# Medical Waste Treatment via Waste Electrospinning of PS

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**Abstract:** Body fluid medical wastes are infectious clinical wastes (blood, saliva, urine) due to their high pathogenic content. Incineration is the most commonly used method in waste management that possess high water content along with molecularly dissolved species such as proteins. The process is costly; so that the removal of solid content dissolved in aqueous part by preliminary filtration can reduce the volume of the waste material. In this study, fibrous mats were prepared by electrospinning of PS wastes from DMF and THF solutions. Then they are employed in the removal of protein-based solid contents of body fluid medical wastes before their disposal. Two sources of PS waste (CD cover and Styrofoam) were employed along with virgin PS for comparison. The adsorption capacity of as-prepared electrospun fibers was examined for three model proteins: Bovine Serum Albumin (BSA), Myoglobin (MYO), and Trypsin (TRY). The fibers obtained from PS CD wastes have remarkably larger protein sorption capacities (particularly BSA) than the fibers obtained from virgin PS. XPS reveals the presence of $CaCO_3$ domains in CD covers added into PS during their production steps probably to increase mechanical properties. There may be an electrostatic interaction between $Ca^{2+}$ and the negatively charged groups of the protein. In this way, PS wastes could be converted to a beneficial secondary product by electrospinning and also resulting materials promises for the disposal of body fluid medical wastes. This may be one of the frontiers study on the removal of medical wastes by adsorbents produced via electrospinning of waste polymers.

**Keywords:** CD case, Medical waste, Polystyrene, Recycling, Waste-electrospinning, Waste PS

## Introduction

The management of the medical wastes is one of the demanding challenges humanity facing as population increases. When these wastes are not properly handled, they represent a high risk of infection or injury to healthcare personnel and also to the general public. Because of these concerns, there is a worldwide awareness about the effective control and safe handling of these wastes [1-5]. Over the total amount of medical wastes, 85 % of them are non-hazardous while 15 % of them are considered hazardous that might be infectious, toxic or radioactive. However, both hazardous and non-hazardous wastes were generally mixed and disposed together so that the hazardous waste amount increases [2]. Among the various types of body fluid medical wastes, blood wastes come in to prominence due to their enormous generation and the presence of appropriate nature for the growth of pathogens [6]. Landfilling, steam autoclave sterilization, and incineration are the main methods currently being used and considered technologies for the disposal of medical wastes [7]. Landfilling of medical wastes with large amounts is not recommended, because the hazardous substances could contaminate the groundwater and they require large empty spaces [8]. In sterilization, the volume of wastes is limited with the size of autoclave, i.e. it requires running the system many times one after the other suggesting a tedious process. Incineration, on the other hand, appears out the unavoidable solution for the management of medical disposal. However, blood waste contains about 92 % water that increases the cost of this process [5,8]. The isolation of solid content of fluid wastes prior to dispose may remarkably reduces the volume and accordingly the cost of the disposing process. Thereafter, the non-hazardous liquid part (mainly water) could be disposed by spilling into sanitary sewer [8,9].

Polystyrene (PS) is a commodity polymer used in various applications such as packaging, insulation, CD/DVD cases, containers, and various single-use accessories. The disposal and degradation of these plastics are not only harmful to the environment, but it also represents missed economic opportunities [10]. In addition, recycling and reuse approaches save remarkable amount of energy when compared with the virgin material production that ~130 million kJ of energy could be saved for each ton of recycled plastic [11]. Plastics can be widely recycled, both in waste treatment and in the production of secondary products. The recycled PS has been employed for various applications as secondary products. Zare *et al.* discussed the comprehensive applications of nanofillers in the recycling process of polymer composites [12]. Chaukura *et al.* presented an overview on the production and potential uses of current waste PS, and also employed waste PS precursors for the synthesis of porous and functionalized conjugated microporous polymers for the removal of dye from wastewaters [13,14]. Recently, Ruziwa *et al.* reported the utilization of sulphonated waste PS for the removal of heavy metal ions from water. Another example for the usability of waste PS materials as sorbent for the separation of $O_2/N_2$ and $CO_2/N_2$ gases was reported by Zhuang *et al.* [15]. Fibrous materials prepared by electrospinning are commonly used as adsorbents in adsorption studies because of their large specific surface area, mechanical integrity, and ease of functionalization [16-18].

