SỬ DỤNG THÁP PHUN NƯỚC NẠP ĐIỆN ĐỂ GIẢM MUỘI TRONG KHÍ XẢ ĐỘNG CƠ DIESEL TÀU THỦY
USING ELECTROSTATIC SPRAYING SCRUBBER TO REDUCE PARTICULATE MATTER IN EXHAUST GAS OF MARINE DIESEL ENGINES

NCS. TRẦN HỒNG HÀ
Advance Energy Research Laboratory,
Faculty of Maritime Sciences, Kobe University
KS. HOÀNG ANH DŨNG
Giảng viên, Khoa Máy tàu biển, ĐHHH

Abstract:

A electrostatic water spraying scrubber is used to treat exhaust gas from Marine Diesel Engine in order to decrease mainly particulate matter (PM) emission. The effect of electrostatic water spraying scrubber on the removal of PM and other pollutants from the exhaust gas in seen investigated experimentally. The PM diameter between 0.1 and 2.5 microns are removed at very high efficiencies by using the highly charged droplets as collectors. Simultaneously, all soluble acid and caustic gases are removed at the same high levels as conventional scrubbers. The results showed that the efficiency of PM collection depended mainly on the particle size, particle retention time, droplet size, water conductivity and electric field effect. The fine PM removal efficiency is significantly increased, as compared to uncharged sprays, when the droplets are electrically charged. Electrospray scrubber is a major advance in multi-pollutant control devices utilizing highly charged water droplets as collectors; it is a proven solution for simultaneously treating fine particles and pollutant gases.

Tóm tắt:

Tháp phun nước nạp điện được sử dụng để xử lí khí xả từ động cơ diesel tàu thuỷ, với mục đích chủ yếu là làm giảm muội trong khí xả. Hiệu quả của tháp nước này trong việc xử lí muội và các khí độc khác trong khí xả đang được nghiên cứu và thí nghiệm. Hạt muội có kích thước từ 0.1÷ 2.5 μm được giữ lại với hiệu quả rất cao bằng các hạt nước được nạp điện. Kết quả cho thấy rằng việc xử lý muội chủ yếu phụ thuộc vào yếu tố như kích thước và thời gian cư trú của các hạt muội, kích thước hạt nước, độ dẫn điện của nước và ảnh hưởng của trường điện. Tháp nước có ưu điểm lớn trong các thiết bị xử lí ô nhiễm bằng cách sử dụng các hạt nước được nạp điện để giữ các hạt muội và các khí độc khác.

Keywords: Electrostatic water spray; charged water droplets; collectors; particulate matter; induction

1. Introduction

Marine diesel engines are major sources of urban air pollution. They emit a large amount of pollutants, including [2]:

- Particulate matter (PM),
- Carbon monoxide (CO),
- Unburned hydrocarbons (HC),
- Nitrogen monoxide (NO),
- Articles, condensable hydrocarbons,
- Soluble VOC formaldehyde,
- Sulfur dioxide (SO_2),
- Ammonia, others by products of combustion.

In where, particulate matter may cause respiratory and mutagenic diseases, such as lung and bladder cancer. Diesel particulate is classified as probable carcinogen to human. Hydrocarbons may react with nitrogen monoxide in the presence of sunlight forming ozone that irritates lungs. Exhaust emissions have been limited dramatically in modern times though the adoption of Annex VI in 1997 “Regulations for the Prevention of Air pollution from Ships” MARPOL

73/78 Convention [9]. The Regulations are going to be extended to pollutant such as PM, volatile organic compounds (VOC), soluble acid and caustic gases.

Size definition for both solid particles and liquid particles as follows:

- Coarse = particles 2.5 micron & larger
- Fine = 2.5 micron & smaller
- Ultra fine particles = 0.1 micron & smaller

The major objective of this study was to evaluate the potential of electrostatic water spray in controlling pollutant in marine exhaust gas. Specific objectives were to:

(1) Compare charged water spray, uncharged water spray, and no water spray in terms of PM removal efficiency; and

(2) Determine the effects of spray duration, spraying method, charge polarity, and PM concentration on the PM collection efficiency of water spray.

2. Theoretical background

1.1. *Electrostatic water spray*

Electrostatic water spray refers to any number of spray processes that use an electric field to increase the collection efficiency. Electrostatic water spray can be categorized based on three specific criteria:

- Direct conduction,
- Corona,
- Induction;

In direct conduction, the spray material has a relatively high conductivity (e.g. fresh water, sea water) and the voltage is applied to the source of the sprayed material. For this technique, the spray is emitted from the nozzle already charged and atomizes instantly. Atomization in sprays using direct conduction often achieved using a stationary, low flow nozzle.

