International Journal on "Technical and Physical Problems of Engineering" (IJTPE)
Published by International Organization of IOTPE
ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com
June 2022 | Issue 51 | Volume 14 | Number 2 | Pages 353-359

CONTRIBUTION TO AIR POLLUTION CONTROL WITH A NOVEL ELECTROSTATIC PARTICLE REPELLING DEVICE

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Abstract- Air pollution has become a global problem. Pollutants, especially those <10 microns in diameter, are harmful. Because clean air is essential in places, such as homes, hospitals, and food and electronics industries, we designed a novel electrostatic filter, called electrostatic particle repellent, to clean air from a polluted environment. This novel electrostatic particle repellent can be placed in the outer nozzle of outdoor air intake tubes and allow the pure air to enter and push aerosols and other pollutants out. Pushing can be performed using pin electrodes surrounding the circular entrance; the air around the tip of the pins ionizes on the application of a sufficient voltage. The pollutants become charged and move away under the influence of a strong electric field resulting from the pin voltage. In this article, we explained the operating mode of the model and performed a set of experiments on the developed prototype to verify its reliability and efficiency. The proposed device provided encouraging results.

Keywords: Electrostatics, Repelling Device, Dust Particles, Air Pollution, Corona Discharge, Ionization, Electric Field, Health.

1. INTRODUCTION

Air pollution affects all the countries worldwide and all the strata of society [1], [2]. In 2016, according to WHO, 91% of the world's population lived in areas with poor air quality [3], and most countries affected by dust are primarily in the "dust belt", a region encompassing North Africa, the Middle East, and South till East Asia [4].

Polluting particles contain products, such as heavy metals and polycyclic aromatic hydrocarbons, which are harmful to health. Furthermore, these products can carry living microorganisms, such as molds, bacteria, viruses, and microbial fragments [5].

Particles present in the air are referred to as particulate matter (PM), which includes fine dust, dirt, soot, smoke, and liquid droplets [6]. Particle size ranges from approximately 0.001 (molecular aggregates) to 100 microns (industrial or natural dust) [5, 8]. The effects of PM on human health vary according to their size as follows:

- >10 μm particles are retained in the upper respiratory tract and rapidly released [5].
- <10 μm particles (PM10) pose a health concern because they can be inhaled and accumulate in the respiratory system [5], [6], and [7].
- 0.1-2.5 μm particles (PM2.5), relating to the rapid coagulation and agglomeration of ultrafine particles [8] are referred to as "fine" particles and cause the highest health risks because they can lodge deep in the lungs [5, 6].
- Ultrafine particles (0.005-0.1 μm) are generated from combustion processes (e.g., diesel engines) [8] and pose the same health risks as fine particles.
- Particles <0.001 μm are similar to a molecule and can be released after inhalation.

The origin of air pollution is diverse; it can occur naturally or is associated with human activities (transport, industrial, agricultural, or domestic activities) [9]. Emission sources are generally classified into the following categories [8]:

- Punctual sources: These sources typically include large plants with one or more flue stacks (incineration and waste treatment).
- Areal sources: These sources typically involve cooking, service stations, or pesticide use.
- Mobile sources: These sources are non-stationary, such as automobiles, trucks, buses, motorcycles, airplanes, or trains.
- Natural sources: These sources include the natural processes of soil or vegetation transformation (erosion and volcanic eruptions) [10].

Marine aerosols play a crucial role on islands or coasts. On the Mediterranean coast of Turkey, between April 2001 and April 2002, sea salts constituted up to 77% of the composition of PM10 [11].

Air pollution does not stay in a source zone but is transmitted on a global scale. The dust resulting from human activities diffuses into the atmosphere and moves to zones separated by a few tens to hundreds of kilometers [10]. Therefore, human-made particles do not remain concentrated in industrial and urban areas but contaminate residential and natural areas [10]. Dust from Sahara (the present or actual Sahara dust) can reach heights of 5 km in the atmosphere and travel as far as Western and Central Europe [12].

Various techniques have been developed for specific industries to prevent pollution emissions from industrial chimneys used in industries, such as power stations or cement, into the atmosphere. Electrostatic precipitators (ESPs) are commonly used to control pollution. Section 2 presents a summary of these technologies, their evolution, and their limitations.

