IOP Conf. Series: Materials Science and Engineering **310** (2018) 012137 doi:10.1088/1757-899X/310/1/012137

Design and Optimisation of Electrostatic Precipitator for Diesel Exhaust

A.Srinivaas[1], Samanyu Sathian[1], Arjun Ramesh[1]
Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Amrita University, India

E-mail: a_srinivaas@cb.amrita.edu

Abstract. The principle of an industrially used emission reduction technique is employed in automotive diesel exhaust to reduce the diesel particulate emission. As the Emission regulation are becoming more stringent legislations have been formulated, due to the hazardous increase in the air quality index in major cities. Initially electrostatic precipitation principle and working was investigated. The High voltage requirement in an Electrostatic precipitator is obtained by designing an appropriate circuit in MATLAB -SIMULINK. Mechanical structural design of the new model after treatment device for the specific diesel exhaust was done. Fluid flow analysis of the ESP model was carried out using ANSYS CFX for optimized fluid with a reduced back pressure. Design reconsideration was done in accordance with fluid flow analysis. Accordingly, a new design is developed by considering diesel particulate filter and catalytic converter design to ESP model.

1 INTRODUCTION

Automotive emission regulation is one of the major problem faced by the automotive manufactures. Due to the hazardous increase in the air quality index in major cities legislations have been formulated that are very stringent. Research & development of different range of effective after treatment devices like catalytic convertors, Diesel particulate filters (DPF), Lean De-NOx catalyst, SCR catalyst, NSR Catalyst is carried out by different OEM'S around the globe. In the last few years, diesel emissions have caused increasing concerns, because of their impacts in the mainly urban areas [1]. Finer particles with diameter less than 100 nm can enter blood tissues and human brain [2][3][4]. Stricter control and more endeavours are should be adopted in order to decrease the discharge.

Numerous methods have been implemented for reduction in the particulate matter. Biofuels can rep lace the conventional fuels for achieving desired emission levels by esterification reaction using potassium hydroxide and sodium hydroxide. As a consequence of there is reduction in emission levels of smoke, carbon monoxide and hydrocarbons that remain in the mixture unburned [5].When turbocharged single cylinder engine was used emissions of NOx, HC, CO, CO2 was reduced drastically [6][7]. But implementing a turbocharger though effective is not economically viable. Generally to diminish the Particulate manner discharge, a particulate channel which is used. It comprises of a straightforward earthenware or silicon carbide channel with successive recovery [8] .But it has many drawbacks. In this manner, electrostatic precipitator (E SP) innovation has turned into a vital part to arrest particulate emissions by large, ESP have a low weight drop and low electrical utilization [9]. Sediment particulate issues are smaller than 10 μm in the climate for quite a while and low resistivity [10].

Electrostatic precipitators (ESPs) are utilized to clean the dirty condition. Customary ESPs have high accumulation productivity. Yet at the same time have an issue regarding it gathering proficiency which diminishes because of molecule re-entrainment while gathering of low resistive diesel particulates. The impact of terminal setup on gathering execution of diesel particulates was explored utilizing one - phase and two-arrange ESPs. The molecule focus for the molecule estimate scope of 20 to 5,000 nm was measured utilizing a scanning mobility particle sizer (SMPS) and a particle counter (PC). The gathered particles on cathodes were observed utilizing a scanning electron microscope (SEM). The gathering efficiencies as a component of the terminal length and the molecule distance across were evaluated. Thus, the molecule re- entrainment was stifled with expanding number of release anodes in the one-organize sort ESP and expanding accumulation terminal length of the gathering segment in the two-arrange sort ESP [11].Several parameters are considered such as particle size, dielectric constant and residence time in ESP[12]This investigation uncovers that the utilization of both DC and AC electric fields is favored over consistent DC fields for effective combination; however the choice of the ideal field recurrence from the earlier is as yet impractical and requires additionally study. Some current examinations have illuminated imperative parts of the procedure, for example, halfway blend and drop –drop non-mixture. Then again, some key marvels, for example, thin film separation and chain development are as yet misty. A few plans of inline electrocoalescers have as of late been proposed; however with constrained achievement: the insufficient learning of the basic material science still keeps this innovation from leaving the domain of observation and completely creating in one in view of thorough logical technique [13].

High voltage requirement, requires a proper High voltage power generation circuit which can convert the available power from automotive subsystems. Selection of material for the different component of the scaled down model of ESP was the next problem addressed in this project. The main two component ESP module are negative high voltage charging phase and positive high voltage collector phase. The ESP module consist of a stacked aluminum perforated tubes as positive electrode collector and hexagonally close packed perforated stainless steel tubes as negative ionizer.

