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Short Communication

Single-use surgical face masks, as a potential source of microplastics: Do they act as pollutant carriers?

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A B S T R A C T

Millions of people are using face coverings (including single-use surgical face masks) as a result of the COVID-19 pandemic and a large number of used masks, particularly single-use masks enter uncontrolled the environment since most of the users have little information on how to dispose of them safely. This new important waste is a potential source of microplastics, which is found nowadays in many parks, streets, and coastlines. Discarded masks will be finally drained to the ocean polluting the marine environment and threatening marine life. This short communication examines the role of face masks and subsequently mask-derived microplastics as pollutant carriers in environmental compartments (e.g. hydrosphere, biosphere, etc.) by investigating their sorption characteristics regarding dye molecules. In this context, batch-type equilibrium experiments were performed and the effect of different sorption parameters has been explored (i.e. contact time and temperature). The results show that single-use surgical face masks can act as dye carriers (Methylene Blue, Crystal Violet and Malachite Green) in the aquatic environment. In addition, preliminary experiments on the thermal treatment of face masks and the use of the resulting carbonaceous material as efficient adsorbent have been performed, pointing out a possibility for used mask disinfection and recycling.

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1. Introduction

SARS-CoV-2, which is a new type of coronavirus and is transmitted largely by the respiratory route has recently led to COVID-19 pandemic. In order to control the extensive disease spread via the respiratory route, the experts suggest social or safe distancing measures (e.g. avoiding close contact between individuals) and where this is not possible, personal protective equipment (PPE) (e.g. mask, glove, protective gown, etc.) is the widely accepted way of self-protection [1].

Because of lack of information, PPE will be most likely discarded without safety measures along with other organic waste in regular municipal solid waste or will be, even worse, directly discarded in the environment. Uncontrolled discarded disposable gloves and masks have been found littering public places (e.g. parks, streets) around the world [2]. This is because of the difficulty to achieve a reliable disposal scheme, since PPEs have heterogeneous composition and the risk of contamination, assuming that disposable face masks and gloves were used in areas of increased contamination risk (e.g. medical centers, public transportations, and centers) [3]. The COVID-19 pandemic has put additional pressure on the waste management systems, leading to inappropriate management practices such as local burnings and direct landfills. However, uncontrolled of even 1% of face masks correspond to 10 million pieces of a mass between 30 and 40 tons. Moreover, COVID-19–related plastic has been observed in marine environments, forming a potential new source of oceanic microplastics [6].

Surgical face masks particularly are composed of many different kinds of polymers such as polyester, polypropylene, polyethylene, poly-carbonate, polycrylonitrile, etc., which are used also as raw materials for the production of different plastic products [4]. Hence, discarded single-use face masks, which could under ambient conditions slowly degrade into smaller particles (< 5 mm) may form a new source of microplastics causing environmental pollution and threatening living organisms [5].

Generally, microplastics are not only a major environmental health hazard found in many marine habitats and biota [7,8], but they also affect sustainable crop production and food safety, and act as carriers of major chemical pollutants in environmental systems, affecting living organisms and subsequently food safety [9,10]. Recent studies point out the potential role of MPs as carriers for hydrophobic organic chemicals (HOCs) [11], antibiotics [12] and heavy metals [13,14]. In this context, studies related to the interaction of organic pollutants, including dyes, and other toxic substances (e.g. toxic metals, radionuclides etc.) is of fundamental importance to understand and describe the role of masks and mask-derived microplastics as pollutant carriers in environmental compartments (e.g. hydrosphere, biosphere etc.), and perform related environmental impact assessments.

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The present study deals with the sorption of cationic dyes (e.g. crystal violet, malachite green and methylene blue) by single-use clinical masks by means of batch-type experiments, evaluation of the corresponding kinetic parameters and the effect of temperature. In addition, masks were pyrolyzed under inert atmosphere and the obtained carbon residues were also tested for their dye sorption properties. It has to be noted that the purpose of the present study was not to compare the sorption properties of surgical face masks towards dyes but mainly to indicate their ability to act as pollutant carriers.

