RESEARCH ARTICLE

Calculation of Microplastics Emitted from Vehicles in Turkey and Their Collection Using the Principle of Static Electricity

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ABSTRACT: Contrary to common belief, pollution caused by land vehicles is not limited to exhaust emission. Friction between the road and the tires can also release microplastics, polluting the environment and threatening human health. Microplastics are pieces of plastic smaller than 5 mm, with their primary sources being synthetic textiles and car tires. Exhaust problems can be solved with new technologies such as electric cars, while microplastics originating from textiles can be addressed by using modified washing machines. This study aims to highlight the severity of the microplastic pollution in Turkey and propose a feasible solution to the problem by using a new product design. Calculations based on the loss of volume of car tires done in this study show that approximately 54,613 m³ of microplastics are released annually from car tires in Turkey alone. The contribution to this pollution for different types of vehicles was also calculated, revealing that almost half (49.6 %) is caused by automobiles. The proposed product, to be placed behind each wheel, utilizes static electricity to collect microplastics. This process is carried out by a rotating, acetate-covered cylinder that is negatively charged. The system creates a cycle, continuously collecting microplastics and depositing them inside a container. The capability of acetate to attract microplastics was tested in an experiment, demonstrating that acetate is an effective material for the capture of microplastics generated from vehicles.

KEYWORDS: Environmental Engineering; Pollution Control; Microplastics; Car Tires; Static Electricity.

Introduction

Microplastics are defined as "solid polymer particles generally smaller than 5 mm in size".[1] They are formed due to the abrasion of plastics used in many materials such as synthetic fabrics, paint, car tires, plastic bags, and plastic bottles. Even though microplastics are tiny in size, they cause serious environmental pollution.

With the continuous increase in plastic production in recent years, the release of microplastics to the environment has increased significantly. According to a study published in 2018, the plastic industry had an annual growth rate of approximately 12 % during the last 10 years.[2] The immense amount of microplastic release, therefore, is a problem that needs urgent attention.

Microplastics are categorized as primary and secondary microplastics according to their source. Primary microplastics are pieces of plastic that are directly emitted into the environment in sizes less than 5 mm. Today, many countries have banned their use. Examples of primary microplastics are microbeads used in the cosmetics industry, glitters used in the textile and make-up industry, industrial production pellets and recycled plastic pellets. Secondary microplastics are formed as a result of the wearing of macroplastics due to external factors. Microfibers detached from synthetic textile products and fragments detached from vehicle tires are examples of secondary microplastics. During the life of a single product, as many as 100,000 microplastic particles can mix into water resources and affect the food chain.[3]

Plastics have serious effects on nature, despite their small size, since the decomposition time of plastics in the environment can reach up to a thousand years.[4] Their effects are most common in aquatic ecosystems. For example, it is estimated that there are more than 150 million tons of plastic in the seas. By 2025, there will be a ton of plastic in seas for every three tons of fish. Additionally, 80 % of this plastic waste in the seas is caused by activities on land. While secondary microplastics are directly mixed into the food chain through the ingestion of aquatic organisms, primary microplastics cause the natural pollutants to remain on the water surface. Humans, who are at the top of the food chain, are also exposed to the negative effects of microplastics through fish consumption. Due to their small size, microplastics can enter the human body by mixing with food products or beverages, passing through respiratory barriers and can sometimes be absorobed through the skin. The abundant presence of microplastics in human urine and blood samples confirms this situation. When microplastics enter the human body, they profoundly affect human health due to their toxicity. They are particularly retained in the lungs at a high rate, causing significant respiratory problems.[3]

A study estimates that the annual per capita consumption of microplastics in the US varies between 39,000 and 52,000 particles. When the microplastics inhaled by respiration are considered, these values increase to between 74,000 and 121,000 particles and possibly higher.[5]

Car tires, synthetic textiles, marine coatings, road markings, and personal care products are the major contributing factors to microplastic pollution. Among these, car tires and synthetic textiles are the most prominent, making up 35 % and 28 % of the total microplastics in the oceans, respectively.[6] There have been efforts to prevent synthetic textiles from polluting the oceans. "Cora Ball" is a product resulting from one such effort. It is meant to filter microfibers during the clothes washing process.[7] Some brands, such as Arçelik have also started producing washing machines with integrated filtering systems, to reduce microplastic pollution.[8] Though these are positive developments for the environment; the pollution stemming from car tires has largely been ignored, not garnering the attention it deserves.

