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***Journal of Scientific and Engineering Research*, 2017, 4(2):65-70**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Results of the Characterization of Hygroscopic Flare Material using SEM and EDX Techniques

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Abstract Results of the randomized cloud seeding experiments in South Africa has received renewed interest in seeding the clouds with hygroscopic particles and prompted the search for the optimal size of hygroscopic seeding particles to seed the clouds for precipitation enhancement. The hygroscopic flares used in the operational cloud seeding programme for precipitation enhancement over a rain shadow region have been subjected to material characterization. Thin films have been prepared on the silicon glass substrates from the smoke ejecting from burning hygroscopic flare material in a clean and dry environment where hygroscopic expansion was not possible. Deposited thin films have been characterized with the Scanning Electron Microscopy combined with Electron Dispersion X-Ray spectroscopy (SEM-EDX) to know the chemical composition and size of the particles (CCN) released. The results suggest that the flare used in the operational cloud seeding programme is producing the theoretically optimal size giant CCN of hygroscopic nature. The details of the characterization of hygroscopic flare material have been discussed in this paper.

Keywords Hygroscopic flares, Characterization, Optimal size

Introduction

Years of research and application of cloud seeding technology in many countries have demonstrated that properly-designed programs can increase seasonal rainfall appreciably and improve water resources. Water availability for rain based crops has always been a critical issue in Andhra Pradesh, as the state is vulnerable to drought and the associated lack of rainfall in many regions coming under the rain shadow region that is formed at the eastern side of the Western Ghats. The first rainfall enhancement efforts in India date back to the early 1970s (11-year experimental programme of air-borne cloud seeding experiments was in progress in the Pune region (18^{0}32’N, 73^{0}51’E, 559 AMSL) from 1973 to 1986 except during 1975, 1977 and 1978). And the Andhra Pradesh state has started operational mode of “precipitation enhancement program” in the year 2004”. The Rain Shadow Area Development Department (RSAD) identified 12 regions whose average annual rainfall is less than 600 mm that are not receiving sufficient rainfall for agricultural purposes and initiated the rainfall enhancement project for the purpose of rain based crops over RSAD identified 12 regions during the South West and North East monsoon periods. The status of modification of precipitation from warm clouds has been discussed in an excellent review paper by Cotton (1982) [1]. Later progress on the topic was reviewed by Ramanamurty (1984) and Czys and Bruintjes (1994) [2-3]. The whole scenario of weather modification up to the year 1995 has been discussed by Orville (1995) in his report on the WMO Scientific Conference on Weather Modification held at Paestum, Italy during 30 May – 4 June 1994 [4]. Cloud simulations and observations showed that hygroscopic seeding is most effective with the particles whose diameter is ~1 µm and more than 1µm [5]. Not only the size of the particle but chemical composition along with size of the particle used in the cloud seeding programme will help the scientists involved in the weather modification programme. So from this discussion it is understood that there is need to know the size and chemical nature of the particles emanating from the flares. So an attempt has been made to analyze the hygroscopic flare material that was used to seed the clouds over rain shadow region of Andhra Pradesh state with SEM (Scanning Electron Microscope) and EDX (Electron Dispersion Spectroscope), which are used for the characterization of material properties in thin films research. The results of the characterization of hygroscopic flare material have been discussed in this paper.

Data and Analysis

The operational cloud seeding programme was monitored every week by Technical Monitoring Committee (TMC) of eminent RADAR Meteorologists and professors of Atmospheric Sciences. The question about the chemical composition and size of the particles emanating from the burning flares has attracted the attention of the Monitoring Committee members of the programme during every TMC Meeting. And the flares used in the cloud seeding programme have been characterized to know the chemical composition and size of the particles released from the burning flare material.

Analysis of the Hygroscopic Flare Material before burning

Samples collected from the Hygroscopic Flares used in the Cloud Seeding operations has been analyzed with electron microscopy and electron dispersion spectroscopy to know the size and chemical composition of the granules present in the flare before burning and after burning. The scanning electron microscope (SEM) images of the samples collected from the Hygroscopic Flare before burning are presented in the figure.1a. From the Fig.1a, it can be seen that, on an average the granule size is in the order of 80 to 100 µm before burning. And the same sample has been analyzed with the electron dispersion technique (EDX) to know the chemical composition of the material present in the flare used for cloud seeding operations (Fig.1b).

