PiscoMed Publishing
doi:10.18282/i-es.v6i1.600

Original Research Article

# Direct triboelectricity from friction of wheel tires on pavements

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***Abstract:*** Energy consumption in road and street traffic is significant and increasing. A partial recovery of this energy is the objective of the research briefly presented in the present paper. The proposed technique is totally innovative and has not been investigated, even through laboratory research, anywhere else. It aims to harvest triboelectric energy generated while wheel tires are directly rubbed against a pavement surface where oppositely charged electrodes are properly attached. The laboratory testing device consists of a rotating wheel bearing a vehicle tire, set up adequately to move down to a solid bench where flat bars, rods or tubes, susceptible to being oppositely charged by pairs, are attached. Metals, such as copper, bronze and aluminum, developing high electrical conductivity, were used in most experiments, as electrodes. Triboelectricity tests, under different placement of the electrodes regarding the wheel, were conducted in the laboratory and provided noticeable values of electric potential. Even more promising seem the results obtained following an intermittent application of the wheel load. Further experimentation introducing a much bigger wheel load, a different tire texture and other test improvements are ongoing, aiming at higher values of electric potential.

***Keywords:*** energy; friction; triboelectricity; direct; recovery; pavement

**Received:** 10 October 2023; **Accepted:** 26 October 2023; **Available online:** 17 November 2023

## 1. Introduction

In a quickly changing and evolving world, the energy issue is a persistent challenge not only for industrial countries but also for developing countries. It is an issue that touches every single aspect of life on the continent and raises complex social, political, economic and technical issues that must be addressed by means of three discrete and parallel policies: a) smarter and more effective exploitation of resources; b) reduction of energy consumption; and c) technological innovation producing energy by alternative and environment-friendly techniques.

Societal changes and science-driven technological achievements will together ensure a sustainable energy future for Europe. Sustainable energy systems are nowadays at the core of engineering research. Solar and wind energy are at rise, while biomass fuels and hydropower constitute solid solutions for energy production in some countries[1]. However, electric power from fossil fuels still makes the rule in the greatest part of the industrialized world[2,3]. The largest amount of electric power, produced following different technological processes, is directed to urban areas.

Urban areas have seen increasing numbers of residents and vehicles during the last decades. In most cities in developed and developing countries, traffic congestion is a trivial phenomenon[4–6]. Accordingly, energy consumption in road and street traffic is also significant and increasing[7]. A big part of the kinetic energy is totally wasted. A partial recovery of this energy may constitute a decisive step towards the era of sustainable and low-carbon cities[8,9].

The technological innovation hereafter presented is intended for application on road and street pavements to harvest a part of the energy generated by the friction forces between tires and the pavement, under real traffic conditions. At this stage of the research, bus stops and intersections, where vehicles are driven to decelerate and friction forces get higher, are identified as the most suitable street sections for energy harvesting using the proposed technique.

## 2. A science-enabled technique for power generation

The movement of vehicles on road pavements is made possible by means of friction forces developed between the wheel tires and the pavement surface. Under constant vehicle speed, these friction forces raise up to 2% of the vehicle weight, while under accelerating or braking conditions, they increase rapidly, attaining 20%–30% of the vehicle weight. The energy produced by these friction forces along a vehicle itinerary is, therefore, proportionate to the vehicle weight, the friction coefficient and the length of the traveled course. Allowing for the traffic density and the street extent in a metropolitan center, it is conceivable that a large amount of energy is spent every day in friction forces and wasted as thermal energy. The challenge for the present technique consists of recovering a large part of this energy, storing it at adequate electrical cells and directing it to public electrical assets, especially street lighting.

The scope of the hereafter innovative approach is the development of a technique for power generation from tire/pavement friction forces to be directed to public electrical assets. At this first stage of research, a simple but effective electrical setting was elaborated. It consists of a pair of electrodes directly rubbed against a rotating wheel tire. The proposed technique is totally innovative and has not been investigated, even through laboratory research, anywhere else. In this regard, comparison and juxtaposition with other research efforts in the same direction are impossible.

In a similar direction, but still different, research initiatives have been undertaken by the Georgia-Tech University (USA)[10] and by the University of Wisconsin (USA)[11]. These initiatives provided evidence of a technique, widely known as TENG, the Triboelectric Nanogenerator. In general, the TENG seems that it aims to be applied to harvest all kinds of mechanical energy that is available in our daily life, such as human motion, walking, vibration, mechanical triggering, rotation energy, wind, a moving automobile, flowing water, rain drops, tides and ocean waves[11]. However, it is based on a concept quite different from the hereafter presented innovation.

