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RELATION BETWEEN QUALITY OF TRANSPORTATION AND NANO-SCALE AIR POLLUTION

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Abstract. This study has two parts as determining traffic LOS and nanoscale analyses on the filters which can collect nanoparticle materials sourced by exhaust waste. Therefore, at first, determination of the traffic behaviour as the level of service (LOS) in Sıhhiye campus of Hacettepe University in Ankara was studied. Then, exhaust gas analysis by using facing masks was conducted for different parameters and these masks were used to collect and analyse exhaust on them. The parameters were determined as vehicle and fuel types, filter masks, sampling distances respect to exhaust source. The measurements and samplings were realized for the vehicles which are public cars and service

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minibuses which use different fuel types as petrol, eco-diesel and diesel. Additionally, 5 different filter types were used to analyse traffic behaviour as exhaust gas may affect human health. For this reason, different mask types with different specified parameters, which are using as face masks for health and a new type was prepared by Argiope lobata spider silk membrane, were also investigated in relation to the filtered exhaust gases. Measurements were made for three different distances as 30, 60 and 90 cm from exhaust pipe output and with a constant sampling time range of 3 min. Apart from the previously known microscopic and macroscopic analyses on exhaust gases, it was examined whether the exhaust outputs frequently spread nanoparticle waste or not by using SAXS analyses on samples. As a result of the study, relation with traffic conditions with clear transportation can be affirmed. Additionally, the study reported important outcomes, such as a new designed filter mask material, which prevents the nanoparticles waste material, the critical distance from the exhaust sources and the importance of different fuel usage.

Keywords: clear products, face masks, gas analysis, hospital, level of service, traffic.

Introduction

As known, transportation plays an important role in human life and the number of vehicles is increasing according to human population day by day. Ankara, which is the capital city of Turkey, has a lot of vehicles and every four people in Ankara have one vehicle according to research done by the Turkish Statistical Institute (TUIK, 2017). However, increasing population of vehicles can cause some health problems due to exhaust gas emissions. Based on the Turkish Statistical Institute (TUIK, 2017), the total number of vehicles in the country was 22 218 945 in 2017. Approximately 8.4% of these vehicles are located in Ankara with 1 376 928 cars, 24 517 minibuses, 17 878 buses, 282 287 vans, 78 373 trucks, 46 000 of 1 887 491 motor vehicles. Furthermore, 37.9% of the 12 398 190 cars registered in traffic were recorded as LPG, 36.8% – diesel, 24.9% – gasoline fuel, 0.4% – unknown fuel type cars. Therefore, the number of cars and their type can affect health of people and environment.

LOS has a critical role in road design and determining the effects of the vehicles. According to the literature review, it can be seen that determining the traffic jam and quality of the road as LOS has a critical effect on improving the metropolitan cities. There are some studies about LOS behaviours in the literature. For example, Shalanova (2017) reported that traffic congestion for Istanbul in Turkey was emerging as one of the biggest problems worldwide. The approaches and methods used in analysis were based on HCM-2000. The change of seasonal and peak hour traffic volume according to a flow rate was determined by the approaches specified at the analysis stage. According to the obtained results, road capacity must be used effectively, traffic mobility must be increased, access points must be regulated and level of service improvements must be done to overcome traffic congestion. Babu and Pattnaik (1997) studied traffic of roads under mixed traffic conditions as prevailing in India, and it was ambiguous as it varied with time, composition of traffic and roadway encroachments. High incidence of slow-moving vehicles and tricycles added to the problem. Volume – capacity ratio appeared to be an inadequate measure of determining level of service under mixed traffic situations. An attempt was made in this paper to explore the possibility of presenting unconventional parameters like standard deviation of speed, coefficient of variation of speed and acceleration noise as possible measures of level of service. Tentative ranges of acceleration noise were proposed in association with flow and speed to explain a level of service of urban roads catering to mixed traffic. The results were based on a study conducted in Madras, a major metropolitan city of India. Bassan (2013) studied the traffic effects. The peak hour factor characterized the fluctuations of traffic flow based on the busiest 15 min during the peak hour. This parameter was used in the process of evaluating the traffic flow conditions such as capacity and LOS of Tel Aviv metropolitan area in Israel. As a result, it was found that the rural model calibrations could be beneficial in estimating traffic flow rates for traffic engineering analysis when traffic counting was incomplete or not achievable. The urban models need further examination.