In a corona charging system, the sprayed droplets are charged after atomization by passing through a corona field. This is an effective technique, The corona charging method requires the use of high voltages in order to ionize the air surrounding the liquid This method has proved more difficult mainly due to fragile nature of the exposed corona discharge electro, charge leakage problems associated with the elevated ionization required voltages as well as the limiting effect. Also, from a practical standpoint, liquid can land on the corona-producing electrode prior to charging causing a decrease in performance. However, for particles, corona charging can be very efficient.

In induction charging, the voltage is applied in proximity to the nozzle so that the liquid travels near the source and picks up some of the electric charge. The one found that to be most consistent and reliable is the induction charge method. The high voltages associated to these charging will lead to problems such as surface tracking. It is therefore required to use of very high voltages in order to use a lower voltage system if possible. For induction charging, in principle, there is no electrical energy consumption. Mechanical energy is used both to disperse the liquid into droplets and to direct the charged particles past the induction electrode. Some of this mechanical energy is thus converted into electrical energy contained in the charged space cloud. In a practical system, the only current flowing through the power supply is the leakage current and the current due to deposition of droplets on the induction electrode

1.2. Mechanisms of particle collection by charged water droplets

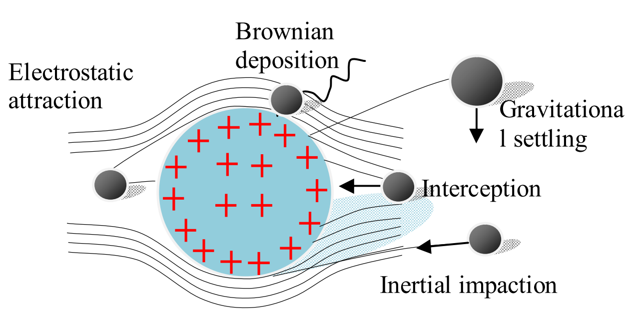

Fig 1. Mechanisms of PM collection by charged water droplet

There are five major mechanisms of particle collection by water droplets [11]:

(1) interception;
(2) inertial impaction;
(3) gravitational settling;
(4) Brownian deposition;
(5) electrostatic attraction.

Interception. Direct interception occurs when the fluid streamline carrying the particle passes within one-half of a particle diameter of the droplet

Inertial impaction. Inertial impaction occurs when the particle would miss the droplet if it follows the streamline, but its inertia resists the change in direction taken by the gas molecules and it continues in a direct enough course to be collected by the droplet

Gravitational settling. Gravitational settling is due to the difference in mass of the PM and the carrier gas

Brownian diffusion. Brownian deposition occurs as the particles are bombarded with gas molecules that may cause enough movement to permit the particle to come in contact with the droplet. Brownian motion may also cause some of the particles to miss the droplet because they are moved away from it

Electrostatic deposition. Electrostatic attraction occurs because the droplet sufficient electrical charge to overcome the inertial forces; the particle is then collected instead of passing the droplet by induced electrical attraction. If a droplet is purposely charged by an applied electric field, the charge on the droplet will be larger than the random ions on it, then for some droplet sizes the electrostatic attraction is the dominant mechanism for particle removal.

When the particles and/or the droplets are charged, there are five possible different electrostatic forces of attraction

(1) The Coulomb attraction between a charged particle and an oppositely charged collector
(2) The dipole attraction between the charged particle and the dipole that this charge induces on the neutral collector
(3) The dipole attraction between the charged collector and the dipole induced upon the neutral particle
(4) The space charge repulsion of the cloud of charged particles. The electrostatic repulsive force between two point charges of like sign separated by a distance ***r*** is given by Coulomb's law
(5) The attraction between the charged particle and the earthed collector, which carries an image charge, induced by the space charge of the surrounding aerosol.