Section 3 presents the novel electrostatic particle repellent (EPR). The proposed model blocks pollutants and only allows clean air to enter.

2. ESP MODEL

In the ESP type of filter, the pollution particles are precipitated electrostatically, and the precipitator is subsequently cleaned of the deposit. ESP types and their evolution are presented in [13].

Initial ESPs comprised a set of sharp wires, functioning as discharge electrodes, which were connected to the high negative voltage and were placed in the middle of collector plates. Another widely used model in the industry is a grounded metallic cylinder. A thin wire, which serves as a negative discharge electrode, protrudes from its axis in Figure 1. In a recently developed laboratory-type model, the wire was placed outside the cylinder [14].

The operation of an ESP is simple. However, understanding the phenomena involved in filtration remains a study subject [15].

After numerous steps, the ionization along the high-voltage wire leads to the charging of pollution particles, which then move toward the collecting cylinder under the influence of the electric force (F_e) resulting from the electric field [16]. The pollution particles are then precipitated and accumulated on the inner surface of the cylinder.

On deposition on the collection electrode, the particles slowly lose their charge and are removed mechanically through scraping or vibration in a dry precipitator [17] or by using a wet film of water or other fluid in the wet precipitator.

The accumulation of negatively charged particles on the surface of the collector causes the creation of a field opposite to that of the original field, which considerably weakens sedimentation. To overcome this phenomenon, two-stage precipitators were used. Particle charging and deposition occur in the first and second stages, respectively [18], [19].

To improve the efficiency of fine dust filtering, another model with an agglomeration section was developed and used in the industry. In this model, in the first section, the particles are charged to opposite polarities, and in the second section, they are subjected to alternating electric fields, which causes the particles to collide resulting in agglomeration [13], [20].

ESPs can be used to collect wide-ranged particle sizes in both dry and wet states, and the collection efficiency for ESP can be up to 99% [13]. The efficiency is influenced by the applied voltage and particle size [21].

ESPs are currently used to filter harmful particles emitted from industrial plants thermal power stations, and cement industries to prevent environmental dust pollution.

In all the aforementioned models, the pollution particles accumulated in the filter must be removed by scraping, vibration, or by using a wet film of fluids.
However, the non-industrial sources of pollution account for a high proportion of air pollution and can only be partially controlled. Furthermore, many facilities, such as microelectronics, pharmaceutical, and agro-food industries, must be protected from dust because dust can cause serious malfunctions in these industries.

To protect the health of citizens in places, such as homes, schools, and public buildings, clean air is filtered from a polluted environment. Using ESPs in such situations is difficult. Therefore, we designed a novel electrostatic air filter, in which pollution particles are pulled away and not allowed to enter into the clean air, by using DC corona discharge.

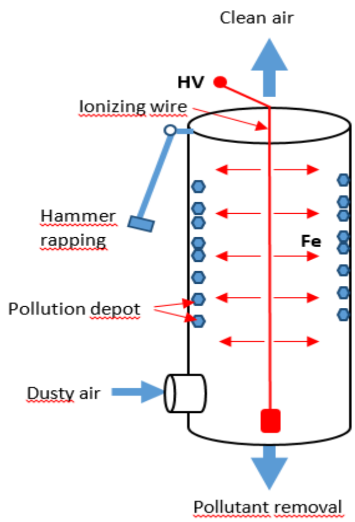

Figure 1. Electrostatic precipitator [17]

3. EPR

3.1 Operating Principle

EPR is placed between a dusty exterior and a clean interior as shown in Figure 2. The air enters through an air aspirator (number 6 in Figure 2). The small-radius wires (number 3) serve as a discharge electrode, which is maintained at a high negative potential of several kilovolts. The metal grid (number 1) that faces the wires is connected to the earth and represents the filter's earth electrode. The metal assemblies (number 3) and (number 1) promote the production of a strong electric field near the wires. This electric field rapidly decreases toward the grid. For certain high-voltage values, the electric field near the wire becomes ionized, which causes the corona effect around the wire.

In the high-field region, electron energy is sufficiently large to generate an electronic avalanche. However, when the electrons reach the weak-field zone, their energy becomes insufficient to generate electronic avalanches, and they attach to the neutral atoms of the air. The heavy negative ions thus formed move toward the earth electrode. This movement leads to negative charging of the pollution particles and pushes these charged particles toward the grid. Thus, only clean air crosses the cylinder (number 4) toward the clean interior.