Additionally, studies are continued because of the critical topic in recent years. Afrin and Yodo (2020) studied the traffic congestion and a sustainable and resilient traffic management system by computing LOS behaviours. Pulugurtha and Imran (2020) modelled a basic freeway section LOS with travel time and reliability. Study was made on Jacksonville urban corridor. They reported that road geometries such as length, the number of lanes, etc. can effect density and travel time and more research should be continued about LOS. Isradi et al. (2021) investigated that unsignalized intersections in Cileungsi District, precisely on Jalan Cileungsi Setu and Jalan Raya Narogong. When they analysed the solutions they found that the busiest traffic flow at the intersection was on Sunday, and LOS degree was F. Therefore, they added signs and analysed the solutions to improve the quality of the road. Raj and Vedagiri (2022) studied LOS on the urban road. They also reported that urban road travellers are more tolerant of congested conditions, evidenced by a 3% decrease in perception-based thresholds. Gore et al. (2023) investigated a new congestion index by using traffic flow and travel time-based congestion measures and LOS thresholds were developed. AlKheder and Al-Jazzaf (2024) studied scenarios about LOS and different impacts such as peak hours, rumps, emissions, etc. on intersection of Blajat Street and Amr Ibn Al Aas Street. The aim was to increase the validity of the models. The public involvement was founded as very significant to check the scenario satisfaction.

Traffic behaviour can also be important for exhaust gas behaviour. Therefore, this study focused on the effects of the quality of roads according to LOS levels and relations with emission of exhaust gas. Thus, face mask potentials to prevent harmful effects of exhaust gas were studied by different car types using different fuels and the source distances from the cars.

Toxicological effects of the exhaust gas cannot be eliminated for humans according to Kagawa (2002). Shakya et al. (2017) declared that cloth face masks every time should be used to filter particulate matters in air. Apart from this fundamental usage, newly designed face masks developed by Yang et al. (2017) have multi-purpose usage potentials and may be useful against the nonstructural harmful air pollutants. Particulate matter (PM), one of the main pollutants in the air, has been raising serious concerns in recent years. PM is classified as PM2.5 and PM10 by particle size, referring to PM, whose particle size is below 2.5 and 10 μm, respectively. PM2.5, which has small particle sizes, can penetrate the bronchi and lungs and poses a serious health threat to the public.

Face masks are widely used as safety masks to filter out airborne pollutants. Commercial face masks are usually made from many layers of fiber (a few μm in diameter) and physically block PM particles and capture them by a combination of adhesion. To achieve high PM lift efficiency, these face masks need to be thick and therefore are generally voluminous and resistant to airflow. Exposure to particulate matter is associated with respiratory and cardiovascular health effects, and reflects a global public health concern.

Particles of < 2500 nm (2.5 micron) (PM2.5) are generally considered more harmful than larger-sized particles due to their penetration into human bronchi and lungs. Wearing personal face masks is thought to provide an immediate and short-term practical solution to people living in developing countries who are willing to reduce high rates of exposure to air pollution without having to avoid highly polluted environments. With this study, the filtering ability of the several face masks against nano-structured waste materials (in air) crated in exhaust pipe of vehicles was also investigated.

Briefly, this study was conducted in Sıhhiye, which is in the centre of Ankara, and it is one of the places most affected by this heavy traffic flow. The underlying objective of traffic analysis is to quantify a roadway performance with regard to specified traffic volumes. This performance can be measured in terms of travel delay as well as other factors. The comparative performance of various roadway segments is important because it can be used as a basis to allocate limited roadway construction and improvement funds. Additionally, traffic in front of a hospital can cause a huge problem. This study firstly focused on LOS calculations of the hospital road for Hacettepe University in Sıhhiye campus, and the second part of this study focused on gas analysis of face mask of vehicle passing through the road by using SAX analyses.

2. Materials and methods

This study includes the harmonization of two comprehensive studies. In the first part, the effect of the number of cars was analysed by determining the traffic behaviour of a hospital region of Sıhhıye campus of Hacettepe University in Ankara. Firstly, proper places should be chosen for counting cars and taking measurements. Accurately counting cars is a primary factor for determination of LOS. Manual counting method was used to measure the number of cars. It was decided to count at the beginning of two roads: 1) exit from the campus (Road 1 and 2) entrance to the campus (Road 2). The photos of selected places and details can be seen in Figure 1.

