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Effect of Negative Air Ions on Fog and Smoke

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ABSTRACT

A negative electric discharge voltage generator (NAI Generator) was designed and used to investigate the possibility of reducing (neutralizing) fog, dhoop smoke, and vehicle smoke collected in closed glass containers. The experiment was carried out in a dark room, and two identical glass containers were used. Various sensitivity tests were carried out with fog and smoke. Light intensity was measured for each run as a function of time with and without a negative air ion generator. Negative air ions attach to particulate matter to enhance visibility. At a high negative ion emission rate, the particle mobility becomes sufficient so that particle migration results in their deposition on walls and other indoor surfaces. The performance characteristics of the negative electric discharge generator designed in this work, which produces uni-polar ions by corona discharge at a relatively high emission rate, were evaluated. This device, if operated continuously for six minutes, resulted in the removal of about 93% to 97% of the particles in the glass container, in addition to the natural decay effect. The rate of change of particle removal was higher for fog than for smoke. This study demonstrates that it is possible to neutralize and reduce the concentration of fog and smoke to a significant degree using negative air ions, resulting in increasing visibility in a closed chamber.

Keywords: Air pollutants; NAI generator; Light intensity; Visibility; Removal efficiency.

INTRODUCTION

Fog is a weather phenomenon where in tiny water droplets suspended in the vicinity of the earth's surface cause a reduction in visibility. The poor visibility leads to severe disruption and delay in rail, road and air traffic, causing great economic loss (Mohan and Payra, 2009). Particularly due to inversion during winter in hilly area and in north India the fog along with other pollutants is responsible for reduction in agricultural yield considerably. It is essential to search for solution for fog dispersal according to requirement. Hence it is needed to have detailed information about the optical nature of fog particulate system (water droplet + fog condensation nuclei), leading to poor visibility. Atmospheric fog is typically composed of sub-micron size inactivated particles associated with activated droplets of size range up to ten microns (Pinnick *et al*., 1978; Hudson, 1980; Gerber, 1981; Frank *et al*., 1998). The study of understanding of the formation of fog and its effect on visibility is carried out by several authors in past (Bott, 1991; Yuskiewicz, 1998; Baumer, 2008). Fog, Dhoop smoke and Vehicle Smoke is used for experiments. Ultrasonic water fogger with Teflon coated disc of MainLand Mart Corp. EL Mount.CA 91732, U.S.A. was used to saturate the glass container with fog. This fogger works between the temperature ranges of 5°C–40°C and generates liquid particulates of size ~1 µm–14 µm. The experiment was carried out room temperature (27°C–30°C) (http://www.epa.gov/oar/particlepollution/). Smoke contains mainly solid particulates from various pollutant sources. Dhoop candle is made up of camphor, incense, sandal and some ayurvedic contents with oil base. Although dhoop is burnt for holy purpose, dhoop smoke generated by combustion of the candle introduces solid oil based particulates in air, of the size ranging from 0.01 µm to 4 µm (http://www.engineeringtoolbox.com). Vehicle smoke generated by a two stroke engine petrol bike. This smoke consists of various pollutant gases and carbon particles of size up to 2.5 µm (http://www.epa.gov/oar/particlepollution/) (http://www. engineeringtoolbox.com). Our aim is to find the effect of air ions on these air borne particles.

Shiue *et al*. (2011) reported that negative air ionizers are typically applied to clean air in indoor environment. Daniels (2002) reported that negative air ions (NAIs) reduce aerosol particles, airborne microbes, odors and volatile organic compounds (VOCs) in indoor air. The removal efficiency of aerosol particles using NAIs is studied by various workers (Grabarczyk, 2001; Wu and Lee, 2003; Wu *et al*., 2005).

