Novel Electrically Stimulated Catalytic Converter Prototype for Replacement of Conventional Auto Exhaust Emission Converters

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Abstract

High voltage electrostatics and corona discharge are utilized for various applications in pollution and environmental control. The traditional applications have many flaws due to improper construction of electrode design and assembly that cause system failure, in particular when electrically stimulated devices are exposed to high humidity. A new innovative-patented design by Hamade[1], Electrically Stimulated Catalytic Converter (ESCC), eliminates such flaws and shows the wide practical applications of the new design. The new design utilized previous patented designs and work of the same inventor[2-3] but retrofitted for catalytic auto exhaust emission control. The current and previous patents include: employing Electrically Stimulated Filtration (ESF) to replace HEPA (High Efficiency Particulate Air) filters, treatment of biological and infectious diseases, electret fabrication, and, most notably, the invention of a new electrically stimulated catalytic converter ESCC[1]. The electrically stimulated catalytic converter invention includes an exhaust conduit fed from the engine exhaust port with a housed corona charger apparatus. The opposite end is opened to the atmosphere outside of the vehicle or connected to a reduced-size catalytic converter. The corona charger is intrusively or non-intrusively associated with a main flow path defined by the exhaust conduit. The corona charger includes at least one electrode, which may be recessed away from, the main flow path. A plurality of corona chargers may be used in various combinations, optimally a two dimensional grid. The electrically stimulated catalytic converter is adapted to treat and eliminate auto exhaust pollution emission to air.

Key words: corona, catalytic converter, diesel exhaust, Electrically Stimulated Catalytic Converter (ESCC)

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Nomenclature

ESCC -- Electrically Stimulated Catalytic Converter
HEPA -- High Efficiency Particulate Air
ESF -- Electrically Stimulated Filtration
NO_x *-- nitrous oxides*
CO_x *-- carbon oxides*
HC -- hydrocarbons

0 Introduction

In automobile vehicle exhaust systems, catalytic converters are widely used to reduce unwanted emissions from internal combustion engines[4-8]. Catalytic converters are also used on many engine-equipped machines including generator sets, forklifts, mining equipment, trucks, busses, trains, etc., to treat the engine exhaust from engines of these machines to reduce pollutants in the exhaust.

A catalytic converter provides an environment for supporting a chemical reaction, wherein unwanted gaseous combustion by-products from an internal combustion engine are converted to more inert gases, which are generally discharged into the atmosphere outside of the vehicle. The exhaust gas flows through a conventional honeycomb catalytic converter[10] which contains imbedded precious metals such as palladium, platinum, and rhodium. The converter has an operating temperature range 350 to 400 ^{0}C. The high temperature allows a chemical reaction within the monolith to occur. Ideally, all harmful gasses are converted to safer bi-products such as nitrogen gas, carbon dioxide, water, etc.

However, when engine exhaust contains excessive amount of unwanted contaminants including high levels of nitrous oxides (NO_x), carbon oxides (CO_x) and unburned hydrocarbons (HC), conventional catalytic converters may not be able to effectively treat such an excessive amount of unwanted contamination[4]. In such cases, it may be desired to pre-treat the engine exhaust prior to its passage through the conventional catalytic converter, and/or post-treat the engine exhaust after it is discharged from the catalytic converter, to reduce the volume of pollutants present in the engine exhaust to a safer, acceptable level (typically mandated by government regulators) which will not harm the environment.

Westbrook et al[4] show a plasma assisted catalytic reduction system, which has been referred to as the “Westbrook apparatus”. This apparatus (Figure 1) has been proposed to reduce and eliminate exhaust pollution from a diesel engine prior to the exhaust entering a conventional catalytic converter.

The Westbrook article hypothesizes that the non-thermal plasma (corona) produced by the single wire electrode oxidizes nitric oxide and hydrocarbons to nitrogen dioxide, and partially oxidizes hydrocarbons. Subsequently, the conventional catalytic converter converts the nitrogen dioxide and hydrocarbons to nitrogen, carbon dioxide, and water.

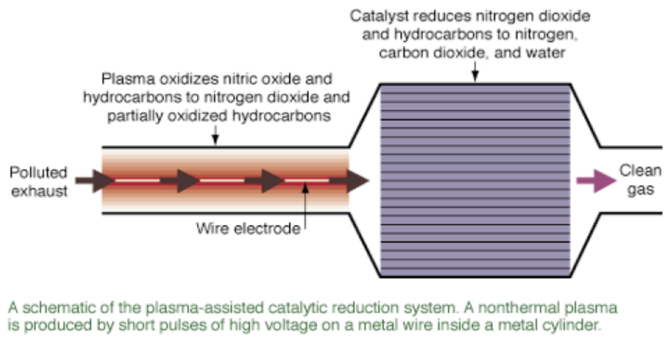


Figure 1. Westbrook Apparatus: Plasma-Assisted Catalytic Reduction Using Single Wire

Independent from Westbrook's work, the inventor of ESCC designed and optimized various corona pre-chargers that deliver orders of magnitude higher non-thermal plasma into the auto exhaust emission than Westbrook Apparatus. In addition, the ESCC corona pre-chargers engulf and directly stimulate the catalytic converter (upstream & downstream). These important enhancements over Westbrook's Apparatus were disclosed with the patent application and were primary reasons for USPTO to allow the claims in the most recent issued patent[1]. Further future work can quantitatively assess the charge performance of ESCC. Figure 2 shows the ESCC multiple grid wires design that can be stacked upstream and downstream of the catalytic converter. The charging wires are made from tungsten metal and the details of the design and structure are shown by the patent[1]. In comparison with Westbrook's Apparatus of Figure 1, Hamade's novel ESCC multiple wire electrode grid charger design can deliver higher charging effect on treating auto exhaust emission instead of just merely rely on a single wire electrode charger.