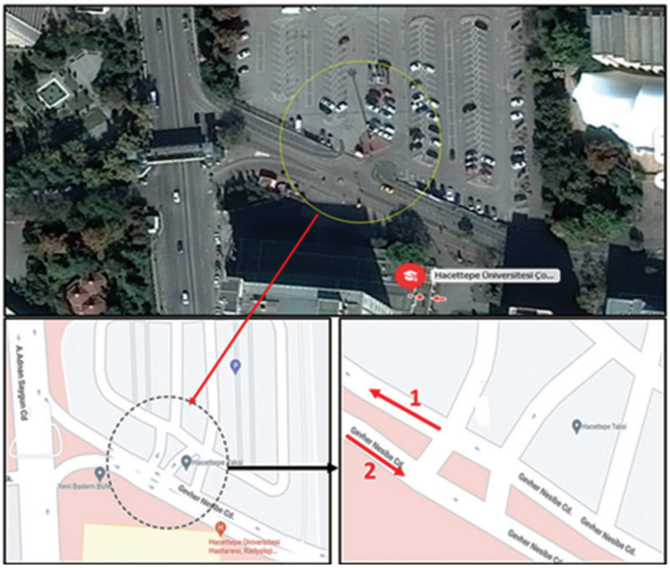

Figure 1. Maps showing the bird's-fly view of the campus and the measurement points (roads 1 and 2)

Measurement time was determined as two days of the weekdays as Monday and Friday and one day of the weekend as Saturday. Hours were determined between 07:00 and 19:00, and it was also decided to make 15-min counts. This counting system was important because of Peak-Hour-Factor (PHF). In Figure 1, each road was counted separately and also heavy vehicles were counted since heavy vehicles percentage was determined and then the road widths and dimensions were measured. In order to express the quality of the service of a road, the term 'service level' is used as the quality measure to describe the operating conditions in the traffic flow.

LOS is a quality-related measure of the effects of various factors, including speed and travel time, traffic interruptions, freedom of manoeuvrability, safety, driving comfort and operating costs (HCM, 2000). Service levels represent three important characteristics of traffic flow such as speed, density and flow; shown by the letters A, B, C, D, E and F. If service level A defines the best operating conditions, service level F defines the worst operating conditions. In many ways, the design or planning in Turkey, mostly level C or D conditions are defined as adequate (Yayla, 2004). Using the characteristics of the traffic flow, service levels on multi-lane highways are defined in the Highways Capacity Handbook (HCM, 2010). LOS A defines the operational conditions of the free flow of traffic. LOS B represents the traffic situation in which free flow rates can be maintained and represent free flow rates. Within the traffic flow, the freedom of manoeuvring of vehicles is not very limited. LOS C is the highways in the free flow rate value and the freedom of manoeuvring of vehicles within the traffic flow is sufficiently limited. LOS D level refers to a level where the speed tends to decrease by slowing down as traffic flows and intensity begins to increase rapidly. Within the traffic flow, the freedom of manoeuvring of vehicles is further restricted. LOS E – flow becomes irregular and speed varies rapidly because there are virtually no usable gaps to manoeuvre in the traffic stream and speeds rarely reach the posted limit. LOS F defines the disruptions in vehicle traffic flow such as interruptions, blockages, and deterioration. It shows the characteristics of the current traffic flow in the queue resulting from the disruptions in the traffic flow (HCM, 2010). Briefly, manual counts were conducted and then peak hours were selected to calculations. Road geometries were determined and LOS levels were calculated by HCM (2010).

For study, firstly, all counts were made and then the number of cars for each 15-minute time periods were written. Hourly volume was found by total of these 15-minute time periods ($V15$) and peak-hour factor was determined. Based on the Peak-Hour Factor (PHF), formula values were determined as in Equation (1).

$$PHF = \frac{V}{V15 \times 4} \tag{1}$$

Heavy vehicle factors were determined by a heavy vehicle formula. There was no recreational vehicle so E_R was taken 0. Type of terrain was the level of terrain, so E_T was taken as 1.5 for a heavy vehicle factor. Heavy vehicle adjustment factor f_{HV} was determined as in Equation (2). Here, P_T, P_R, E_T, E_R are proportion of recreational vehicles in the traffic stream, passenger car equivalent for trucks and buses, passenger car equivalent for recreational vehicles, respectively.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} + P_R(E_R - 1) \tag{2}$$

$$V_P = \frac{V}{PHV \times N \times f_{HV} \times f_P} \tag{3}$$

The observed speed value of this road was 30 km/h. To determine LOS for each hour interval charts were used from Mannering and Washburn (2013). When the number of flow rate increased, LOS degree was named from A to F. Road was becoming more crowded and it was needed to stop moving.

