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# Development of Defogger Equipped with a Roller Horsehair Brush

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## ABSTRACT

In order to remove fog often causes various troubles in our daily lives, the novel defog blower equipped the roller brush made of recycled horse's mane hair was developed. This work presents the overview of new defog devices and the experimental data obtained at two different kinds of defogging experiments. In the model experiment carried out at the enclosed cleanroom (W 5.9 m×L 5.1 m×H 2.4 m) targeted a vinyl house, fog was dissipated in less than 30 seconds in case with wind entrainment and two minutes 45 seconds in case without wind entrainment after running of the newly designed defog blower. When the demisting blower was run in a duct, it has an excellent mist sweeping qualities as well as a great removal effect for the background particles (89.5% and 65.4% scavenging rates for fine and coarse particles, respectively). It can be therefore said that the mist eliminator presented in this paper is ideal for use in the sealing space like a vinyl house and the industrial sites where required to remove both harmful mist and particle.

**Key words:** Fog, Mist, Defog, Duct, Horsehair

## 1. INTRODUCTION

Fog, a widespread meteorological phenomenon, always has adversely influenced on our various outdoor activities such as sports, recreation, and travel. Fog also causes many accidents on various fields like, roads, airport, harbor and so on. The horrific chain-reaction collisions which occur in fog can happen frequently. The dense fog causes accidents because it degrades driver's perceptual judgments of vehicle distance and speed.

Many car accidents arise at mountainous areas coastal road, which often accompany a foggy morning. The thick foggy condition on February 11, 2015 caused 106-car pileup on Yeongjong Bridge in Incheon, South Korea. There were two men died and more than 65 people were injured in that accident (Gyeonggi Daily, 2015). Also, due to bad visibility by fog, at least four people have been killed and 25 injured in a pile-up of more than 50 vehicles in western Slovenia on January 30, 2016 (Agence France-Presse, 2016). Thick fog also adversely affects the plane's takeoff and landing. The ships collision can be happened in thick fog too.

Meanwhile, the polluted fog droplets in the stable meteorological conditions can lead to potential damage on plants and crops. Through their field studies, Musselman *et al.* (1988) reported that acid fog contributed to forest degradation by impairing trees' growth and increasing their susceptibility to insect infestation and drought.

Added to traffic accident and crops damage, inhalation of naturally occurring acid fog may have adverse effects on our respiratory tract (Hackney *et al.*, 1985; Koenig *et al.*, 1983). The result of two-year follow-up study of the effect of acid fog on adult asthma patients (Tanaka *et al.*, 1996) indicated that hospital visits for asthma symptoms was increased on acid fog days in 8.8% of adult asthma patients.

Till now several attempts for fog removal have been presented. Kawamura *et al.* (1995) carried out the basic experiments on electric quenching for fog removal and reported that the high voltage applying was very effective for the for quenching in the static and the flowing conditions. The method of blowing hot dry air with temperatures of about 800 K into the fog has been applied at the Orly airport in Paris in the 1970s (Dennis, 1980). More aggressive trying for fog dissipation has been carried out in the United States, where helicopters flying slowly across the top surface of the fog mix warm dry air into the fog (Plank, 1969).

However, with regard to the method of fog dissipation and probability, one has to consider energy saving and good maintenance. And furthermore no fog reforming after defogging is absolutely vital because in the case of electric field method the fog returns back to its