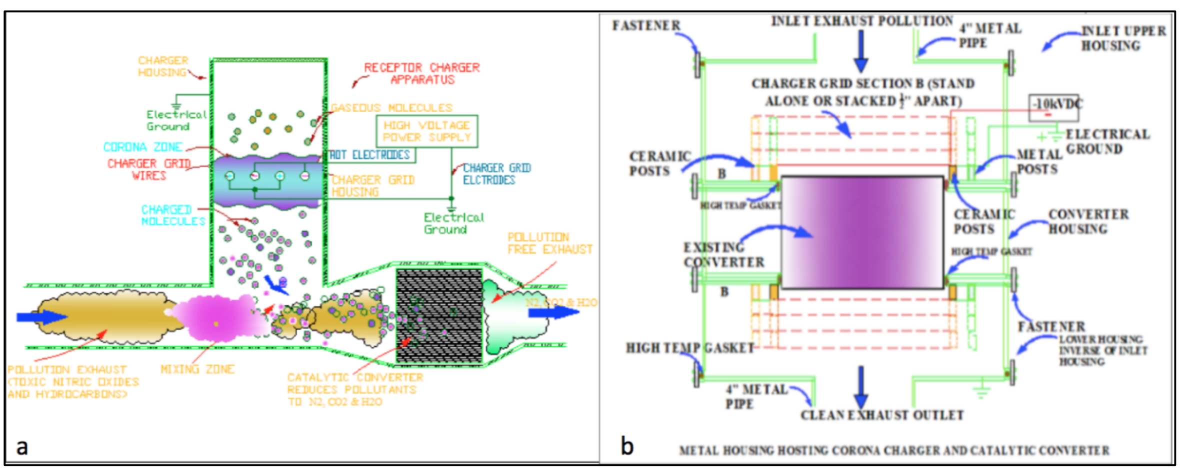
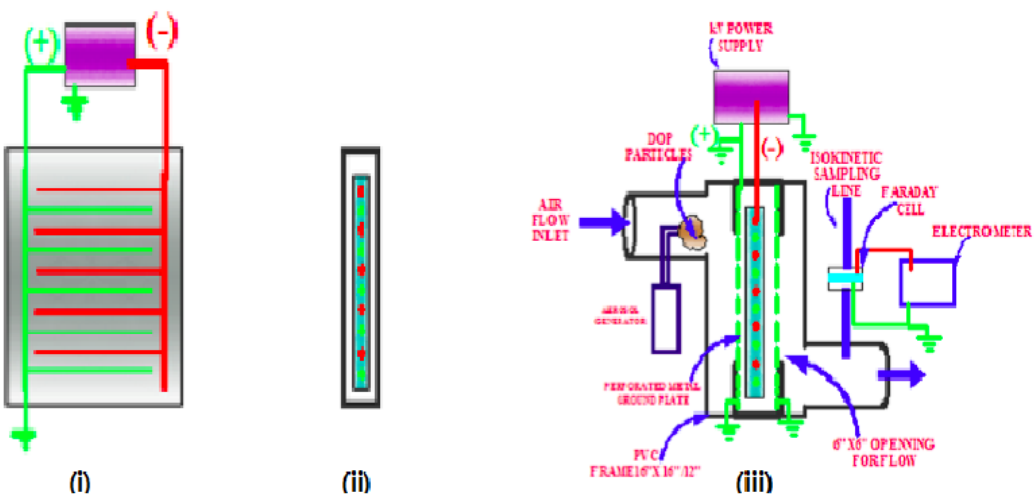


Figure 2. a) Conceptual view of ESCC auto exhaust emissions and pollution control potential to replace expensive catalytic converters b) Hamade's ESCC novel apparatus inside metal housing using 3 dimensional corona charger grid wires assembly upstream and downstream conventional catalytic converter.

The greater number of wires in ESCC generate much more corona and also pollutants flow through the corona field (across the wires). As claimed by the invention, the corona wires can be stacked to deliver more corona ions where flowing pollutants through the path of corona will be exposed to larger period of residence time mixing with the corona ions. Also, entire pollutants flows through the corona field and not like Wesbrook's apparatus where most of the pollutants tend to bypass the single wire corona ions (generated closely to the wire and not across the entire flow) or have minimum charging effect. The early design by the inventor of an intrusive wire pre-charger is shown by Figure 3 where a depiction of this design was shown to outperform other state of the art pre-chargers such as that used by Masuda[9]. Masuda's pre-charger produced much lower particle charge with increased applied field than the alternating charged wire grid design. The earlier work will be discussed in later sections.

The charger wire grid was further improved so it would be used intrusively and non-intrusively, but more reliably than the earlier design. This new novel design required less frequent cleaning and replacement. The ESCC corona charger grid wire design depicts an earlier charger design as shown by Figure 3 and described in details by the patents[1-2]. Various similar designs with slight variations in the electrodes arrangements were tested to configure optimum design that delivered highest aerosol charge using an experimental apparatus to that shown in Figure 3. Dioctyl phthalate (DOP) aerosol particles generated with a calibrated nebulizer were directly charged with those chargers and best performed chargers were selected for further studies and in the development of the ESCC. For the purpose of comparing this grid wire design with prior designs, aerosol was charged directly (intrusively) by forcing the entire aerosol to pass through the charger grid wire section. This was also the case for most of the prior charger applications.



(i) Charger (B) top view (ii) Charger (B) cross sectional view (iii) Charger (B) test section

Figure 3. Typical corona charger layout

1 Theory of Corona Generation

Theory of corona generation under high voltage applications related to our work with the various designed chargers were investigated[1-3,11, 12-16]. Corona formation and transport first depicted by White[17] when he attempted to electrically separate particles from gases using negative corona discharge from a wire. Figure 4 depicts his geometry which is different than the wire corona discharge used in our invention. However, no theory found in literature describing the exact generation and transport of corona for charger grid design such as that used by our invention, even for simpler charger grid design with multiple electrodes. Corona discharge generation is of great interest for our applications because of their possible commercialization.

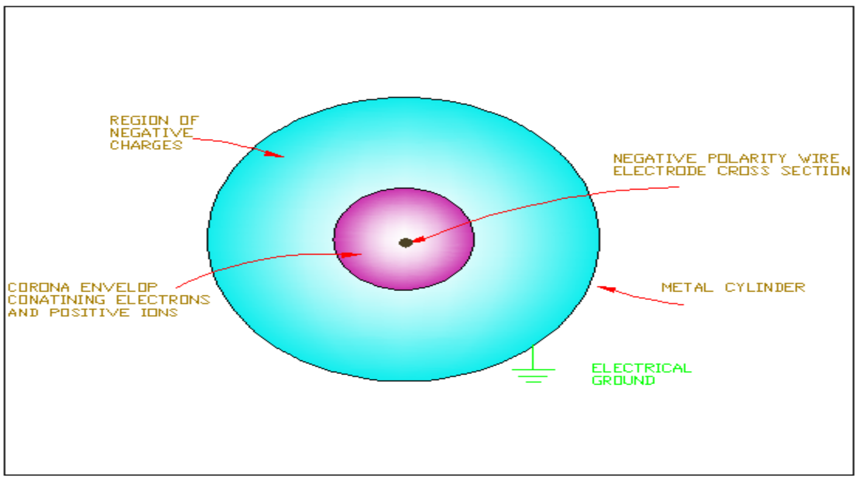


Figure 4: Typical Corona Wire Discharge Pattern and Arrangement Used by White[17].