In the second part of the study, SAXS–HECUS system (X-ray systems, Graz, Austria) with Kratky optic was used (in X-Ray Laboratory of Physics Engineering Department) to measure Small Angle X-Ray Scattering data for the nanoscopic analyses of exhaust gases on face masks. As it is known, there is a high traffic density, vehicles cannot move as they wish in traffic. Therefore, one of the main elements is determining Level of Service (Mannering and Washburn, 2013). When the traffic is at high level exhaust gas diffusion can be seen. This case

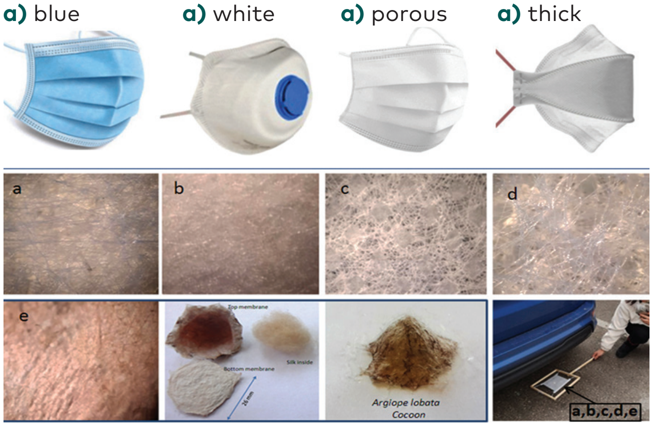

Figure 2. Filter materials obtained from pharmacies (a–d), new designed spider silk membrane filter material (e), the related silk cocoon to obtain the membrane and filter holder view

can have a harmful effect on human life. Therefore, these effects and protecting situations should be determined. Using SAX analysis, the size and shape of nanoparticles samples (collected by filtering of air around the exhaust pipe) were determined applying Guinier region of the scattering data. The sizes (radius of gyration values) of the nanoparticles with Globular (3D), Plate (2D) and Rod (1D) like morphologies were obtained by plotting $\ln(I) - q_2$, $\ln(I\,q) - q_2$ and $\ln(I\,q_2) - q_2$ graphs using Guinier analysis method and the related equations to find the radius of gyration values (Putnam, 2016). This way the effectiveness of the facial mask to protect from these effects can be known.

SAXS experiments were performed with a linear collimation system and X-ray tube Cu target (λ = 1.54 Å). The generator was operated at a power of 2 kW (50 kV and 40 mA). Linear-position-sensitive detector with 1024 channels was used during the measurement time range of 900 min for each sample. The mask samples were prepared in rectangular shape with dimension of 3×8 mm cut off from the central part of the used face masks.

Five face masks of different type as filter materials were used to collect the nanoparticles in air medium about the exhaust pipes. As Ogbuoji et al. (2021) reported, penetration percentage range values measured from filtration tests for surgical masks could be minimum almost 11.98% to 47.18%. Therefore, in this study enough amount of particles was measured. Figure 2 shows a microscopic view of the control groups in 3 mm scale. Four of them (a–d) were purchased from pharmacies. The fifth one (e) was the first case designed by using spider silk cocoon weaved by Argiope lobata. Bottom part of the cocoon was used to prepare silk membrane and this membrane was fixed in the central part of the filter holder before the measurements. The filter holder was also prepared in rectangular shape as seen in Figure 2. Additionally, different vehicle types were used to evaluate the exhaust gas to see the performance evaluation and their results were compared in the study. They were named VPD, RCD, FD because full names were not given in compliance with ethical rules. However, generally, it can be said that fuel and model types were different.

3. Results and discussion

3.1. Results

LOS evaluations of hospital region at three place numbers were calculated as in Table 1. On Saturday, the number of cars was almost non-existent. There was no problem for road quality on Saturday. Average

LOS for each road was level "A" so there was no problem for traffic jam. However, on weekdays this situation was completely different. Average LOS of entrance and exit of the roads was level "D". It can create problem for some hour intervals, especially for hospital zone. Road quality should be better in an area where ambulances frequently enter and exit. On Friday from 07:00 to 09:00 LOS was "F". Traffic flow almost did not exist during this time interval. On Monday, this situation was similar. On Road 2 traffic is high. Likewise, especially after 18:00 traffic values were decreasing. The data show that on Friday between 16.00 and 18.00 LOS was "F". It is the critical value and can be dangerous for hospital zone. Figures 3 and 4 show the number of cars and hours for different road types and days. This means that on Mondays and Fridays in the morning (07:00–11:00) and in the evening (16:00–18:00), the roads were very crowded and exhaust gas could be released more when cars waited. However, on Saturday which was a holiday for workers of the hospital and students there were the free roads and least exhaust gas could be released.