2 WORKING PRINCIPLE OF ELECTROSTATIC PRECIPITATOR

ESPs are the most well-known particulate discharges control gadget which is broadly utilized as a part of coal fired power plants. ESP's just give electrostatic drive to the molecule. The gasses are not straightforwardly sent to the ESP module. It realizes a drop in weight. In this way, the cost can be dropped down when contrasted with other mechanical filtration strategies. ESP module works when the wind currents into the ESP. A high voltage electric field is produced by a utilizing a wire and a terminal. Positive and negative component formation occurs due to the ionization of the gas molecule in this setup. In this manner, negative particles will move in the electric field, making an electric current between the terminals. A portion of the particle will diffuse to the surface of molecule and charge them. Charged molecule will relocate to collecting plate because of electrostatic compel. Accordingly, the molecule will be stored on the collecting electrode. Suspended particulate from collecting electrode are evacuated in the last phase of ESP operation.

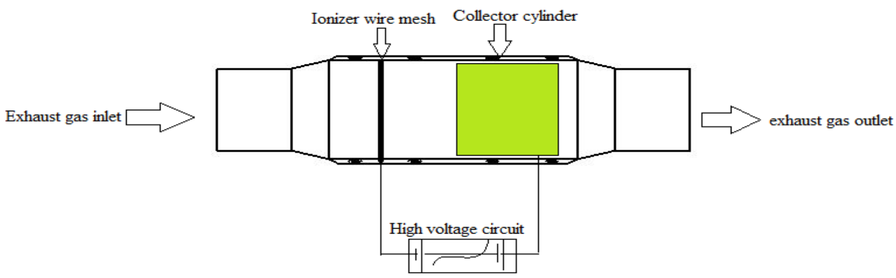


Figure 1 ESP Working layout

3 METHODOLOGY

3.1 Design and development of ESP porotype

Design of ESP (figure 2) was done taking into consideration the tubular ionizing and collecting cartridge adapted from the working and design features of Diesel particulate filter and Catalytic convertor ceramic monolith packing efficiency. In this design the ionizing is done by multiple perforated(3mm holes) conducting tube of diameter 8mm enclosed in conducting stainless steel tube with phase perforation of 8mm holes to hold the tubes. Collection of emission particle is done by aluminum

IOP Conf. Series: Materials Science and Engineering **310** (2018) 012137 doi:10.1088/1757-899X/310/1/012137

perforated tube cluster of the same dimensions as that of the ionizing cartridge. Casing is design to accommodate both the ionizing and the collecting cartridge (figure 3) is within the safe limits of spark jumping between the same.

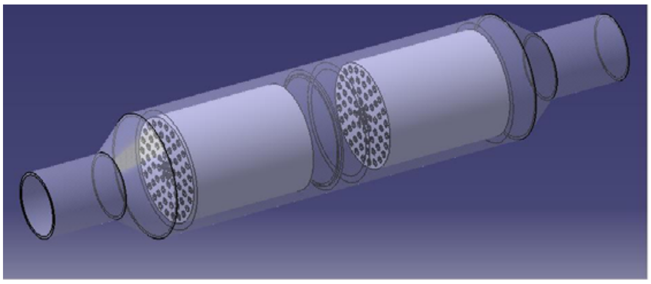


Figure 2 Concept model of ESP module

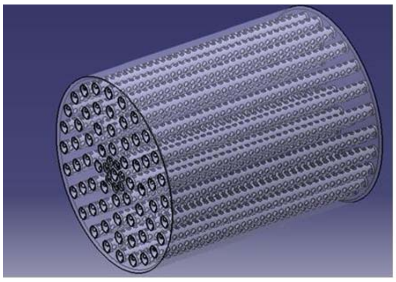


Figure 3 Cartridge design of ESP module

3.2 Redesigning of the ESP model

After the proper investigation of the fluid flow simulation of the ESP model, we infer that the cartridge design is the main reason for the high back pressure development. Hence for more optimized flow, hexagonal close packing of the perforated tubes was considered with a relative increase in the diameter of collector side perforated aluminum tubes about 9.5mm and wall thickness of 1mm. Optimized exhaust flow was obtained by iterative design of the new ESP after treatment device.