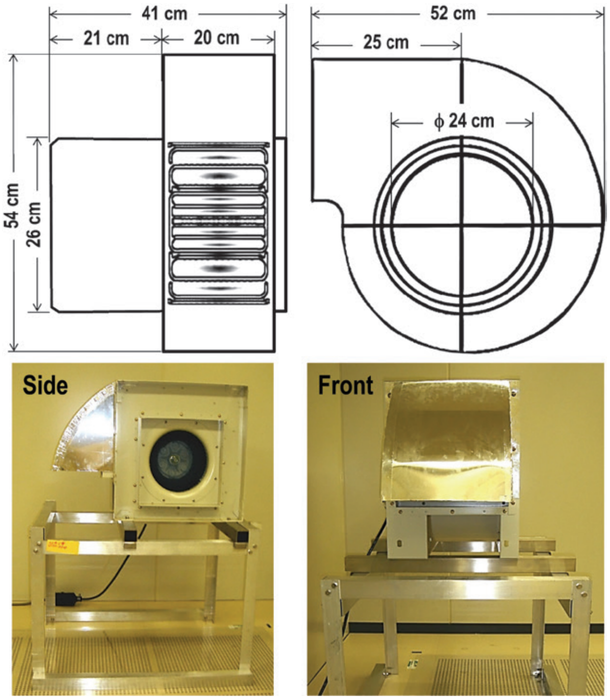

**Fig. 1.** The drawing sheets (top) and the real views (bottom) of the original defog blower.

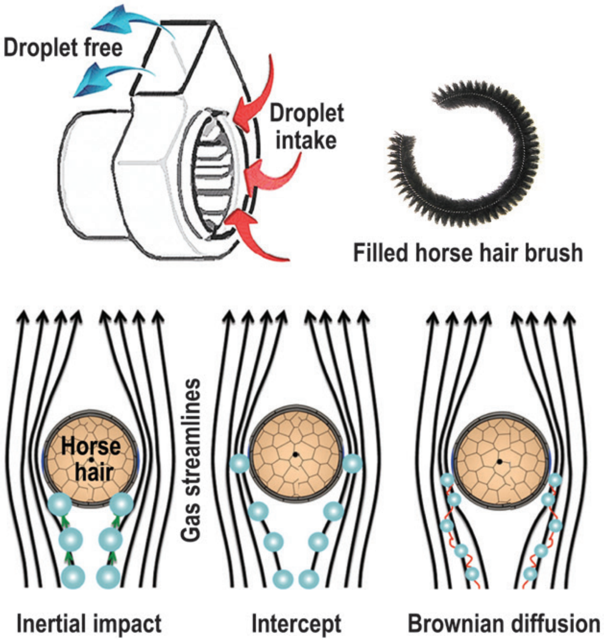

**Fig. 2.** Defogging image of the original defog blower equipped with horse hair (top) brush and defogging principles (bottom).

high density again when electric applying is turned off.

In order to remove fog, a novel approach was attempted in the present study. Here, we briefly report the results of defog experiments with the newly developed defog blower.

## 2. DEVELOPMENT OF A NOVEL DEFOGGER

In the first stage, the most widely used fog eliminator was impaction devices equipped with packing materials such as perforated plates in column. Afterwards, cyclonic type demisting devices were developed to reduce the size of packed columns (Brunazzi *et al*., 2003). Then wire-mesh mist eliminators developed to lower the pressure drop of the cyclonic separators are used commonly in many industrial plants (Brunazzi and Paglianti, 2001). However, these wire-mesh mist eliminators are largely ineffective for the separation of droplets in the 1-3 μm because of the mesh's random structure, irregular density, and coarse fiber diameters.

In order to resolve the shortcomings of the existing fog eliminators, we developed the unique defogger by using horse hairs and blower. Fig. 1 illustrates the drawing sheets and the real views of the original defog blower. Its sizes of the front and side are 41 cm and 52 cm, respectively. Fig. 2 shows the defogging image, the rolled horse hair brush (88 cm of overall length) installed in the defog blower, and defogging principles. Its flow rate is 86.4 $m^3$/min.

Horsehair is one of the natural protein fibers which are hydrophilic in nature. Hydrophilic horsehair has hydrophilic radical (-OH radical), which is characterized by high affinity of water. In contrast with conventional synthetic fibers such as polyester and polypropylene, horsehair can absorb and diffuse water. The hygroscopic property of horsehair is a very important for the initial stage of fog removal without droplet bounce-off the fiber. Other physical characteristics of horse mane hair typically include a slightly stiff texture and heat resistance. The slightly stiff texture of mane hair gives a very good durability without appropriate supports such as beams and rings. Straight pull tensile strength of horsehair was found to be 0.5851 ± 0.122 kg and knot pull tensile strength was 0.3998 ± 0.078 kg (Yedke *et al*., 2013). The demisting device equipped with the medium thermal resistance of horsehair (heat tolerant to 188°C) can also be applied to the slightly hot gas that comes out of duct. Using mane hair contributes to waste recycling because our roller brush was made from the recycled mane hair used as the packing material of sofa.