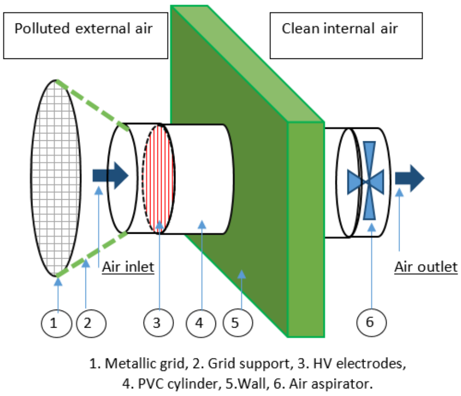

Figure 2. Electrostatic Particle repellent

3.2 Experimental Setup

Figures 3 and 4 presents the experimental setup of the model. The apparatus comprises a 300-mm-diameter transparent plexiglass ball, representing the space to be cleaned. The polluted air enters through a 32 mm diameter PVC tube to the left of the ball, and clean air comes out through a 30 mm diameter transparent plexiglass tube on the right side. The apparatus is equipped at the end with an adjustable flow aspirator. To test the electrostatic repellent of Figure 2, it was placed at the entrance of the left tube, its wires were connected to a direct, negative, adjustable high-voltage generator, and its grid was connected to the earth. To study the effect of air velocity on the working of the filter, an Air meter Fluke 975 was installed at the outlet tube. At the bottom of the ball, the probe of an airborne particle counter (Fluke_985) is added to count the number of pollution particles in a certain volume. Fine particles of diameters 0.3, 0.5,1, 2, 5, and 10 µm, which pose a risk to human health as defined by WHO, were identified. Note that the diameter of a human cell is 10 microns, and that of the microbe is 0.4 microns.

Figure 3. Experimental setup

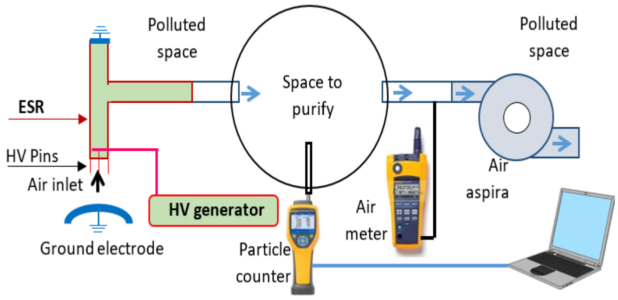

Figure 4. Schematic of the experimental setup

3.3 Experimental Analysis

We first operated the electric air aspirator and adjusted the velocity of the airflow V_a to the desired value. After filling the ball with polluted outside air, we counted the number of particles inside the ball by using the particle counter, which records the number of each type of particle in the liter. This value corresponds to the quantities existing before purification. Immediately after this measurement, we applied the required voltage to the high-voltage pins to begin the purification process. After 22 s, we measured the number of particles per liter and repeated this measurement three more times at the intervals of T = 22 s.

3.4 Experimental Results and Discussion

We determined the feasibility of this model. The variation in the model efficiency in purifying the air with suspended particles was studied as a function of the speed of the inlet air, the electrical voltage applied, and voltage polarity.

3.4.1 Effects of the Applied Voltage

Figures 5, 6, and 7 shows a decrease in the number of particles as the percentage of their number before purification as a function of the purification time. The air inlet speed was fixed to 1 m/s, and the applied negative voltages were 15, 17, and 19 kV. Tables 1, 2, 3 provide the number of particles per liter before and at the end of purification corresponding to Figures 5, 6, and 7. The results of these experiments led to the following findings:
1. The smallest pollution particles (smaller than bacteria) are in large numbers. The number of pollution particles decreases with an increase in particle size.
2. The decrease in the percentage of large particles is greater than that of small particles.
3. Increasing the applied voltage leads to an increase in the purification efficiency.

3.4.2. Effects of the inlet air velocity

Figures 8, 9, and 10 shows the decrease in the number of particles for an applied voltage of −17 kV, for three air speeds of 1, 1.5, and 2 m/s, respectively.
The increase in speed leads to the deterioration of purification. Thus, an increase in speed requires higher voltages to improve purification.

