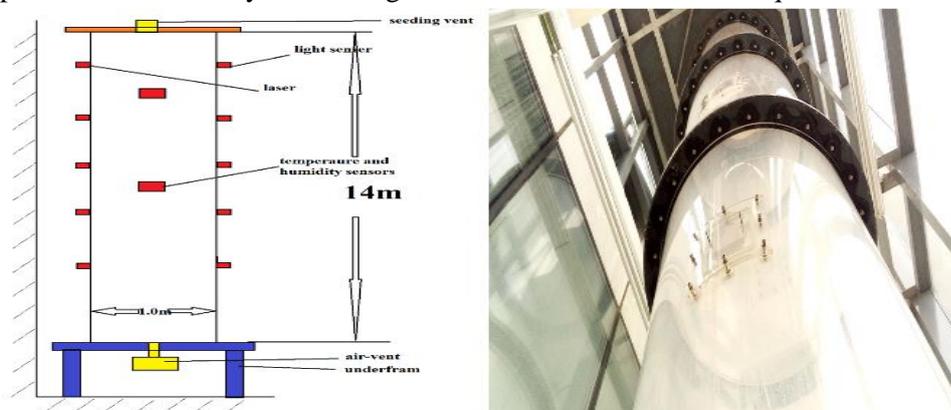
NaCl, PAM, and PAAS were separately milled in a planetary ball mill, then sieved by a 360 mesh sieve tray. After sieving, we put aside the powder that can penetrate the sieve tray, and dried the powders in a vacuum drying oven at 60 °C for 6 hours. A Malvern laser particle size analyzer Mastersizer 2000 was used to measure the catalysts' average diameters. Table 1 gives the purity, manufacturer and particle size of major reagents.

**Table 1.** Major reagents used in the experiment

Reagent	Purity	Manufacturer	volume average diameter
PAM	AR	Tianjin Fuchen Chemical Reagents Factory	27.868 $\mu\text{m}$
PAAS	AR	Tianjin Kemiou Chemical Reagent Co. Ltd.	42.856 $\mu\text{m}$
NaCl	AR	Beijing Tongguang Fine Chemicals Company	27.214 $\mu\text{m}$

### 2.2. The cloud chamber and its usage for measurements

Experimental studies on the catalyst cloud seeding effects were performed in a cloud chamber, which was designed for modelling clouds and fogs similar to those found in a real atmosphere. The chamber is an airtight cylinder 14 meters tall and with a 1-meter diameter; it is made of polymethyl methacrylate (PMMA). The chamber's total volume is 10.99 m<sup>3</sup>. Figure 1 shows the sketch and physical map of the cloud chamber. It is equipped with an ultrasonic fog making machine, a series of wireless temperature and humidity sensors, light sensors, lasers, and a data acquisition unit.



**Figure 1.** Sketch map and physical map of the cloud chamber

The light sensors monitored laser transmittance in the chamber, and the laser transmittance was proportional to the cloud's water vapor content in the chamber. The higher the water vapor content is, the lower the laser transmittance is. Therefore, we can use laser transmittance to measure the catalytic effects of catalyst powders.

To measure rain enhancement, an experiment was designed. After seeding the catalyst powder into the chamber, a 10cm diameter culture dish was placed at the bottom of the chamber. We weighed the dish every two minutes. Higher water collection resulted in higher weights, which indicated that the experimental catalyst had a better effect on rain enhancement.

### 2.3. *Experimental procedure*

First, we opened the sensors and the ultrasonic fog making machine to create a cloud in the chamber. The machine was closed after 1 hour when the cloud reached its saturation condition. Then, a certain mass of catalyst powder (the control group was not seeded) was seeded from the top of the chamber. Meanwhile, a culture dish was placed at the bottom of the chamber and weighed every 2 or 5 minutes. A computer recorded the temperature, humidity, and illumination data every 5 seconds. We stopped the experiment after 50 minutes, opened the chamber's ventilation, and cleaned the chamber.