Corona generation and mass transport of ionized air by convection from the corona zone around the grid wire design into a target receptor such as polymer films or suspended particles are not found in literature. The closest model is the one given by White[17] and we propose to engage in modifying this model in future studies. Figure 5 shows the particular geometry for negative corona discharge that is used in our invention and need the theoretical modeling. The figure illustrates a corona discharge pattern different from White's but suggests that there are common theoretical areas between the various possible corona discharges. In the present studies, White's model would still have to be modified. In addition, the new charging method of the invention transports the corona (via the ionized air molecules) onto a receptor surface such as conventional catalytic converters used in reduction of auto exhaust emission, polymer film substrates or into a fluid (i.e. aerosol, blood, etc.). Another set of transport equations need to be developed in future studies describing corona mass transfer and charging mechanisms for complex grid wire design influencing a neighboring receptor (i.e. polymer film or aerosol fluid).

Corona envelop generation depends on the boundary conditions of the wire grid model and how that responds the flowing gases and other surrounding environment such as temperature, pressure, humidity, particle concentration and composition. The selection of boundary conditions largely depends on the type of charger design (whenever stacked wires, multi charger grids, recycling of charged streams, common polarity, etc.) and the level of current and voltage that can be attained before electrical breakdown of media or receptor. A number of correlations already exist in the literature that would describe the basic theoretical transport phenomena of heat, mass, and momentum in the case of electrostatics and particularly corona formation. Different gas flow patterns and flow rates and wire shapes, wire diameters and applied currents can be used as boundary conditions. The evolving transport phenomena can be a powerful tool model to manage the level of charge as in operating an air charger for efficient aerosol charging.

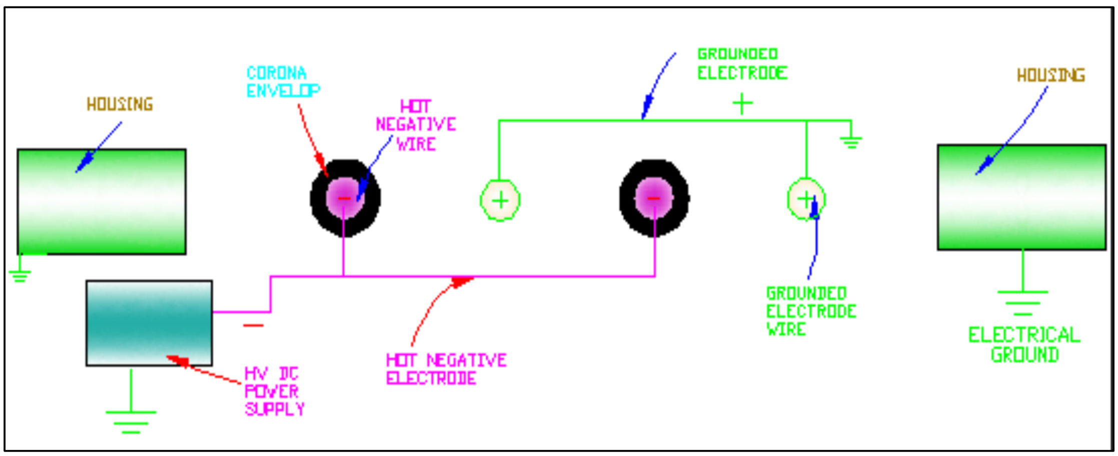


Figure 5: Typical corona wire discharge pattern and mechanisms used in invention.

Corona discharge is one of several forms of electrical discharge that been adopted because of commercial advantages over the other techniques. Other methods is being glow discharge, corona spark (i.e. spark plug), and arc formation[17]. In our study, only smooth corona envelop was desired (not erratic sparking) and occurred when air molecules were passed through the charger wire grid. This discharge was caused by the electrical breakdown of air leading to ionization of the air molecules. The air ionization to corona was characterized by high voltage, low current, a pale blue to purple color around the wires (due to O_2 ionization hence N_2 not ionized with corona), a slight crackling or hissing sound, and the odor of ozone.

Corona discharge is viewed as complex not well understood phenomena[18]. In spite of this, field experience has shown that an electrode surface must have a sharp point, edge, corner, or any other feature where the radius of the curvature is very small so that corona can be generated. The idea is to produce the highest possible electric field intensity in the smallest possible space[19]. The corona works to generate electrical charges in the surrounding gas medium by creating a condition of ion attraction at the electrode surface. The gas molecules are attracted to the intense field of the leading corona edge on the electrode and tend to migrate toward the electrode. If the electrode has positive polarity, electrons will break away from the gas molecules and migrate toward the corona. This motion of molecules causes collisions with other molecules producing an avalanche (and hissing sound) charge transfer effect. The process becomes sufficiently sustainable as long as the corona ions remains effective in causing electron stripping.

The common corona discharge (also known as “glow discharge” or “corona”) is the most effective mean of charging aerosol[17]. A corona can exist at sharp point or fine wire surface when high voltage applied to it, emitting electrons to a collector as shown by Figure 5. The potential emitter (hot electrode) and the collector (opposite polarity electrode to hot electrode) is set by the gap (spacing) and it defines the shape and nature of the particular corona. A corona may result from a negative or positive voltage applied to the hot electrode (emitter) while the collector is grounded to the power supply of the applied voltage (making opposite polarity to the hot electrode, see Figure 4 and Figure 5). For positive emitter (+), corona appears motionless as a diffuse glow. For negative emitter, corona appears as localized brush spread out in the gap immediately surrounding the emitter sharp edge or round edge (for wire emitter).

Ambient dry gases such as air are nearly perfect insulators since they contain virtually no free electrons or ions. At low voltage potentials, the ionization of the gas is negligible, and difficult to measure. As the electrical potential increases, the gas reaches a flash point where the ionization and the electrical conductivity of the gas increases rapidly. The gas ionization (corona) results from two effects[17], (i) the Townsend first ionization potential, which involves electron avalanche due to collisions of electrons and ions, and (ii) the Townsend second ionization potential, which involves the generation of primary electrons at the electrode emitter (this provides the basis for electron avalanches that are self-sustaining with continuous application of the electrical potential). The ionization processes are generally confined to the areas surrounding the emitter. For a corona to remain self-sustaining there must be copious source of ionization near the corona electrode, and the ions flowing from the active or ionization region must build up an effectives space charge that requires collision with gas ions between the emitter and the collector.