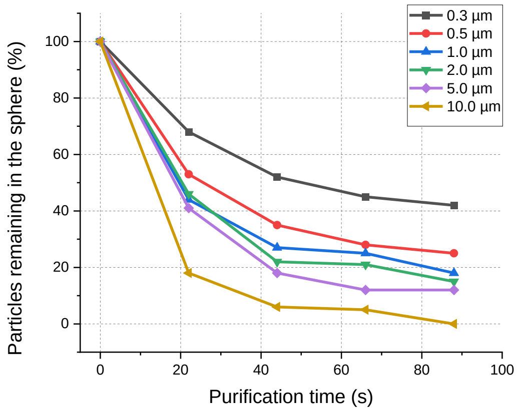

Figure 5. Percentage of particles remaining in the sphere according to the purification time for V_a = 1 m/s and application voltage −15 kV

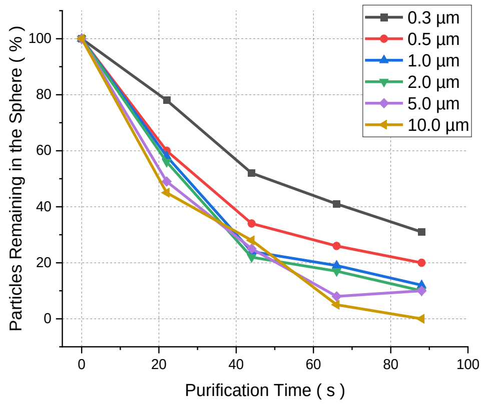

Figure 6. Percentage of particles remaining in the sphere according to the purification time for V_a = 1 m/s and application voltage −17 kV

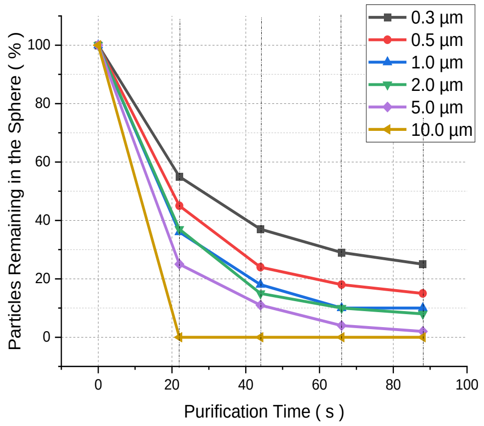

Figure 7. Percentage of particles remaining in the sphere according to the purification time for V_a = 1 m/s and application voltage −19 kV

Table 1. V_a = 1 m/s , U = −15 kV

Particle diameter	Particle/liter	
	Before purification	After purification
0.3 µm	69454	29571
0.5 µm	5707	1453
1.0 µm	1556	289
2.0 µm	742	106
5.0 µm	87	11
10.0 µm	18	0

Table 2. V_a = 1 m/s, U = −17 kV

Particle diameter	Particle/Liter	
	Before purification	After purification
0.3 µm	62335	19959
0.5 µm	5384	1069
1.0 µm	1465	191
2.0 µm	725	72
5.0 µm	96	9
10.0 µm	18	0

Table 3. V_a = 1 m/s, U = −19 kV

Particle diameter	Particle/Liter	
	Before purification	After purification
0.3 µm	57510	15017
0.5 µm	4477	669
1.0 µm	1138	123
2.0 µm	562	39
5.0 µm	98	2
10.0 µm	24	0

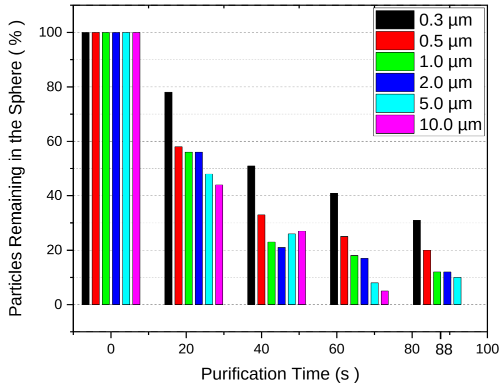

Figure 8. Percentage of particles remaining in the sphere according to the purification time for U = −17 kV and air speed V_a = 1 m/s

