DETERMINATION OF COLLECTION EFFICIENCY OF ATMOSPHERIC IONS BY THE SYSTEMS OF PARALLEL CONDUCTIVE PLATES

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ABSTRACT. – Determination of collection efficiency of atmospheric ions by the systems of parallel conductive plates. We present a theory that describes the scenarios of equations of motion of clustered air ions entering into specific systems. The system analyzed here is composed by two or three conductive parallel plates. In the first case (system of two parallel plates) one plate collects air ions which enter into the area between these plates. In the second case (system of three parallel plates) the collector plate is the middle one.

Air ions usually are classified into several categories according to their electrical mobility (size). The main categories are: cluster ions (mobility 0.5-3.2 cm2/V.s), intermediate ions (mobility 0.034-0.5 cm2/V.s), and large ions (mobility 0.0042-0.034 cm2/V.s).

This theory has an important application on ion counter operations. Usually the apparatus measures the concentrations of only cluster air ions (mobility > 0.5 cm2/V.s). Air ions are deflected by the electric field established by a potential difference of polarized plates. Air ion concentrations are derived from measurement of electrical current caused in the system.

Based on this theory, we can determine analytically the efficiency of the collection of air ions of different electrical mobility by above mentioned systems.

Keywords: air quality, atmospheric ions, air ion counter, measurement efficiency.

1. INTRODUCTION

Among the major parameters of atmospheric electricity is electrical conductivity, and ionization level, which are indicators of changes in climate and air pollution Tammet (1992). This fact makes measurements of atmospheric electrical parameters provide important information on these studies Israelsson and Tammet (2001). To air ionization are closely related problems very important, as the assessment of air pollution, natural radioactivity, different areas, and evaluation of physical parameters of the atmosphere, such as its electrical conductivity Wahlin (1989), Laurikainen et al. (2001) . All the above aspects make it very actual and important study of the atmosphere ionization level Pits et al. (2000). Determination of environmental parameters, especially in the lower layers of the atmospheres,

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which constitutes the environment where people live, is one of the most actual studies in recent years Seinfeld and Pandis (1998).

The study of the physical aspects of the atmosphere ionization processes starting at the beginning of the century. XX, while in mid-century XX was Hollen who made the first steps on the study of the effects of air ions on human health and comfort, as well as other biological beings.

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Since 1899, when J.Elster and H.Geitel, to explain the conductivity of air, used for the first time the concept of positive and negative atmospheric ions, began the instrumentation for measurements of atmospheric electricity Israel (1952). The firsts who may be mentioned in this regard are Gerdien, who in 1905 proposed a method for measuring the electrical conductivity of air, using a cylindrical capacitor and CTR Wilson in 1906, who using an instrument built by itself, had measured earth-air current and electrical potential gradient Tinsley (2008). The fact that the level of ionization is essential in atmospheric electricity makes the apparatus for measuring the concentration of ions very important Aplin (2000). Therefore just for this reason, in this paper is treated the theory of measurement methodology, one of these measurement instruments like Air Ion Counter Kolarz and Marinkovic (2005). The theory treated in this paper allows us to determine the interval of ion sizes, for which the device has maximum effectiveness.

2. SPECIFICATION OF MEASUREMENT DEVICE

Operational scheme of Air Ion Counter examined here is composed by three parallel conductors (figure 1).

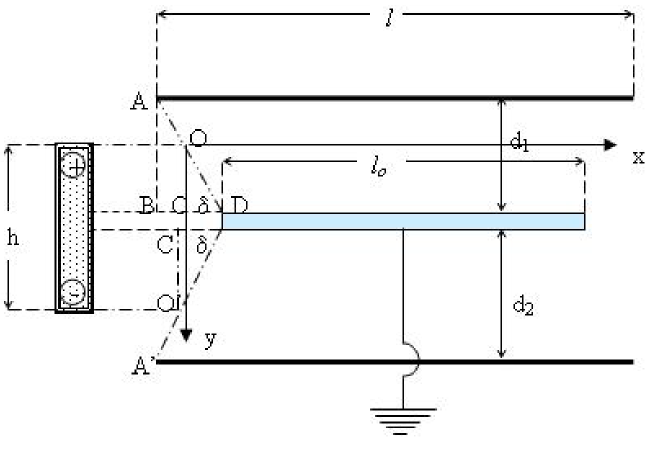


Fig. 1. ***Schematic presentation of measurement instrument***

The distances in figure 1 are respectively:

$$h = 1.2cm, b_0 = 5{,}5\ cm, l = 7.3cm, l_0 = 4.3cm, d = 1mm, d_2 = 7mm,$$

$$AB = d_1 = 10mm$$

$$BD = \frac{l - l_0}{2} = \frac{7.3 - 4.3}{2} = 1.5cm, OC = \frac{h - d}{2} = \frac{1.2 - 0.1}{2} = 0.55cm$$