Much more complicated process is involved when negative polarity emitter is used to cause similar ionization of gas molecules but a much more complicated process is involved with secondary electron emissions possible[19] that increases the charge intensity. The negative polarity was selected and emphasized in the invention because it has the ability to hold much higher currents and voltages for charging[17]. In industrial charging, corona discharge is also sensitive to humid air which interferes with reproducibility in a receptor charging such as in production runs of electret[18]. There is no fundamental difference between positive and negative polarity charging except negative is preferred in practice because of above reasons. But in limited cases of gas cleaning operations positive polarity is preferred to keep low ozone concentrations.

Another consideration in the corona method is the avoidance of disruptive discharging caused by arc spark between the charging electrodes or between an electrode and a receptor sample such as polymer film to be charged. Even without corona occurs, spark over may occur because of improper design such as presence of sharp metal objects or other hidden metal objects that are closer in position to the emitter than the target electrodes. Previous sections already pointed out the shortfalls of current industrial practice, in addition humidity increase drastically reduces electrical field supply to the emitter, thereby reduce or cease corona generation. Also, if an insulator target such as plastic is placed between the emitter and the target then that would cease corona. However, these effects have been eliminated by the new charger grid design of this invention and with his prior work, so corona remains self-sustaining as long as there is proper electrical field supply, and regardless if the sample to charge is insulator or not, or humidity is low or high. Also, carefully ensuring that there is no other metal sharp objects between the emitter the target electrodes. This effectively makes the charger grid an un-intrusive method and not subjected to contamination by samples (receptors).

2 Mechanisms of Electrically Stimulated Catalytic Converter (ESCC)

No theory found in literature describing the exact generation and transport of corona for charger grid design such as that used by our invention, even for simpler charger grid design with multiple electrodes and in the absence of pollutants or aerosol. This becomes even more complex to predict a theory describing mechanisms for charging receptors of auto exhaust pollutants by corona and how the corona with charged pollutants stimulate a catalytic converters in absence or presence of additional electrical fields (surrounding a converter). Using corona to break down pollutants for single wire design has been heavily tested and is not a new concept[4-8]. It is beyond the scope of our work to make a theory to predict mechanisms explaining how ESCC interact with auto exhaust pollutants (such as NO_x, CO_x, HC) and eliminates them from auto exhaust emission. What makes it more complicated to predict kinetics of possible thousands of reactions and chemical mechanisms during collision of pollutants with corona and the catalytic converter function with the charged pollutants and corona ions..

For a typical preferred ESCC wire charger grid design as shown by top of Figure 3, the gap between the alternating polarity wires is about ½ cm and the maximum applied voltage is be about 10 kV or less to prevent arc spark or breakdown of corona. The high voltage feed power electrodes are well insulated and the entire ESCC is encased in a well-grounded metal. When there is a large localized electric field gradient due to applied high voltage, a corona forms in the gas or air immediately surrounding the wires with a visible purplish color glow. The corona ions around the wire causes neighboring pollutant molecules to breakdown into complex radicals, cluster with other ions, molecules, and atoms to create hydroxyl radicals interacting together to form non-harmful molecules when they pass through the catalytic converter as a result like water, carbon dioxide, and nitrogen[4]. Westbrook's one wire corona design oxidizes the nitric oxide to nitrogen dioxide and hydrocarbons to partially oxidized hydrocarbon byproducts[6]. The wire grid increases this breakdown with additional coronas[11]. With ESCC of multiple charger wire design, stacking multiple chargers upstream and downstream of the catalytic converter, and engulfing the converter with corona will create a pollution reduction environment than the single wire design[1]. The electrically stimulated convertor splits up harmful auto exhaust emission. Inside the chamber is a honeycomb ceramic structure that is coated with a 3-way catalyst of platinum, palladium, or rhodium[8]. The catalyst causes chemical reactions that break down remaining engine fume molecules like carbon monoxide and nitric oxide into atoms[6]. These atoms reform with other atoms in the air to make water and carbon dioxide[6].

Previous experiments using the combination of a one wire corona and a catalytic converter eliminates the majority of pollution from engine fumes[6]. The grid of corona enhances and increases catalytic active reaction sites that results in rapid conversion of pollutants to non-pollutants[4-8]. The ESCC uses much more corona wires than Westbrook apparatus, in addition the charger wire grids can be stacked upstream and downstream of the catalytic converter to deliver the greatest possible effect in treatment and elimination of auto exhaust pollutants. With employment of ESCC, it was discussed in the invention[1] to reduce the conventional catalytic converter size substantially since it is much more efficient than without employing ESCC. That may upset any increased cost due to employment of high voltage fields. Also, it raised the possibility of eliminating the conventional catalytic converter completely when the charger wires are sufficient and made of the 3-catalyst metals.

2 Evolution of Hamade's ESCC Novel Design

A single wire corona and catalytic converter design was proposed by Westbrook[4]. Figure 1 depicts Westbrook's single wire corona and catalytic converter design. Figure 6 displays the test results of the single wire corona charger design effects on reducing engine exhaust pollution emissions. The results clearly demonstrate that the combination of plasma from a single wire and catalyst is the most effective design at lowering the amount of pollutants leaving the exhaust.

The wire electrode of Westbrook's apparatus (Figure 1) is not recessed away from the main flow path of the engine exhaust therefore, the wire electrode may be subjected to contamination from engine exhaust. Also, most of the pollutants tend to bypass the very narrow path of corona ions surrounding the wire and pollutants are subjected only to minimum treatment with corona. Also, the catalytic converter was not subjected to direct corona charge since it sets away from the corona envelop. In addition, contamination causes build up on the single wire electrode due to its direct exposure to the engine exhaust[5]. Consequently, a single-wire corona charger may not be a long-term solution to reducing pollutants from the engine exhaust. However, even with such narrow treatment, it was shown that Westbrook's apparatus (Figure 6) can eliminate pollutants of the auto exhaust emission from entering ambient air after leaving the catalytic converter. This issue inspired a more effective and long-lasting charged wire grid design that would be more commercially acceptable such as using the ESCC.

