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ELECTROSTATIC PRECIPITATORS- ESP WITH CORONA DISCHARGE FORMATION FOR DIESEL ENGINE - A COMPREHENSIVE REVIEW

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Abstract:-
Nowadays ESP- Electrostatic precipitators are executed and several new methods have used to increase the emission devices efficiency. For removing the particulate matter-PM especially electrical force, filters and corona discharge formation used in order to increase the collection efficiency in diesel engine. With respect to particle properties and health effects researches results, measurement systems are evaluated. This paper performed comprehensive review based on fundamental of ESP and corona formation in improving the efficiency of collection of particles. The ESP concept is only then to apply the electrostatic force to particles. Several factors are also considered like size of particle, residence time and dielectric constant in ESP, charging mechanisms used for field charging and diffusion are discussed. Here the diesel particles composition, ESP with corona formation are clearly described with existing researches. Finally the comparative analysis are performed to exhibited the outcomes, different benefits from the previous studies

Keywords: Diesel engine, ESP, corona formation, particulate matters

Introduction

Diesel engine plays major role for agricultural and transportation sector due to lower maintenance cost, greater fuel economy and initial torque. The major problem is with diesel engines use due to the hazardous pollutants release in exhaust namely unburnt hydrocarbon emission HC, particulate matter-PM, nitrogen emissions- NOx and carbon monoxide emission- CO. these pollutants are not influencing the environment which affects the human beings health. The diesel engines discharge PM in smaller form at 10M particulates concentration per cm3. The primary carbon particles diameter lies in range of 0.01 to 0.08 μms with 90 percent of particles shows 1 μm lesser diameter. The government agencies are categorized the PM as probable human carcinogen which raises the respiratory and heart diseases risks like bronchitis and asthma. In PM, presence of two or more benzene ring hydrocarbon refer as PAHs- nuclear aromatic hydrocarbon refer as human carcinogens. The PM soluble organic fraction comprised with five and four rings which is the most harmful compounds, in overcoming the pollutant problems the global emission norms are becoming more severe[1, 2].

In the recent years diesel particles are shows higher concern because of their urban areas' adverse effects. Different epidemiological and toxicological researches have established due to the PM's adverse health effects. There exists different evidence in health effect related with ultra fine particle with below 100 nm diameter[3].

For vehicles fitted with catalytic converter #
Selected regions of earlier introduction †
NMHC and a = 0.068 g/km

Table 1: Emission standard for diesel passenger cars

Stage	Year	CO	HC	HC+NOx	NOx	**PM**	
		g/km					
Diesel Vehicles							
	1992	17.3	2.7	-	-	-	
	1996	5.0	-	2.0	-	-	
India 2000	2000	2.72	-	0.97	-	0.14	

BS II	2005.04†	1.0	-	0.7	-	0.08	
BS III	2010.04†	0.64	-	0.56	0.50	0.05	
BS IV	2017.04†	0.50	-	0.30	0.25	0.025	
BS VI	2020.04	0.50	-	0.17	0.080	0.0045	

The PM reduction is widely performing by using the particulate filter comprised with silicon carbide filter or ceramic or catalytic converter with sequential way of regeneration, but the effective technology is not without the drawback. Another approach is hydraulic filter which is of not in practical use. Therefore ESP- Electrostatic precipitator technology is plays significant role in capturing the diesel engine's particulate emission. Generally, ESP shows lower electrical consumption and lower pressure drop and thus the particulate matters are lesser than 10 μm in atmosphere for more time and lesser resistivity. Different researchers worked out on ESP of aerosol emitted through diesel engine focusing on the automotive application. For example different studies presented about the diesel particle with respect to agglomerator conversion efficiency, simple wire cylinder without corona discharge with electrostatic filter. Further the ESP from exhaust pipe using corona plasma method from greater voltage pulse used. This approach is new, improved and lesser expensive in collecting the particles which further saves structured materials and energy. Different developments has been made to increase collection efficiency[4-6].