## 3. Results and Discussion

### 3.1. *Catalyzed by NaCl*

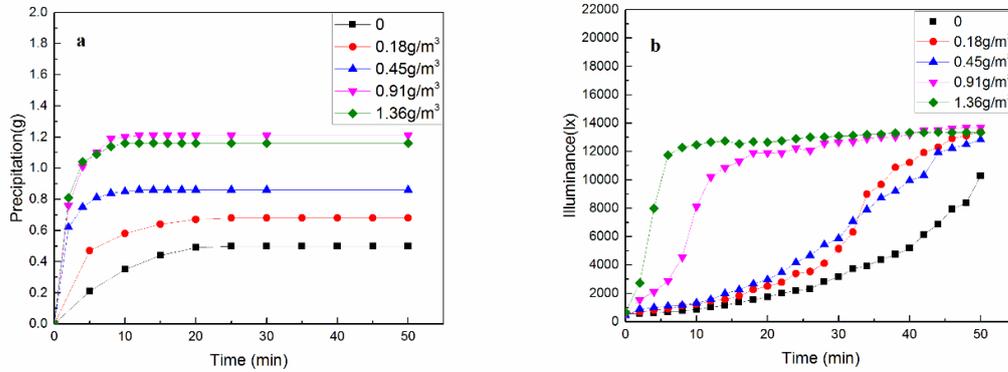
This section discusses the effects of catalyst mass on precipitation. Precipitation efficiency is the ratio of water that reaches the ground against the total condensation in the cloud [7]. We derived the temperature and relative humidity (RH, units: %) in the chamber from the temperature and humidity sensor; therefore, the absolute humidity (AH, units:  $\text{g}/\text{cm}^3$ ) can be determined from the humidity table. The water content can then be easily obtained using the below formula [8]:

$$M = AH \times V \quad (1)$$

Figure 2(a) shows the precipitation of different masses of NaCl seeded into the chamber. There was not a significant increase when  $0.18 \text{ g}/\text{m}^3$  NaCl was seeded, but the precipitation experienced a sharp rise in the first 2 minutes when the amount of NaCl reached  $0.45 \text{ g}/\text{m}^3$ . Seeding  $0.91 \text{ g}/\text{m}^3$  and  $1.36 \text{ g}/\text{m}^3$  NaCl produced similar results, but the results of the former were slightly higher. Figure 2(b) shows this tendency. Higher amounts of NaCl seeded into the chamber resulted in faster cloud dispersal, and more water dropping to the ground. When  $1.36 \text{ g}/\text{m}^3$  NaCl was seeded, the cloud dispersal was faster than it was when  $0.91 \text{ g}/\text{m}^3$  was seeded, however, the precipitation had the opposite effect. The reason is that when cloud dispersal is very rapid, a significant amount of water droplets falls, so the number of droplets in the chamber is reduced, and the chances of collision and coalescence are reduced.

Table 2 summarizes the precipitation of different NaCl masses seeded within 50 minutes. From the table, we can see that the precipitation enhancement and efficiency increased with the increase of NaCl mass. They reached their peak value when the NaCl mass was  $0.91 \text{ g}/\text{m}^3$ , while they fell slightly when NaCl mass reached  $1.36 \text{ g}/\text{m}^3$ . This change indicates that  $1.36 \text{ g}/\text{m}^3$  of NaCl is excessive for

catalyzing.



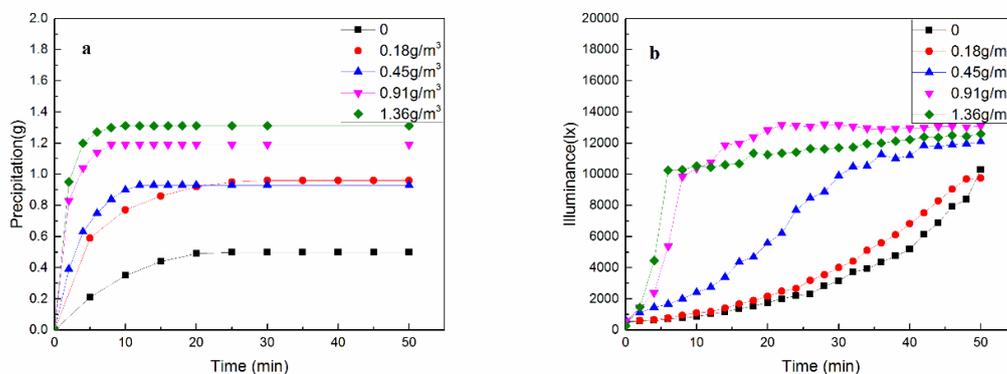
**Figure 2.** (a) Precipitation of different mass of NaCl seeded (b) Illuminance of different mass of NaCl seeded

**Table 2.** Catalytic effect of different mass of NaCl (T:20°C, RH:90%)

Mass of NaCl	Precipitation	Rate of Precipitation Enhancement	Precipitation Efficiency
0 g/m <sup>3</sup>	0.50g	0	29.3%
0.18 g/m <sup>3</sup>	0.68g	36%	39.8%
0.45 g/m <sup>3</sup>	0.86g	72%	50.4%
0.91 g/m <sup>3</sup>	1.21g	142%	70.8%
1.36 g/m <sup>3</sup>	1.16g	132%	67.9%

3.2. Catalyzed by PAM

Figure 3(a) shows the precipitation of different PAM masses seeded into the chamber. Unlike clouds catalyzed by NaCl, there was a significant increase when 0.18 g/m<sup>3</sup> NaCl was seeded. Also, there was a sharp rise in the first 2 minutes when PAM reached 0.91 g/m<sup>3</sup> and 1.36 g/m<sup>3</sup> respectively. Figure 3(b) also shows the same tendency. Seeding more PAM into the chamber resulted in faster cloud dispersal.



