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Review on Enhancement of Electrostatic Precipitator in Automobiles

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Abstract: *The Electrostatic Precipitator (ESP) is a widely employed device in boilers to mitigate the release of particulate matter. This study proposes the design and fabrication of a similar device tailored for reducing emissions from automobiles, particularly targeting older versions of BS vehicles lacking dedicated emission control mechanisms. Despite the catalytic converters equipped in BS-6 vehicles, there exists a need for an efficient emission reduction solution for their predecessors. This research aims to analyse various ESP designs through Computational Fluid Dynamics (CFD) simulations using ANSYS software. The design optimization will be conducted based on fluid flow analysis, leading to the fabrication of the most optimal prototype. The final step involves testing the fabricated prototype to ensure compliance with Pollution Under Control (PUC) standards, contributing to environmental sustainability.*

Keywords: *automobiles, emission, analysis, prototype, optimal, sustainability.*

1. INTRODUCTION

The escalating concerns regarding vehicular emissions and their adverse environmental impact have underscored the necessity for innovative solutions. While modern automobiles, conforming to BS-6 standards, integrate catalytic converters for emission control, the same cannot be said for their predecessors adhering to earlier standards. In light of this, the Electrostatic Precipitator (ESP) emerges as a promising device for mitigating particulate matter emissions from older vehicles lacking dedicated control mechanisms. this research endeavours to address the gap by proposing the design and fabrication of an ESP specifically tailored for automobiles. The study involves a comprehensive analysis of various ESP designs using Computational Fluid Dynamics (CFD) simulations executed through ANSYS software. The focus lies on optimizing the device's design based on fluid flow analysis, with the ultimate goal of fabricating the most efficient prototype. The significance of this research extends beyond theoretical considerations, as the fabricated prototype will undergo practical testing to ensure its effectiveness in meeting Pollution Under Control (PUC) standards. By providing a viable solution for emission control in older vehicles, this study contributes to environmental sustainability and aligns with the broader efforts to curtail the impact of vehicular emissions on air quality.

Particle collection: It focuses on the electrohydrodynamic flow in the ESP. It focuses on reducing the escape window in the inlet of an ESP. The approach was based on a modification of ESP's geometry and increasing in voltage. The increase in voltage helps to attract finer particles and coarse particles. The numerical approach was based on corona discharge, gas flow dynamics and particle motion dynamics EHD flow analysis, Particle flow analysis, Multiparticle motion, Particle dispersion pattern and deposit pattern and particle collection efficiency are analysed. It is observed that collection efficiency is greatly improved.[1] It is based on increasing dust dust-collecting efficiency of an ESP. The collection efficiency of an ESP is affected by mud particles collected by the electrodes. Conventionally these mud particles are removed by creating vibrations. It aims to improve the vibration conditions. Modelling and FEA analysis of the electrodes are done along with the Implicit Transient Dynamic Analysis. A hammer hammer-punching mechanism is used to create the vibration in the ESP. The enhancement is done based on parameters such as applied voltage and flow of air.[2] It aims to investigate the effects of repetitive voltage impulses on the treatment efficiency of soot particles and to compare results with those achieved when a DC supply is used. Experiments have been performed on a motor test bench where the temperature and flow velocity of the exhaust gas are perfectly controlled. Several configurations of power supply have been tested at four-engine revolution speeds.[3 The aim to reduce PM 2.5 emissions using a two-stage electrostatic precipitator (ESP), but several technical challenges must be addressed. Key considerations include optimizing charging efficiency for PM 2.5 particles, minimizing ozone emissions from corona discharge, and improving collection efficiency for high-resistivity particles.[4] Maintenance and cleaning protocols, integration with other pollution control devices, and addressing power consumption and operating costs are also crucial. Additionally, managing temperature and moisture effects, and ensuring consistent collection efficiency across different operational conditions, are essential for the success of the ESP system in reducing PM 2.5 emissions. It addresses the issue of fine carbon particle emissions in internal combustion engine exhaust, even when using biofuels. Traditional ceramic filters burn these particles during regeneration, releasing more CO2. The study introduces an electrostatic precipitator using wood ceramics, an eco-friendly material made from sawdust, as grounded electrodes. Varying firing temperatures during production adjust wood ceramics' resistivity and roughness. Compared to stainless steel, wood ceramics show higher resistivity and roughness.[5] The research evaluates their impact on the electrostatic precipitator's electric field, calculates charge distribution, and assesses the particle-collection efficiency through experiments. This eco-friendly solution aims to effectively capture and manage fine carbon particles in exhaust gases. While discussing the optimization of pipe and spike discharge electrodes using a numerical method. The researchers employed a numerical model to predict the collection efficiency of an Electrostatic Precipitator (ESP), and the results were validated through experiments. The findings indicate that the dust collection efficiency of the ESP increased by approximately 15% after the optimization process. This suggests that the numerical approach to electrode design had a positive impact on the ESP's performance, as confirmed by experimental results.[6]