The proposed technique claims to be simple, effective and productive. It aims to harvest triboelectric energy generated while wheel tires are directly rubbed against the pavement and against both attached electrodes. This is the reason why it is qualified as direct triboelectricity. The electrical assemblage, the shape, the materials and the proper placement of the electrodes with regard to the wheel load and the loading process, properly set up with a view to testing and providing proof of concept of the technique, are some of the main issues of the present research.

It must be clearly stated that the present technique is purely and totally original and does not constitute a variation or a continuation of any other technique in the field of triboelectricity generated by moving or breaking vehicles.

## 3. Basic concept

The basic concept consists of retrieving energy from friction forces developing between wheel tires and road pavement. According to the fundamental theory of triboelectricity[12], specific materials are charged, either positively or negatively, when rubbed against chargers (electrodes). If a rotating wheel is being rubbed, at the same time, against triboelectric-opposite materials, the electrodes, an electric potential may be generated. This potential is related to the triboelectric susceptibility of the materials, the friction coefficient, and the vertical load on the electrodes.

At the first stage of research, a laboratory assemblage was used to test the basic concept. The assemblage consisted of a rotating wheel tire over a solid bench, where round tubes, rods or flat bars were firmly attached. The rotating wheel tire moves down to the bench and is rubbed against two tubes, rods or flat bars susceptible to developing opposite electric charges. In each test the shape of the two electrodes must be identical, and the electrodes must be symmetrically placed with regard to the rotating wheel, either in a transverse or a parallel direction, so as to be subjected to equal forces by the wheel load.

## 4. The testing equipment

The testing equipment used throughout the experimental stage was designed specifically for the tests of triboelectricity. It consists of a rotating wheel bearing a vehicle tire, set up adequately to move down to a bench where flat bars, rods or tubes, susceptible to being oppositely charged by pairs, are attached. The equipment bears several sensors measuring variables of the experiment: the load applied, the rotational speed, the electric intensity of the circuit and the electric potential difference (**Figure 1**).

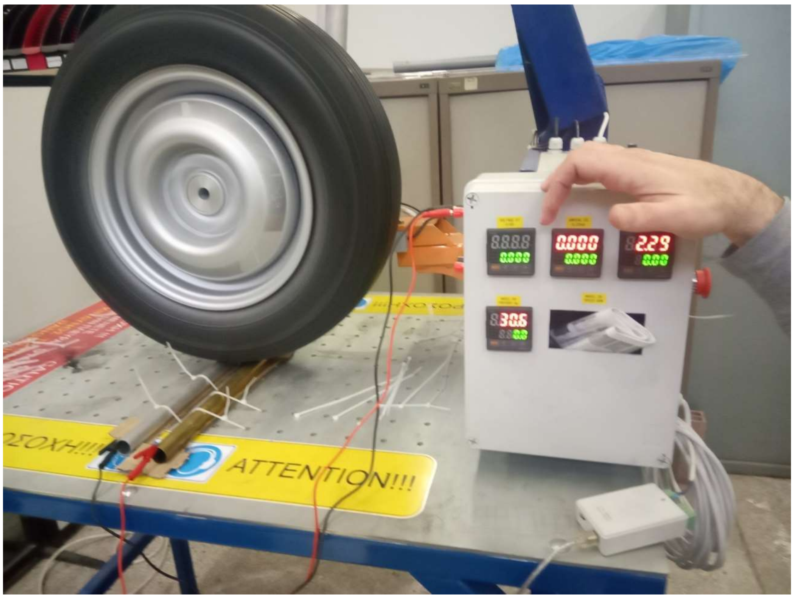

**Figure 1.** Perpendicular placement of electrodes.

In the experiments, the rotating wheel was adjusted in a way to enable the tire to be rubbed, at the same time, against the oppositely charged materials, thus providing electric potential between bars/tubes. Metals, such as copper, bronze, and aluminum, developing high electrical conductivity, were used in most experiments as electrodes. Reasonably, each pair of electrodes consisted of one positively and one negatively charged material. In several tests, insulators, such as plastics, glass, and acrylic plexiglass, were used to produce electricity from friction. In these cases, a wire was properly fixed on the insulator (“wired insulator”) to establish an electric circuit.