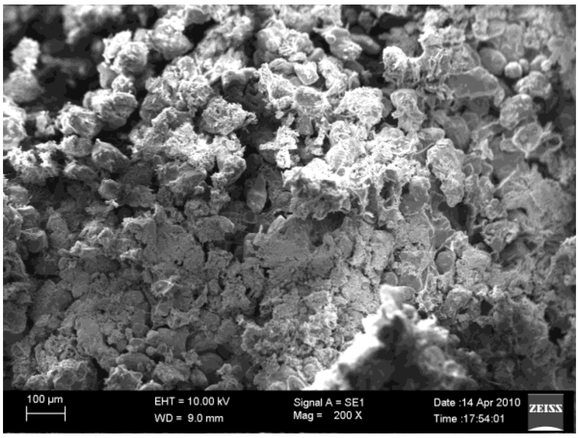

Figure 1a: Size of the granules present in the Hygroscopic Flare sample before burning

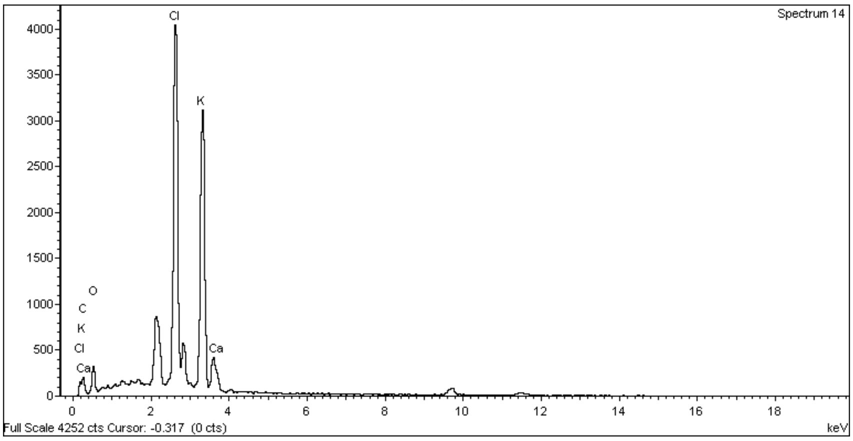

Figure 1b: Chemical composition of the Hygroscopic Flare sample before burning

From the Fig.1b, it can be seen that there are several peaks corresponding to the materials like Calcium, Chlorine, Potassium, Carbon and Oxygen showing the presence of these materials in the Flare used for Cloud Seeding operations. And the Weight Percentage of these chemicals in the sample analyzed is presented in Table 1.

Table 1: Weight Percentage of the chemicals in the Hygroscopic Flare sample before burning

Element	Weight %
Carbon (C)	14.95
Oxygen (O)	19.38
Chlorine (Cl)	30.91
Potassium (K)	32.92
Calcium (Ca)	1.85
Totals	100

From the Table 1 it can be seen that, on an average 33% of the material used in the flares is of hygroscopic nature and the remaining material is useful for free burning of the flare in a unit sample collected from the Hygroscopic Flare before burning.

Analysis of the Hygroscopic Flare Material residues after burning in the free atmosphere

The sample collected from the residues of the burnt Hygroscopic Flare used to seed a cloud has been analyzed with the same techniques to know the particle or granule size and chemical composition present in the residues after burning the flares. The electron microscopic image of the sample collected from the residues of the Hygroscopic Flare is shown in Figure 2a.

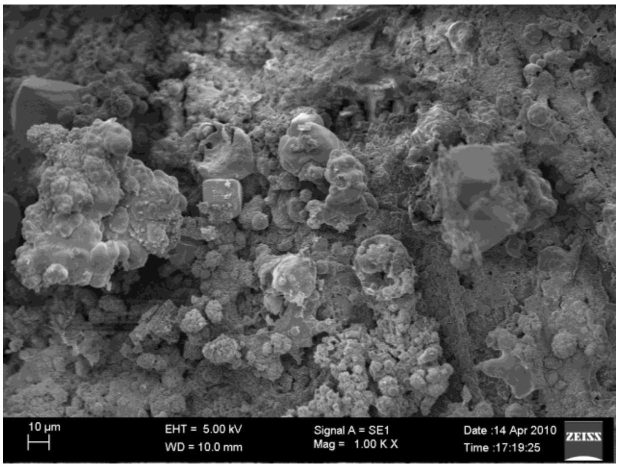

Figure 2a: Size of the granules present in the Hygroscopic Flare sample after burning