By focusing on this, the comprehensive review is made with the objective of,

- To analyse and discuss the diesel particles composition and its suitable measurement methods.
- To illustrate the ESP principle which performing as emission control device.
- To discuss the Corona formation and discharge characteristics of ESP on CI engine
- To perform comparative analysis related with harmful substances emission reduction using ESP corona discharge approaches and its outcomes.

The following section 2 illustrates the diesel particles composition and its suitable measurement methods. Further in section 3 ESP principle and its types are clearly demonstrated. In section 4 appropriate corona formation of ESP on CI engine described. In section 5 the comparative analysis are performed. Finally in section 6 the paper is concluded.

Composition of Diesel Particles

Diesel particles comprise a composite of hydrocarbons, elemental carbon and sulfur compounds. These components varies in composition, size, toxic properties and solubility [2]. The composition of the heavy duty diesel engine particles are presented in the figure 1. Certain compounds are observed in volatile condition and the volatile fraction is highly depends on the various conditions like temperature. Few of the particles remains in the condensate mixture or gaseous phase on the nucleate or existing solid particles that develops into new particles. The particles will be developed and also create a secondary particles because of the cooling process in sampling area and exhaust from the combustion process. General particles of the diesel comprises spherical particles with size ranging from 15 to 40 nm of diameter. These primary particles generates from modern engine that was incorporated with Euro IV are small in size when compared to old engines [10]. With reference to particle microstructure, the traditional engineers were found to be dormant with graphic structure and amorphous in nature. The figure 2 represents the typical size distribution. Here the size depends on the engine operation. The extreme condition causes varied distribution of size[7, 8].

Measurement methods

Various methods are presented for the estimation of the particle emission exhausted by the engine. The parameters for the estimation process includes

PM – Total particulate matter in grams

Distribution of the size in number/ centimeter^3

Concentration in grams/centimeter^3

Every measurements has to be performed after dilution process. This dilution process are referred in accordance to current legislative system in US and Europe. So this dilution process is adequate for dropping the temperature to below 52 degree Celsius. In addition all the legal emission limits that describe the reference to total mass and are estimated through gravimetric analysis. through temperature drop the volatile substances has been condensed and consequently the stationery test could be performed in full flow or partial flow dilution tunnel. In case of transient test full floor is observed to be adequate for estimation. The main issue in this technique in terms of direction limits occurs for most of the modernized and low emission engines. Hence the environmental protection agency formulated in the year 2007 describes that high resolution, new filter media, and tight tolerance for the temperature is permitted to reduce the limit of deduction. The pre classifier are the cyclone has been utilised for capturing the course material before it enters the filter. [9]state that the exist a collection of organic vapour by the corresponding filter. Similarly [10]experiment and compared the results with the prevailing methods in terms of European regulations. Certain gravimetric analysis and thermal mass analysis for sulfate and organic carbon where investigated by [11]. The sulphur and carbon will be oxidized and estimated as sulfur dioxide and carbon dioxide. Thereby the MEXA 1370 PM was generator by Horiba for analysing comparatively low density particulate matter. However that detection of Ash could not be accomplished. Several methods for the determination of mass has been discussed below which are quartz crystal micro balance and tapered elemental oscillating micro-balance dispense upon the modifications of resonance frequency equipment for mass collection. The above discussed two methods provides better sensitivity and better time resolution. QCM has been found to be a promising device but several disadvantages also found within the system in which the performance is highly depending on the total mass loading[12]. The opacimeters is a method in which the indirect measurement of mass is estimated full stop this kind of instrument is used to conventionally detect the mass but this instrument faces issues in terms of deduction limit. Hence a long optical path for minimizing the direction limit in the multi system has been investigator. It employees 3 kinds of wavelength with 15 m of optical length to achieve a better sensitivity rate. Meanwhile [13]demonstrated the transient estimation of low concentration particles through light extension method this is based on the concept that nitrogen dioxide leads to light extension at reduced particle concentration. Several concentration estimations has been performed with condensation particle counter by[14].