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The particle removing mechanisms by NAI is due to particle charging by emitted ions and electromigration which increases migration velocity of particles (Lee *et al*., 2004a, b; Mayya *et al*., 2004; Wu *et al*., 2005). The particle removing efficiency for different chambers is studied by various workers on glass And acrylic (Crump *et al*., 1983, Okuyama *et al*., 1986), on Teflon film bags (McMurry and Rader, 1985) and on aluminized Mylar bags (Cooper *et al*., 1979; Wu *et al*., 2005), Review of the relation of ion density, residence time of particles, shapes of particles, particle material, mobility etc. is given by (Adachi *et al*., 1985; Wiedensohler *et al*., 1994; Oh *et al*., 2004). Lee *et al*. (2004a, b) indicated that the mobility and removal efficiency of aerosol particles increased with an increase in NAI emission rates. Conversely, if the NAI concentration is too high, an electrostatic shield on wall surfaces is produced that prohibits the deposition of charged particles, especially when surface materials have low-level conductivity.

Several studies have been conducted for particle removing efficiency using ionic cleaners to remove particles from the air (Grabarczyk, 2001; Grinshpun *et al*., 2001; Lee *et al*., 2004; Grinshpun *et al*., 2005). A study examining wearable ionizers (Grinshpun *et al*., 2001) found that particle removal efficiency of the ionizer was 80% after 30 minutes and 100% after 1.5 hours in a 2 m^3 chamber. A later study by Grinshpun *et al*. (2005) tested commercially available ionic air cleaners in a 2.6 m^3 chamber and found that the unit which produced the most ions demonstrated 100% particulate matter removal within 10 to 12 minutes for particle sizes between 0.3 and 3.0 µm. Lee *et al*. (2004) tested commercially available ionic cleaners in a 24.3 m^3 test chamber and found that a 30 minute operation of the device, which produced the most ions, resulted in removal of about 95% of 1.0 µm particles from the air above, which was beyond the decay rate, due to particle settling.

The physical and biological effects of small air ions on indoor air quality as well as various health benefits of air ionization have been discussed in detail by (Grinshpun *et al*., 2005). The high voltage used for ion generation produces Ozone above threshold voltage of 16000 volts (Wu and Lee, 2004). Hence precaution is to be taken to avoid Ozone production which is an air pollutant at ground level that can be harmful to breathe and damages crops, trees and vegetation (http://www.epa.gov/oar/particlepollution). Harrison (1997) discussed the aerosol removal processes in detailed by three mechanisms i) modification of Brownian aerosol coagulation for the charged aerosol leading to aerosol growth and subsequent sedimentation. ii) attraction of charged aerosol to charged (or conducting) surfaces, leading to enhanced deposition. iii) electrical repulsion of negatively charged particles by the excess of negative space charge, leading to dispersal of the aerosol to distant surfaces. In closed chamber experiment, the excess of negative ions attached to aerosols lead to settle on surface of chamber. However in open air the coagulation will be dominant in sedimentation. The ion emission has been tested by several investigators for its ability to reduce the indoor aerosol concentration (Kisieliev, 1966; Bigu, 1983; Li and Hopke, 1991; Hopke *et al*., 1993; Bohgard and Eklund, 1998; Khan *et al*., 2000; Grabarczyk, 2001). The bactericidal effect of air ionization has also been assessed (Marin *et al*., 1989; Shargavi *et al*., 1999; Lee, 2001; Seo *et al*., 2001).

Hence it was felt necessary to study the fog removal capacity of NAI to control fog for various applications. A special type of negative air ion generators was designed and developed for this purpose which is claimed to be capable to neutralize particulate matter from air. These ion generators do not use a fan to move air and thus offer nearly silent operation. In this paper, we present results on a series of experiments on Fog, Dhoop and Vehicle Smoke and how they neutralize by using negative air ion generators. In the laboratory experiment the goal of our work is to study the fog removal efficiency by using negative air ions.

METHODOLOGY

The artificial generation of air ions is required for different applications such as fog dispersion, smoke dispersion, etc. The negative ion generator and experimental chamber is designed, developed and tested for deriving particle removing efficiency for fog, dhoop smoke and vehicle smoke in a closed chamber.

