### **GENERATION OF CHARGED CLOUD DROPLETS FOR LABORATORY** EXPERIMENT

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#### ABSTRACT

Atmospheric rain cloud contains charged cloud droplets. To study the homogenous effect of electric charge E on formation of atmospheric cloud droplets, charged cloud droplets were generated in the laboratory using a cloud chamber at room temperature and calorimetric system (at about 100°C). During the investigation, ionization effect of  $N_2$  gas and contact charging technique using Zn-Cu and Al-Cu electrodes; powered by direct current DC source, were utilized. Estimated induced charges in the chamber ranges between 0.417 - 0.534 pC, 2.20 - 8.50 pC and 0.60 - 414.75 pC for Zn-Cu, spiral Al-Cu and spiral Al/insulated Cu, respectively. The sizes of the charged droplets D<sub>C</sub> that formed in about 15.0 s ranges between 1.0 - 3.0 mm for experiment in calorimetric system, and D<sub>C</sub> for uncharged condensed vapour formed in about 120.0 second were inestimable ( $D_C \ll 1.0$  mm).

Keywords: Cloud chamber, Calorimetric system, Induced charges and Coulomb force.

#### **INTRODUCTION**

Water vapour is one of the states of water cycle and it can be produced from evaporation, boiling or sublimation of ice. The formation of atmospheric cloud begins with condensation of droplets from the vapour phase through homogenous or heterogeneous nucleation. Energy change associated with droplet formation consists of surface  $E_S$  and bulk thermodynamic  $E_T$ energies, expressed as (Cotton and Anthes, 1989):

$$E_T = n_L V(\mu_L - \mu_V), \qquad (1)$$
  

$$E_S = A_S \delta_{LV}. \qquad (2)$$

In liquid phase,  $n_L$  is the number of water molecules/unit volume, V is volume of water molecules,  $\mu_L$  is the chemical potential. While,  $\mu_V$  is chemical potential in vapour phase,  $A_s$ is surface area and  $\delta_{LV}$  is the surface tension associated with the liquid-vapour interface.

As cloud droplets form within atmospheric cloud, they become electrically charged (Gunn, 1952). The droplets grow larger by sticking to each other in the aftermath of collisions due to electrical attraction which resulted from charges on cloud droplets and atmospheric electric field. In 1955 and 1956, Twomey observed that, the relationship between charge q (pC) and cloud droplets diameter d (µm) is

$$q = Ad^n, (3)$$

where A is correlation coefficient and n is exponential value between 2.0 and 3.0; while the charge q acquired by a rain drop of radius r during its fall in the presence of atmospheric electric field  $E_r$  is given by (Takahashi and Isono, 1966),

$$q = 0.52 |\mathbf{E}_r| r^2. \tag{4}$$

## CHARGING OF WATER VAPOUR

The electrical processes in atmospheric air arise from the combined effect of natural ionization and electric field generated by charge separation in thunderclouds. Thus, atmosphere between the surface of the earth and the ionosphere is subject to great electric potential gradients and water contained in an electrically isolated container is non-electroneutral (Leandra, *et.al*, 2011). Charging processes that contribute to atmospheric electric phenomenon include contact electrification, freezing and splinting of ice and electrochemical charging (Byers, 1965).

Contact electrification involves mechanical contact between solids where electrons (of few tenths of coulomb) from a lower work function material spill over to a high work function material. Other methods of ionizing water vapour include chemical ionization e.g. radioactive ion source (Donald, 1952) and the use of crown (or corona) discharge (Satyanand, 2005). Also, charges on a spherical water drop in the air under the impact of the electric field from corona discharge is represented (Belevtsev and Biberman, 1983) by

$$Q(t) = 12\pi\varepsilon_o Er^2 \left(\frac{\varepsilon}{\varepsilon+2}\right) \left(\frac{t}{t+t_o}\right)$$
(5)

where E is the intensity of electric field generated by corona discharge, r is the radius of the drop, t is charging duration,  $t_o$  is the time constant of charging,  $\varepsilon_o$  is the dielectric constant of vacuum and  $\varepsilon$  is the dielectric constant of the drop. In this work, water vapour molecules (inside the cloud chamber) were charged to produce charged cloud droplets using; ionization effect of nitrogen gas and induction effect of Zn-Cu and Al-Cu charging systems. These were powered at room temperature and calorimetric cupboard using; direct current DC power supply and corona discharge from line transformer  $T_L$  circuit.