As displayed at the bottom of Fig. 2, the defogging is achieved by impingement of fog droplets on the horsehair brush where droplets coalesce. Finally, the large coalesced drops are drained in a direction perpendicular to the gas flow and dropped off to the defogger bottom. As shown in Fig. 2, the original defog blower, referred to as the usual mesh mist eliminators, collect droplets by the interception, inertial impaction, and Brownian diffusion mechanisms. Among these three defogging principles, the main principles are interception and inertial impaction because the Brownian diffusion is not meaningful for the droplets with large diameter. Interception occurs when a droplet follows an airstream but still comes close enough to a mane hair of the defog blower to adhere to it. Inertial impaction works as the airstream is displaced by the mane hair of the defog blower while the droplet continues on its original course because of its mass.

To calculate the limiting trajectory distance for direct interception ($D_{tra}$) the equation derived by Bürkholz (1989) was applied:

$$D_{tra}=\frac{d_h}{2}\,\frac{(1+N_R)\ln(1+N_R)-\frac{1}{2}(1+N_R)+\frac{1}{2}\,\frac{1}{2(1+N_R)}}{K_u}$$

where $d_h$ is the mane hair diameter, $N_R$ the interception parameter is a ratio of droplet to mane hair diameters, and the Kuwabara number ($K_u$) is defined as follows:

$$K_u=-0.5\ln(1-\varepsilon)-0.75+(1-\varepsilon)-0.25(1-\varepsilon)^2$$

where $\varepsilon$ is the porosity of the mane hair brush.

Meanwhile, according to Wessel and Righi (1988), impaction rates are dependent upon target geometry and size (e.g., mane hair radius $R$); free-stream gas velocity $U_o$, gas viscosity $\mu_g$, gas density $\rho_g$; droplet diameter $d_d$, and droplet density $\rho_d$. These parameters are expressed in nondimensional form with a Stokes number ($Stk$), and a free-stream particle Reynolds number ($Re_o$):

$$Stk=\frac{\rho_d d_d^2 U_o}{18\mu_g R};$$

$$Re_o=\frac{\rho_g d_p U_o}{\mu_g}.$$

## 3. EXPERIMENTS

### 3.1 In the Enclosed Space Like a Vinyl House

Our defogging project was aimed at two circumstances, namely, fog appearance at the enclosed space like a vinyl house and a large scale duct, and the opened spaces such as an express highway, a sports stadium, and an airport. In this study, the results of the former two cases (i.e., in the enclosed spaces like a vinyl house and a duct) experiments are presented.

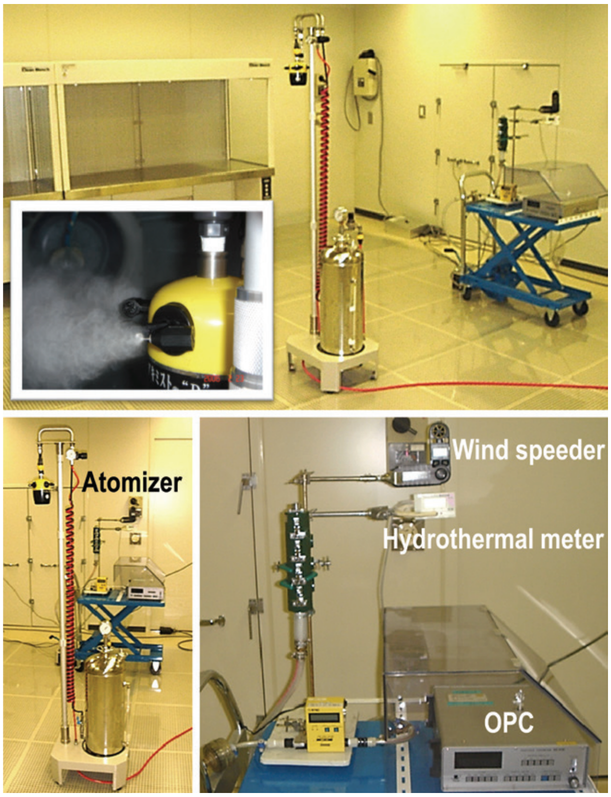

**Fig. 3.** The view of defog experiment at a clean room (W 5.9 m × L 5.1 m × H 2.4 m).

For the experimental estimation of the novel defog blower at an enclosed vinyl house, an experimental setup was designed at a clean room (W 5.9 m × L 5.1 m × H 2.4 m). Fig. 3 shows the view of defog experiment at a clean room. The experimental setup consists of the defog blower, an atomizer (fog generator), a wind speeder, a hydrothermal meter, an optical particle counter (Rion Co.), and a wind generator (0.2-1.9 m/s). In a clean room, HEPA filtration can trap 99.97% of all particles larger than 0.3 μm. The number size distribution of blank particles at a clean room chamber was on a par with the ISO Class 5 (i.e., the 10,200 particles per cubic meter shown at 0.3 μm include all particles equal to and greater than this size) without the particles larger than 1 μm.