Design

Commercially designed ion generators usually use a transformer to raise the initial voltage from either mains or battery voltages up to about 1KV. Then they have about 5 voltage multiplier stages feeding a pin farm of 3 or 4 pins. However the transformer and fan used in the commercial units are fragile components which will blow air or get damaged in long run of device. Negative air ionizers are also developed by generating a high voltage from the mains supply using a voltage multiplier circuit. In our system 230 volts AC is used as input and voltage multiplier configuration of Cockcroft-Walton multiplier is used. We chose this design as shown in the Fig. 1 because it uses more readily available components. While choosing the components precaution is taken to enhance durability, sturdiness and repeatability of the system designed. There are 30 diodes and 30 capacitors. The resistor R2 rapidly discharges the chain when the power is turned off. The final three resistors leading to the pin farm are for safety if you touch the emitting pins. A fiber Glass PCB is used for component wiring and high voltage Epoxy/Resin combination is used to avoid shorting of components due to high voltage in the system during any weather condition. A multiple wire shielded cable is used as antenna for ion transmission. In last stage the condenser neon lamp combination is used to regulate the ion emission according to impedance of antenna to ground. This design is noiseless, consumes minimum power of few mill watts for each pulse of ions during operation. Hence during each pulse the amount of ions is of the order of 1.6×10^{12} are generated. Hence this ion generator is useful to count number of ions by simply measuring the number of pulses during experiment. The continuous operation of ion generator has been successfully tested for more than 2 years.

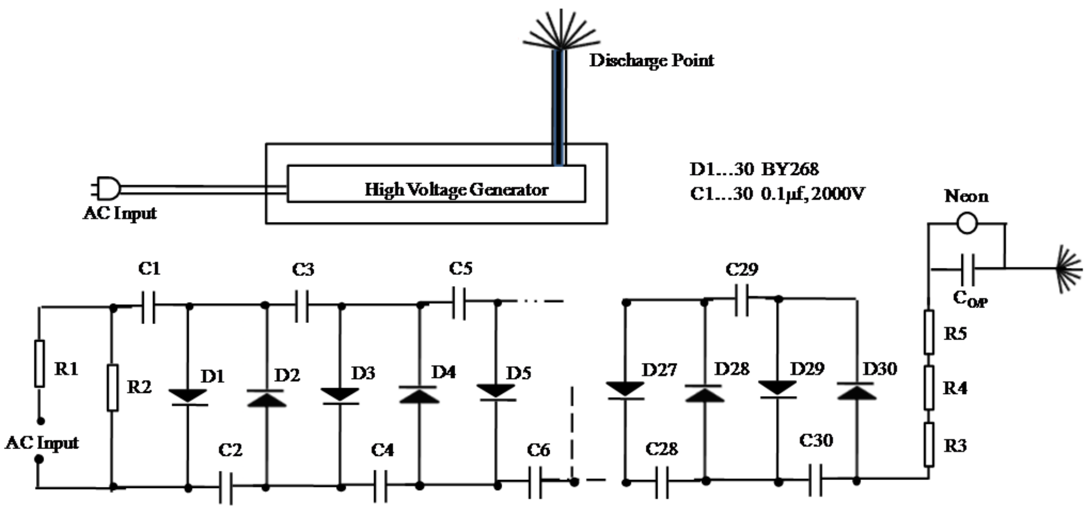

Fig. 1. Schematic of an air ion generator.

Construction

The components are mounted on fiber glass PCB. The precaution is taken to put all the diodes with correct polarity. The fiberglass PCB after soldering was washed thoroughly to avoid sparking at high voltages. The pointed pins of diodes and condenser were avoided. Instead of using the pins or needles as antenna we have used shield of the shielded cable wires as antenna. The shielded cable is fitted in to nylon rod along with Teflon spacers and nut. These shielded wires are positioned in such a way that they almost protrude out from the box into the air. The antenna is soldered to nut which fits on a bolt soldered to component PCB. Thus in transportation the antenna can be separated from main component box. A white wax and high voltage hardener resin/hardener combination is used to protect the circuit in any weather condition. Particularly in humid atmosphere the leakage and sparking is avoided using the above sealing method. The total weight of the ion generator is around 1700 grams.