Jaisinghani et al[12-14] produced the Masuda[9] model (Figure 7-C1) in 1989. In Figure 7, initial and alternative grid designs of pre-chargers are depicted. The Masuda design proposed an electrically stimulated filter assembly for separating suspended charged particles from a flowing fluid stream. Test results in Figure 8 showed that the original pre-charger design by the inventors[12-14] (Figure 7-Design B) outperformed Masuda's pre-charger design (Figure 7-Design C1). After further investigation by the inventor[1] a secondary invention[2,3], depicted as Design A in Figure 7, was created. This new design of Figure 7 (Design A) outperformed the other older versions of pre-chargers of Figure 7 (Design B and C1) with regards to ion concentration creation[2,3]. This new discovery led for further investigations of various pre-charger versions of Figure 7 (Design A) as discussed next.

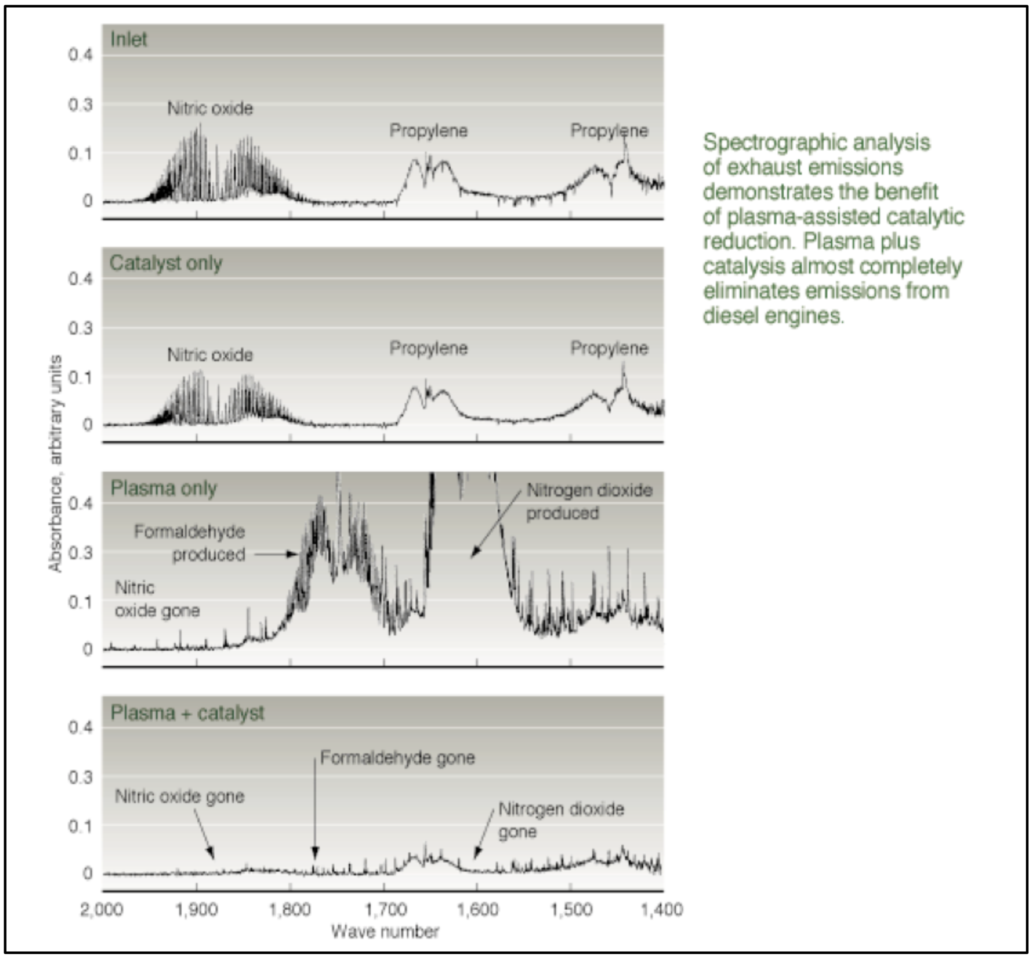


Figure 6. Spectrographic Analysis of Exhaust Emissions

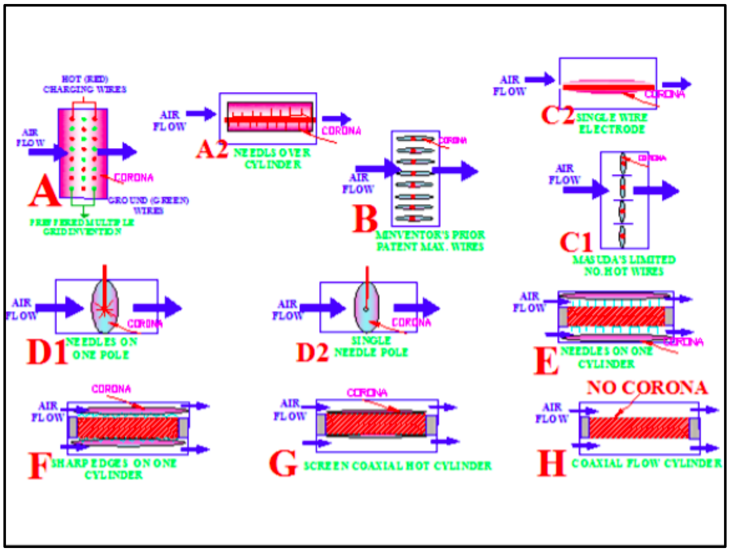


Figure 7. Various Designs of Investigated Grid Corona Pre-Chargers

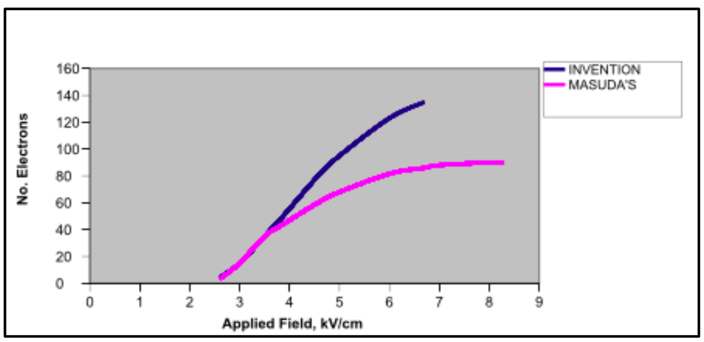


Figure 8. Initial Pre-Charger Invention (shown as Figure 7, Design B) Outperformed Masuda's Pre- Charger (shown as Figure 7, Design C1).