### 3.2 In a Large Scale Duct

Properly-designed mist eliminators are essential for the cost-effective operation of every plant as well as the improvement of the working environment. The poorly performing mist eliminators lead to corrosion of not only ducts, but also every production facility. In

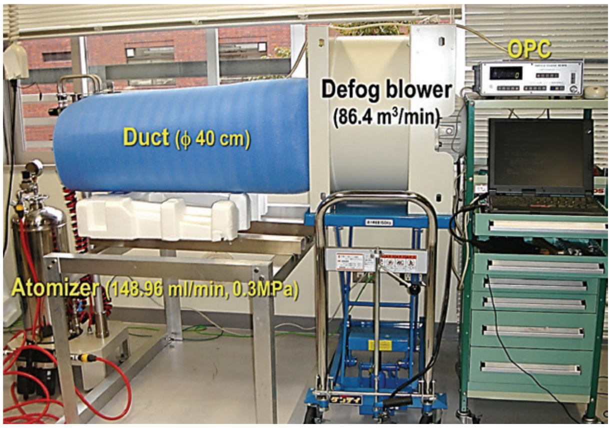

**Fig. 4.** Experimental set-up for mist removing from a circular duct.

the present study, the laboratorial demisting experiment taking account of a large scale duct was performed. Fig. 4 shows the laboratorial experimental set up for demisting from the inner of a large scale duct. The duct used in experiments was a common circular duct with a diameter of 40 cm. The generated droplets at 0.3 MPa of jet pressure of atomizer were brought into a duct and the droplet number concentration in a duct was continuously measured by the end of each experimental period.

## 4. RESULTS AND DISCUSSION

Droplet size is one of critical parameters in the experimental estimation of defogging by the novel fog remover. If droplet size is larger than 500 μm, droplets can be naturally dissipated by a simple gravity settling. In this study, in order to create a similar circumstance to natural fog event the jet pressure of atomizer was adjusted. Fig. 5 shows the droplet number size distribution as a function of the jet pressure of atomizer. As shown in Fig. 5, the droplet number size distribution greatly depends on the jet pressure of atomizer.

Atomization, i.e., the breakup of a liquid into droplets can be achieved by can be achieved by creating a high velocity between the liquid and the surrounding air. Droplet sizes are increased by increases in liquid viscosity and are reduced by increases in jet pressure of atomizer.

The equations for mean drop size (*SMD*) presented below are considered as being among the best available in the literature. According to Elkotb (1982), a typical equation of *SMD* is the following:

$$SMD = 2.25\sigma^{0.25}\eta_L{}^{0.25}m_L{}^{0.25}\Delta P_L{}^{-0.5}\rho_A{}^{-0.25}$$

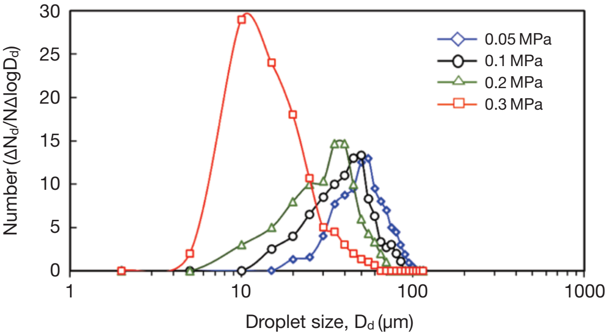

**Fig. 5.** Droplet number size distribution as a function of jet pressure of atomizer.

where $\sigma$ is surface tension (kg/s$^2$), $\eta_L$ is dynamic viscosity of liquid (kg/m s), $m_L$ is flow rate of liquid (kg/s), $\Delta P_L$ is pressure differential across nozzle (Pa), and $\rho_A$ is density of air (kg/m$^3$).

Hackney *et al.* (1989) reported that mean droplet diameter ranged from more than 10 microns in dense fog to less than one micrometer at low relative humidity. The number size distribution at the 0.3 MPa jet pressure of atomizer was applied well in this range.