Testing

When the instrument is switched on the neon indicator will light after few seconds and the antenna will give a faint hissing sound after 4 to 10 seconds. This is the indication of ions being injected into the air. The ion wind can be experienced by holding a wet finger near the ends of the pins. We will not get a shock even if we accidently touch the antenna. Thus the high voltage circuit (–8.5 kV) is designed and connected to discharge antennae tip electrode surrounded by non conducting potting material inserted in flexi glass box. A specially designed constant negative voltage air ion generator is tested. The estimated ion densities produced by these devices at each pulse is 6.25×10^{11} ions. In the range of $\sim 5 \times 10^5$ to $\sim 20 \times 10^6$ ions/cm^3 are observed at a distance of 1 m. This is in accordance with our above emission rates. As we reach near the antenna the meter goes out of scale. These types of ion generators are in the literature; however our proper selection of components and some modifications give us better performance of system.

The ion density produced by the corona discharge was measured with the Air Ion Counter (Alpha Lab Inc., Salt Lake City, UT, USA). This device is capable of measuring within the range of 10^1–2×10^6 ions/cm^3.

Experimental Procedure

The light emitted by light sources enters the experimental chamber where fog/smoke/dhoop is generated by different sources according to requirement. The source of ions and fog/smoke/dhoop was housed inside the chamber. At time t = 0, light intensity was recorded and fogger machine was then started to generate fog. Light intensity was measured for every 15 second time interval till it becomes minimum. Both containers become milky white (opaque) and light passing from container becomes zero i.e. zero visibility. After this the negative air ion generator placed inside the container was switched on. Light intensity was again measured for every 15 second time interval. The detector and other electronics equipments were placed at other end of chamber. Experimental set up is as shown in Fig. 2. Two types of light sources were used for different sets, one a Helium-Neon Laser of 2 mW, 633 nm wavelength and spot light or halogen lamp of 500 Watt. Visibility was measured in terms of light intensity using light meter (lux) model LX – 101A of Lutron. Fog was generated by using ultrasonic water fogger with 230 V adaptor, Teflon coated disc of MainLand Mart Corp. EL Mount.CA 91732, U.S.A. Smoke was generated by using Dhoop Coil and Petrol scooter smoke, Cigarette smoke. The tests were conducted in an unventilated glass container of size 72 cm^3 (L × W × H = 60 cm × 30 cm × 40 cm).

The experiment was carried out in a dark room. More than six runs were carried out with fog, smoke. Light intensity was measured for each run as a function of time in presence and in absence of negative air ion generator. The glass container was cleaned by using soap, water. And the container was perfectly air dried by using dry air to insure that the ions generated during the test had been removed and the initial natural aerosol concentration in the container had been restored. Then the experimental procedure was repeated for the dhoop smoke and vehicle smoke.

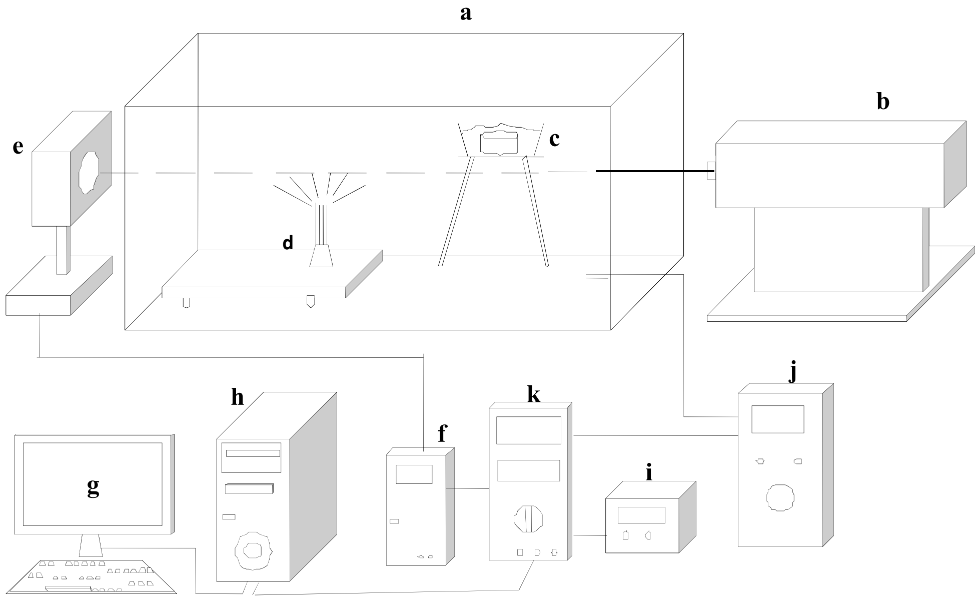

Fig. 2. Illustration of experimental system (a) Glass container (b) He-Ne LASER (c) Ultrasonic water fogger (d) NAI generator (e) Receiver (f) Light Intensity meter (g-h) Computer (i) Timer (j) Air ion counter (k) Data logger.