To determine optimal corona ions creation, tests were run on various wire layouts (Figure 9) with the new design (Figure 7-Design A). Each assembly in Figure 9 was tested independently by housing it in the test section shown in Figure 10 (a). For these tests, the presence or absence of two perforated metal sheets electrodes were installed before and after the well wire grid of the new pre-charger in the conduit. The feed electrodes (+) and (-) were well insulated from each other by feeding the wires through glass tubes and ceramic rods. Aerosol of uniform size DOP particles and air were passed through the metal and grid of the charged wires. As shown by Figure 10, a typical constructed Faraday cell apparatus was used to sample downstream isokinetically the charged aerosol. The sampled aerosol were captured by a glass filter paper sandwiched between the metal screens (see Figure 10(b). Electrodes of an electrometer were connected to the screens to measure the drained current from the aerosol particles into the screens. The captured aerosol weight was measured gravimetrically, then the electrometer readings were converted to e- (electron) charge per aerosol particle.

The charger grid was subjected to six different types of configurations (as shown by Figure 9) to determine which yielded the most particle charge[2,9]. The same wire grid (Figure 7- Design A) was used for all the wire assemblies. Chargers of Figure 9 (Design A-F) had the power polarity exchanges and the position of the ground plates varied. Test results and parameters for each charger of Figure 9 assembly are shown in Table 1. The test results of the assemblies are compared in Figure 11. The design of Charger B in Figure 9 produced the highest charge per aerosol particle. The benefit of using a charger wire grid powered with high voltage DC power is displayed in Figure 12. As the strength of the electric field provided increases, the charging efficiency increases[2,9], up to the point of electrical breakdown of corona due to arc spark then readings becomes erratic and not useful. One of the primary key success of the new charger performance design is the complete elimination of any unwanted sharp metal that can interfere with the charging mechanism to cause premature arc spark upon increasing voltage supply and before reaching a high concentration corona field.

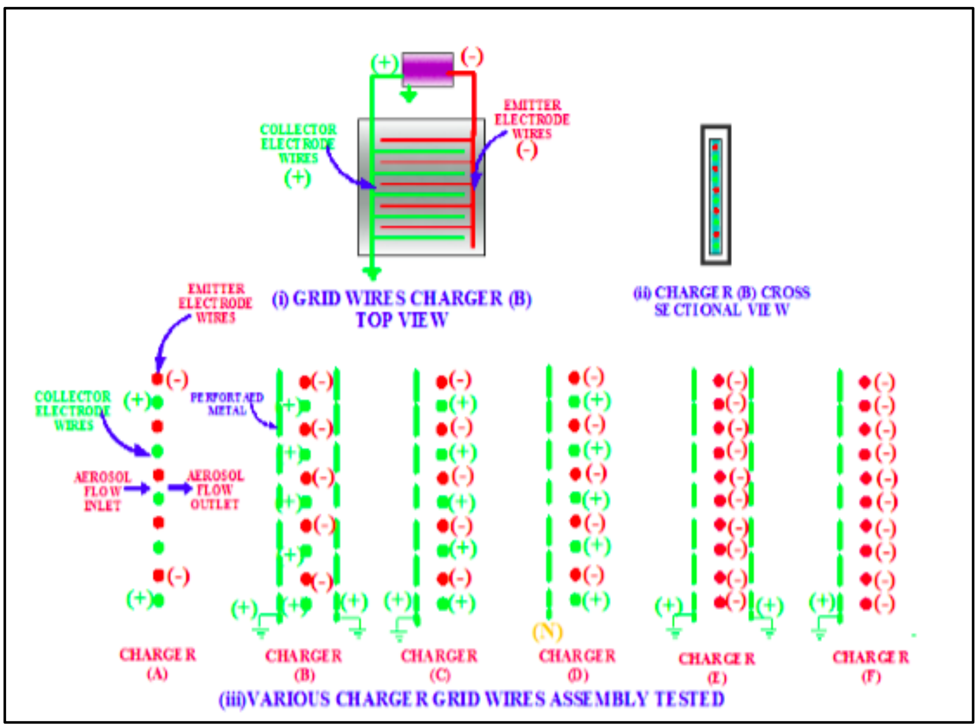


Figure 9. Different Designs to Optimize Original Design

The high charge per particle of Charger B signifies a large amount of ions present in the air flow. Prior research indicates ion counts reached 10^6 - 10^7 per cubic centimeter with a single wire design[4]. The layout and aerosol test results signify that the alternating positive and negative wires create a large amount of ions; this amount is hypothesized to be greater than twice that of the single wire[1]. As a result, more ions are present and a higher number of pollutants can be

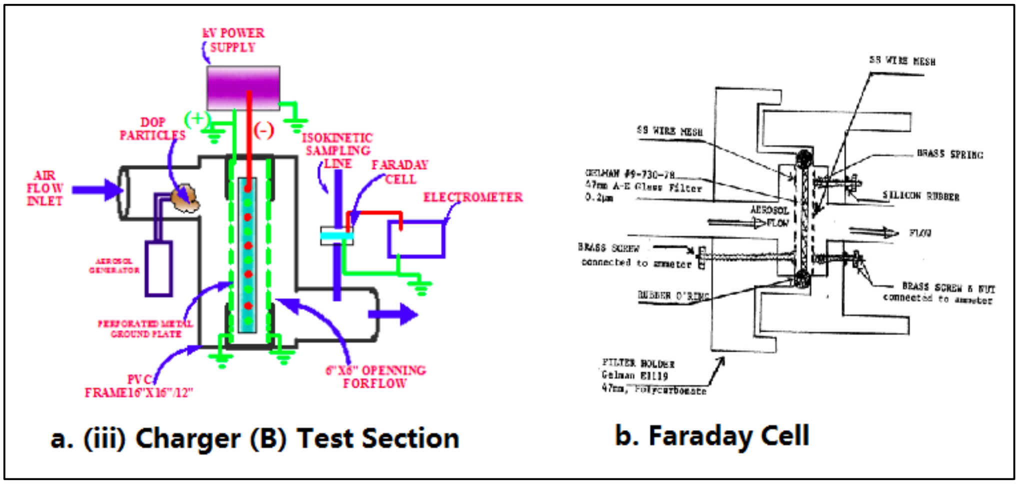


Figure 10: a. Apparatus used to measure a typical corona charger performance using DOP aerosol, b. Schematic of typical Faraday cell that capture aerosol charge.

eliminated[4]. The Charger B design is more effective at pre-charging exhaust than a single wire design, as shown by Figure 8. This work led to the final evolution of ESCC patent[1] and its multi-wire chargers that can be stacked upstream and downstream of a catalytic converter to treat and eliminate auto exhaust emission pollutants (see Figure 2).