The coagulation is found to be a major problem in measuring the concentration number and so adequate dilution and shorter time or primary need in obtaining good results. Further for avoiding the undesirable domination of nucleation particle to the number of concentration volatile treatment is carefully performed. Other such vital solutions are lowering the size limit of the particle to abort 3 nm to 15 nm. If this size is found to impact the detection limit the measurement will also be affected. The distribution size is generally measured in terms of impaction or mobility analysis. The scanning mobility particle sizer has been investigated by [9]. In addition the electrical low pressure impactor has also been used by a better size resolution can be obtained using mobility analysis that can cover size rangers up to 700 NM in accordance to the flow rate. The upper limit represents the multiple charging ability of the larger particles and the lower limit represents the influences of diffusion[15].

Basic operations of ESP

The discharge of corona and the electrostatic rate in the airborne particle and the separating gasses were investigated and the discharge of corona for making clear smoke in bottle has been employed by [16]. The ESP which are the general device in the control of particulate emissions has been extensively utilized for the industrial purposes and the coal fired power plant equipment. As per the mechanical filtration concept, the gas flow through porous media or foam or fiber followed by the gas bending depends on separation. The drop in pressure has been initiated when the filter surface is hit by gas flow. In addition ESP provides only electrostatic force to corresponding particle. These occurrences will comparatively reduce the pressure drop. And hence the overall cost could be

minimized than the prevailing filtration approaches like mechanical filtration and cyclonic filtration. Therefore ESP could able to archive 99 percentage of effectiveness in removing particulate matter with considerably low pressure drop[16].

Working Principle of Electrostatic Precipitator

This section represents the moderately simple working principle of the electrostatic precipitation unit. This system comprises positive and negative electrodes in which the negative electrodes are present in the form of wireless and consequently the positive electrodes or present in the form of plates then negative and positive electrodes are placed vertically and alternatively to each other the gas born substances like as are being ionized by the corona effect caused by high voltage discharging electrode. The substances ionised to negative charge and therefore they are positively attracted to the collector plates. The positive plates and the negative plates of the equipment where connected by using the positive terminal and negative terminal of the DC source. An estimate distance has been maintained in between the negative and positive electrode as well as with DC source for ionising the medium present between the two electrodes. This results in high voltage gradient. Air is the medium found between the two electrodes. Around the wire mesh or electrode rods Corona discharge occurs because of the high negativity charges. The whole equipment is found to be enclosed in a unique metallic container comprising inlet and outlet for flue gas and filter gas. The exist more number of free electrons due to electronic ionization full stop this occurs due to the interaction with the dust particles that makes them to be negatively charged. Particles will travel towards the positive electrodes and the because of the gravitational force it tends to falls. Apparently there is Free Flow gas since it travels through the electrostatic precipitation and it is being discharge through the chimney to the atmosphere[17].

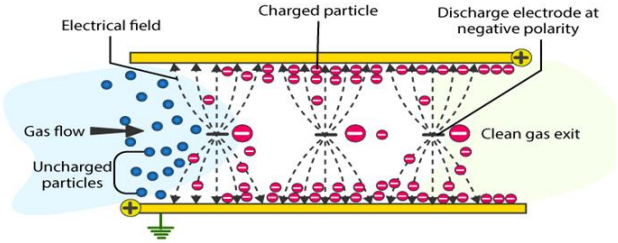

Fig.1. Electrostatic precipitator

Tube type ESP

ESP is a single stage model comprising high voltage electrode tubes which are parallely arranged to one another and runs on their axis. The tube arrangement maybe either square, circular, or hexagonal honeycomb. The gaseous particles will flow towards upwards motion download motion. The gas passes throughout all the tubal region and removes the sticky particles. High pressure and high temperature are in favorable to each other that promotes the favorable operation of wire plate design and wire tube geometry. Hence ESP is easy to clean and has other benefits like easy handling[18].