Light intensity and number of pluses on generator were measured for every 15 second time interval. Due to negative air ion generated inside the container light intensity i.e. visibility drastically increases with time. During the experiment the air temperature was 26 ± 3°C and the relative humidity was 52 ± 5% was monitored with a Thermometer/hygrometer. Similar procedure was adopted for Vehicle smoke and dhoop smoke experiments.

Data Analysis

According to Beer – Lambert Law

$$I = I_o \exp(-\alpha m) \quad (1)$$

where I_o is incident light intensity, I is observed light intensity, m is number of particles and α is scattering cross section. For fog particles, calculated average value of scattering cross section $\alpha = 1 \times 10^{-10}$ cm^{-2} and for smoke particles, average scattering cross section value $\alpha = 1.2 \times 10^{-11}$ cm^{-2} is considered (Solar Radiation by Robinson, N. Elsevier Publishing Company, 1966, p. 59).

The natural decay of particles concentration was determined as a base line test for each particulate matter. Prior to the test, particles of different substrates were generated in the chamber. Then the particle concentration decay with NAI was determined. For each particulate matter (Pm), two concentration decay curves were obtained: the natural decay i.e. when the NAI was 'off' [$C_{Natural}$ (Pm, t)], and the one with the NAI 'on' [C_{NAI} (Pm, t)].

The particle removal efficiency has been obtained by the following equation:

$$\text{Particle removal efficiency} = \frac{C_{Natural}(Pm, t = 0) - C_{NAI}(Pm, t)}{C_{Natural}(Pm, t = 0)} \times 100\% \quad (2)$$

A similar relationship has been reported earlier by considering particle dimensions (Grinshpun *et al*., 2005).

For every particulate matter the Air Cleaning Factor (ACF) is defined as the ratio of concentration of particles measured at a specific time point during the natural decay process to the concentration measured at the same time point when the negative air ion emitter was operating (Lee *et al*., 2004):

$$ACF = \frac{C_{Natural}(Pm, t)}{C_{NAI}(Pm, t)} \quad (3)$$

To quantify the efficiency of the particle removal caused exclusively due to the ion emission, the **air cleaning factor (ACF)** was determined.

The rate of change of particle removing efficiency with respect to time is determined by equation.

$$\text{Rate of change of Particle Removing Efficiency} = \frac{(\Delta PRE)_{NAI} - (\Delta PRE)_{Natural}}{\Delta t} \quad (4)$$

where (ΔPRE) is successive change in particle removal efficiency with natural decay and with NAI.

RESULTS AND DISCUSSION

The ion generator designed in the present investigation showed production of 1.6×10^{12} ions/pulse. In the absence of ion emission, the particulate matter in the glass container decreases slowly with time. The natural air cleaning mechanism in calm air is primarily due to gravitational sedimentation and diffusion (Grinshpun *et al*., 2005). Initially the experiments were performed using Tungsten-Halogen lamp (300 W) as the light source. However it was observed that the convection in the matter increased in the chamber. This may be due to the high temperature produced by the light source placed near the chamber. It was found to interfere with the particle removing efficiency. As a result the rate of decay was affected. To minimize this thermal interference, all further experiments have been carried out by using He-Ne laser source. Several pilot experiments were performed with different time periods and an optimum time of 6 minutes was selected for the existing experimental conditions. Parameters like light intensity, particle concentration, PRE and rate of change of PRE have been determined as a function of time.

Variation of light intensity with time under natural decay and with NAI application has been shown in Fig. 3 for fog, dhoop smoke and vehicle smoke. The natural decay for fog and smoke is slow as compared to the decay in ionic environment. From the natural decay plots shown in the inset of Fig. 3, we observe that decay rate for fog is higher than that of dhoop as well as vehicle smoke. It is alarming to note that natural decay of vehicle smoke is almost negligible.