2. Materials and methods

All experiments were performed at room temperature (20 ± 2 °C) under ambient atmospheric conditions in aqueous solutions. Generally, the experiments were performed in duplicate and the mean values have been used for data evaluation. The preparation of the dye solutions was carried out by dissolution in the desired aqueous solution the appropriate amount of a dye stock solution (1000 ppm) prepared by dissolution of crystal violet (C25H30ClN3, MW: 407.979 g/mol; CV), malachite green (C23H25ClN2, MW: 364.911 g/mol; MG) and methylene blue (C16H18ClN3S, MW: 319.85 g/mol; MB) in distilled water. pH measurements were performed by a commercial glass electrode, which was calibrated prior and after each experiment using a series of buffer solutions (pH 2, 4, 7 and 10). Single-use clinical masks were used for the sorption experiments without any prior special treatment, except that the aluminum strip and the rubber straps were removed.

In order to investigate the effect of the initial dye concentration, temperature, and contact time on the dye sorption on single-use masks batch-type experiments were conducted. In those experiments, the parameter under investigation was varied, while other experimental parameters were kept constant. For studying the effect of initial dye concentration, stock solutions with dye concentration between 1 mg/L and 20 mg/L were prepared and the sorption experiments were performed at a prefixed adsorbent dosage (a single-use surgical face mask, 2.6 g) at pH 5.5 (for MG dye) or 6.0 (for MB and CV dyes), 50 mL test solution, and 24 h of contact time. The effect of temperature was studied at two different temperatures (293 and 323 K) under similar conditions as described above. For kinetic studies, masks were mixed with dye solution (10 mg/L) at pH 5.5 (for MG dye) or 6.0 (for MB and CV dyes), at 293 K and using the aforementioned adsorbent/liquid ratio and following adsorption in successive time intervals between 4 and 80 min for MB, 4–1440 min for CV and 1–1620 min for MG, respectively.

Face masks were thermally treated and the carbonaceous by-product was applied to remove the examined dyes. The mass of a single mask was equal to 2.6 g and subsequently the total mass used for carbonization was 51.2 g, and the carbonization was performed at 500 °C for 1 h, under inert N2-atmosphere. The sorption experiments with carbonaceous material obtained from face masks were performed using an adsorbent dose of 0.01 g, 50 ml of initial dye concentration of 8 mg/L at pH 8.0 (for MG dye) or 9.0 (for MB and CV dyes), for 24 h at 293 K.

The amount of sorbed dyes at time \( t \) was evaluated using the Eq. (1):

\[
q_t = \frac{(C_i - C_f)V}{m}
\]  (1)

where \( C_i \) (mg/L) is the initial dyes' concentration in the solution, \( C_f \) (mg/L) is the final dyes' concentrations in solution at time \( t \), \( V \) (L) is the solution volume and \( m \) (g) is the dry weight of the mask.

In order to evaluate the rate of the sorption processes, pseudo-first-order kinetic [15] (Eq. (2)) and pseudo-second-order [16,17] (Eq. (3)) kinetic models were applied to the kinetic sorption data. For studying the sorption isotherms, the Langmuir [18] (Eq. (4)) and Freundlich [19] (Eq. (5)) isotherm models were fitted to the experimental data at the equilibrium.
\[ q_t = q_e \left(1 - e^{-\frac{k_1 t}{1 + k_2 q_e}}\right) \]  
\[ q_t = \frac{k_2 q^2_e t}{1 + k_2 q_e t} \]  
\[ q_e = q_m \frac{K_C e}{1 + K_C e} \]  
\[ q_e = K_F C_e^{1/n} \]

\( C_e \) is the equilibrium concentration of the dyes in solution (mg/L), \( q_e \) is the amount of the adsorbed dyes per gram of mask at equilibrium (mg/g), \( q_t \) (mg/g) is the amount of adsorbed dye at time \( t \) (min), \( k_1 \) (min\(^{-1}\)) is pseudo-first-order rate constant, \( k_2 \) (g/mg min) is pseudo-second-order rate constant, \( q_m \) (mg/g) is saturated monolayer sorption capacity and \( K_C \) (L/mg) is constant related to the energy of sorption and equilibrium constant, \( K_F \) (mg/g)(L/mg)\(^{1/n}\) and \( n \) are the Freundlich constants.

### 3. Results and discussion

#### 3.1. Effect of temperature and isotherm modeling

The effect of equilibrium concentration on the dye sorption by the masks was investigated at 293 K and 323 K (Fig. 1) and the estimated parameters obtained by applying isotherm adsorption models are summarized in Table 1. As shown in Fig. 1, the sorption corresponding to CV increases significantly with increasing temperature from 293 to 323 K, whereas the opposite effect is observed for the MB and MG dyes. The opposed impact of temperature on the removal efficiency of dyes by the masks could be attributed to different adsorption mechanisms associated with the chemical and geometrical structure of the investigated dyes, which affects their interaction with the mask components. The order of the sorption capacity values is following: MG > CV > MB and CV > MG > MB at 293 and 323 K, respectively. The Langmuir isotherm model was found to fit better the data associated with MG (293 and 323 K) and CV (only at 293 K), whereas all other data were better fitted by the Freundlich isotherm model, indicating more complex sorption reactions.