Maintenance: It gives a detailed view of the construction, working types and maintenance of ESP in boilers. The construction of a generic industrial electrostatic precipitator is discussed. The ionisation of gas particles is discussed in detail. The types of ESPs are listed and described along with the advantages and disadvantages of using an ESP. An expedition of components consisting of an ESP is given. Then the commissioning of ESP is explained. It was followed by safety measures, maintenance and emission standards. The terminologies used in ESP are enlisted at the end of the paper.[7] It is focused on addressing the challenge of capturing ultrafine black carbon emitted from ships and vehicles, particularly those difficult to trap using standard Electrostatic Precipitators (ESPs). The research explored the use of a square-grooved collecting plate. The findings revealed that increasing voltage had a notable impact on reducing larger black carbon particles; however, its effectiveness diminished for particles below 20 nm. The study also experimented with slowing the flow rate, which proved to be more effective in capturing smaller particles. This adjustment resulted in an impressive capture efficiency of over 90% for particles ranging from 20 to 100 nm. These insights offer a potential solution for enhancing the collection of ultrafine black carbon, especially in the challenging size range of 20-100 nm, through tailored adjustments in voltage and flow rate.[8] Traditional industrial electrostatic precipitator designs rely on high-voltage currents. However, a novel approach is suggested for the charging sections, utilizing the properties of materials commonly found in thermocouples. This design employs thermocouple materials for constructing the chambers of electrostatic precipitators, eliminating the need for high-voltage currents. The proposed design offers an alternative solution for efficient air pollution control without the use of high voltage.[9] Electrostatic Precipitators (ESPs) commonly encounter the challenge of dust accumulation on collecting electrodes, affecting their efficiency. To address this, a cleaning method known as 'rapping' is employed. In this design, collecting plates are arranged in parallel, suspended from the Top Hangers at the top and connected to the Bottom Hangers at the base. The dusty gas flows between these plates. An anvil is positioned at the bottom-middle side of these plates. To facilitate periodic cleaning, a rotating hammer mechanism is utilized. This hammer is attached to a rotating shaft powered by an electric geared motor. The hammer continuously taps on alternating collecting plates, each having anvils at their base. This process ensures consistent and periodic rapping, causing vibrations that detach accumulated dust and allow it to fall into hoppers for efficient cleaning.[10]

Types of collecting plates: This gives us the study of various positions of corona discharge and 6 different w-type geometries. The results were compared with benchmarks. The collection efficiency of particles with a radius of range 0.01 - 5 μm is taken as a result and compared with the benchmark efficiency.[11] The introduction to a new way to handle the edge of a wire-plate electrostatic precipitator, a device that cleans air. The traditional method is adjusted for better accuracy. The change is validated by comparing it with past experiments, showing that this new approach gives more accurate results than the old one.[12]

Various test methods: Re-entrainment phenomenon decreases the collection efficiency of the esp. The collected particles sometimes get neutrally charged and therefore get detached from the electrode. This is called re-entrainment and these particles are known as re-entrained particles. This paper gives a study on these RPs using the particle image velocimetry method. This study helps in increasing the collection efficiency of ESP by reducing the RPs.[13] In a recent study evaluating a new filtration arrangement of electrodes, it was found that PVC particles produce a higher corona discharge current than incense smoke particles due to their larger surface area. The new electrostatic precipitator (ESP) design shows better efficiency in submicron particles than micron ones it is attributed to the electrode design the compact size of the ESP and the high resistivity levels of the particles. The system's collection efficiency also increases with higher voltage and larger particle diameters. Further research is needed to know the effectiveness of varied fly ash samples.[14] This focuses on optimizing the design of turning vanes in the ESP with minimal pressure drop. Various turning vane designs differ mainly in the inclusion of guide vanes at the inlet and outlet elbows, and the count and geometry of the guide vanes in the diffuser. The research revealed that the presence of guide vanes at the inlet greatly improves flow uniformity, while those at the outlet had a positive but lesser impact. Generally, more blades in the diffuser enhanced flow homogeneity. The best design was chosen for better flow uniformity across the ESP chamber after the redesign. The old vane design underscores the efficacy of the new vane design in enhancing particulate emission reduction.[15]