3. Experimental apparatus and method

a. Experimental set up

A diesel engine specification given in table 1 was use as a stationary PM and other pollutant emission source. Low sulfur diesel fuel oil (0.08 %S) in table 2 was used throughout these experiments. The experiments with exhaust gas cleaning by means of charged droplets and charged PM were carried out in a chamber shown schematically in Fig. 2. The scrubber consists of two chambers. In the first chamber a mount of larger coarse PM are removed, ultrafine PM and condensable are grown to a few tenths of a micron in preparation for removal. In the second chamber the particles were charged by a corona charger. The charger was made of stainless steel saws (6 pcs) as negative electrodes that connect to high voltage supplier adjusted to various voltages range from 1.0 to 10 kV to charge PM. These saws were mounted between 4 steel plates which connected to earth. The liquid was pumped from a tank by centrifugal pump and discharged through two nozzles with orifice diameter of 1 mm. Two brass ring electrodes (induction electrode) of inner diameter 2.0 mm is placed around upper edge of spaying head of each nozzle. The induction electrodes were connected electrically to a high DC voltage power supply (type) adjusted to various voltages range from 1.0 to 5.0 kV to charged water droplets as shown in Fig1. Thus under stable operating conditions, a negatively charged space cloud is formed. This arrangement provides a strong charging field with a relatively low voltage. Then relatively clean water from the top of the tank is re-circulated by pump to the charging electrode, where it is recharged, completing the cycle.

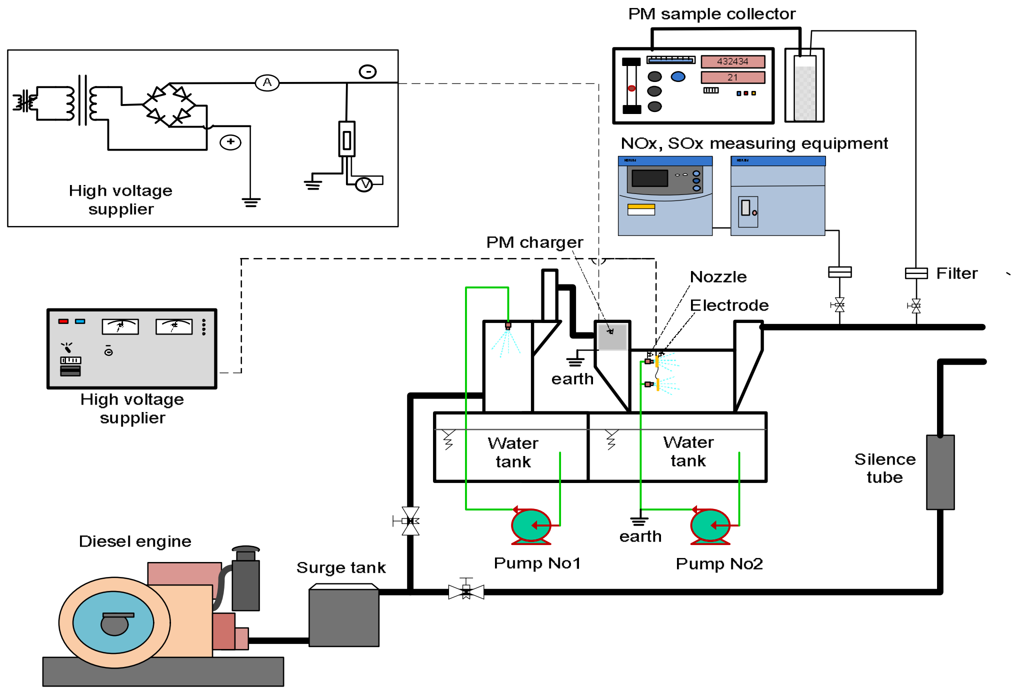

Fig 2. Experiment set up

Table 1: Engine specification

Engine type	Horizontal single cylinder, 4 stroke
Engine model	YANMAR NF 19-SK
Cylinder bore and stroke	ϕ 110 x 106 mm
Swept volume	1007 cm
Compressor ratio	16.3
Maximum output	14 kW
Maximum speed	2400 rpm
Nominal output	12.6 kW
Nominal speed	2200 rpm

Table 2. Properties of A Oil

Property	Composition
Density [g/cm^3] 15^{0}C	0.8615
Flash Point [^{0}C]	72
Kinetic viscosity [mm^2/s]	2.374 (50^{0}C)
Pour Point [^{0}C]	-25
Ash [mass%]	<0.001
Sulfur [mass%]	0.08
Water [vol%]	0.01
Residual Carbon [mass%]	0.55
Low heating value	42.6 MJ/kJ

b. Determination of PM removal efficiency

The PM removal efficiency η was calculated basing on following equation:

Uncharged water spray (UWS):

$$\eta = \frac{PM\_mass\_without\_ES - PM\_mass\_with\_UWS}{PM\_mass\_without\_ES} \quad (1)$$

Charged water spray (CWS):

$$\eta = \frac{PM\_mass\_without\_ES - PM\_mass\_with\_CWS}{PM\_mass\_without\_ES} \quad (2)$$

Charged PM and charged water spray (CPM&CWS)

$$\eta = \frac{PM\_mass\_without\_ES - PM\_mass\_with\_CWS\ \&\ PM}{PM\_mass\_without\_ES} \quad (3)$$

The PM mass in treated or untreated exhaust gas were determined by gravimetric method. Particulate matter samples are taken by composite filter paper. The filters, before and after collecting the samples, are weighed under strictly controlled temperature.