Comparative study of light intensity with NAI for the three substrates reveals that for fog the transmitted light intensity increases rapidly compared to other smoke varieties. For dhoop smoke the rate of increase of transmitted light intensity is low compared to vehicle smoke. During 60 to 150 seconds most of the fog is dissipated, however for vehicle smoke, 60 to 260 seconds is the active dissipation range. Dhoop's active dissipation range is 60 to 360 second. Thus time required to get maximum light intensity is 90 seconds for fog, 200 seconds for vehicle smoke and 300 seconds for dhoop smoke in presence of our ion generator. The slow increase in light intensity in case of dhoop smoke may be accounted for the oil base in dhoop.

Comparison of increase in light intensity for vehicle smoke with and without NAI shows more than 1000 fold increase in presence of NAI application. This may be useful to minimize the concentration of pollutant gases introduced in the atmosphere by vehicles.

The increase in light intensity is related to the decrease in particle concentration. This trend can also be confirmed from Fig. 4 in which particle concentration is plotted against time. Particle concentration shows negligible decrease in natural decay process while in presence of NAI the particle concentration shows a sudden decrease in the initial 50 to 100 seconds. Comparative study of these curves shows that the decay is highest in case of fog with NAI.

The curves in Fig. 4 reveal that the rate of reduction in particle concentration with NAI application exceeded that of natural decay for all the three substrates. The natural decay of fog was faster than that of dhoop smoke and vehicle smoke. The experimental data proved that the order of particle concentration decay was quite different for all particulate matter. The particle concentration decay was of the order, **natural decay of smoke < natural decay of fog << smoke decay with NAI application < fog decay with NAI application**. Shiue *et al.* (2011) shows similar curves for different diameter particles, however their ion generator efficiency is low (2 million/sec) and chamber diameter (2.6 m^3) is high. Our system changes ion emission according to air impedance. The volume of our chamber is 0.072 m^3 and ion production is 1.6×10^{12} ions/pulse. The decay time noted in the present investigation is 2.5 to 3 minutes which is 20 times less as compared to that reported earlier. This difference may be attributed to the difference in particle source, ion generator efficiency or chamber volume.

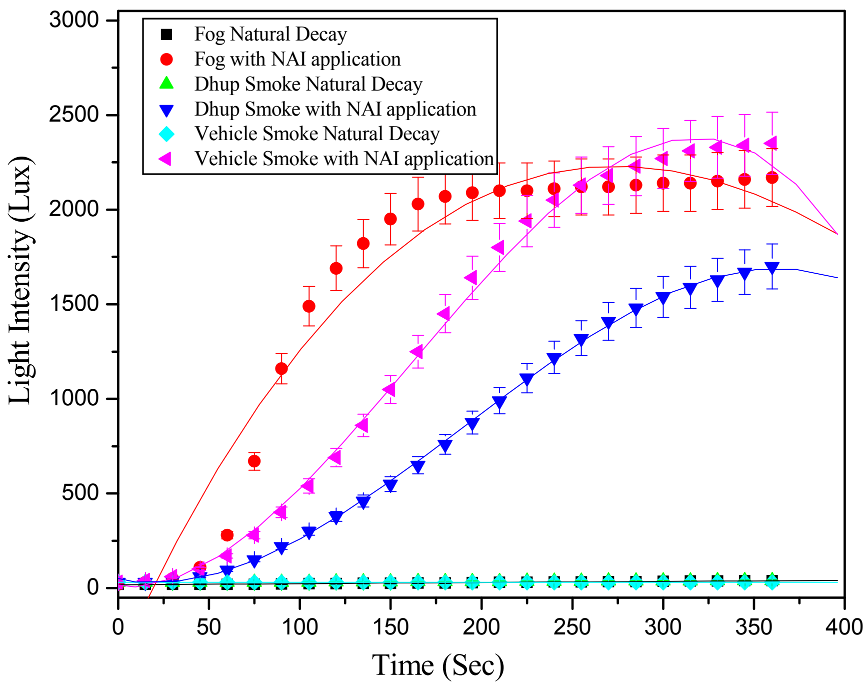

Fig. 3. Light intensity variation verses time with natural decay and NAI application for Fog, Dhoop Smoke and Vehicle Smoke.