The whole device must be solid and stable to bear dynamic forces exercised by the rotating wheel. The maximum permissible load on the electrodes depends on the whole setting and the eventual metallic frame, supporting the wheel. The device used was rather simple, enabling the wheel to exercise loads up to 80 N. These loads are, in fact, very low, and this is certainly a significant barrier to the present research since the real loads of car wheels on the pavement attain 5000 N, while truck wheels exercise loads of 30.000–40.000 N.

## 5. Laboratory experimentation

Different materials in different forms were used to produce electric current according to the basic concept[13]. All bars, rods, and tubes used were attached to the testing bench in a direction, either perpendicular (**Figure 1**) or parallel (**Figure 2**) to the rotating wheel. Flat bars present the advantage of receiving a bigger vertical load, while rods and tubes are more uniformly rubbed against the wheel tire. In either case, insulating films were interposed between these elements and the bench to safeguard the potential generated.

**Figure 2.** Longitudinal placement of electrodes.

**Table 1.** Transverse loading.

| **$A_1$** | **2 Conductors** | | | |
|---|---|---|---|---|
| **Positive** | **Negative** | **Form of electrodes** | **Load (N)** | **Open circuit voltage (V)** |
| Aluminum | Bronze | Tubes | 50 | 0.08–0.15 |
| Aluminum | Copper | Flat bars | 30 | 0.15–0.25 |
| **$B_1$** | **2 Insulators (wired)** | | | |
| Plexiglas | Teflon | Tubes | 50 | 0.07–0.12 |
| **$C_1$** | **Conductor vs. Insulator (wired)** | | | |
| Plexiglas | Bronze | Rods | 30 | 0.25–0.32 |
| Glass | Copper | Flat bars | 50 | 0.16–0.27 |
| Aluminum | PVC | Tubes | 50 | 0.14–0.21 |

Laboratory experiments kept on going for several months. Different testing patterns, materials and forms have been used. Failures recorded were related to insufficient material strength (glass), friction effects, or inadequate application of the vertical load. In **Tables 1**, **2** and **3**, the results of the experiments are presented. In **Table 1**, the electrodes were placed perpendicular to the direction of the rotating wheel.

Maximum values of electric potential are drawn out of 2 to 4 tests for every different setting of electrodes. In each case, the no-load rotational speed of the wheel was 300 rpm.

In **Table 2**, the electrodes were parallel to the wheel and in **Table 3**, the effect of an intermittent loading is presented. The latter variation produced the most promising results.

**Table 2.** Longitudinal loading.

| **$A_1$** | **2 Conductors** | | | |
|---|---|---|---|---|
| **Positive** | **Negative** | **Form of electrodes** | **Load (N)** | **Open circuit voltage (V)** |
| Aluminum | Bronze | Flat bars | 80 | 0.38–0.51 |
| Aluminum | Copper | Flat bars | 80 | 0.11–0.15 |
| Aluminum | Bronze | Tubes | 80 | 0.21–0.29 |
| **$B_1$** | **2 Insulators (wired)** | | | |
| Plexiglas | Teflon | Tubes | 50 | 0.12–0.16 |
| **$C_1$** | **Conductor vs. Insulator (wired)** | | | |
| Glass | Bronze | Flat bars | 50 | 0 |
| Plexiglass | Bronze | Flat bars | 50 | 0 |

**Table 3.** Intermittent longitudinal loading.

| **Positive** | **Negative** | **Form of electrodes** | **Load (N)** | **Open circuit voltage (V)** |
|---|---|---|---|---|
| Aluminum | Copper | Flat bars | 30 | 0.20–0.29 |
| Aluminum | Copper | Flat bars | 80 | 0.81–0.91 |
| Aluminum | Bronze | Flat bars | 30 | 0.18–0.28 |
| Aluminum | Bronze | Flat bars | 80 | 0.76–0.88 |

Throughout the laboratory experimentation, the maximum wheel load varied from 30 to 80 N. Any variation of the vertical load applied to the electrodes led reasonably to a variation of the electric potential generated.

During the testing procedure, the variation of the electric potential with time was recorded. Reasonably, the vertical load was applied gradually and was maintained at the intended maximum value until the end of each test.