This meter (Air Ion Counter) pulls air into the slot in the top. Then the air exits out the hole in the bottom. The top slot, which is shielded by a snap-in black "wind-guard", should be pointed toward the area of air that you want to measure. For reliable measurement, the meter's case should not have any static charge (static electricity) on it. The case is conductive and will remain free of static charge if the meter is connected to earth ground through the long ground cord (supplied). The meter's feet are also conductive so if they are sitting on a grounded metal sheet, there will be no static charge, and measurement will be accurate. If you use the ground cord, the allegator clip side of the cord must be connected to earth ground. A metal water pipe or faucet will work as a ground. Usually, the metal screw in a wall switch plate or outlet plate is also grounded, so it can be unscrewed a little in order to connect the allegator clip to the screw head.

This meter operates by sampling the air, which is pulled into the slot in the top and exits out the round hole in the bottom, at the rate of 800 cm^3 per second. While inside the meter, either negative or positive ions (depending on how the POLARITY switch is set) are taken from the fast-flowing air and deposited onto an internal collector plate. The number of elementary charges per second that hit the collector plate is measured (by measuring the voltage of the collector plate, which is connected to ground through a 10 G ohm resistor). The POLARITY switch selects which polarity of ions (+ or -) will be measured. This switch forces the voltage of a metal chamber, which surrounds the collector plate, to be either +10, 0, or -10 volts with respect to ground. If POLARITY is set at "+", the chamber will be at +10 volts and the positive ions in the air inside the chamber will be accelerated away from the outer walls of the chamber and toward the "grounded" central collector plate. At this "+" setting, the negative ions will actually be accelerated away from the collector plate so in that case, the collector plate will only detect positive ions, and not detect negative ions. Similarly, if the POLARITY is set at "-", the collector plate will only detect negative ions.

Air flow: 800 cm^3/sec (linear speed is 160 cm/sec through a polarization field of 2500 V/m and the system is designed to collect 60% of the ions in still air. A lower percentage is collected if air is forced faster than 160 cm/sec through the inlet slot and a higher percentage than 60% is collected if a reverse air flow slows the air flow. This maintains the accuracy in windy conditions.)

The specifications of the measurement instrument are listed below.

Dynamic Range: 10 - 1,999,000 ions/cm3, both selectively "+" and selectively "-".

Setting time: Approx. 2 seconds (response time), and 10 sec (after switchover between "+" and "-")

Noise level: (2 second-weighting) approximately 10 ions/cm3

Input resistance: 1010 Ohms.

Accuracy: +/-25% for fast ions (mobility greater than 8 x 10-5 m/s per V/m - these are the most numerous ions. The Air Ion Counter is less sensitive to "slow" ions such as charged pieces of dust).
Battery: One 9V alkaline. Current drain is about 4ma on STANDBY, and 35ma on MEASURE. All 3 decimal points display when battery becomes weak (below 7.9V). Battery life is about 60 hours on STANDBY and 5 hours on MEASURE.
Ion Selectivity (crosstalk): 1:5000.

3. THEORY OF MEASUREMENT PRINCIPLE

The relationship between ion concentration and the voltage of collector plate is:

$$n = \frac{V}{RQq_j} \tag{1}$$

where q_j is an ion electric charge.

Ion movement is studied on the Cartesian plan OXY. Its origin is located at the point where ion enters in the intern area of measurement instrument (where the ion trajectory is influenced by electric field of the device).

The forces which influence ion trajectory are supposed by Vila and Mandija (2009);

$$F_1 = eE \text{ and } F_2 = \frac{\mathrm{CS\rho S_y^2}}{2} \; F_2 = \frac{1}{2} CS\rho S_y$$

Thus the movement equation of an ion is:

$$m\frac{dv_y}{dt} = eE - \frac{1}{2} CS\rho S_y \tag{2}$$

where C is resistivity coefficient, which is depended on Reynolds number. In our case (assuming ions of spherical shape), C = 0,34. The surface of a cross section of ions is $S = \pi r^2$. Their sizes belong to the interval (100-200 nm). Air density in normal conditions is $\rho = 1{,}19 \; kg/m^3$.

Another assumption is that ions are singly charged. This is true for small ions (measured by Air Ion Counter), while large ions can be even multi charged.