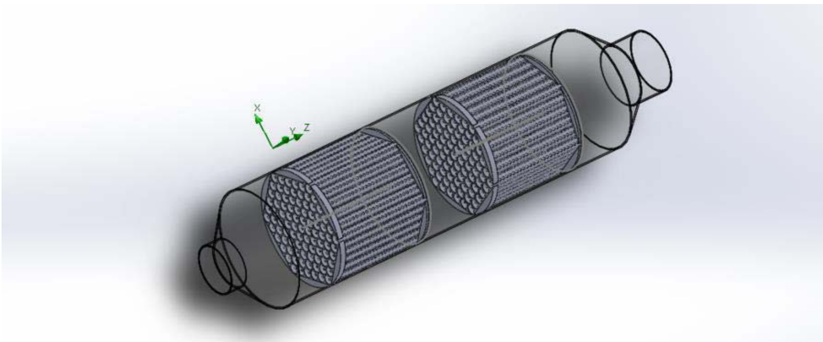


Figure 4 Final Model of ESP module

3.3 Prototype development and optimisation

The electrostatic precipitator work on the principle of charging the emission particles to high voltage negative charge of approximately 18 kV by a negative charging cartridge of numerous stainless-steel perforated tubes. Then these charged particles are send to a high voltage positively charged cartridge of aluminum perforated tubes where the particles get attracted to the these tube due its positive charge , get regimented there. Hence the emission from an internal combustion engine can be reduced. Development of the prototype of the ESP required highly efficient insulating material to avoid the charge discharging flow or else sparking effect will happen. This was achieved by insulating the entire inner surface of ESP enclosure with ceramic filter paper (6 mm thickness) which can withstand 1200 degree Celsius and high voltage current. Voltage requirement for the Electrostatic precipitators should be very high and continuous; this was obtained by MATLAB Simulink model of the required circuit by iterative diode and transformer values in figure 5.

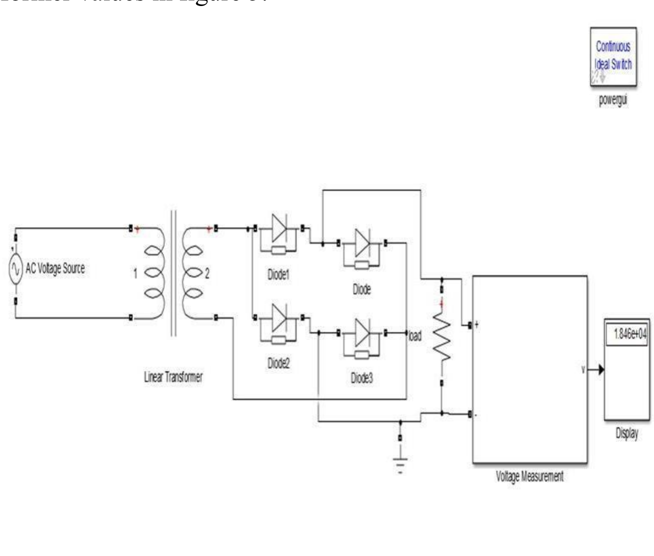


Figure 5 High voltage circuit in MATLAB Simulink

Components of the HV circuit: Linear transformer, Full bridge diode circuit, Voltage measurement block, AC voltage of source. Conditions applied Input AC voltage – 220, Output generated – 18460 V DC. Similar circuit used in the real time application- LOPT (line output transformer) circuit (figure6), which is mainly used in cathode ray tube when there is a high voltage requirement. It is also called as fly back transformer which produces 25 kV DC output. High voltage generation from the available current input was obtained by integration of line output transformer circuit. This circuit is able to convert the 220V AC supply to the desired amount of 18 kV DC. So the minimum voltage requirement of the charging and collecting cartridge of the ESP system is meat so that electrostatic precipitation is triggered.