Car tires wear and tear by contact with the road. The amount and size of plastic particles resulting from this wear and tear is dependent on the temperature, the structure of the tire, the surface on which the tire moves, the speed of the vehicle and the way the tire and the road come into contact (rotation of the tire, tire slip, brake, etc.). As a result of the friction between the car tire and the road, heat is released and microplastics rupture from the tire. These microplastics spread into the air and waterways.[9] This corresponds to a total of 6.1 million tons annually, or approximately 1.8 % of plastic production. If the microplastics released during braking are also considered, this number increases by a further 0.5 million tons.[10]

The structure of modern car tires consists of 19 % natural rubber and 24 % synthetic rubber, or plastic polymers.[11] Metals and other substances make up the rest. Nowadays, there are car tires obtained by using recyclable and environmentally friendly materials instead of synthetic rubber to reduce environmental impact. However, their overall fraction remains low.[12]

Another potential solution to the microplastics problem is changing the structure of the tire, but such methods are difficult to apply. This is because these methods cannot be readily adapted to existing tires using current technologies. Solutions such as reducing the use of cars, preferring lighter cars, not making sudden moves while driving, and frequent clearing of roads are also suggested. Still, these suggestions are not very realistic or applicable for all drivers.

In a recent study, Shah and Foo[13] proposed the direct collection of microplastics emitted by car tires with electrostatic forces to be ready for use by the year 2025. This device, named "Dustin", is based on a positively charged carbon steel attached to the rear of the vehicle wheel to attract negatively charged microplastics due to friction. A vibration motor then causes the microplastic particles to fall, and a vacuum motor collects the microplastic particles. Although it is a well-designed device, it cannot be used on a wide scale. This is due to the fact that it is designed for public transport only. Since the target audience is municipalities and automobile brands, materials and technologies have been used that causes an increase in the price of the product. For this reason, it will not be possible for a standard car user to purchase this product, leaving the issue of microplastic pollution caused by everyday automobiles unresolved.

In another study conducted by Steffen,[14] titled "The Tire Collective", it was determined that it would be most efficient to use the principle of static electricity instead of vacuuming or adhesion principles for the collection of microplastics from vehicle tires. For this, the positive charge generated during the friction of plastic particles to the asphalt was used. The copper plates in the designed device are negatively charged with the energy it receives from the alternator of the vehicle, attracting car tire particles. In order to efficiently capture particles before they are released into the atmosphere, the unit is placed in the natural airflow path around the tire. It is claimed that 60 % of microplastics from car tires can be caught with this device. The collected rubber pieces are stored in a removable container that needs to be emptied once a month. The rubber waste obtained can be reused in recycled tires or for other purposes. The biggest challenge of this study is that the design is complex and not easily applicable. These features make production difficult and require a lot of experimentation before it can be put into use.

In order to find an effective solution to the microplastics problem, it is necessary to develop a simple design that is accessible to everyone. For this reason, in this study, a product that can efficiently collect the microplastics caused by car tires with low-cost materials is proposed. Additionally, the amount of microplastics the car tires produce to cause pollution in Turkey was calculated. This calculation also showed the distribution of microplastics emission among a variety of vehicle types.

Methods

Car tires are one of the primary sources that contribute to the emission of microplastics, which can have adverse effects on human health and the environment. Understanding the scope of pollution is an essential initial step to creating a solution for this widespread and critical environmental problem. Therefore, this study starts by estimating the emission of microplastics from vehicle tires in Turkey. The main aim of the study is to design and test a device that can reduce the amount of microplastics polluting the environment using the principle of static electricity.