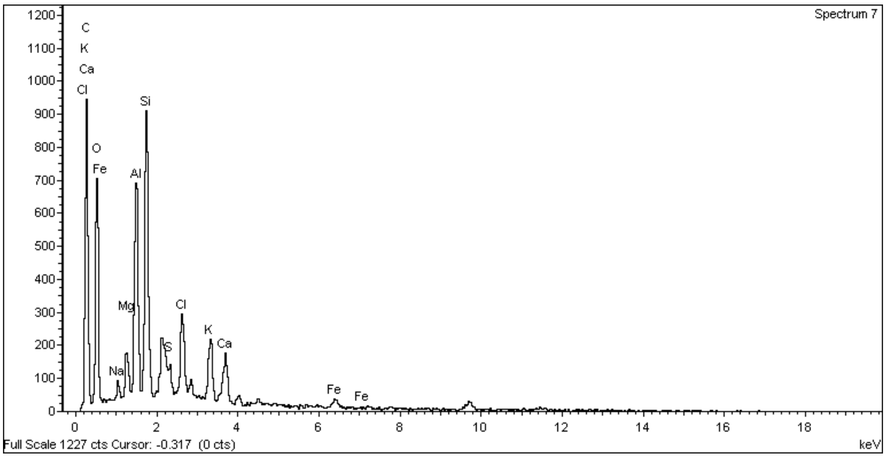

Figure 2b: Chemical composition of the Hygroscopic Flare sample after burning

From the Figure 2a, it can be seen that there are granules of residues whose average size is in the order of 10 microns. These granules are composed of all the chemicals of the flare along with other materials, due to the exposure in the free atmosphere while seeding the clouds. This sample has been analyzed with electron dispersion analysis to know the chemical composition of the residues on the sample after burning. The peaks obtained for different material residues on the sample in the electron dispersion analysis are shown in Figure 2b along with the weight percentage data of the residue material present in the same sample Table 2.

Table 2: Weight Percentage of the chemicals in the Hygroscopic Flare sample after Burning in the dry atmosphere

Element	Weight%
Carbon (C)	47.98
Oxygen (O)	33.14
Sodium (Na)	0.57
Magnesium (Mg)	1.08
Aluminum (Al)	4.36
Silicon (Si)	5.92
Sulfur (S)	0.29
Chlorine (Cl)	2.25
Potassium (K)	2.01
Calcium (Ca)	1.73
Ferrous (Fe)	0.67
Totals	100.00

From the Figure 2b, it can be seen that there are several peaks corresponding to the materials like Calcium, Chlorine, Potassium, Carbon, Ferrous, Aluminum, Silicon, Magnesium and Oxygen showing the presence of these materials along with Calcium and Chlorine after burning the flares. This may be due to the exposure of the sample to the free atmosphere at the time of seeding a cloud. Similarly from the Table 2, we can see that the sum of the weight percentage of the main compounds of hygroscopic nature, namely Calcium and Chlorine is 3.98% only in the entire 100% of the sample composition and the other residues like Carbon and Potassium are the burning agents used in the flare. We can also observe the peak corresponding to Silicon, as the sample is collected on a silicon glass substrate. And the reason for the presence of other materials may be due to the exposure of the sample to the free atmosphere during seeding the cloud. From this analysis it can be understood that the entire hygroscopic material was ejected in to the atmosphere while seeding the cloud and roughly 4% of the hygroscopic material is present in the form of residues. From the preliminary observations of the material characterization of the Hygroscopic Flares before burning, we can understand that, nearly 33% of the material present in the flares is of hygroscopic nature and the remaining is pyrotechnic material. It is observed that the average size of the granules composed of hygroscopic and other pyrotechnic material present in the flare sample before burning are in the size range of 80 to 100microns. And from the material analysis of the residues of the Hygroscopic Flares after burning, we can understand that, nearly 3% of the hygroscopic flare material is present in the form of residue and the entire 97% of the hygroscopic material has been ejected in to the atmosphere while seeding the clouds. And the average size of the most of the granules present in the form of residues on the sample collected from already burnt hygroscopic flares is in the order of 10microns.

Analysis for the size of the particle (CCN) releasing from burning Hygroscopic Flare Material in the dry atmosphere

The hygroscopic flares used in the operational cloud seeding programme has been burnt in the dry atmosphere to know the exact size of the CCN releasing from the burning hygroscopic flares. The smoke composed of CCN emanating from the burning flare material was made to deposit on a silicon glass substrate in the form of a thin film on the silicon glass substrate in a clean and dry atmosphere, so that further hygroscopic expansion can be minimized during the formation of thin film. This helps to know exact size of the CCN releasing from the flare in a moisture free environment. The importance of clean and dry environment during the preparation of thin films deposited by the smoke emanating from the burning flares is to minimize the presence of atmospheric pollutants as much as possible during the characterization of the thin films. If the size of the size of the hygroscopic CCN is found in the dry atmosphere, then it becomes easy to estimate the size of the CCN released in moisture rich environment (at the premises of the cloud) which would be definitely become more than that of the CCN released in a clean and dry atmosphere. Why because there is a possibility for the increase of the size of the CCN when it is released in moisture rich environment as it will undergo hygroscopic expansion. If the CCN released in the dry atmosphere is in the size range of more than 1µm to 2µm then definitely the size of the CCN released in a moisture rich environment will fall in the optimal size range due to hygroscopic expansion which is effective for precipitation enhancement. The thin films prepared from the smoke of burning flares coated on the cleaned silicon glass substrate was analyzed with the Scanning Electron Microscope to know the size of the particles emitted in the smoke. The scanning electron microscope image of two thin films coated by the smoke emitted from the burning hygroscopic flares is presented in the figures 3a&3b.