Analysis: The study involves assessing the interference of a two-stage electrostatic precipitator (ESP) in controlling particulate matter (PM) emissions from a stationary internal combustion engine (SI engine) fuelled by fossil fuels in rural areas. Initially, baseline PM levels were measured without the ESP in villages. The ESP was then designed and implemented to mitigate PM emissions from the SI engine. During a one-hour operational test of the SI engine with the ESP, PM levels were monitored and compared with the baseline values. The effectiveness of the ESP in reducing PM emissions was evaluated, considering factors like engine load and ambient conditions. The study aims to determine the practical implications of ESP implementation in rural areas for controlling PM emissions and may provide recommendations for optimizing ESP performance in such settings.[16] It presents the concept of incinerating captured particulates within the same reactor, focusing on the experimental setup for the Plasma Electrostatic Precipitator (ESP). The study demonstrates that the Electrohydrodynamic (EHD)-assisted plasma ESP achieved a collection efficiency of more than 90%. This suggests that the incorporation of EHD assistance in the plasma ESP system significantly enhances its effectiveness in capturing particulates, showcasing its potential for efficient particulate removal within the experimental framework.[17] The system focuses on a diesel emission control system employing an Electrohydrodynamic (EHD)-assisted Electrostatic Precipitator (ESP) for particulate matter (PM) collection. Additionally, it incorporates a nitrogen plasma system to address NOx emissions. The results demonstrate a collection efficiency of over 90% for particulate matter, indicating the system's efficacy in capturing and controlling PM emissions. Furthermore, the system exhibits a notable suppression of particle re-entrainment. Regarding NOx removal, the surface discharge plasma reactors achieved a remarkable efficiency of more than 90%. This suggests the potential of the combined EHD-assisted ESP and nitrogen plasma system for effective and comprehensive control of both particulate matter and nitrogen oxide emissions in diesel exhaust.[18] The research looks at using a special kind of plasma (nanosecond pulse transient plasma or NPTP) in a device (coaxial electrostatic precipitator) to clean very tiny soot particles produced by burning ethylene. They tested two setups with different sizes. When they used only a high voltage, they could clean almost all the soot, but at lower voltages, the cleaning efficiency dropped. With the addition of NPTP, they saw a significant improvement in cleaning efficiency, especially at lower voltages. The key is that NPTP generates more ions that help clean the soot particles. This research suggests that using NPTP in electrostatic precipitators can be a more effective way to clean air pollution caused by small soot particles.[19]

2. EFFICIENCY IMPROVEMENT

It demonstrates the efficacy of incorporating a special liquid, known as a wetting agent, to enhance the performance of an Electrostatic Precipitator (ESP) in capturing fly ash particles from the air. The key findings reveal that utilizing a mixture in the ESP resulted in a remarkable 60% increase in fly ash capture. The introduced wetting agent, composed of SBE and T-100 as the agglomeration solution, played a crucial role. It facilitated the grouping of smaller particles into larger aggregates, allowing for more effective capture within the ESP. The improved spreading of the special liquid on the fly ash contributed significantly to the enhanced trapping of fly ash particles. This method offers a promising approach to augment the efficiency of ESPs in capturing airborne fly ash by utilizing a specific wetting agent mixture.[20] It also demonstrates that employing a two-stage Electrostatic Precipitator (ESP) system enhances the efficiency of collecting smaller particles. This finding suggests that the dual-stage setup is effective in capturing and removing finer particulate matter, potentially providing improved air quality control compared to a single-stage ESP. The utilization of multiple stages in the ESP system appears to be a promising approach for enhancing the overall collection efficiency, particularly for smaller particles in the air.[21] The study reveals that the diameter of holes in the Electrostatic Precipitator (ESP) significantly influences the efficiency of particulate matter (PM) collection. In a series of hole diameters, namely 1mm, 2.5mm, and 5mm, distinct collecting percentages of PM were observed. Notably, the findings indicate that the ESP with 5mm diameter holes outperformed the others in terms of PM collection efficiency. This suggests that, within the given series, the larger 5mm holes are more effective in capturing and removing particulate matter compared to the smaller hole diameters.[22] In this modification, aluminium electrodes underwent a coating process with an activated carbon paste mixture. This coating led to an increase in specific capacitance and a reduction in electrode resistance. As a result, the removal efficiency experienced a significant 31% improvement. To address back-corona discharge, which can diminish collection efficiency, insulating material was strategically inserted between the electrode plates. This addition not only enhanced dust collection but also outperformed the collecting electrodes in capturing particulate matter. Ultimately, the system featuring activated carbon-coated electrodes and insulating material proved to be the most effective in improving overall performance.[23] It represents a practical experiment involving the installation of an Electrostatic Precipitator (ESP) on a two-wheeler, specifically an Activa 3G. The study provides a detailed report on the percentage of carbon monoxide and hydrocarbon trapped by the ESP. By conducting this experiment, the researchers aim to evaluate the effectiveness of the ESP in reducing emissions from the two-wheeler, particularly in terms of carbon monoxide and hydrocarbon levels. The findings offer insights into the potential of using ESP technology for pollution control in small vehicles.[24]