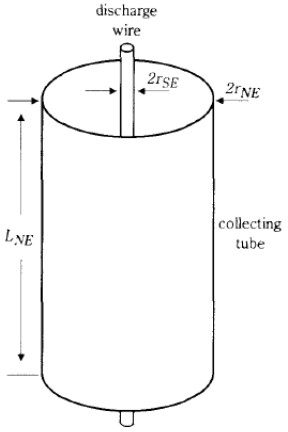

Fig.2. Tube type ESP

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Plate type ESP

This precipitator contains several rows of stacks and thin vertical wires that are arranged vertically to the metal plates under being placed at 1 cm to 18 cm distance apart. Air stream passes through huge stack of plates and horizontal to the vertical plates. A negative voltage has been employed between the plate and the wire for particle ionization. These particles were made to be diverted to the ground plates with the employment of electrostatic force. And consequently they are eliminated from the air stream when the particles are collected on collection plate. The collecting electrode maybe a tube or a plate as well as the discharging electrode can be a wire. When air flow into ESP it starts working and generates high voltage electric field produced to buy the electrode and wire. The positive and negative component develops after gas ionization. The negative ions will travel to the generated electric current in which the certain ions will be subjected to particle diffusion followed by charging. Because of the electrostatic force the charged particle will be migrated to the collection plate and hence the particles are being deposited into the collecting electrodes. Finally the EXP removes the corresponding suspended particulate form the electrode[19]

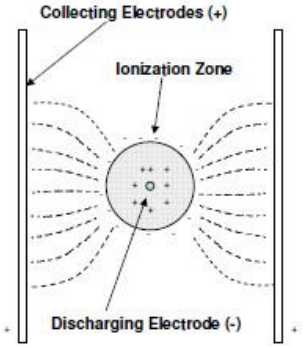

Fig.3. Plate type ESP

Corona formation and discharge characteristics of ESP on CI engine

On air environment, diesel engines emitted the harmful substances in exhaust gas like nitrogen oxides, sulfur compounds and other particulate matter shows higher impact. Specifically in PM, the black carbon shows negative impact on the global warming. Exhaust gas using the fuels which comprised with heavy fuel oil shows higher temperature and PM concentration. Hence the generate diesel particulate filter will not be appropriate since it leads to minimal efficiency and clogging for collection. Likewise various other issues are arise due to harmful substances in diesel engine and therefore electrostatic precipitator with simpler structure, greater collection efficiency with greater concentration particles and reduced pressure loss can be considered. For improving the efficiency the corona discharge generation is considered used for ESP stable operation[20-22].

Formation of corona

Formation of corona is to ionizable gas, which generates stronger electric field near the electrode for the molecule energy. Generally the air compounds are ionized easily through potential electric field wither in clean or polluted air. Corona is the place of several chemical reactions, generates current in positive and negative ions for electrostatic corona normal air. Chemical reactions are formed in positive and negative corona shows variation and related with positive corona the negative corona produce twice current. Based on discharging electrode polarity, corona type and charge will be communicated. When the discharge electrode is negative, the negative ionic current produce from corona and travels to collecting electrode from discharge electrode through air gap. Alternatively, n the discharge electrode shows positive, the corona produces positive ionic current and travels to collecting electrode it travels from discharge electrode. In terms of efficiency of particle collection, negative corona performs well[23].