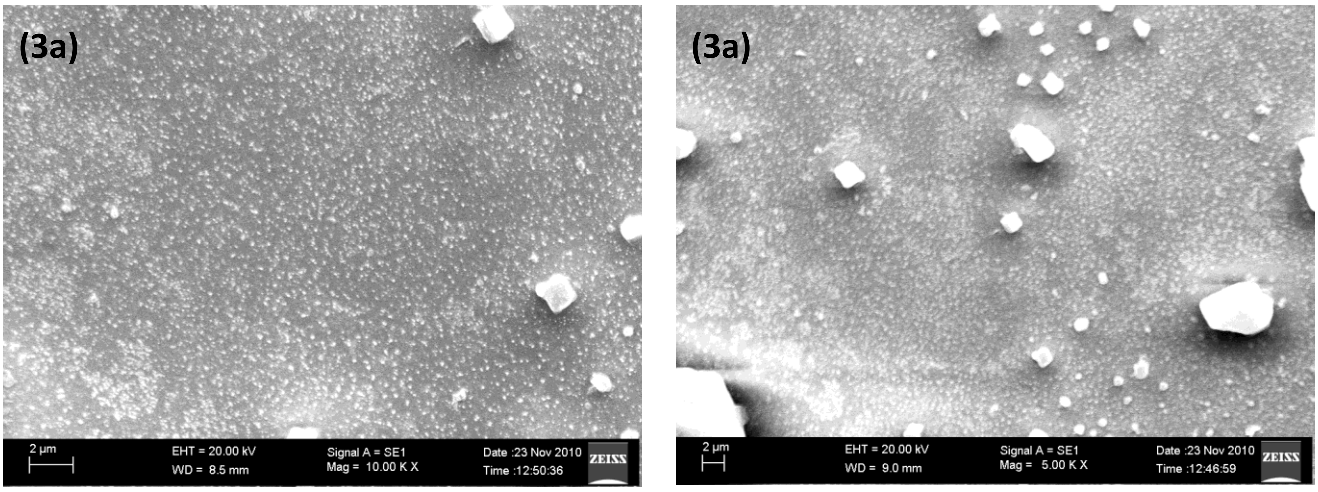

Figure 3: Size of the CCN released from the hygroscopic flare burned in dry atmosphere (a) CCN deposited on one of the thin films (b) CCN deposited on another thin film prepared from the smoke emitted from burning flares.

From the figure 3a, we can see that the CCN released in the smoke emitted from the burning hygroscopic flare is in the size more than 1µm, which may probably fall in the optimal size range (GCCN) required for the efficient precipitation enhancement after hygroscopic expansion in the moist rich environment near the cloud. From the figure 3b we can observe that the size of the hygroscopic CCN released from the hygroscopic flares burnt in the dry atmosphere was in the size range of 2µm to 5µm. from results obtained in the present study in comparison with the recent research reports it is understood that hygroscopic CCN of optimal size (between 2 to5 µm) are releasing from the burning flares at the premises of the cloud base. So from the present study it can be observed that the size of the CCN which are dispersed at the premises of the cloud base where the updrafts are found to be more falls in optimal size range will behave as embryos of raindrops.

Results and Discussion

The results obtained from the characterization of flare material with the Scanning Electron Microscope and Electron Diffraction X-ray spectroscopy has confirmed that the flare used to seed the cloud contains 33% of hygroscopic material and the remaining material used is for free combustion, binding purposes. It is observed that the residues of the burnt flare also in the size range of more than 2 µm and contains roughly 4% of the hygroscopic material which may contribute for the formation of cloud droplets due to its hygroscopic nature that means entire material used in the preparation of the flare was utilized effectively. The results obtained from the characterization of flare material with the Scanning Electron Microscope and Electron Diffraction X-ray spectroscopy it is understood that the flare used in the operational cloud seeding programme of the Andhra Pradesh state are releasing giant CCN of hygroscopic nature. And the size range of CCN releasing form the hygroscopic flares is in the optimal size range (>2µm), suitable for efficient precipitation enhancement. Further research is required to develop the technology to produce entire hygroscopic CCN in GCCN size range (> 2µm) from the flares with different chemical combinations for efficient precipitation enhancement. And there is a need to develop cloud chamber technology to know more about the aerosol cloud interactions especially in a country like India whose economy depends up on the amount of rainfall received.

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