Estimation of Microplastic Emissions from Tires:

First, the number of car tires in use in Turkey was calculated using the data provided by TÜİK (Statistics Institution of Turkey). The data for the number of active vehicles, along with the percentage of vehicle types was used for December 2020.[15] After calculating the number of each vehicle type, the total number of car tires associated with the vehicle type was calculated using the average number of tires per vehicle.

Since each vehicle model uses different kinds of tires, an averaged size was assumed for each vehicle type to simplify calculations. To best determine a standard size, a technical data book for car tires was used.[16,18] Standardized radius and width values were determined based on the data gathered from the tire data book. These values are shown in the diagram below. Table 2 shows better some of these values. In the "Tire sizes" column, the leftmost number is the width of the tire in milimeters, the second is the percent value of the height divided by the width of the tire, and the last is the rim diameter in inches. This is the standard tire size notation.[19] In Figure 1, the tire sizes taken for automobiles are exemplified.

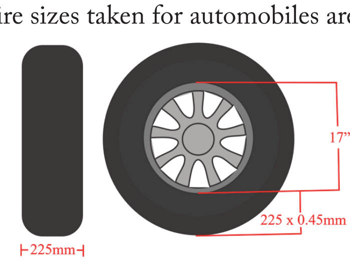

Figure 1: Representative tire sizes for automobiles (225/45 R 17).

Based on these values, the total volume loss of tires during their lifetime and the distribution of this volume loss by vehicle types were calculated. The legal limit for tire tread depth in Europe is 1.6 mm.[13] The tread depth of a never used tire is between 7-9 mm.[20] In this study, the tread depth of a new tire was assumed to be 8 mm and the tire was assumed to be changed when the tread depth was 1.6 mm. In other words, it was assumed that the tire lost 6.4 (8 – 1.6) mm of tread depth through its lifetime. Using the knowledge that a tire has an average life of 5 years,[20] the annual amount of plastic released from a tire was calculated. In addition, since the volume of the tread on the tire varies according to the brand and tire type, the ratio of tread area to the tire surface for each tire type was taken as 90 % in this study. The amount of microplastics emitted by the tires was calculated with the following relationship based on the volume loss experienced by the tire.

$$\Delta V = 2\pi r \times \Delta r \times L \times \psi$$

where

ΔV Tire's loss of volume

r Wheel radius

Δr Change of tread depth (assumed to be 6.4 mm for each tire)

L Tire width

ψ Ratio of contact area to total surface area (assumed to be 0.9 for each tire)

The calculated volume loss per tire rubber was multiplied with the number of tires used in Turkey (Table 1), and the total volume loss of all tires was found. This volume loss corresponds to the amount of microplastic emitted into the environment during the lifetime (5 years) of tires. Microplastic emitted into the environment in one year by all vehicles in Turkey was found through this calculation.

Results and Discussion

Results of the microplastic emissions from different vehicle types in Turkey are given in the tables and figures presented below. Table 1 provides the number of tires used in Turkey, broken down for each vehicle type. Table 2 presents the tire sizes taken for each vehicle type and the radii and widths calculated according to these dimensions. In Table 3, the volume of released tire material for each tire type during its lifetime is presented. Table 4 provides the total volume loss of tires in Turkey for five years, which corresponds to the amount of microplastic emitted into the environment during the lifetime of tires, and one year. In Figure 2, the distribution of microplastic volume emitted to the environment for each vehicle type is summarized.

Table 1: · Vehicle and tire quantities in Turkey as of December 2020.

Vehicle type	Tires per vehicle	Number of vechicles	Total number of tires
Automobile	4	13,110,657	52,442,629
Van	4	3,935,612	15,742,447
Motorcycle	2	3,501,004	7,002,009
Tractor	4	1,955,733	7,822,934
Truck	6	869,215	5,215,289
Minibus	4	482,897	1,931,589
Bus	4	217,304	869,215
Special purpose*	4	72,435	289,738
Total		24,144,857	91,315,849

*Vehicles used for special purposes, including ambulances, fire trucks, and funeral vehicles.

Table 2: Standard tire dimensions for each vehicle type.