#### 3.2. Effect of contact time and kinetic modeling

Fig. 2a, b and c illustrate the effect of contact time on the sorption capacity of MB, CV and MG on masks, respectively. The dye removal was rapid at the initial stage of contact time and gradually declined until equilibrium was reached. The sorption of MB, CV and MG, reached

| Dye  | Isotherm | Parameter | 293 K | 323 K |
|------|----------|-----------|-------|-------|
| MB   | Langmuir | \( q_m \) (mg/kg) | 42    | 33    |
|      |          | \( K_L \) (L/mg) | 0.14  | 0.12  |
|      |          | \( R^2 \)     | 0.94  | 0.96  |
|      | Freundlich | \( K_F \) (mg/g)(L/mg)\(^{1/n}\) | 0.01  | 0.01  |
|      |          | \( n \)      | 1.74  | 1.59  |
|      |          | \( R^2 \)     | 0.99  | 0.98  |
| CV   | Langmuir | \( q_m \) (mg/kg) | 39    | 244   |
|      |          | \( K_L \) (L/mg) | 1.76  | 0.27  |
|      |          | \( R^2 \)     | 0.98  | 0.88  |
|      | Freundlich | \( K_F \) (mg/g)(L/mg)\(^{1/n}\) | 0.02  | 0.05  |
|      |          | \( n \)      | 3.15  | 1.76  |
|      |          | \( R^2 \)     | 0.80  | 0.99  |
| MG   | Langmuir | \( q_m \) (mg/kg) | 247   | 131   |
|      |          | \( K_L \) (L/mg) | 0.42  | 3.26  |
|      |          | \( R^2 \)     | 0.84  | 0.99  |
|      | Freundlich | \( K_F \) (mg/g)(L/mg)\(^{1/n}\) | 0.07  | 0.07  |
|      |          | \( n \)      | 1.47  | 2.88  |
|      |          | \( R^2 \)     | 0.65  | 0.72  |

Fig. 2. Effect of contact time (4 – 80 min for MB, 4–1440 min for CV, 1–1620 min for MG) on the sorption capacity of dyes (MB, CV and MG) by single-use surgical face masks. Experimental conditions: pH 5.5 (for MG dye) or 6.0 (for MB and CV dyes), initial dye concentration 10 mg/L, adsorbent/solution ratio 2.6 g/0.05 L, agitation rate 125 rpm, temperature 293 K.
equilibrium after 45 min, 250 min and 1400 min, respectively. The \( q_e \) predicted and \( R^2 \) values have indicated that the experimental data for the MB dye were better fitted by the pseudo-first-order kinetic model and for CV and MG dyes, by the pseudo-second-order kinetic model, respectively (See Table 2).

### 3.3. Carbonaceous material obtained from single-use surgical face masks

To propose a mask management scheme, masks were thermally treated (pyrolyzed under inert, \( N_2 \)-atmosphere) and the carbonaceous by-product was applied to remove the MB, CV, and MG dyes from aquatic solutions. It is worth mentioning that by-products of the mask carbonization process were a carbonaceous material (less than 0.5 g carbon obtained from 20 masks) and a paraffin-like sublimation product. The results of the sorption experiments are graphically summarized in Fig. 3, and the sorption capacity of the obtained carbonaceous material follows the order: \( \text{MG} \approx \text{CV} > \text{MB} \).

### 4. Conclusions and future works

The results of the present work show that single-use surgical face masks can act as dye carriers in aquatic systems, especially for MG and CV and to a lesser extent for MB. Carbonization of single-use surgical face masks leads to the production of a carbonaceous material that presents high sorption capacity, especially for CV and MG dyes. More systematic work must be done to investigate the sorption mechanism and recommend a safe, environmental-friendly and effective management scheme of used masks. Moreover, the investigation of other types of pollutants (toxic metals, antibiotics, etc.) and other matrices (seawater, real wastewater, etc.) is also of paramount importance to better understand and describe the sorptive behavior of single-use surgical face masks and assess their impact on the contaminant migration in the environment.

### CRediT authorship contribution statement

Ioannis Anastopoulos: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

Ioannis Pashalidis: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

### Declaration of Competing Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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