It was observed that the electric potential increased with the increase of the wheel load, kept on increasing for some time under constant load, remained at the peak value constantly for a while, and then it started decreasing to attain a zero value after a total time duration of 3 min. The duration of the time interval of the friction phenomenon under constant load was 1.5–2.0 min (**Figure 3**).

The afore-presented long experimentation, introducing a totally original setting of the rotating wheel ("charger") and electrodes, concluded to significant findings:

- The friction forces generated by the rotating wheel in contact with the electrodes, definitely produce electric potential difference.
- The maximum electric potential recorded between the two electrodes is higher in the case of intermittent charging.
- The difference in electric voltage generated between settings using either conductors or wired insulators is still difficult to accurately estimate. Especially in the case of wired insulators, geometrical factors such as the height of the flat rods seem to affect the value of the potential difference recorded.

- The intensity of the electric current recorded is very low (infinitesimal).

At this stage of research, the electric potential and the other variables of the experiments were recorded, but no attempt to collect the power generated has been undertaken. Although it seems difficult to harvest and store the electric power using the aforesaid process without significant improvement, it is certain that, so far, this constitutes a reliable proof of concept, inviting to the next stage of research.

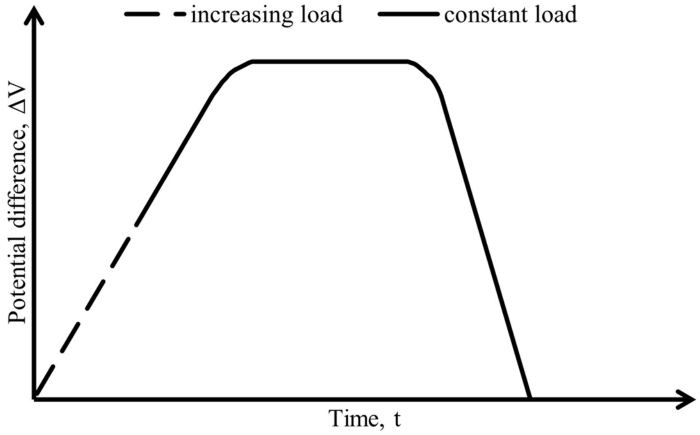

**Figure 3.** Qualitative representation of time-dependence of the open circuit voltage.

## 6. Theoretical approach

As more than one physical mechanism may contribute to the charge generation, a theoretical formula, predicting the value of the electric potential, needs much more experimental data to be accurately set up[12,14–16]. At the next stage of research, a semi-empirical relationship will be developed after a longer experimentation aiming at specific and explicit data required.

However, in general, the electric potential generated by a triboelectric setting may be given by a function depending on the friction forces and the specific electric charges of the electrode materials:

$$\Delta V = \Delta V\,(Q1, f1, P1, Q2, f2, P2)$$

where $Q1$, $Q2$: specific electric charge of materials; $f1$, $f2$: friction coefficients; $P1$, $P2$: vertical loads on tubes or bars.

Other variables, related to the susceptibility of each material to the triboelectric phenomenon, may also play a significant role in the development of the electric potential[17–21].

Each triboelectric test in the laboratory lasts about 3 min. During the first minute, the load is gradually applied since it is very difficult to directly apply a high wheel load. According to the experimental findings, the electric potential is also a function of time (**Figure 3**).

## 7. Conclusions and prospects

The experimental research presented is original and promising. It constitutes proof of a different concept of triboelectricity developing on road pavements under traffic. Using different electrode materials, different forms of electrodes and different loading settings, the research proved that there may be a significant amount of electric power to be retrieved from vehicles moving and breaking on road surfaces.

Most research findings to date, for instance, the relationship between the vertical load and the generated electric potential, are reasonable; others, such as the results of the tests by intermittent loading, require further study. Certainly, there is room for improvement in many aspects: electrode materials, tire texture, vertical load, loading setting, and others. Moreover, a concise theoretical approach to the triboelectric phenomenon and the experimental findings is in progress. The research is under full development, and further expected outcomes are likely to be available for presentation shortly.

## Author contributions

Conceptualization, AM; methodology, AM and GT; software, AM and GT; validation, AM and GT; formal analysis, AM and GT; investigation, AM and GT; resources, AM; data curation, AM and GT; writing—original draft preparation, AM; writing—review and editing, AM and GT; visualization, GT; supervision, AM; project administration, AM; funding acquisition, AM. All authors have read and agreed to the published version of the manuscript.

## Conflict of interest

The authors declare no conflict of interest.

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