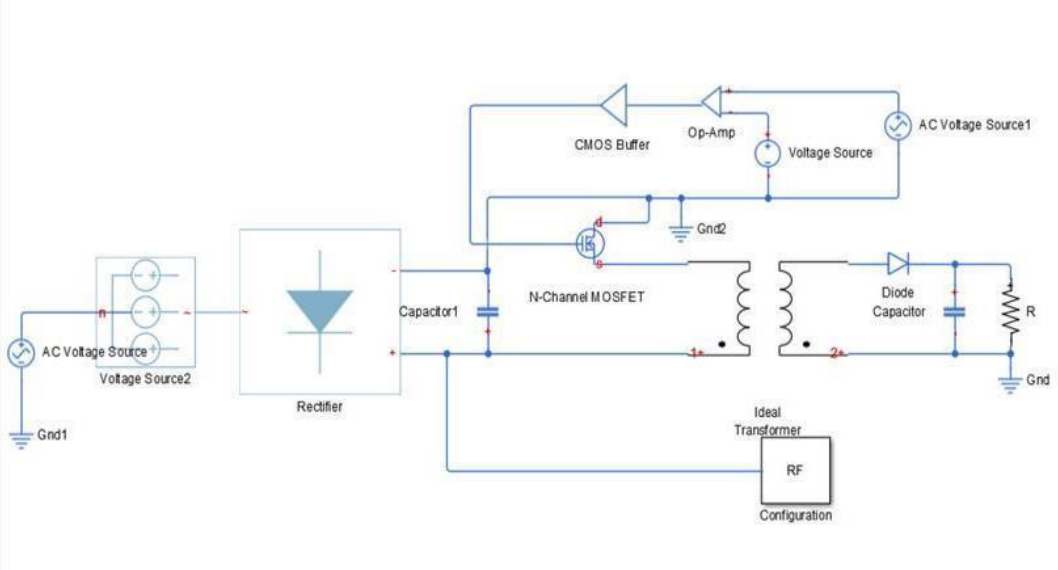


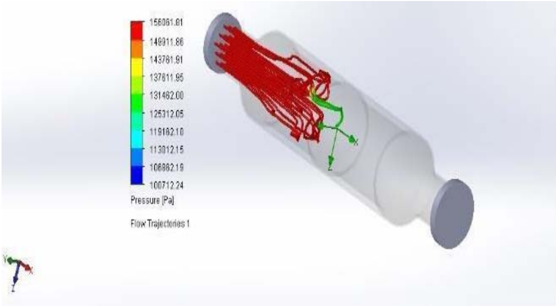
Figure 6 Line output transformer circuit

4 RESULT AND DISCUSSION

Fluid flow simulation of the prototype design was done to study the pressure variation and the flow trajectory of the fluid through the setup in accordance with diesel exhaust conditions at the inlet & boundary condition of the ESP module using ANSYS CFX. The initial flow simulation results of the primary design are depicted below in figure 7 and 8. The higher flow restriction was inferred from the simulation and result shows the large pressure is developed at inlet portion of the first cartridge and the

IOP Conf. Series: Materials Science and Engineering **310** (2018) 012137 doi:10.1088/1757-899X/310/1/012137

flow is discontinued. The maximum pressure developed is 156.061KPa. The Back pressure developed here was 54.73KPa



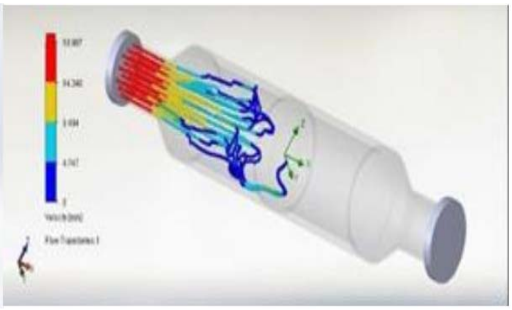
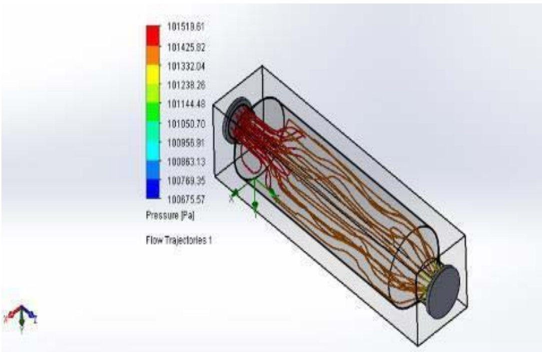


Figure 7 Pressure variation results **Figure 8** Velocity profile

Flow disturbance was witnessed from the velocity profile plot. The flow of the gas was not reaching the collecting cartridge hence the design of the refined ESP is to be reconsidered for further design changes for optimized fluid flow through setup so that proper electrostatic precipitation occurs. After the design reconsiderations and modification the new design of ESP was developed for optimized exhaust flow. The fluid for simulation for the new hexagonal close packed ESP model was carried out



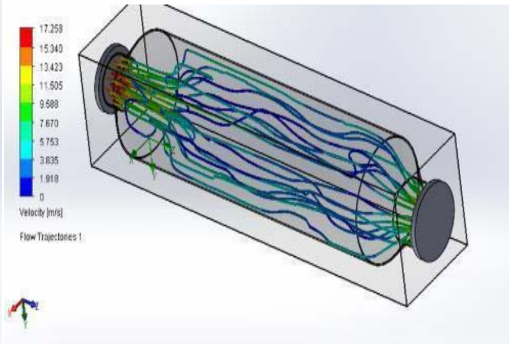


Figure 9 Pressure variation results **Figure 10** Velocity profile of the Final design

From the result it is clear that there is huge reduction in back pressure from the initial design. And the flow restriction is as also reduced to a remarkable level which evident from the velocity profile results. Hence proper flow of the exhaust gas will take place, resulting to efficient electrostatic precipitation. Maximum Back pressure = 194.81 Pa which is within the limit for proper functioning of the diesel engine.