Under the experimental condition of the 0.3 MPa jet pressure of atomizer, the droplet (> 5 μm) number concentration at an enclosed space was measured as a function of air (dry wind) entrainment. In terms of this defogging experiment, droplets were generated for one minute 45 seconds ((A) in Fig. 6) at 46% of initial RH, and then the vent-defog blower was run for one minute 45 seconds ((B) in Fig. 6). In our enclosed space defogging experiment, there was 10.21 m$^3$ min$^{-1}$ dry air entrainment on the assumption that the vents of vinyl house were opened. Fig. 6 indicates that the droplet number concentration varied greatly depending on condition of wind entrainment. This time serial droplet number concentration was severely fluctuated throughout the whole experimental period. Fogs were immediately dissipated after running of defog blower under the situation of the dry air entrainment. Meanwhile, in the case of no-wind entrainment the number concentration of droplet fell right down to the level of initial condition in three minutes after defogger running. The smaller droplets, from 100 μm down to a few micrometers diameter, settle very slowly or not at all. The sudden disappearance of droplets (the bold line of "No. conc. with entrainment") just after defogger running was therefore strongly affected by droplet evaporation by the dry-air entrainment. The fog dissipation could easily be checked visually by the visibility index as displayed in the inner of Fig. 6. They were filmed at two meters away from the visibility index during the

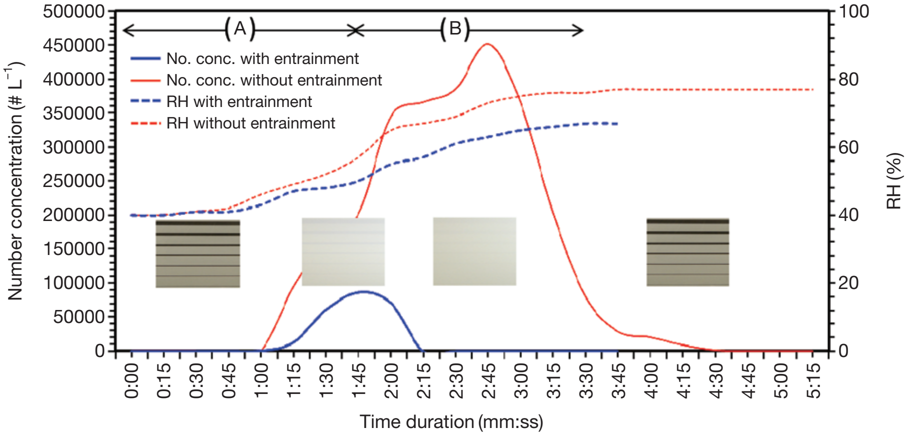

**Fig. 6.** Variation of droplet (>5 μm) number concentration as a function of air (dry wind) entrainment at an enclosed space.

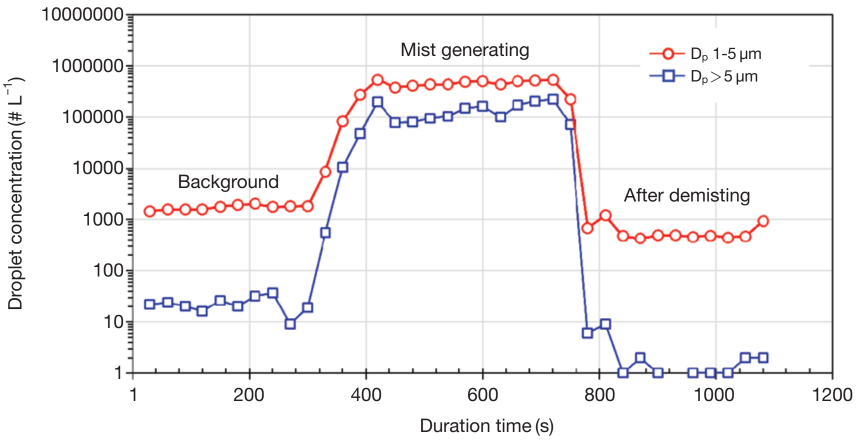

**Fig. 7.** Variation of number concentration for two different types of droplet size (1-5 μm and >5 μm).

experiment without wind entrainment.