Charger	Particle Size µm	Sampling min	Ratio of Areas	kV (-)	e^-/particle
A	2.0	10	1 to 1	16	1728
B	2.0	10	1 to 171	18.5	5896
C	2.0	10	1 to 86	18	5513
D	2.0	10	1 to 1	17	362
E	2.0	10	1 to 42	19	3401
F	2.0	10	1 to 85	19	5149
A	1.9	10	1 to 1		
B	1.9	10	1 to 171	18.5	5988
C	1.9	10	1 to 86	17.4	5875
D	1.9	10	1 to 1		
E	1.9	10	1 to 42	19	4483
F	1.9	10	1 to 85	19	5907

Table 1. Results of particle charge measurements for various chargers where Charger (B) design outperformed other designs

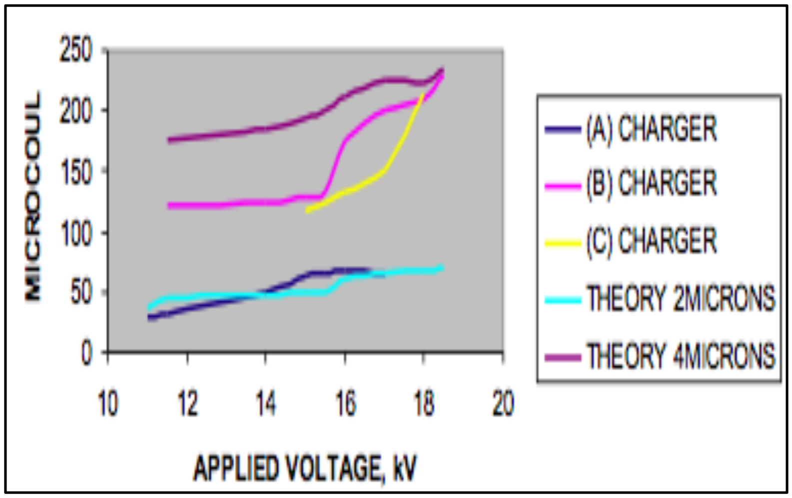


Figure 11. Variation of Aerosol Particle Charge for Various Chargers Compared to Theory

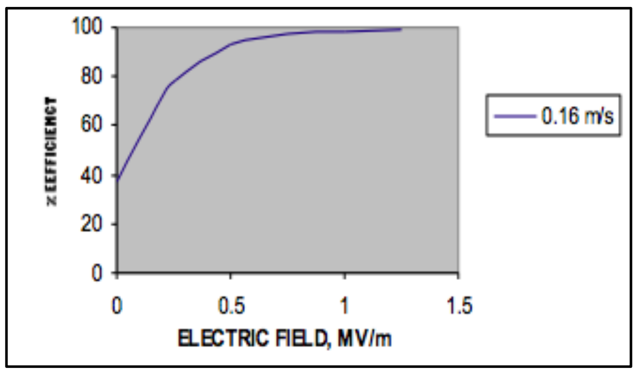
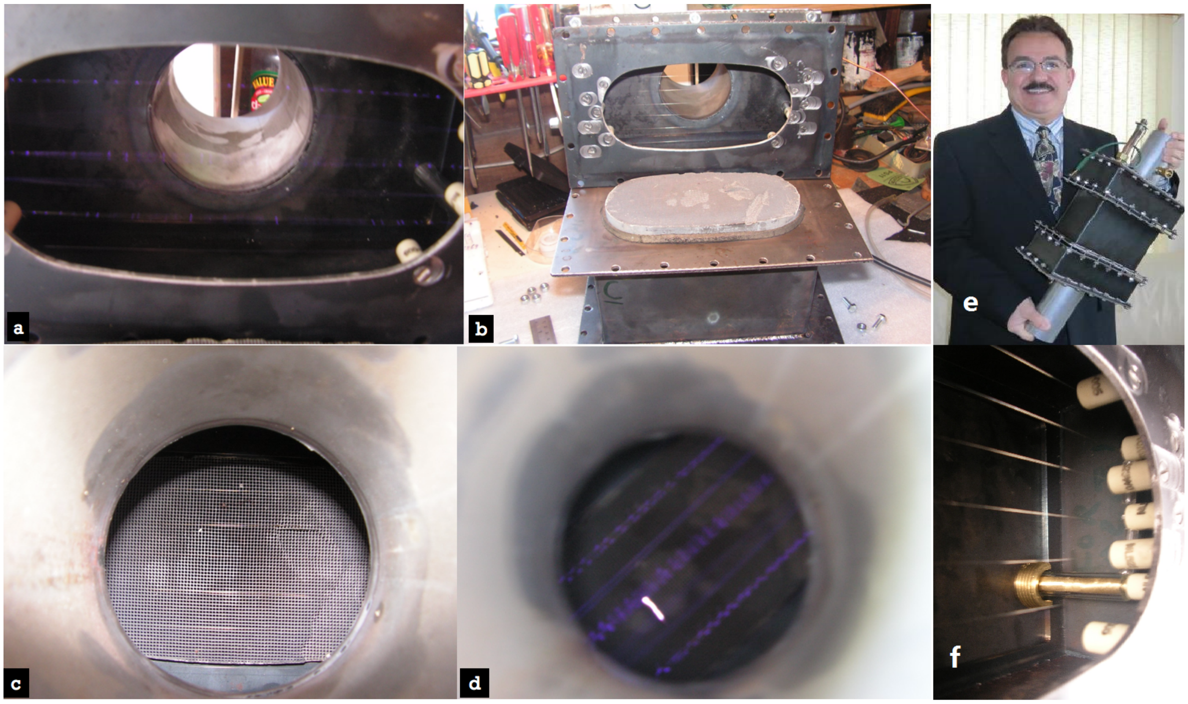


Figure 12. Effect of Electric Field Strength on Filter Efficiency

3 Compelling Analysis and Discussions Resulted in the ESCC Patent[1]

C.H. Lin et al[5] studied the effect of soot (conducting carbon particles) on corona discharge. This study was done in order to determine the effect of corona discharge on soot particles inside of a diesel engine for the purpose of breaking down soot along with other harmful molecules. Their experiment measured NO_x, CO_x, and HC at various combinations of applied corona voltages as well as operating combinations of the engine. Continuous charging of corona in diesel engine exhaust had been unsuccessful due to the soot electrically shorting the conductive materials used to produce the corona. This shorting of the high voltage conductor led to the development of a corona charger whose insulating surfaces are kept clean by a field of air in vortex motion[8]. C.H. Lin et al[5] tested two conditions of soot, 0.092 mg/L and 0.377 mg/L. They showed that the outlet of the collector electrode produced a lower relative particle count in respect to the inlet of the corona charger. C.H. Lin et al[5] concluded that their corona charger-



collector plate system provides an effective means to control diesel smoke with future incorporation of burn off soot from the plates.