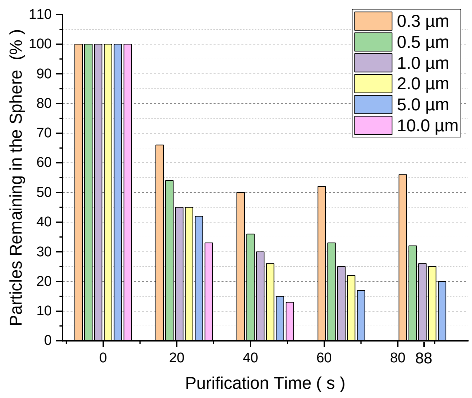

Figure 9. Percentage of particles remaining in the sphere according to the purification time for U = −17 kV and air speed V_a = 1.5 m/s

At the end of purification (T = 88 s), in Figures 8, 9, and 10, the number of fine particles (diameter 0.3 and 0.5 µm) entering the purification zone increases with the speed of inspiration, while the particles of larger size (diameter 2, 5, and 10 µm) are less acceding because they have too great an inertial force to be able to accompany the current of air when this is inspired towards the purification zone with the ionic wind. This phenomenon is owing to the effect of electric force and driving force.

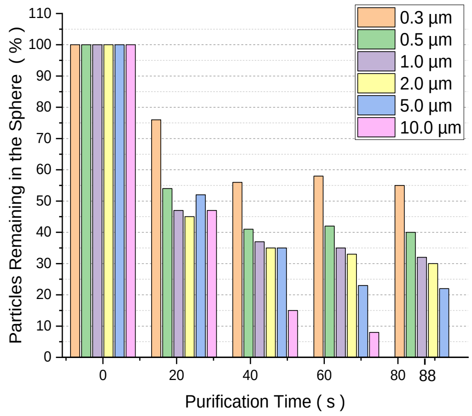

Figure 10. Percentage of particles remaining in the sphere according to the purification time for $U = -17$ kV and air speed $V_a = 2$ m/s

3.4.3 Effect of voltage polarity

Figures 11 and 12 presents the purification results of applying a negative polarity (–17 kV) and positive polarity (+17 kV), voltage respectively, at a rate of 1 m/s. with the same purification time (22, 44, 66, 88 s), and for the different sizes of polluted particles (0.3, 0.5, 1.0, 2.0, 5.0, 10.0 µm), the purification using negative is even better (lower percentage) than positive polarity voltage because The charging of the particles is carried out employing a corona, which produces ions which attach themselves to the polluted particles. Generating a corona requires the development of a highly non-uniform electric field, a condition that occurs near the pins when high voltage is applied between the needles and the ground electrode.

The electric field near the pins accelerates electrons in the air to speeds sufficient to cause ionization in the region near the high voltage electrode. Ions are produced as a result of the corona in negative polarity and are more efficient than in positive polarity, resulting in energetic migration to the electrode, in the process collide and attach to polluted particles suspended in the flowing air. The binding of ions results in the accumulation of an electrical charge, the magnitude of which is determined by the number of bound ions.

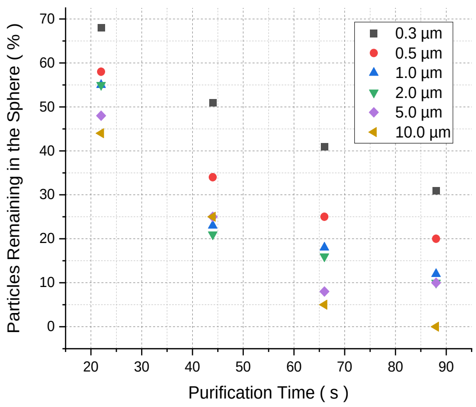

Figure 11. Percentage of particles remaining in the sphere according to the purification time for $V_a = 1$ m/s, $U = -17$ kV

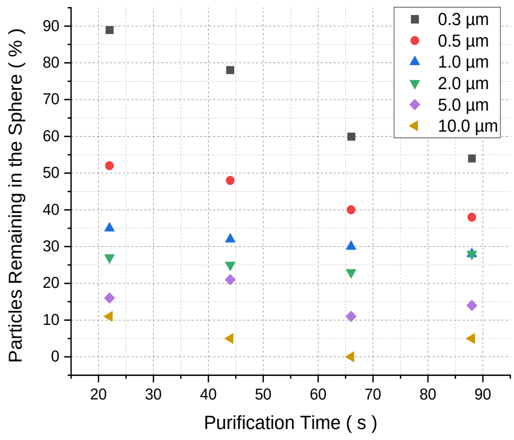

Figure 12. Percentage of particles remaining in the sphere according to the purification time for $V_a = 1$ m/s, $U = +17$ kV