The solution of equation 2 is given as below:

$$v_y = \frac{1}{C_1}\left(\frac{e^{2C_1C_2} - 1}{e^{2C_1C_2} + 1}\right) \tag{3}$$

where, t is the time of travelling ion.

$$\mathrm{C_1 = r\sqrt{\frac{\pi C\rho}{2eE}}} \text{ and } \mathrm{C_2 = \frac{eE}{m}} \tag{4}$$

After some calculations we obtain:

$$\frac{h-d}{2}=\int_0^{\tau} v_y dt=\frac{1}{C_1}\int_0^{\tau}\frac{e^{2C_1C_2t}-1}{e^{2C_1C_2t}}dt=$$

$$=\frac{1}{C_1^2C_2}\left[\ln\left(\frac{1+e^{2C_1C_2\tau}}{2}\right)-C_1C_2\tau\right] \qquad (5)$$

where τ is the time required for an ion to be captured by collector plate

Having in mind that $e^{C_1C_2\tau} >> 1$, and after some approximations, τ is determined by this relation:

$$\tau=\frac{C_1(h-d)}{2}=\frac{r(h-d)}{2}\sqrt{\frac{\pi C\rho}{2eE}} \qquad (6)$$

In order that collector plate has maximal efficiency, must below condition fulfilled:

$$\tau=\frac{r(h-d)}{2}\sqrt{\frac{\pi C\rho}{2eE}}\leq\frac{l_0+\bar{\delta}}{v_0} \qquad (7)$$

Air ions "suffer" electric field before they enter into the intern area of measurement device. Electric field influences more ions which enter on the device in the extremities of the aspirator. Their distances from the inner plate are respectively δ_1 and δ_2. Their average value is $\bar{\delta}=\frac{\delta_1+\delta_2}{2}$.

Let us determine δ_1 and δ_2. Looking at the deice scheme we find:

$$\delta_1=\frac{BD\cdot OC}{AB}=\frac{\left(\frac{l-l_0}{2}\right)\left(\frac{h-d}{2}\right)}{d_1}=\frac{(l-l_o)(h-d)}{4d_1}=0.825\ cm$$

and

$$\delta_2=\frac{(l-l_o)(h-d)}{4d_2}=1.178\ cm$$

So the average distance $\bar{\delta}$ would be:

$$\bar{\delta}=\frac{\delta_1+\delta_2}{2}=\frac{(l-l_o)(h-d)(d_1+d_2)}{8d_1d_2}=1.001\ cm \qquad (8)$$

From equations 7 and 8, we obtain this condition:

$$r\leq\frac{2(l_0+\bar{\delta})}{(h-d)v_0}\sqrt{\frac{2eE}{\pi C\rho}} \qquad (9)$$

Electric current passing in the collector plate (through ion movement) is determined by Ohm's law.

$$I=Qne=\frac{V}{R} \qquad (10)$$

In the case of maximal collection efficiency, this electric current may be written:

$$I = \int \vec{j} d\vec{S} = ne[v_0 b_0 d + 2 v_y(\tau) b_0 l_0] \qquad (11)$$

where $v_y(\tau)$ is the vertical component of ion velocity (the velocity by which ion hit collector plate).

Taking into account also equation 3, after some calculations, we obtain this analytical expression of $v_y(\tau)$.

$$v_y(\tau) = \frac{1}{C_1}\left(\frac{e^{2C_1C_2\tau} - 1}{e^{2C_1C_2\tau} + 1}\right) \approx \frac{1}{C_1} = \frac{1}{r}\sqrt{\frac{2eE}{\pi C\rho}} \qquad (12)$$

Applying equation 12 for the vertical component of ion velocity, equation11 is transformed as below:

$$I = ne\left(v_0 b_0 d + \frac{2b_0 l_0}{r}\sqrt{\frac{2eE}{\pi C\rho}}\right) \qquad (13)$$

Let us note with g the maximal error of our methodology. Thus we can state:

$$\left| v_0 b_0 d + \frac{2b_0 l_0}{r}\sqrt{\frac{2eE}{\pi C\rho}} - Q \right| \le gQ \qquad (14)$$

Equation 14 yields the condition of minimal ion size (on the maximal efficiency conditions).

$$r \ge \frac{2b_0 l_0}{Q(1+g) - v_0 b_0 d} \qquad (15)$$

Combining equations 9 and 15, we obtain the ion size range for which measurement instrument has a maximal collection efficiency:

$$\frac{2b_0 l_0}{Q(1+g) - v_0 b_0 d} \le r \le \frac{2(l_0 + \bar{\delta})}{(h-d)v_0}\sqrt{\frac{2eE}{\pi C\rho}} \qquad (16)$$