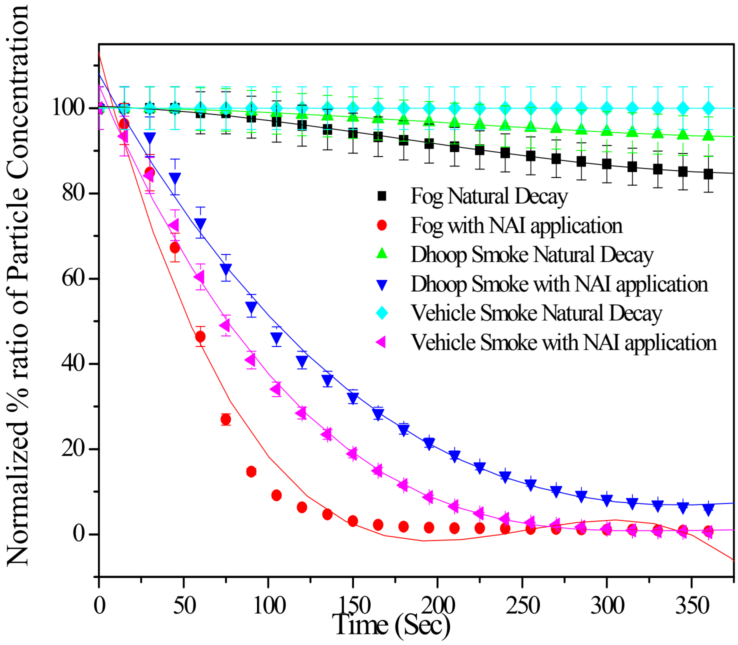

Fig. 4. Particle concentration decay (normalized %) verses time with natural decay and NAI application for Fog, Dhoop Smoke and Vehicle Smoke.

Particle removal efficiency as calculated from Eq. (2) has been plotted against time with natural decay and NAI application for fog, dhoop smoke and vehicle smoke in calm air as shown in Fig. 5.

The particle removal efficiency is obtained by subtracting the natural decay from the observed value, refer Eq. (2). Fogs natural decay is fast as compared to natural decay of smoke due to vehicle/dhoop. It is noted that PRE in presence of NAI shows a continuous increase for all the three substrates. On comparison of the plots it can be observed that PRE is highest for fog with NAI application and minimum for dhoop smoke with NAI application. The nature of the plots shows a similar trend with an initial rise and a constant limiting value after sometime.

The air cleaning factor by negative air ions for fog is significantly higher (2 to 10 times) as compared to dhoop and Vehicle smoke (see Table 1). The difference between the data obtained for dhoop and vehicle smoke is statistically insignificant.

When the rate of change of PRE is plotted against time as shown in Fig. 6 it is noted that the rate increases and reaches to a maximum after 70 seconds for all the three substrates. The rate of change of particle removing efficiency is highest (1.25 s^{-1}) for fog and it is 0.8 s^{-1} and 0.7 s^{-1} for vehicle and dhoop smoke respectively. The fast decay of fog as compared to vehicle and dhoop smoke can be clearly noted.

The half period for rate of change of particle removing efficiency for fog is 75 seconds, for vehicle smoke is 100 seconds, and for dhoop is 110 seconds. This indicates that the vehicle smokes particle removing efficiency is 25% less than that of fog while dhoop's particle removing efficiency is 83% less than fog.

CONCLUSIONS

An Ion generator is designed and developed indigenously which is tested to be weather proof, adjusts output ion pulses according to the atmospheric resistivity and have very low power consumption. Ion density has been calculated by measuring the pulses of the ion generator. Other commercial ion generators also change their efficiency according to air resistivity but it is not taken into account by the manufacturer of the ion generator which has been done in this work.