As previously described, Westbrook[4] produced an exhaust system capable of reducing harmful emissions such as nitric oxide, propylene, and formaldehyde, among others. Figure 6 shows a clear reduction in these harmful emissions when plasma generated from single wire corona charger is paired with a catalytic. Westbrook successfully ran bench tests along with field tests, however, they have yet to be reported on.

Previous works which employ a catalyst and a single wire corona charger plasma system have proven to successfully reduce the harmful emissions of exhaust. Then no proof was needed beyond Figure 6, to show the potential of ESCC invention[1] to greatly and more effectively decrease harmful emissions as well as better handle soot particles due to the bounty emission of corona upstream and downstream of a catalytic converter.

Figure 13. ESCC Prototype tested in ambient air: (a) View of opened charger grid section upstream Ford Mustang® catalytic converter. (b) Electrically Stimulated Catalytic Converter housing (c) converter inlet top view through 4" exhaust pipe with charging tungsten wires spaced above the converter (high-voltage power supply off) (d) same view as photo (c) but corona blocks view (ambient air corona generated), (e) Inventor Hamade[1] with ESCC prototype, and (f) charger wires-electrode-ceramic insulator assembly view.

Figure 13 & and Figure 14 shows some of the prototype ESCC components & design and also in action with ambient air with bounty of corona and ions (upstream of a conventional catalytic converter). Tests with auto exhaust emission were not actually performed or required to present as compelling evidence on the effectiveness of ESCC in eliminating pollutants. Figure 6 of Westbrook's apparatus was sufficient enough for the USPTO to issue the Hamade's ESCC patent[1]. It was obvious that if a single wire corona tests eliminated auto exhaust pollutants then ESCC should outperform such tests in removing auto exhaust pollutants.

The evolution of the ESCC opened the doors for further studies to see its actual impact on treating and eliminating pollutants. The invention in Figure 13 & Figure 14, with or without an existing catalytic converter, is hypothesized to be self-cleaning due to presence of corona and increased wire temperature. The increased wire temperature is due to the electrical current passage from a high voltage power source. The increased wire temperature will ensure the combustion of any contaminants deposited on the electrodes and in addition, will aid in increasing the catalytic chemical conversion. The presence of the single wire corona and electrostatic fields will also enhance the catalytic chemical conversion of pollutants into non-toxic gases as evidenced by Figure 6. A high voltage coil, such as that used in the ignition system, can be retrofitted to power the charger grid electrodes.

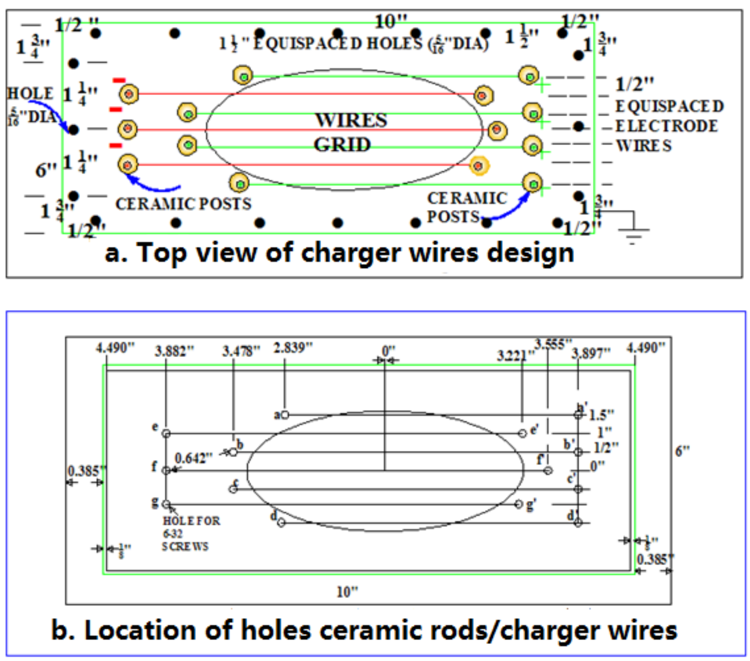


Figure 14: ESCC prototype in metal housing and the design of its multi-wire corona charger where exhaust pollutants flow directly between the wires.

The ESCC builds off of Westbrook[1] and C.H. Lin[5] by creating a system that can handle soot and other large particles which, in the past, have caused electrical failure. Also, there is clear data shown on Table 1 that proves the effectiveness of this invention. Figure 13 & Figure 14 show how the ESCC is built as well as providing a visual understanding of how the invention works. The invention is adaptable and there are many potential applications of the ESCC invention.

In addition to the efficient performance of the grid design invention (Figure 14), the grid design will lead to reduced operational costs as it allows for a smaller catalytic converter than today's mainstream converters[1]. The grid design will not require the same maintenance and cleaning that the single wire design currently requires. In terms of integrating the technology into the commercial world, this charger is also much cheaper and easier to economically and ergonomically implement than the existed no-corona assisted catalytic converter. The replacement cost of the new invention is also expected to be much lower than the current existing replaced catalytic converters.

4 Conclusions & Recommendations

Corona as well as catalytic converters have been used for many years in order to further clean the emissions of diesel vehicles[4-8], among many other applications. Traditional applications have many flaws due to improper construction of electrode design and assembly that causes system failure. The invention[1] builds on this history of corona usage by designing a charged grid wire system upstream from the catalytic converter in order to reduce emissions even further[5]. This grid has the capability of producing more ions than other designs that utilize different layouts and wire amount. The increase in ion creation will result in a greater amount of pollutants. The invention[1] spurs additional patents which utilize the corona technology: employing Electrically Stimulated Filtration (ESF) to replace HEPA (High Efficiency Particulate Air) filters, treatment of biological and infectious diseases, electret fabrication, and, most notably, the invention of the novel electrically stimulated catalytic converter[1].

With global population and pollution on the rise, it is imperative that a solution to harmful emissions is established. The invention[1] aims to help the ever increasing need to reduce vehicle emissions as well as introduce a revolutionary technology.

Many applications are not yet understood or evaluated therefore, further research is needed in each of these applications before retrofitting into commercial products. These applications will need to comply with safety, energy and economic needs. Also, further studies are needed to understand the theoretical and empirical mechanisms in this paper.

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