Table 1. LOS calculations of child hospital region

Day	**Saturday**		**Monday**		**Friday**	
	Road No.		**Road No.**		**Road No.**	
Time	**1**	**2**	**1**	**2**	**1**	**2**
07:00–08:00	A	A	A	F	B	F
08:00–09:00	A	A	C	F	D	F
09:00–10:00	A	A	D	F	E	E
10:00–11:00	A	A	C	F	C	D
11:00–12:00	A	A	D	D	C	C
12:00–13:00	A	A	B	C	C	C
13:00–14:00	A	A	C	D	B	E
14:00–15:00	A	B	C	D	D	E
15:00–16:00	A	A	E	D	E	E
16:00–17:00	A	A	D	B	F	B
17:00–18:00	A	A	F	B	F	B
18:00–19:00	A	A	B	B	B	A
Mean LOS	A	A	D	D	D	D

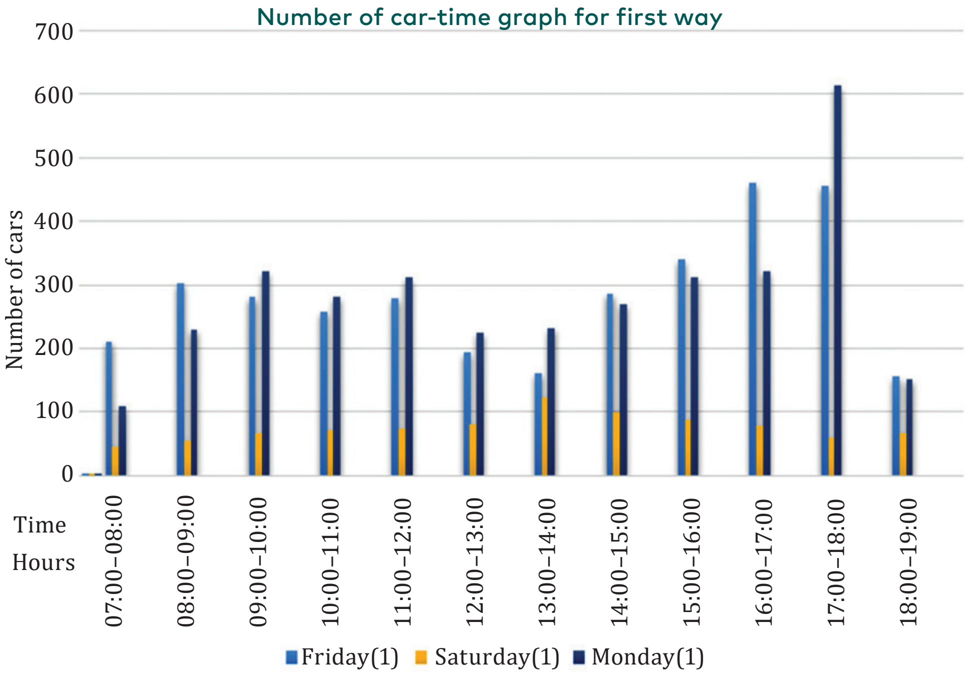

Figure 3. Number of cars for Road 1

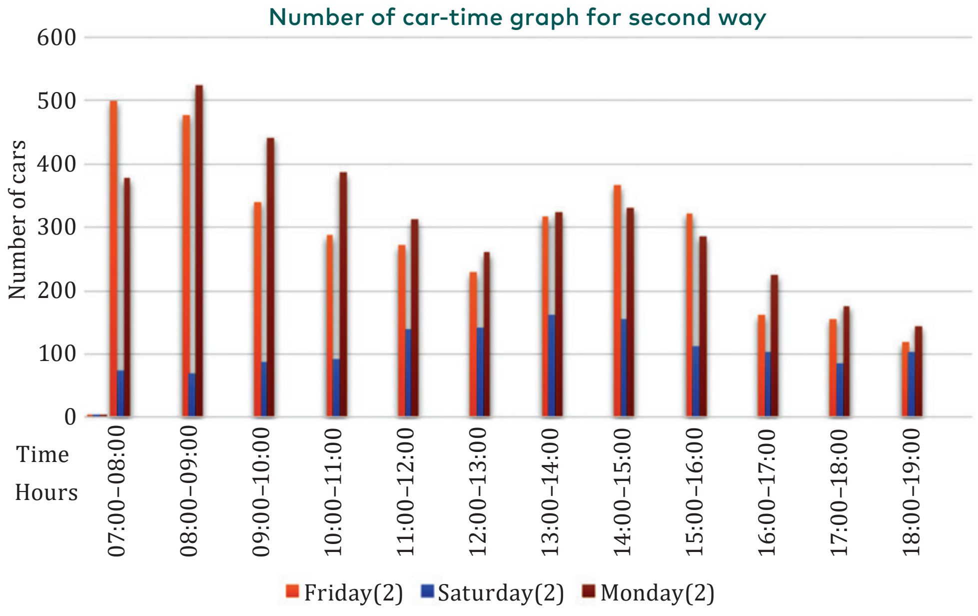

Figure 4. Number of cars for Road 2

Additionally, the number of trucks can be seen in Table 2 for Sıhhiye campus, and as it can be seen a lot of trucks can be seen at this region. When Table 1 and Table 2, Figures 3 and 4 are discussed together, it can be stated that on Saturday there is the least number of vehicles and they can be used on the road freely. However, on weekdays there are a lot of vehicles and therefore LOS level can be seen as