5 CONCLUSION

Automotive diesel emission can be reduced by using electrostatic precipitation principle. This could prove to be a feasible replacement for the present after treatment devices used for diesel exhausts. A model of ESP was developed. Voltage requirement for the Electrostatic precipitators which is very high and continuous was modelled in MATLAB Simulink model of the required circuit by iterative diode and transformer values. Backpressure issue in the developed model was addressed and brought down by flow analysis there by establishing a continuous flow for electrostatic precipitation. After the design reconsiderations and modification the new design of ESP was developed for optimized exhaust flow. The fluid for simulation for the new hexagonal close packed. ESP model was done which resulted in reduced backpressure.

6 FUTURE SCOPE

The high voltage requirement for the efficient working of the ESP module which could be generated from the automotive system itself with lead to development innovative , feasible after treatment device replacing the costly device like diesel particulate filter, NSR , De-NOx systems. The serviceability of the ESP module developed is also very easy compared to the present system as the collecting cartridge is Aluminum perforated tube, this could be chemically treated with acetone for the particle entrapped in the same. Development of closed loop feedback system with respect to higher emission engine operating and cutting of the power supply to the ESP module during the low load condition will lead to effective use of the power and higher emission reduction. This setup requires more intelligent embedded control system which can process the various sensor output and give required signal to actuate the ESP high voltage circuit based on the real time conditions.

REFERENCES

[1] J. S. Lighty, Veranth, J. M., & Sarofim, A. F., "Factor governing their size and composition and implications to human health," Journal of the Air and Waste Management Association 50, 1565–1618., 2000.
[2] B. H, "Physical characterization of particulate emissions from diesel engines: a review," Journal of Aerosol Science, vol. 36, pp. 896-932, 2005.
[3] D. M. Brown, Wilson, M. R., MacNee, W., Stone, V., & Donaldson, K., "Size -dependent proinflammatory effects of ultrafine polystyre particles: a role for surface area and oxidative stress in the enhanced activity of ultrafines," Toxicology and Applied Pharmacology, 175,191–199, 2001.
[4] G. Oberdörster, Sharp, Z., Atudorei,V., Elder, A., Gelein, R., Kreyling,W.,& Cox, C., "Translocat ion of inhaled ultrafi ne particles to the brain," Inhalation Toxicology, 16, 437–445, 2004.
[5] Kotebavi V, Shetty D, Sahu D, "Performance and emission characteristics of a CI engine run on waste cooking oil-diesel blends", pollution research, Enviro media, Vol 35(2016).
[6] Vishnu Varthan R, Senthil kumar D, "Emission characteristics of turbocharged single cylinder diesel engine", Indian journal of science and Technology, vol 9(2016).
[7] PR Suresh, Arjun Ramesh, Ananthan Mohan, Anoopnath PR, Samanyu Sathian. "Experimental studies on reducing Turbolag", International journal of Advances on automotive and technology", Vol 1(2017).
[8] R. Boichot, et al., "Agglomeration of diesel particles by an electrostatic agglomerator under positive DC voltage: Experimental study, "Journal of Electrostatics, vol. 66, pp. 235 -245, 2008.
[9] N. Thonglek, et al., "Soot Treatment by Using High Voltage Pulse Energized Electrostatic Precipitator," Energy Procedia, vol. 9, pp. 292-298, 2011.
[10] B. K. David, "Engines and Nanoparticles: A Review," J. Aerosol Society, 29(5/6): 575 -588, 1998.
[11] H Kawakami, A.Zukeran, K Yasumoto , M Kuboshima, Y Ehara, , T Yamamoto," Diesel Exhaust Particle Reduction using Electrostatic Precipitator" 179-184.
[12] Agung Sudrajada and Ahmad Fitri Yusofb, "Review of electrostatic precipitator device for reduce of diesel engine particulat e matter,"Energy Procedia, vol 68(2015) 370-380.
[13] T.Takahashi, T.Takamatsu, H.Kawakami, A.Zukeran, H.Fujimura, Y.Ehara, and T.Ito, "Particle deposit on the surface of the wall by electrostatic precipitators," The Journal of Institute of Electrical Installation.