In this study, we concluded that the Negative Air Ions can remove the aerosol pollutants such as fog and smoke in a closed chamber almost completely if operated for several minutes. The particles are charged primarily by the diffusion charging mechanism. The particle removal depends on the ion emission rate and the time of emission. The increase in light intensity i.e. visibility with NAI application is significant in reducing particulate matter in air thereby helping in controlling air pollution.

The rate of change of particle removal efficiency is highest for fog as compared to other smoke sources. Hence in future we need to design different capacity ion generators for removal of fog and smoke in the atmosphere. From this study we may conclude that a high capacity ion generator is suitable to reduce harmful effects of fog and smoke. High capacity negative air ion generator may be used for improving visibility.

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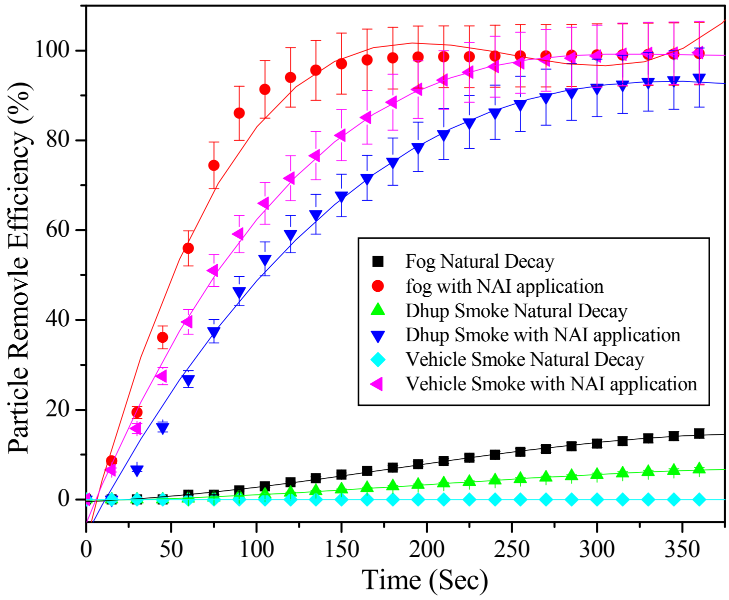

Fig. 5. Particle removal efficiency verses time with natural decay and NAI application for Fog, Dhoop Smoke and Vehicle Smoke.

Table 1. The air cleaning factor (ACF) determined by operation of negative air ion

Particulate matter	Air Cleaning Factor (ACF)					
	60 Sec	120 Sec	180 Sec	240 Sec	300 Sec	360 Sec
Fog	1.99	16.74	59.78	72.13	94.43	126.78
Dhoop Smoke	1.34	2.22	4.8	14.62	35.60	60.94
Vehicle Smoke	1.35	2.64	6.45	14.70	33.49	62.51

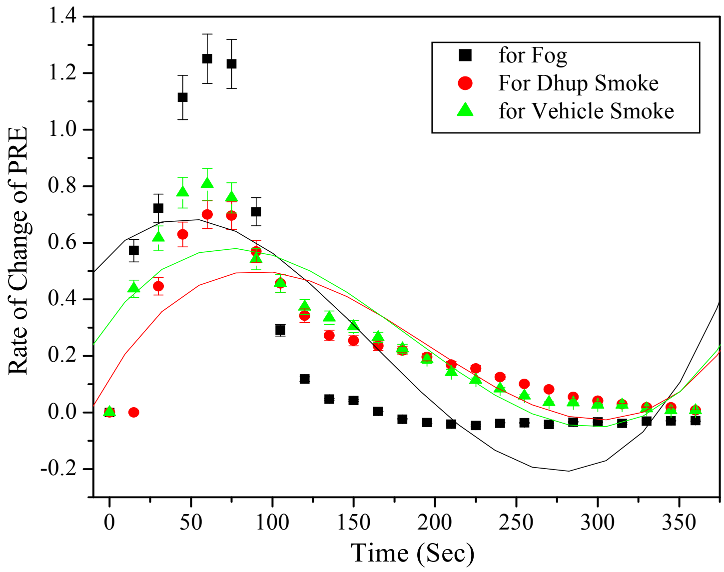

Fig. 6. Rate of change of particle removal efficiency verses time for Fog, Dhoop Smoke and Vehicle Smoke.

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