**Figure 3.** (a) Precipitation of different mass of PAM seeded (b) Illuminance of different mass of PAM seeded

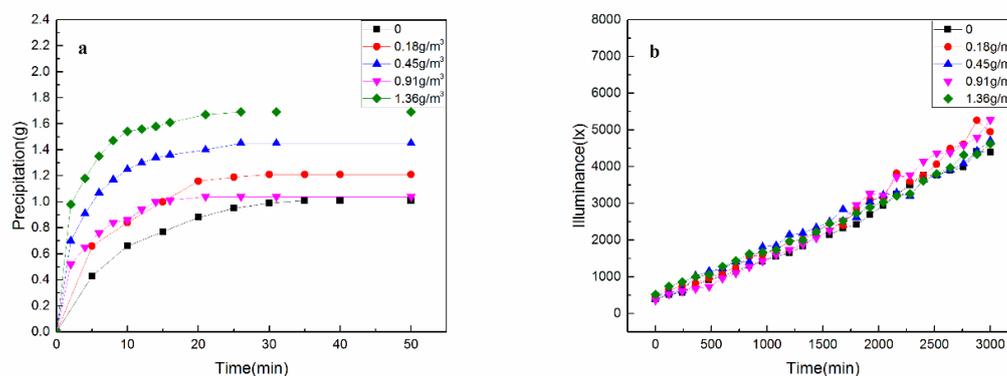
Table 3 summarizes the precipitation of different PAM masses seeded within 50 minutes. The precipitation enhancement and efficiency increased as PAM mass increased. The precipitation enhancement and efficiency reached their peak values when PAM mass was  $1.36 \text{ g/m}^3$ . Compared with NaCl with the same conditions, PAM created higher precipitation enhancement and efficiency values, except for  $0.91 \text{ g/m}^3$ . PAM therefore had better precipitation enhancement.

**Table 3.** Catalytic effect of different mass of PAM (T:20°C, RH:90%)

Mass of NaCl	Precipitation	Rate of Precipitation Enhancement	Precipitation Efficiency
$0 \text{ g/m}^3$	0.50g	0	29.3%
$0.18 \text{ g/m}^3$	0.96g	92%	56.2%
$0.45 \text{ g/m}^3$	0.93g	84%	54.4%
$0.91 \text{ g/m}^3$	1.19g	138%	69.7%
$1.36 \text{ g/m}^3$	1.31g	162%	76.7%

### 3.3. Catalyzed by PAAS

Figure 4(a) shows the precipitation of different PAAS masses seeded into the chamber. As can be seen, precipitation increased as more PAAS was seeded into the chamber. In Figure 4(b), the 5 curves roughly conform. This indicates that PAAS seeding does not significantly affect cloud dispersal.



**Figure 4.** (a) Precipitation of different mass of PAAS seeded (b) Illuminance of different mass of PAAS seeded

**Table 4.** Catalytic effect of different mass of PAAS (T:25°C, RH:95%)

Mass of PAAS	Precipitation	Rate of Precipitation Enhancement	Precipitation Efficiency
$0 \text{ g/m}^3$	1.01g	0	42.1%
$0.18 \text{ g/m}^3$	1.21g	19.8%	50.4%
$0.45 \text{ g/m}^3$	1.45g	43.6%	60.4%
$0.91 \text{ g/m}^3$	1.04g	3.0%	43.3%
$1.36 \text{ g/m}^3$	1.69g	67.3%	70.4%

Table 4 summarizes the precipitation of different PAAS masses seeded within 50 minutes. PAAS seeding had much lower precipitation enhancement rates compared with those of NaCl and PAM seeding. This indicates that PAAS is not as effective as NaCl and PAM as a catalyst.

#### 4. Conclusion

The conclusions drawn from the experiments carried out in the cloud chamber are as follows:

- NaCl and PAM seeding can enhance warm cloud precipitation. NaCl's optimal seeding mass was  $0.91 \text{ g/m}^3$ , reaching a 70.8% precipitation efficiency rate and a 142% precipitation enhancement rate respectively. PAM seeding was more effective than NaCl seeding under the same condition. Its optimal seeding mass was  $1.36 \text{ g/m}^3$ , resulting in 76.7% precipitation efficiency and 162% precipitation enhancement rate.
- PAAS seeding cannot disperse the cloud, and its ability in precipitation enhancement was much lower than that of NaCl and PAM. It is not an effective warm cloud catalyst.

In summary, the experiment showed that PAM was effective at precipitation enhancement. It can be used as a novel catalyst in warm cloud seeding. However, the experiment was carried out in the cloud chamber; more experiments in the field are needed for further researches.

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