Used in various sector: It discusses the use of electrostatic precipitators (ESPs) in Japanese road tunnels to address visibility issues caused by diesel engine emissions from large vehicles. With Japan's mountainous landscape, long tunnels exceeding 2 km have been constructed, and ESPs are installed in bypass tunnels to improve driver visibility. The paper introduces a new (spiked) plate-type ESP designed specifically for road tunnels, offering enhanced efficiency compared to traditional wire-type ESPs. Additionally, the paper highlights an ozone reduction method using intermittent high-frequency power supply energization. This technology aims to provide practical solutions for visibility and air quality challenges in road tunnels, contributing to safer and more environmentally conscious transportation infrastructure.[25] The system operates on electrostatic precipitation and consists of two Electrostatic Precipitators (ESPs) placed at both ends, with a low-voltage brushless fan in the middle. Ceramic foam filters are positioned at both ends of the system. The process begins with the first filter, which blocks larger particles and directs the air through the first-stage ESP. Assisted by the brushless fan, the air then passes through the second-stage ESP before finally flowing through the ceramic foam filter at the end. This design effectively reduces diesel engine emissions by 40%.[26]

3. DESIGN AND FABRICATION OF ESP

The main goal of this paper is to investigate how well an electrostatic precipitator (ESP) can remove particles of various sizes, considering different operational conditions. The study also aims to compare the actual collection efficiency of the ESP with predictions made by existing theoretical models. Two types of ESPs are discussed: the tubular precipitator and the plate precipitator. When the discharge and collection electrodes are subjected to vibrations (rapped), the particles collected are dislodged and fall into a hopper for subsequent removal from the system.[27] This paper provides insights into three different modes of operating Electrostatic Precipitators (ESPs): DC mode, AC mode, and AC mode with a neutralizer. It discusses the arrangement of the ESP and identifies sampling locations for a comprehensive understanding of its performance. The focus is on comparing the DC and AC operating modes and exploring the impact of introducing a neutralizer in the AC mode. The paper aims to offer a detailed perspective on the configuration and operation of ESPs, shedding light on their effectiveness under different conditions.[28] While describing the development of an electrostatic precipitator using a circuit designed in MATLAB-SIMULINK. Additionally, fluid flow analysis of the electrostatic precipitator is conducted using ANSYS CFX to optimize fluid dynamics and minimize back pressure. The combined approach involves circuit design in MATLAB-SIMULINK and computational fluid dynamics analysis in ANSYS CFX, aiming to achieve an efficient and well-performing electrostatic precipitator with reduced back pressure.[29] It discusses the impact of an electrostatic precipitator on exhaust emissions in a Compression Ignition engine fuelled by biodiesel. It demonstrates that the emission reduction setup can effectively decrease emissions without compromising engine performance. The study employs a Kirloskar TAF-1 engine, a four-stroke, air-cooled, direct injection, single-cylinder engine, to assess the effects of the electrostatic precipitator on exhaust emissions, emphasizing the potential for cleaner and more environmentally friendly operation.[30]

4. CONCLUSION

ESP in Rural Areas: A study focuses on using electrostatic precipitators (ESP) to control PM emissions from fossil fuels in rural villages. Modified ESP Electrodes: Coating Aluminium electrodes with activated carbon paste increases efficiency by 31%, reducing diesel engine emissions. Diesel Emission Control: A new design integrates EHD-assisted ESP and a nitrogen plasma system, achieving over 90% PM and NOx removal in diesel exhaust. Fly Ash Capture Improvement: Adding a wetting agent to an ESP enhances fly ash particle capture by 60%, offering a more effective solution for airborne fly ash. Road Tunnel Emission Control: Combining EHD-assisted ESP and a nitrogen plasma system in road tunnels reduces diesel engine emissions by over 40%. PM Reduction in Biofuel Engine: ESP reduces exhaust emissions in a biodiesel-fuelled Compression Ignition engine without compromising performance. ESP Cleaning Mechanism: Periodic cleaning of ESP collecting electrodes is achieved through 'rapping,' using vibrations to dislodge and remove accumulated dust. Theoretical Models Validation: A study evaluates ESP performance using theoretical models, comparing predictions with actual collection efficiency under different operational conditions. Dual-Stage ESP: Using a two-stage ESP system enhances efficiency in capturing smaller particles, improving air quality control compared to a single-stage ESP. Nanosecond Pulse Transient Plasma: Implementing nanosecond pulse transient plasma in an ESP significantly improves remediation efficiency, especially at lower DC voltages.

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