Applications

The application for corona discharge process occurred over hundred years concerning to initial lodge

electrostatic precipitator. Since then in multiple commercial ways corona has used widely and acquired attention for use in other applications. Corona discharges are associatively lower power electrical discharges which carried out at or close by atmospheric pressure. The corona is always generated by stronger electric fields related with smaller diameter wires, sharp edges, needles on electrode. Significantly corona taken its name 'crown' from the discharges observation of mariner from masts of ships during an electrical storms. From the discharge electrode, corona appears as faint filamentary which is discharge outward radiating. Since corona is associatively easy in establishing, it shows wide application in different process. The application of corona process gives importance to two aspects such as energetic electrons in plasma production or ions produced. The identities of ions are based on gas mixture characteristics and polarity of discharge particularly on electron attaching species. Energies of electron are based on characteristics of gas and on corona generation technique. In simple, for the application using the ions, small fraction is occupied by corona induced plasma zone, compared with total volume process, the process which using the electrons fills most of volume with plasma[24].

Corona types

Corona discharges has been presented in different forms based on electrode geometrical configuration and field polarity. In configuration of needle plate electrode with positive corona, the discharges are begins with burst pulse corona and to with glow corona, streamer corona and spark discharges it proceeds as increase in applied voltage seen. In similar geometry of negative corona the starting form is the trichel pulse corona which is followed by spark discharge and pulseless corona as increase in applied voltage observed. For the wire-plate or wire-pipe electrode configuration, at positive wire electrode corona generated and it may appears as steamer moving away from electrode or as tight sheath around electrode. Corona generated at an negative electrodes moves as glow or focused into beads or tufts considered as smaller active spots. Negative corona propagates generally through ionization effect of gas molecules. For its propagation, positive corona is based more on photoionization[6].

Generally corona discharge is limited space charge magnitude because in inter electrode space the plasma emitted ions with singe polarity accumulated. It provide the corona a characteristic of positive resistance which increases in the current needs higher voltages for drive them. If the current in discharge is increases then extra current carrying species produces and resulted in spark discharges. The spark is generally characterized through characteristic of negative resistance however the corona discharge transition to spark discharge is not determined sharply. In ESP corona is generated at greater voltage electrodes generally round wires which are centered among the flat collecting plates. The corona plasma only lodges lesser volume near the wire and corona ions filled the remaining inter-electrode space. In this region movement of particles and charging carried out. For the best dust particles charging environment with lesser power consumption, industrial precipitator performs in negative corona for streamers formation avoidance and lesser sparking potential related with them. In the field charging regime the particle diameter persists the ESP collection efficiency is proportional to electric field squares among the electrodes. Alternatively, the field strength maximizing is the designers major goal. Corona ions serves to charge the dust particles individual as through ESP the gas carries out. Similarly the electric field pushes the particles on aside the counter electrodes, are referring the flat collecting plates[25].

The nudge word is used since the gas flow turbulent velocity alterations are greater than particle velocity which attains in still air. The whole process of particle collection is statistical and explained through negative exponential in treatment time or length. Nearly space charge immobile created through particulate charging related with ionic carriers of greater mobilities. The space charge impacts the corona generation leads to higher kv voltage with no particles occurs at similar current. The particulate density is sufficient in absorbing all ions for extremely fine particulate fumes before the counter electrode reached. The ESP performs with no current in these case even several particles are charged and detached. For the ozone production reduction, indoor air cleaner operated with positive corona. From the collection, particles charging is separated usually. Both process are optimized here

and results shows better one attained through standard one-stage model. The smaller volume of gas treated permits the indoor cleaner which is sized more conservatively compared with industrial unit. ESP full description needs more considerations and without ion source of corona the ESP will not be perform[25].

The technologies are seems capable in controlling the sulfur and nitrous oxides and there shows no developments in controlling CO2 emissions previously other than trees planting. However most of the CO2 removing from flue gases are with intensive energy and most of utility output needs direct cleaning impact. The methods utilized are dry absorption technique which is the CO2 absorption through Zeolite, wet absorption method which is the CO2 absorption by liquid and technique namely membrane separation. The construction cost experienced becomes 70 percent increase in plant cost and whole efficiency of power plant decreased to 34 percent from 42 percent current. Nearly 90 percent of emitted CO2 is recovered from these processes. The CO2 reduction examined from the different studies through flue gas combustion using corona discharge in certain period with NO and SO2 reduction. The most effective method is the corona discharge process in removing the CO2, SO2 and NO from diesel engine[26].