4. CONCLUSIONS

We tested the reliability and efficiency of the prototype of the proposed filter, which allows cleaning of the air from the polluted environment. The results were encouraging, and particle removal efficiencies of 74%, 85%, 93%, 98%, and 100% were obtained for particles of 0.3, 0.5, 1, 2, 5, and 10 microns, respectively.

Electrically, the application of a high voltage significantly affects the propagation of charged particles, and the disturbance of the particles was manifested by their dispersions, thus an effective obstruction for the polluted particles not reaching the purification zone. On the other hand, the ionic wind Influences the trajectory of polluted particles less than the other parameters. it does not prevent a new trajectory to be processed and studied to know its impact on the effect of the air speed on the operation of the filter.

These preliminary results revealed that a detailed barometric study could lead to superior results, especially for fine particles, that are harmful to human health.

In the future, we will use other high-voltage electrodes that are smaller than the pin electrodes to achieve sufficient voltage.

NOMENCLATURES

1. Acronyms

ESP ElectroStatic Precipitator
EPR Electrostatic Particle Repelling
HV High Voltage

2. Symbols

V_a: The velocity of the airflow
U: The applied voltage
T: The purification time

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to all the members of the Electrical Engineering Laboratory of Oran (LGEO), in particular to Mr. Mohamed Bouzid for his precious help.

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BIOGRAPHIES

Habib Benamar was born in Oran, Algeria, in October 1968. He obtained his bachelor degree in June 1994 and his master degree in electrical engineering in July 2005. From December 2005 till now, he is a teacher at University of Sciences and Technology, Oran, Algeria where he taught several educational modules in the electrical engineering department. He currently holds the position of assistant professor and he is also a researcher in the electrical engineering laboratory of Oran (LGEO), Algeria. His research area is mainly on electrostatic filters and air pollution control.

Samir Flazi was born in Alep, Syria in January 1950. He received his B.E degree in electrical engineering from Aleppo University, Syria in 1973 and then he completed his D.Eng. and D.E at Paul Sabatier University, France, in 1981 and 1987, respectively. He started working at University of Sciences and Technology of Oran, in Algeria, in 1979 until he retired in 2020. He was a Professor in electrical engineering department and also a director of the high voltage laboratory. His research interests are flashover, pollution measurements, breakdown in front of a discharge, and electrostatic application.

Naima Oussalah was born in Bejaia, Algeria in 1973. She received her university applied studies diploma in 1997, the engineering diploma in 2000, the Master degree in 2002, and Ph.D. in 2008 from the University A. Mira of Bejaia, Algeria. From 2002 to 2008, she was an Assistant Lecturer at University of A. Mira of Bejaia. Since October 2008, she teaches at University of Sciences and Technology of Oran, Oran, Algeria where she received the Habilitation in December 2009. Her areas of work include partial discharges in power cables, corona simulation using the finite element method, and field grading in power cable accessories.

Imene Oualid was born in Oran, Algeria, in February 1992. She got her Master degree in Electrical Energy Techniques in 2015 and since then she has been pursuing her doctoral studies in the field of plasmas and electrical discharges engineering. Her research field is mainly dedicated to the study of electrostatic filters.

Amine Boudghene Stambouli was born in Telemcen, Algeria, in January 1959. He graduated from University of Sciences and Technology of Oran (USTO), Oran, Algeria with an Engineering degree in Electronics in 1983 and then he completed his Master degree in Modern Electronics in 1985 and his Ph.D. degree in Optoelectronics in 1989 from University of Nottingham, England. In 1995, he started working on High Field Electroluminescence and Optoelectronics at USTO. In 2002, he was promoted to full Professor of Optoelectronics and Material Science for Environment and Energy Applications at the Department of Electronics of USTO. In 2013, he was appointed as Director of Electrical Engineering Laboratory. His research projects include photovoltaics, fuel cells, hybrid systems, and environment impacts.