#### **GENERATION OF CHARGED CLOUD DROPLET**

The cloud chamber system was constructed using pyrex glass and other functional units shown in Figure 1.0. The calorimetric system is devised to keep a temperature of about 100  $^{0}$ C. It consists of aluminum frame, lagging jacket and electrical heating unit (1.5 kW output power). Charged cloud droplets were generated at room temperature by subjecting the water vapour molecules to stream of electronically excited atoms of N<sub>2</sub> gas and induction effect of Zn-Cu electrodes. The sizes of droplets obtained were shot using Sony digital camera (16.4 mega pixels and focal length *f* of 4.6 to 27.6 mm), processed with Picasa 3.0 software and estimated using;

$$v = f(m+1),$$

$$u = \frac{fv}{v-f},$$
(6)
(7)

where v and m, are size and magnification of droplet's image, and u is actual size of droplet.



Figure 1: The Cloud Chamber

Charging of vapour in calorimetric system was implemented using cylindrical glass chamber (shown in Figure 2a) inserted with spiral Al-Cu electrodes and electrometer circuitry. The diameter  $D_c$  of droplets generated were estimated using venire caliper and induced charge Q was obtained using equation 3.2; where V is induced voltage and,  $C_{cc}$  is the equivalent capacitance of the electrodes and the chamber's medium.  $Q = C_{cc}V$ , (8)



Figure 2: (a) Cylindrical chamber and (b)  $T_L$  circuitry for generating charged cloud droplets.

The electrodes were selected based on their work function capabilities, powered by dc power supply and  $T_L$  circuit consisting of; 555 timer,  $T_L$  (TFP-274,  $V_{out} \ge 1.98$  kV), 12.0 V dc rectifying circuit and BU508 transistor (driver to  $T_L$ ) shown in Figure 2b. Control experiment was performed by generating uncharged droplet and the rates of condensation were compared. Typical set-up of the cloud chamber inside the calorimetric system is depicted in Figure 3.



Figure 3: Set-up of cloud chamber in calorimetric system

#### SIZES OF CHARGED CLOUD DROPLETS GENERATED

The condensation of H<sub>2</sub>O vapour molecules under the influence of electric forces and the sizes of charged droplets were computed. At room temperature, cloud droplets  $D_C$  of about 0.1- 0.5 cm were obtained with induced potential differences of 0.1 - 4.9 mV when Zn-Cu charging electrodes were powered for about 30 minutes using EX354D supply. But, the sizes of droplets obtained using ionization effect of N<sub>2</sub> gas were inestimable ( $D_C \ll 0.1$  cm). The charges induced by the electrodes differ from droplets generated in the calorimetric cupboard. The induced charges as sensed by the probe and size  $D_C$  of the droplets are shown in Table 4.1; while the responses of the electrodes (shown in Figure 4) were generated with Matlab tools.

#### Effect of electric field on water vapour

Generation of water vapour as illustrated in Figures 2 was initialized by latent heat of vapourization. Ionized droplets generated at room temperature were mostly due to attachment of N<sub>2</sub> gas molecules to water vapour molecules. The combination of these molecules  $[N_2^+ + (n+2) H_2O]$  resulted into formation of hydrated hydroniums cluster ions  $[H_3O^+(H_2O)_n + OH + N_2]$ , shown in the chain reaction;

$$N_{2}^{+} + H_{2} 0 \rightarrow N_{2} H^{+} + 0H$$

$$+ H_{2} 0 \rightarrow H_{3} 0^{+} + N_{2}$$

$$+ H_{2} 0 \rightarrow H_{3} 0^{+} \bullet H_{2} 0$$

$$+ H_{3} 0^{+} (H_{2} 0)_{n} \qquad (9)$$

Charged droplets generated from the condensations of water vapour molecules using the electrodes were due to static electric field E (illustrated in equation 10) that developed between the powered electrodes in the cloud chamber.