A diesel engine exhibits greater thermal efficiency compared with gasoline engine which exhausts only lesser carbon dioxide. But the more particulate matter and nitrogen oxide comprised with diesel exhaust. In 40-120 nm range, particulate matter emitted from the diesel engine are smaller. It generates environmental pollution and human health are impacted. Hence different methods are came into exists for addressing the harmful substances removal shown in comparative analysis table below. Here it shows the ESP with corona discharge considered as focused solution in all studies with smaller pressure drop and collective efficiency as an advantage[23].

Comparative analysis

Table 1: Comparative analysis

S.No.	Author	Objective	Type of fuel	Technique	Outcome	Benefits/Limitations
	[6]	Emission reduction setup designed for smoke, NO, CO and HC reduction continuously.	Ignite engine compression from exhaust fuelled with WCO and diesel.	Based on ESP and corona discharge plasma generation technique-emission reduction setup.	For WCO and diesel, NO emission reduced as 20.8 and 16.9, HC emission decreased by 62 and 63. Also CO emission decreased by 60.4 and 53 at full load.	ESP decrease the pollutants from engine's exhaust gas without engine modifications. Hence the research should be carried out in identifying the energy spent on ESP operation and required power optimization, thus balance can exists among the energy requirement and emission reduction efficiency of the model.
2.	[26]	The incineration and collection mechanism	Actual exhaust gas experiment	Comparison of different combination of	PM reduction energy efficiency is measured	Also it is assured that the reduction efficiency maintains for longer period of time.

		in PM after treatment method	performed through 10NL/min sampling from flue gas stationary diesel engine generator.	voltage applied to every corona needles and electrode surface	as 5.2g (PM)/kWh which is measured from measured power average.	
3.	[27]	Examine the emission of nanoparticles collection characteristics from diesel engine in ESP	ESP and diesel engine 400 cc., for engine light fuel oil and residual fuel oil is used.	ESP and corona discharge	In exhaust gas, increased nanoparticle concentration using the residual oil is due to the binary homogenous nucleation and ion induction.	The amount of nanoparticle is raised due to the negative polarity corona discharge which shows higher compared with positive polarity at similar voltage. An optimum voltage is used for concentration of nanoparticle suppression exists for the collection efficiency.
4,	[28]	Emission reduction using the alternative diesel emission control approach.	Full diesel engine exhaust gas.	HVD- High voltage Discharge treatment performed in laboratory scale reactor with full diesel engine exhaust gas. DBD- a dielectric barrier discharge reactor used in diesel exhaust gas direct	Gas composition analysis pointed out the free radical generation of O3, e, OH, O and N through HVD system indicated by No/NO3 ratio and O3 and Co concentration increase. Further the HVD generated free radicals directly	Through PR emission attention recently understanding of the diesel PM oxidation behaviors is further researched using TEM, Raman and DSC enables more insight on advantageous for diesel particle emission reductions.

				contact at temperature of atmosphere with 200 and 400 J/L input energy density	influence the DeNOx, DeNO, CO2 and Co and NO/NO3 selectivities.	
5.	[24]	ESP development parallel plates in CO2 and CO gas pollutants reduction.	Used the diesel engine smoke samples which is possible in reacts with Sox, NOx and other pollutants of molecules	ESP with corona plasma with DC higher voltage generator circuit.	Highest CO reduction efficiency attained through type of parallel ESP plate with 80.7 percent efficiency at 2L/m air flow rate and 2 kV voltage. CO2 reduction efficiency attained as higher on ESP plate type which is parallel with 79 percent efficiency at 2L/m air flow rate and 2 kV voltage.	Electrostatic deposition reduction measurement model performed and used as ESP development parallel plates in decreasing the CO2 and CO gas pollutants.