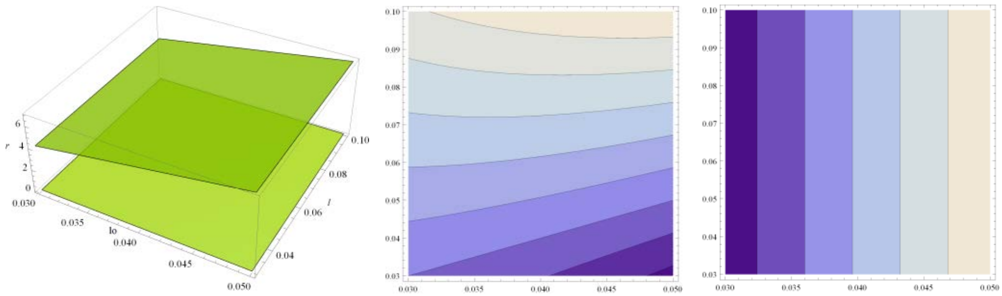
The condition of equation 16 depends on six geometrical dimensions of measurement device; l, l_0, d, d_1, d_2, h.

Numerical application of equation 16, gives ion size interval for maximal collection efficiency.

$$1{,}498.10^{-7}\, m \le r \le 1{,}512.10^{-7}\, m \qquad (17)$$

From equation 17 we can notice that ions with a size of about 150 nm are measured with maximal efficiency by Air Ion Counter.

We can see from equation 17 that r_{min} and r_{max} are dependent by the geometrical configuration of the system. In figure 2 we present the dependence of these two quantities by the dimensions *l* and l_0.

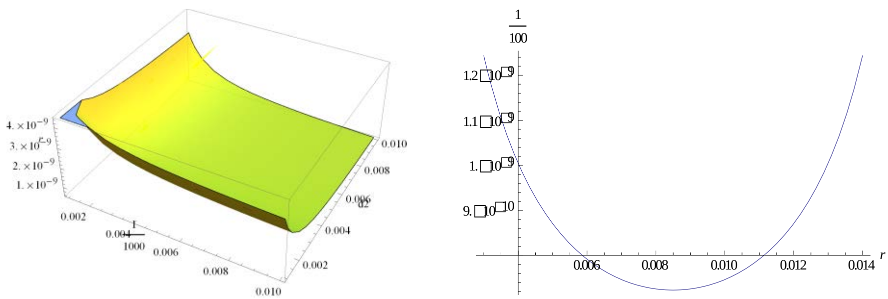


a) b) c)

Fig. 2. ***Size interval vs the dimensions of the plates***

From figure 2.a. and 2.b. we see that both r_{min} and r_{max} are dependent by geometrical dimensions of outer and inner plates. r_{max} gets higher values when l_0 is increased. r_{max} has also a dependence on the dimension l. It gets lower values for small dimensions of l. Thus the most favorable situation is when the dimensions l_0 and l are almost equal. On the other hand, r_{min} depends only on the dimensions of the inner plate. rmin is inversely proportional to the dimension l_0 (figure 2.c.).

r_{max} depends also on the position of the inner plate (d_1 and d_2). This dependence is presented by the figure 3. Smaller values of d_1 and d_2 yield higher vales of r_{max} (figure 3.a.). Meanwhile, we can see that when the ratio d_1/d_2 goes to the unity we obtain the lowest values of r_{max}.



a) b)

Fig. 3. ***Size interval vs the positions of the plates***

Thus, to increase the efficiency of the measurement instrument, the dimensions l and l_o must be almost equal, while the positions of the middle plate d_1 and d_2 should take as different values as possible.

We must keep in mind also the edge effect of the electric field between the outer and the inner plates. This effect reduces somewhat electric field at the edges of the plates. Thus, calculated r_{max} in equation 16 may be somewhat lower.

4. CONCLUSIONS

Principal instruments measuring the concentrations of air ions are Air Ion Counters. These devices are very widely spread over measurement campaigns because they are very simple on the usage. This is the reason why we have concentrated on the study of operation principle of these kinds of measurement instruments.

In this paper is treated the operation principles of air ion counters composed by three parallel plates (the middle is collector plate). Writing equations which govern the ion movement in the intern area of measurement instruments, we have obtained the size interval of ions, which are collected by maximal efficiency.

At the end of the paper are calculated also the appropriate dimensions of this kind of instrument to gain the maximal efficiency during the measurements.

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