Vehicle Type	Tire size	Tire diameter (m)	Tire width (m)
Automobile	225/45 R 17	0.317	0.225
Van	195/75 R 16	0.349	0.195
Motorcycle	120/70 ZR 17	0.300	0.120
Tractor	315/80 R 22.5	0.538	0.315
Truck	315/80 R 22.5	0.538	0.315
Minibus	225/45 R 17	0.317	0.225
Bus	295/50 R 22.5	0.433	0.295
Special purpose	225/45 R 17	0.317	0.225

Table 3: Volume loss per tire for each vehicle type.

Vehicle Type	Volume loss per tire (m^3)
Automobile	0.002583
Van	0.002466
Motorcycle	0.001302
Tractor	0.006130
Truck	0.006130
Minibus	0.002583
Bus	0.004626
Special purpose	0.002583

Table 4: Volume of microplastics emitted by each vehicle type in Turkey for 5 years and 1 year.

Vehicle Type	Total volume loss in 5 years (m^3)	Total volume loss in 1 year (m^3)
Automobile	135,436	27,087
Van	38,823	7,765
Motorcycle	9,120	1,824
Tractor	47,958	9,592
Truck	3,972	6,394
Minibus	4,988	998
Bus	4,021	804
Special purpose	748	150
Total	273,067	54,613

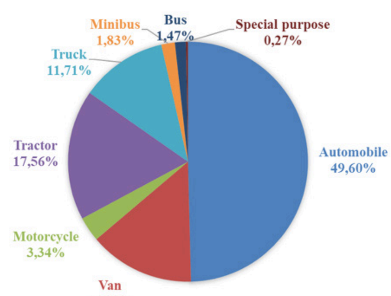

Figure 2: Distribution of microplastics emission from car tires among vehicle types in Turkey.

The calculations show that every year, approximately 54,613 m^3 of microplastics are produced by car tires in Turkey (Table 4). In other words, 4.5 times the volume of The Galata Tower in microplastics is produced annually. This means microplastic pollution equal in volume to The Galata Tower is generated about every 3 months. Around half, 49.6 %, of these are by automobiles (Figure 2), adding up to 27,087 m3 annually

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(Table 4). The remaining vehicle types and their contribution to the pollution (m^3) are as follows: tractors, 9,592; vans, 7,765; trucks, 6,394; motorcycles, 1,824; minibuses, 999; buses, 804; and special purpose vehicles, 150 (Table 4). Due to the sheer amount of microplastics in the environment, it is essential to design a product to combat this problem. Acetate, which is the main component of the product proposed in this study, has proven to be able to collect microplastics in an experiment. To achieve this, the acetate needs to be charged with static electricity (Figure 10, Figure 11). The container in which the microplastics collect must be emptied occasionally. The time in between these emptying was calculated based on the efficiency of the product. Assuming the product works with 100 % efficiency, this time is approximately 22 months (Figure 3).

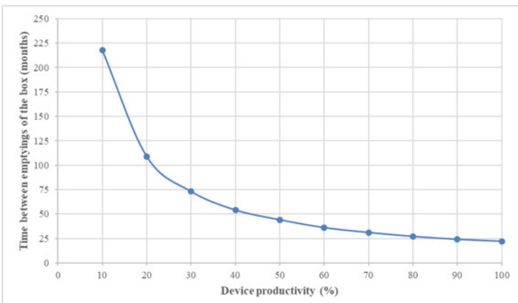

Figure 3: Time between emptying of the box based on device productivity.

Design of a Microplastic Collection Device:

The device designed in this project was drawn with the "AutoCAD" program. Figure 4 shows the three-dimensional view of the design from the outside. Figure 5 shows the position of the product on the car. Microplastics coming out of car tires become positively charged on asphalt as a result of friction.[14] This product works on the principle of static electricity. Attached to the back of car tires, this device collects positively charged microplastics. The microplastics collected in the box can then be recycled and used again to make rubber or other similar materials

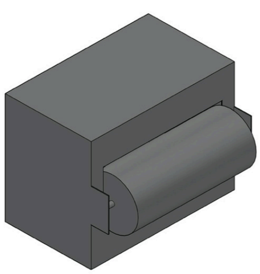

Figure 4: Three-dimensional model of the prototype.