F. Although the number of heavy vehicles should not be underestimated, the percentage of vehicle numbers that day remains relatively low. Therefore, only exhaust gas of cars was investigated in this study.

Within the second part of this study, it can be seen from the traffic behaviour that exhaust gas may affect human health. For this reason, different mask types with different specified parameters were also investigated in relation to the filtered exhaust gases. The obtained morphologies (3D and 1D) and the measured radius of gyration values of the nanoparticles (filtered by the masks) were given according to type of filters in Figure 5.

Table 2. Total number and percentage of trucks for different days and road points in the child hospital region

	PLACE POINTS			
	Road 1		Road 2	
DAYS	Total Number	Percentage, %	Total Number	Percentage, %
Saturday	43	4.8	52	4.3
Monday	110	3.3	119	3.2
Friday	120	3.6	126	3.6

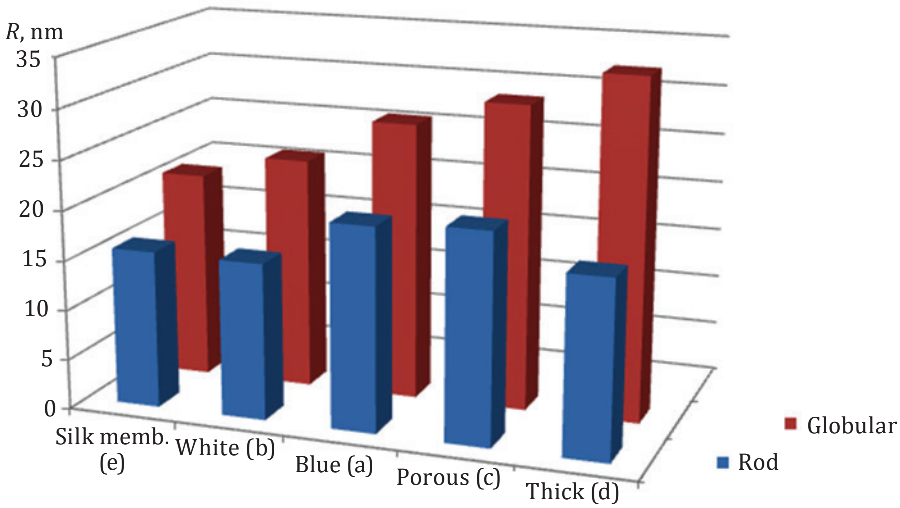

Figure 5. The measured mean sizes (R) of the filtered nanoparticles by the studied mask materials