Fig. 7 displays the time series variation of number concentration for two different size fractions of droplet (i.e., 1-5 μm and >5 μm) in a large scale duct during a whole experimental period. Average number concentrations of small-size droplet (1-5 μm) before (background), during (mist generating), and after demisting were $1.74\times10^3\,L^{-1}$, $3.88\times10^5\,L^{-1}$, and $6.0\times10^2\,L^{-1}$, respectively. And those of the larger droplet than 5 μm were $23\,L^{-1}$, $1.15\times10^5\,L^{-1}$, and $2\,L^{-1}$, respectively. This result clearly indicates that our novel demisting equipment with the natural horsehair has the pronounced demist effect for both size fractions. Moreover, there was also a great removal effect for the background particles. The particle scavenging rate of our demisting blower was 89.5% and 65.4% for fine and coarse particles, respectively. Therefore, it can be said that the mist eliminator presented in this paper is ideal for use in industrial sites where there is a need to remove both mist and particle. Additionally, it is used in the places which creates static electricity because horse hair is non-conductive. However, this mist eliminator may be ineffective at the applications such as an extremely high temperature and strong acid of steam ducts because, as mentioned earlier, the horsehair equipped in the demisting device has heat resistant to 188°C.

## 5. SUMMARY

Our laboratory studies have shown that the original defogger equipped with horse hair brush, which is hydrophilic in nature, can absorb aqueous fog droplets, and then release them as fog water through the vent-defog blower. The model experimental results clearly indicate that our novel defogging/demisting equipment has the pronounced demisting effect. Moreover, the original defog blower could also be used to particle scavenging. As another benefit of our defog blower, it can also be used as a water supplier in a place where fog is a source of water because people can collect the fog using the defog blower. The advantages of using our unique defogger are lower cost than existing defoggers, simple control and operation, excellent maintenance, no fog reforming after defogging, and saving energy and environmental friendly. However, although fog phenomenon was improved while our defogger blower was running, the further effort was required for the effective mist removing at the places of an extremely high temperature and strong acid (or base).

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## REFERENCES

Agence France-Presse (2016) Four die in Slovenian 50-car pile-up. The Guardian. ISSN 0261-3077.

Brunazzi, E., Paglianti, A. (2001) Conventional and complex knitted mesh mist eliminators. Chemical Engineering & Technology 24, 1199-1204.

Brunazzi, E., Paglianti, A., Talamelli, A. (2003) Simplified design of axial-flow cyclone mist eliminators. Fluid Mechanics and Transport Phenomena 49, 41-51.

Bürkholz, A. (1989) Droplet separation, VCH Verlagsgesellschaft, Weinheim.

Dennis, A.S. (1980) Weather modification by cloud seeding. http://digitalcommons.usu.edu/water_rep/670

Elkotb, M.M. (1982) Fuel atomization for spray modelling, Progress in Energy and Combustion Science 8, 61-91. DOI: 10.1016/0360-1285(82)90009-0.

Gyeonggi Daily (2015) 106-car pileup on Yeongjong Bridge in Incheon by thick fog. http://www.kyeonggi.com/? od=news&act=articleView&idxno=912731

Hackney, J.D., Linn, W.S., Avol, E.L. (1985) Potential risks to human respiratory health from acid fog: evidence from experimental studies of volunteers. Environmental Health Perspectives 63, 57-61.

Hackney, J.D., Linn, W.S., Avol, E.L. (1989) Acid fog: effects on respiratory function and symptoms in healthy and asthmatic volunteers. Environmental Health Perspectives 79, 159-162.

Kawamura, M., Kurosaki, K., Masuta, A., Kimura, I., Nakajima, Y., Ikeda, N. (1995) Basic experiments on electric quenching for fog. Engineering Departmental Bulletin Paper of Toyama University 46, 9-15.

Koenig, J.Q., Pierson, W.E., Horike, M. (1983) The effects of inhaled sulfuric acid on pulmonary function in adolescent asthmatics. American Review of Respiratory Disease 128, 221-225.

Musselman, R.C., McCool, P.M., Sterrett, J.L. (1988) Acid fog injures California crops. California Agriculture, Jul.-Aug., pp. 6-7.

Plank, V.G. (1969) Clearing ground fog with helicopters. Weatherwise 22, 91-98.

Tanaka, H., Honma, S., Nishi, M. (1996) Two-year follow-up study of the effect of acid fog on adult asthma patients. Internal Medicine 35, 100-104.

Wessel, R.A., Righi, J. (1988) Generalized correlations for inertial impaction of particles on a circular cylinder, Aerosol Science and Technology, 9:1, 29-60, DOI: 10.1080/02786828808959193.

Yedke, S.R., Raut, S.Y., Jangde, C.R. (2013) Experimental evaluation of horse hair as a nonabsorbable monofilament suture. The Journal of Ayurveda and Integrative Medicine 4, 206-210.

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