Conclusion

In this study, the comprehensive review is performed using the different epidemiological and biological and mechanical studies. The evidence are analysed and shows that harmful substances can cause severe health effects which can penetrate to cell membranes, enters into blood and reaches the brain. Thus the ESP is one of the methods in reduce these particulate matters in diesel engine. Different measurement methods are discussed in diesel particle composition discussion. In this review the

fundamental of ESP, working principle, corona formation with applications and types are illustrated. Further comparative analysis performed in exhibiting the outcomes, benefits and limitation of the research.

References

[1] M. Raza, L. Chen, F. Leach, and S. Ding, "A review of particulate number (PN) emissions from gasoline direct injection (GDI) engines and their control techniques," Energies, vol. 11, no. 6, p. 1417, 2018.

[2] A. Kozina, G. Radica, and S. Nižetić, "Analysis of methods towards reduction of harmful pollutants from diesel engines," Journal of Cleaner Production, vol. 262, p. 121105, 2020.

[3] P. Ni, X. Wang, and H. Li, "A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines," Fuel, vol. 279, p. 118477, 2020.

[4] R. Suarez-Bertoa et al., "Impact of HVO blends on modern diesel passenger cars emissions during real world operation," Fuel, vol. 235, pp. 1427-1435, 2019.

[5] P. Bielaczyc and J. Woodburn, "Trends in automotive emission legislation: impact on LD engine development, fuels, lubricants and test methods: a global view, with a focus on WLTP and RDE regulations," Emission Control Science and Technology, vol. 5, no. 1, pp. 86-98, 2019.

[6] A. Sonthalia, S. Garg, R. Sharma, T. Subramanian, and N. Kumar, "Effect of electrostatic precipitator on exhaust emissions in biodiesel fuelled CI engine," Environmental Science and Pollution Research, vol. 28, no. 10, pp. 11850-11859, 2021.

[7] R. M. Harrison et al., "Diesel exhaust nanoparticles and their behaviour in the atmosphere," Proceedings of the Royal Society A, vol. 474, no. 2220, p. 20180492, 2018.

[8] J. Fang et al., "The effect of operating parameters on regeneration characteristics and particulate emission characteristics of diesel particulate filters," Applied Thermal Engineering, vol. 148, pp. 860-867, 2019.

[9] G. Szabados, Á. Bereczky, T. Ajtai, and Z. Bozóki, "Evaluation analysis of particulate relevant emission of a diesel engine running on fossil diesel and different biofuels," Energy, vol. 161, pp. 1139-1153, 2018.

[10] B. Giechaskiel et al., "Particle number measurements in the European legislation and future JRC activities," Combustion Engines, vol. 174, no. 3, pp. 3-16, 2018.

[11] M. Hoogsteen, E. Lantinga, E. Bakker, and P. Tittonell, "An evaluation of the loss-on-ignition method for determining the soil organic matter content of calcareous soils," Communications in Soil Science and Plant Analysis, vol. 49, no. 13, pp. 1541-1552, 2018.

[12] B. Apicella et al., "Effect of after-treatment systems on particulate matter emissions in diesel engine exhaust," Experimental Thermal and Fluid Science, vol. 116, p. 110107, 2020.

[13] P. Kheirkhah, A. Baldelli, P. Kirchen, and S. Rogak, "Development and validation of a multi-angle light scattering method for fast engine soot mass and size measurements," Aerosol Science and Technology, vol. 54, no. 9, pp. 1083-1101, 2020.

[14] K. Jiang, F. Yan, and H. Zhang, "Hydrothermal aging factor estimation for two-cell Diesel-engine SCR systems via a dual time-scale unscented Kalman filter," IEEE Transactions on Industrial Electronics, vol. 67, no. 1, pp. 442-450, 2019.