4. Experimental results and discussion

a. Effect of spray performance on PM removal efficiency

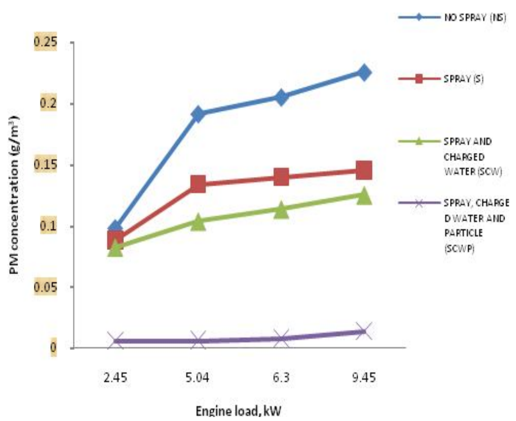

Fig 3. PM concentration after the scrubber with differential water spraying performance at various loads

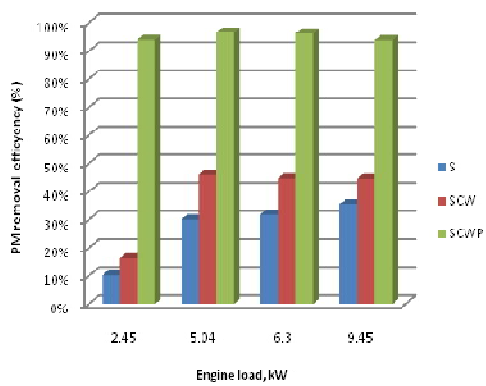

Fig 4. PM removal efficiency after the scrubber with differential water spraying performance at various loads

An affection of spray performance on PM removal efficiency by charged water spray is show in Fig 3. The concentration of particulate matter for each spray performance was determined at various loads of the diesel engine.

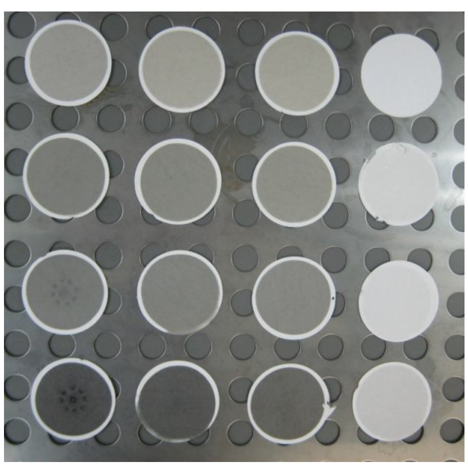

Fig 5. PM removal efficiency after the scrubber with differential water spraying performance at various loads

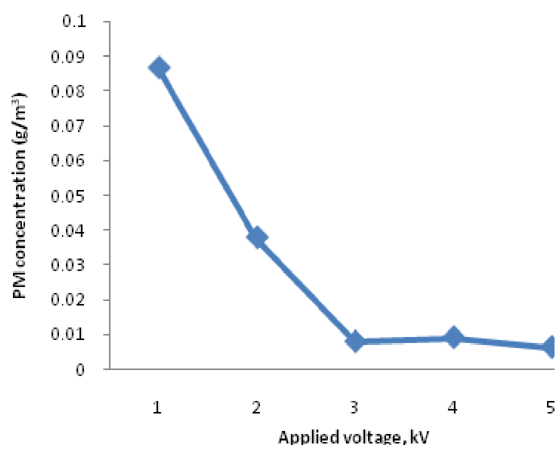

Fig 6. PM concentration with various applied voltage

Comparison of the results shown in Fig 3 between no water spray, water spray, charged water spray and both charged PM and water droplets. The uncharged water removes coarse particles by simple impaction with the water. This is in affection for fine particles. Because of their very lightweight, fine particles are pushes out of the part of the water droplets and are forced to follow the streamlines. It can be note that charging of the droplets result in more effective removal of PM from the exhaust gas than spraying water only. Because of the droplets are purposely charged by an applied electric field, the charge on the droplet will be larger than the random ions on its, then for some droplet sizes the electrostatic attraction is the dominant mechanism for particle removal. Electrostatic attraction occurs because the droplet possess sufficient electrical charge to overcome the inertial forces and the particle is then collected instead of passing droplet because of dipole force.