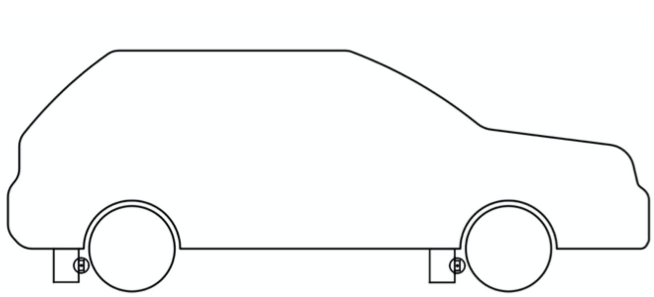

Figure 5: Placement of the product on a car.

Materials and Working Principle:

The aluminum box, whose dimensions vary according to the type of vehicle, is the component where microplastics are collected. Low-cost aluminum has been preferred and allows for the device to be sturdy. As an example, it is designed with a width of 0.15 m, a length of 0.25 m and a height of 0.1 m for automobiles. Figure 4 shows these dimensions determined for automobiles. There is a rectangular opening on one side of the box for a cylinder to pass through and a protrusion at both ends for the cylinder to hold. The gap between the boundaries of the hole and the cylinder is wide enough for microplastics to pass. The box is mounted behind the wheel, on the body of the car, so that it can be easily installed and removed. When the box is filled with the microplastic waste, it can be emptied by opening the cover. Figure 3 shows when the box should be emptied which maximizes the efficiency of the product. The product efficiency was defined as the ratio of the collected microplastics to the total microplastic emitted from the vehicle tires. Through this ratio, the time to empty the box was determined according to the box capacity. For this, the volume of the box that can hold microplastics and when this volume would be filled was calculated. The capacity of the box was calculated such that the height of the collected amount of microplastics was 0.025 m. This calculation is based on the design for automobile tires.

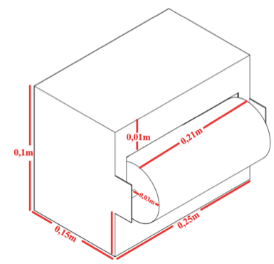

Figure 6: Representative product dimensions for automobiles.

PVC pipes, which are low in cost and easy to access, are proposed for the cylinder that collects microplastics. The circumference of the pipe is covered with acetate, which is also low in cost, easy to shape and can be charged electrically. Since the PVC pipe is an insulator, it does not cause acetate to lose its charge. For automobiles, it is designed with a height of 0.21 m and a radius of 0.025 m. These dimensions are shown in Figure 6.

The battery-powered motor placed in the box enables the cylinder to rotate. This motor can operate in the box, protecting it from external factors.

In order to collect the microplastics in the box, a carbon brush, which is not affected by static electricity, is placed inside the box. Choosing a brush instead of neutralizing the static electricity for this process reduces the cost and avoids having to charge the neutralized area with static electricity again. This brush allows the negatively charged microplastics drawn by the positively charged cylinder to be scraped from the cylinder in the box.

Static sponge will be used to load the roller. If this method is not successful, a static loading bar will be used. A static sponge was selected due to its low cost. These materials will be attached to the top of the cylinder. The photographs in Figure 7 show the static sponge and the static loading bar.

Figure 7: Static sponge and static loading bar, respectively.[21]

As shown in Figure 4, the cylinder charged with static electricity is mounted in a box with a portion of it inside. Figure 8 also shows the interior of the product. The working principle of the product is shown in Figure 9. The acetate-coated cylinder rotates in the direction of the arrow as shown in Figure 9 with the help of a battery-powered motor. As the device is working, the cylinder is negatively charged. As the microplastics break off the tire, their positive charge enables them to adhere to the negatively charged cylinder and enter the box following the rotation of the cylinder. Microplastics are scraped from the cylinder and collected in the box due to the carbon brush mounted in the box.