[15] A. Teo, M. Chiong, M. Yang, A. Romagnoli, R. Martinez-Botas, and S. Rajoo, "Performance evaluation of low-pressure turbine, turbo-compounding and air-Brayton cycle as engine waste heat recovery method," Energy, vol. 166, pp. 895-907, 2019.

[16] A. T. Sobczyk et al., "Particulate matter emission reduction from marine diesel engines by electrohydrodynamic methods," Journal of KONES, vol. 26, no. 3, pp. 203-210, 2019.

[17] S. Yang et al., "Plasma-enhanced electrostatic precipitation of diesel exhaust using high voltage nanosecond pulse discharge," Journal of Environmental Chemical Engineering, vol. 9, no. 6, p. 106565, 2021.

[18] A. Zukeran, Y. Nanjo, K. Ito, and T. Inui, "Removal of polycyclic aromatic hydrocarbons emitted from diesel engine using an electrostatic precipitator and heat exchanger," IEEE Transactions on Industry Applications, vol. 54, no. 6, pp. 6430-6438, 2018.

[19] K. Ito, R. Tamura, A. Zukeran, Y. Kawada, and T. Taoka, "Simulation and measurement of charged particle trajectory with ionic flow in a wire-to-plate type electrostatic precipitator," Journal of Electrostatics, vol. 107, p. 103488, 2020.

[20] T. Yamamoto, S. Maeda, Y. Ehara, and H. Kawakami, "Development of EHD-assisted plasma electrostatic precipitator," IEEE Transactions on Industry Applications, vol. 49, no. 2, pp. 672-678, 2013.

[21] Y. Ehara, M. Kobayashi, H. Muramatsu, A. Zukeran, H. Kawakami, and T. Inui, "Diesel PM incineration for marine emissions using dielectric barrier discharge type electrostatic precipitator," in Proc. ESA Annu. Meeting Electrostatics, 2013, pp. 1-8.

[22] A. Zukeran, K. Ninomiya, Y. Ehara, K. Yasumoto, H. Kawakami, and T. Inui, "SOx and PM removal using electrostatic precipitator with heat exchanger for marine diesel," in Proc. ESA Annual Meeting on Electrostatics, 2013, p. 1.

[23] Z. Yuan, K. Suzuki, Y. Ehara, J. Ikeda, K. Yamashiro, and T. Takano, "Corona discharge characteristics in electrostatic precipitator under high temperature," IEEE Transactions on Industry Applications, 2021.

[24] D. Anggoro, M. R. Hidayat, R. P. Putra, R. A. Wiranata, and I. Fatimah, "Optimization of CO and CO2 Gas Reduction System Based on Electrostatic Precipitator (ESP)," in Journal of Physics: Conference Series, 2021, vol. 1951, no. 1: IOP Publishing, p. 012037.

[25] J.-S. Chang, P. A. Lawless, and T. Yamamoto, "Corona discharge processes," IEEE Transactions on plasma science, vol. 19, no. 6, pp. 1152-1166, 1991.

[26] K. Yoshida, "Aftertreatment of carbon particles emitted by diesel engine using a combination of corona and dielectric barrier discharge," IEEE Transactions on Industry Applications, vol. 55, no. 5, pp. 5261-5268, 2019.

[27] A. Zukeran, H. Sawano, and K. Yasumoto, "Collection characteristic of nanoparticles emitted from a diesel engine with residual fuel oil and light fuel oil in an electrostatic precipitator," Energies, vol. 12, no. 17, p. 3321, 2019.

[28] T. Wongchang, S. Sittichompoo, K. Theinnoi, B. Sawatmongkhon, and S. Jugjai, "Impact of High-Voltage Discharge After-Treatment Technology on Diesel Engine Particulate Matter Composition and Gaseous Emissions," ACS omega, vol. 6, no. 32, pp. 21181-21192, 2021.