The better results were obtained when both PM and water droplets were oppositely charged, PM were charged negative, droplets were charged positive. Removal efficiency was more many time than uncharged droplets and uncharged PM depending on the load of the diesel engine, as show in Fig 4. Because when PM and the droplets charged, there are four possible different electrostatic force of attraction. One or more this forces will be the dominant force that controls the collection efficiency.

b. Effect of applied voltage on PM removal efficiency

The electrical potential of the induction electrode was expected to determine the level of charge achieved on the liquid during atomization, as it would determine the intensity of the electric field. The electrical potential of the induction electrode was controlled by contacting the electrode with a range of voltages between 1 and 5 kV DC. The electrode polarity was negative, so the spray polarity was positive. As show in Fig 6 the more increasing applied voltage step by step, the higher the removal efficiency due to the addition of electric attraction between PM and droplets.

4. Conclusions

An experimental study on the removal of harmful particulate matter and other pollutants emitted by a diesel engine using a electrostatic water spraying scrubber was conducted. A electrostatic water spraying scrubber was found to remove the PM. It was demonstrated experimentally that the electrical charging of droplets and PM allows an increase of the removal efficiency of particles from exhaust gas.

- Capture particulate matter smaller than 0.1 μm the removal efficiency of smoke particles, smaller than 1 mm, can be as high as 92–97%.
- Energy efficiency, the power consumption to charge water (plus moderate pump power for water circulation)
- Pressure drop of exhaust gas very low when crossing the system
- Discharge water usage with low volume that

Further improvement of the removal efficiency was obtained by charging sprays utilizing electrical forces can effectively operate for small sizes of particles.

Acknowledgements

The author wish to gratefully acknowledge the financial support of the Advance Energy Research Laboratory,

Faculty of Maritime Sciences, Kobe University, Japan.

<u>REFERENCES:</u>

[1] A. Jaworeka, W. Balachandranb, M. Lackowskia, J. Kulonb, A. Krupaa, Multi-nozzle electrospray system for gas cleaning processes, J.Electrostats. 64 (2006) 194–202.

[2] M. Moldovan, M.A. Palacios, M.M. Gomez, G. Morrison, S. Rauch, C. Mclcod, R. Ma, S. Caroli, A. Alimonti, F. Petrucci, B. Bocca, P. Schramel, M. Zischka, C. Pettersson, U. Wass, M. Luna, J.C. Saenz, J. Santamaria, Environmental risk of particulate and soluble platinum group elements released from gasoline and diesel engine catalytic converters, Sci. Total Environ. 296 (2002) 199–208

[3] Gabriel Nii Laryea, Soo-young No, development of electrostatic pressure-swirl nozzle for agricultural application, J.Electrostats. 57 (2003) 192–142.

[4] Hoenig, A. 1977. Use of electrostatically charged fog for control of fugitive dust emissions. EPA-600/7-77-131 (NTIS PB, 276645). Tuczon, AZ: University of Arizona.

[5] Gillespie, T. 1955. The role of electric forces in the filtration of aerosols by fiber filters. J. Colloid Interface Sci. 10:299

[6] Mathai, C.V. 1983. Charged fog technology Part II: Prototype tests of a new charged fog generator for fugitive emission control. Journal of the Air Pollution Control Association 33(8):756-759.

[7] W. Balachandranb, A. Jaworeka, M. Lackowskia, J. Kulon, A. Krupaa, Efficiency of smoke removal by charged water droplets , J.Electrostats. 58 (3-4)(2003) 209–220.

[8] I. Made Ariana, Fujita Hirotsugu, Nishida Osami and Harano Wataru, Using Water-Plate Collector on ESP to Reduce Marine Diesel Exhaust Emission,MTC-2007

[9] IMO, Annex VI of MARPOL 73/78 Regulations for the Prevention of Air Pollution from Ships and NOx technical code.1998, IMO London

[10] S. Zhao_, G.S.P. Castle, K. Adamiak. The effect of space charge on the performance of an electrostatic induction charging spray nozzle, Journal of Electrostatics 63 (2005) 261–272

[11] Licht, W. 1988. Air pollution control engineering: Basic calculations for particulate collection. 2nd ed. New York: Marcel Dekker.

[12] K.Donaldson, X.Y.Li, W. MacNee, Ultra fine (nanometer) particle mediated lung injury, J.Aerosol Sci. 29 (1998) 553-560

Người phản biện: TS. Lê Văn Điểm