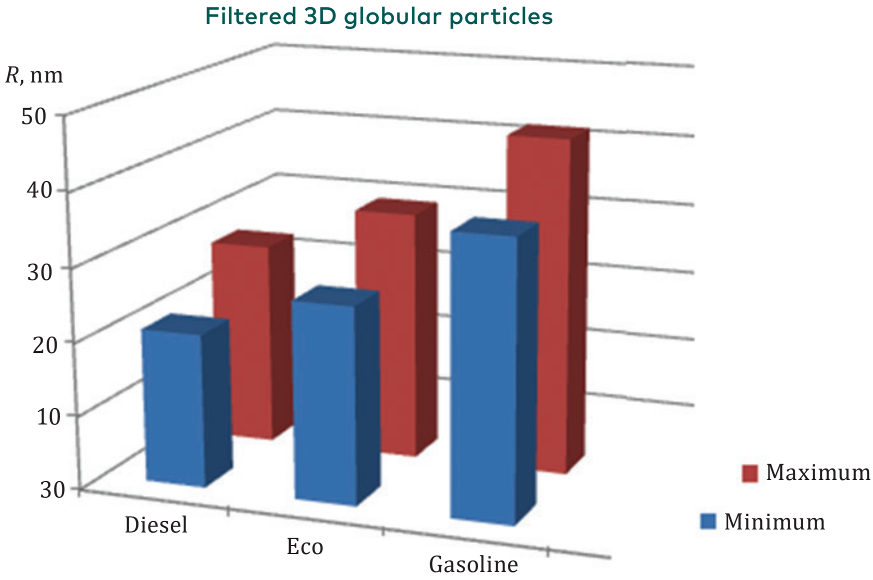

Figure 6. The sizes (*R*) according to the vehicle fuels

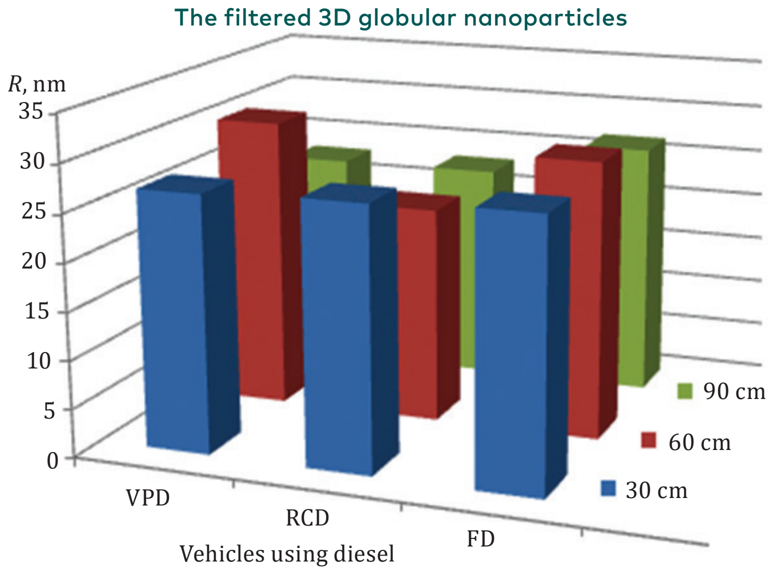

Figure 7. The mean nanoparticle sizes in air spread by exhausts of three different vehicles using diesel

Figures 6 and 7 indicate the sizes of the filtered 3D nanoparticles according to the fuel types and the measurement distances for diesel used vehicles. It may be stated that all types of fuel can lead to the appearance of the nanoparticles in air as expected and the size ranges of the nanoparticles may be indicated according to their types.

According to Figures 5–7, the spider membrane can retain the smallest sized nanoparticles. Then, good filtering can be done with white, blue, perforated and thick filters, respectively. The thick filter can retain both small rod particles and large globular particles. As a result, the size of the particles coming out of the exhaust smoke that are held in the filters and cannot be seen with a microscope varies between 15.7 and 45.7 nm. Nanoparticles with 1D and 3D morphologies are dispersed into the environment. When the distinction between gasoline, diesel and eco vehicles is examined, it is observed that the globular structure size of the particles retained by the perforated filter, white filter, blue filter and spider web filter in a gasoline vehicle (FB) varies between 37.5 and 45.7 nm. It has been determined that the globular structure size of the particles retained by the white filter, blue filter and spider web filter in a diesel vehicle (FD) varies between 20.9 and 27.8 nm. When we look at the size of their rod structures, it is understood that particles varying between 15.6 and 26.7 nm in gasoline vehicles and 15.6–20.4 nm in diesel vehicles are released. The largest globular structure size of the particles coming out of the new generation vehicle called Echo is in the thick filter with 34.2 nm. The smallest size is in the spider web filter with 26.7 nm. In other words, the globular structure size varies between 26.7 and 34.2 nm. The largest rod structure size is in the blue filter with 24.5 nm, and the smallest size is in the white filter with 19.0 nm.

According to these findings, it has been determined that more nanoscopic particles are emitted in the gases released into the environment in vehicles using diesel fuel. In economical and gasoline-powered vehicles, larger particle structures are emitted with exhaust gas. The distance at which the globular structure sizes of the particles coming from VPD and FD coded vehicles are low is 90 cm. Since the filter was kept 90 cm away from the vehicle exhaust, the filter was able to retain small particles. It was thought that large particles were blown away and not filtered due to their weight. In VPD and FD vehicles, the largest particles were kept at 60 cm. However, since the distance is far from the vehicle exhaust, there is a possibility that the nanoparticles on the ground may have been lifted up by the force of the exhaust gas and clung to the filter. Looking at the results of measurements taken from 30 cm, it has been observed that the globular structure size of the particles varied between 17.0 and 28.0 nm.