$$|E| = \frac{DC \text{ voltage applied across the electrodes }(V)}{Distance \text{ between the electrodes } d(cm)}.$$
 (10)

A large quantity of ions is generated by the electric field of the  $T_L$  especially when the Cu electrode was insulated as shown in Figure 5. The collision of ions with water vapour molecules The ions served as condensation nuclei on which mists (cloud droplets) were

formed and, positive charges were collected on Al/Zn electrode and negative charges on the Cu electrode. At the completion of the experiments, Aluminium and zinc electrodes showed whitish thin surface layers due to formation of oxides, while the reddish brown colour of copper electrode became light brown. Oxides formations are expressed by the equations;

$$2AI_{(s)} + 3H_2O_{(Steam)} \rightarrow AI_2O_{3(s)} + 3H_{2(g)},$$

$$Zn_{(s)} + H_2O_{(Steam)} \rightarrow ZnO_{(s)} + H_{2(g)}.$$
(11)
(12)

Table 1. Induced	Charges and Diameter of Cloud Dronlets
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S/N	Charging Electrodes	Induced Voltages V(mV)	Induced Charges Q(fC) @ Max. V(mV)	Operational Condition	Diameter of Cloud Droplet D <sub>C</sub> (cm)
1	Linear Zn-Cu	0.10 - 4.90	0.524	Room Temp	0.1 - 0.5
2	Linear Zn-Cu	0.10 - 3.90	0.417	Cal. Cupboard	0.1 - 0.3
3	Linear Al-Cu	2.20 - 8.50	0.910	Cal. Cupboard	$D_{\rm C} < 1.0$
4	Spiral Al-Cu	5.10 - 9.30	9.860	Cal. Cupboard	$D_{\rm C} < 1.0$
5	Spiral Al-Cu	0.20 - 50.70	53.410	Cal. Cupboard	0.1 - 0.4
6	Spiral Al-Cu*	0.60 -197.7	414.75	Cal. Cupboard	0.2 - 0.5

Note: Cu\*-Insulated copper electrode; Cal - Calometric



Figure 4: Response of voltage induced by charging electrodes in water vapour.



Figure 5: Rate of voltage induction in water vapour by  $T_L$ 

The uncharged water vapour molecules however, condensed in longer period of time (tabulated in Table 2) without formation of estimable droplets. Uncharged inestimable droplets formed in the cloud chamber (internal temperature of cloud chamber in Calometric cupboard was at about 100°C) were due to effect of hydrophobic surface tension  $F_s$  of the glass chamber and supersaturation of water vapour molecules, that partially acted as condensation nuclei.

S/N	Observable Variable of Water Vapour	Responses of uncharged Water Vapour	Responses of charged Water Vapour
1	Period of cloudiness of chamber after vapour's inlet.	121.0 seconds	15.0 seconds
2	Diameter of deflected and condensed water vapour after chamber's cloudiness.	Inestimable droplets, mostly << 1.0 mm	1.0 mm - 3.0 mm
3	Region in the chamber's wall where deflected water vapour firstly condensed.	Simultaneously, almost every part of the chamber	Chamber's side with powered Al electrode
4	Ranges of induced charges' potential difference observed during the experiment.	0.00 mV	0.1 mV - 196.5 mV

Table 2: Responses of Uncharged and Charged Water Vapour

## CONCLUSIONS

Large sizes of ionized water vapour droplets produced by N<sub>2</sub> gas at room temperature was influenced by external natural forces (that acted as condensation nuclei) such as atmospheric pressure and surface temperature. But, formation of charged condensed droplets generated in calometric system (at about 100°C) were mostly due to effect of electric field E and Coulomb's force  $F_e$ , facilitated by gravitational force  $F_q$ .

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