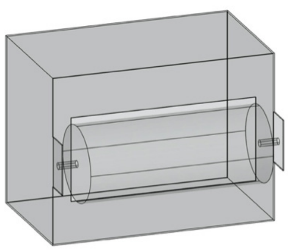

Figure 8: Inside view of the prototype.

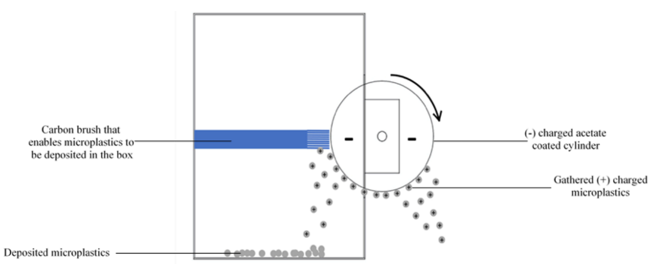

Figure 9: Working principle of the device.

Experimental Procedure:

To test the working principle of the design, an experiment was conducted to show whether acetate catches microplastics from vehicle tires when charged with static electricity. For this experiment, small pieces of a vehicle tire were first removed with the help of a utility knife and sandpaper. Then acetate was rubbed against a wool sweater and an electrical charge on the acetate was generated by friction. Acetate was held over on microplastic pieces immediately after rubbing and it was observed that the microplastic pieces were attracted to and stuck to the acetate. As the experimental control, acetate, which was not electrically charged by friction, was held on microplastic pieces and it was observed that these pieces were not attracted to the acetate. The control group is shown in Figure 10, and the experimental group is shown in Figure 11.

Figure 10: Control group: The microplastics were not attracted to the uncharged acetate.

Figure 11: Experimental group: The microplastics were attracted to the charged acetate.

Conclusion

To conclude, the vast amount of microplastics being spread by car tires in recent years are a significant contribution to pollution. Though the effects of microplastics on human health still require further research, it is known that their inhalation can cause major respiratory problems, including lung cancer. It is essential to propose solutions to this severe threat to health. This study aims to propose an affordable and practical answer to this impending threat. The described solution is based on the fact that microplastics can be collected using opposite electrical charges. The calculations and conducted experiment demonstrate this to be feasible. Another aim of the study is to calculate the amount of microplastics being spread by each type of vehicle, in Turkey, annually. It is predicted that the wide-spread usage of the proposed product would greatly decrease microplastic pollution, also allowing the collected microplastics to be recycled.

Suggestions for Future Research:

The surface of the cylinder used for the product could be coated in a photoconductive material such as selenium, creating a system similar to that of a photocopy machine. Photoconductivity allows materials to conduct electricity only when exposed to light. Placing a light inside of the box would cause the selenium to transfer its charge to the conductive cylinder, dropping the collected microplastics inside the box. This method was not chosen due to the cost of the selenium and the need to modify the design so that no light touched the selenium on the outside of the box. Additionally, the areas where microplastics adhered to the selenium would not be exposed to light so they would not lose their charge, and the microplastics would not be released. If a design effectively bringing a solution to all these problems were proposed, using a photoconductive material would be feasible.

The base of the box could also be negatively charged to prevent collected microplastics from sticking to the cylinder again. This modification was not implemented for this design since the charge of the microplastics was considered too insignificant to create an attraction that strong. The implementation would also

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needlessly complicate the creation of the product, decreasing its practicality. However, if a version of this product was to be used for different purposes, this feature could become necessary to deal with stronger charges.

The principle of using electrical charges can be beneficial outside of collecting microplastics. For example, it could be useful in collecting dust. If a surface were negatively charged; dust particles in the vicinity would be attracted to it, making the cleaning process more convenient. Static electricity could also be used to filter the smoke coming out of factory chimneys. It is common knowledge that factory smoke, containing dioxide and particles suspended, is a major contributor to air pollution. A simple filtering system, using static electricity, could be installed inside the chimneys to collect these particles, reducing pollution.

Lastly, by developing more advanced technology, static electricity could be used on a cellular level. Cells or molecules could be separated since they have different amounts of electrical charge. This would be a breakthrough in biotechnology, allowing for countless possibilities of new techniques, applications and inventions.

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