3.2. Discussion

Although there is no critical problem on the roads, the road is mostly blocked during business arrival and departure hours. The main reason for this situation is that both roads are one lane and therefore when a car stops, all traffic flow stops immediately. There is no other place to pass the lingering vehicles. People who come to the hospital do not have a place to park their cars. Only members of the faculty can enter the parking place, so people coming to the hospital leave their vehicles on the road, which greatly affects the traffic. Due to this feature of this road, it is likely to be blocked at any time even if there are not many vehicles and traffic may occur at any time. Another problem is the turning point on the road. The turning point is very narrow and the vehicles cannot rotate in a single attempt. This turn event affects both roads. This effect can cause releasing exhaust gas much more. Therefore, if the LOS level of the road is poor, bystanders may be more exposed to exhaust gas. Thus, in order to protect the people health a face mask as a solution was investigated to see the effects of different vehicle types, fuels and mask types on various sample distances. According to SAX tests, larger particles cannot reach longer distances as expected. The RCD vehicle releases more nanoscopic particles than others. In the measurement taken on Mondays, the globular structure size of the particles was 49.3 nm and the rod structure size was 28.4 nm. In the measurement taken on Friday evening, the globular structure size of the particles was 45.1 nm and the rod structure size was 34.2 nm. In these measurements, nanoparticles in the air were collected directly. Apart from car exhaust fumes, cigarette smoke and dust from the road have fallen on the filter. Particles less than 2.5 microns in size can travel to the bronchi and lungs. Since vehicle use has a large place in human life and exhaust outlets directly affect the oxygenated air we receive, the size of the particles coming out of vehicle exhausts is also important to us. In this study, the size of the particles in the exhaust smoke was determined. It was investigated how long masks, which are frequently used in human life, can retain these particles. It was determined that masks could retain particles in the range of 15.7–45.7 nm. Although it may seem unimportant, it was understood that these masks could actually prevent breathing polluted air to a large extent.

When the results were compared with literature, it can be stated that the findings can have critical results and addictions. They also showed compatibility with the literature. As an example, Unal et al. (2003) studied traffic signal timing and coordination on exhaust emissions. They reported that signal coordination on a street yielded measurable improvements at the arterial level of service and emissions reduction. The emissions were lower under uncongested conditions for LOS A-B than under congested conditions LOS D-E. Alobaidi et al. (2020) highlighted that traffic congestion could cause the problem of air pollution due to emissions from vehicles. Critical elements of road regarding are the high level of air pollution which is due to the slow-down and stop operations. Velasco et al. (2022) studied effectiveness of wearing face masks against traffic particles. They tested face masks during high traffic times by comparing particle metrics. By this way in this paper the importance of the study can be seen because of the various parameters and critical results to add the literature.

Conclusion

In this study it was observed that traffic jam could be effective for regions and exhaust gas could be critical especially for hospital areas. Therefore, as the first step, road quality (LOS) of entrance and exit of the campus was determined. Then, critical outlines were investigated as various effects of facial masks to prevent exhaust nanoparticles with a new designed filter mask, the critical distance from the exhaust sources and the importance of different fuel usage were declared. SAXS analyses on air samples for health care were also carried out according to different traffic conditions. Results of the study can be summarised as follows:

- As it can be expected, LOS levels for working days on Monday and Friday were at high levels such as F and during holidays these values were at low levels such as A. This means that on these days there can be critical traffic congestions and therefore exhaust gas can be effective for morning and evening hours.
- More efficient filters to collect nanoparticles materials were obtained. The best filter to successfully collect the minimum sized nanoparticles was obtained as a newly designed spider silk membrane filter. Secondly, successful filtering of the nano- and micro-particles is realized by white mask.
- The rank of the nanoparticle size from smallest to biggest was determined for the fuel type as Diesel ≤ Eco ≤ Gasoline. It means that the nanoparticles spread by diesel using vehicles may be more dangerous for health because of their long life in air and penetrating abilities to the cells.
- 90 cm distance from exhaust output is also determined as harmful distance because of the most densely emitted small nanoparticles which are very harmful for bronchi and lungs.

- It is determined that masks can hold particles in the range of 15.7–45.7 nm. Although it seems trivial, it has been understood that these masks can actually prevent the inhalation of dirty air to a great extent.
- Monday measurements indicate bigger size (49.3 nm) of the nano-globular (3D) particles in respect to that (45.1 nm) of Friday measurements. The reason of this result may be explained as more diesel vehicles pass around the hospital region on Fridays than on Mondays.

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