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These materials could be utilized for the adsorption of heavy metal ions, proteins, dyes or cells; however, the application of the electrospun PS wastes has not been reported according to the best of authors' knowledge. The attachment, proliferation, and differentiation of the epithelial cells to form the stratified epithelium using electrospun poly(D,L-lactide) fibrous scaffold membranes were reported by Leong *et al.* [19]. For the protein adsorption studies, dye immobilized polyacrylonitrile nanofiber membranes have potential for bromelain adsorption with high capture capacity [20]. Also, cellulose acetate membranes were demonstrated to capture BSA and bilirubin after regeneration and functionalization with a protein specific ligand [21]. Electrospun PS fibers are excellent candidates for the adsorption due to their large surface area, superior hydrophobicity, and micrometer level roughness [22,23]. Electrospinning is a convenient method for the fabrication of adsorbent materials due to its several advantages such as high surface to volume ratio and high porosity. Also, the solution and process parameters could be easily manipulated to get desired fiber morphology [24]. Haridas *et al.* fabricated submicron PS fibers by modifying the morphology of fibers from smooth to rough, and altered the resulting fibers from hydrophobic to hydrophilic [25]. This study aims to use electrospinning to recycle urban PS waste from different sources (CD cases and foam) to fabricate protein adsorbents, which can then be used as a separation tool for blood wastes disposal. The adsorption capacity of fibrous PS adsorbents is examined using three commonly used model proteins: Bovine Serum Albumin (BSA), Myoglobin (MYO), and Trypsin (TRY). Their adsorption performances are then compared in fibrous adsorbents fabricated from virgin PS. This environmentally friendly approach is promising for the removal of solid components of blood wastes and attains the ability to recycle composites with more than one type of material.

## Experimental

### Materials

Virgin polystyrene (PS, $M_w \approx 350,000$ g mol$^{-1}$, Aldrich), Calcium carbonate (CaCO$_3$, Carlo-Erba), Bovine Serum Albumin (BSA, $\geq$98 %, Sigma-Aldrich), Myoglobin (MYO, Sigma-Aldrich), and Trypsin (TRY, from porcine pancreas, Sigma-Aldrich) were used without further purification. Phosphate Buffered Saline (PBS tablet, Sigma) was used to adjust the pH of protein solutions. *N,N*-Dimethylformamide (DMF, 99 %, Carlo Erba) and Tetrahydrofuran (THF, Sigma -Aldrich) were used as solvent.

### Solution Properties and Fabrication of Electrospun Fiber Mats

Waste PS materials were subjected to a sterilization process prior to experimentation. Waste samples (CD case and foam) were initially rinsed with 70 % ethanol and then autoclaved by steam sterilization at 121 $^o$C for 30 min. The molecular weight of PS samples was determined using a dynamic light scattering (DLS) instrument (Malvern Nano ZS, Worcestershire, UK). Refractive indices of PS solutions (150, 100, 50, and 25 g·$l^{-1}$) were determined using a manual Abbe Refractometer, and the refractive index increment (dn·dc$^{-1}$) of each PS sample was calculated. These records were then entered in Malvern Nano ZS software, the scattering Rayleigh ratio of DMF was taken as $9.82 \times 10^{-6}$, and the weight-averaged molecular weight of samples was calculated. This procedure was conducted for virgin polystyrene (vir-PS), waste foam PS (f-PS), and waste CD case PS (CD-PS). Conductivity of polymer solutions was measured using a multi-parameter (VWR Collection MU6100 L); viscosity measurements of all samples were conducted using a rotational viscometer (Thermo Scientific HAAKE Viscotester C, Massachusetts, USA) with a L1 spindle, where the rotational velocity of the spindle was 6 rpm for 20 wt% solution and 30 rpm for 10 and 15 wt% solutions.

The solutions used in electrospinning (vir-PS, f-PS, and CD-PS with different solid contents of 10-15-20 wt%) were prepared in an equivolume mixture of DMF and THF. Electrospun fibers of vir-PS with a calcium carbonate (CaCO$_3$) additive were fabricated by adding 10 wt% CaCO$_3$ into 10 wt% PS solution from DMF:THF blend. Each solution was then transferred into a 20 m*l* plastic syringe using a stainless-steel needle (18 gauges); the needle was connected horizontally to a high voltage supply under 15 kV (Gamma High Voltage Research Ormond Beach, FL, US). A micro-infusion pump (New Era NE300 Infusion Pump, Farmingdale, NY, USA) was used to fix the flow rate at 1.0 m*l*·h$^{-1}$ and the tip to collector distance was set at 15 cm; therefore, the potential difference was 0.8 kV·cm$^{-1}$. Humidity and temperature were 43 % and 24 $^o$C, respectively. Nonwoven electrospun fibers were collected on aluminum foil, and the morphology of fibers was examined using a scanning electron microscope (SEM, FEI Quanta250 FEG, Oregon, USA); surface chemistry of fibers was studied using an X-ray photoelectron spectrometer (XPS, Thermo Scientific K-Alpha Surface Analysis, Massachusetts, USA); the thermal degradation profile was determined by Perkin-Elmer Diamond TG/DTA; the surface area of the electrospun mats was measured using the brunauer-emmett-teller (BET) gas adsorption method (Micromeritics Gemini V, GA, USA); and fourier transform infrared spectroscopy (FTIR) measurements were conducted using an attenuated total reflection (ATR) attachment (Perkin Elmer FT-IR System Spectrum BX, Waltham, MA).

### Protein Adsorption Study

To examine their adsorption capacity, PS fiber mats were treated with protein solutions. All protein solutions were prepared at pH 7.4 in PBS buffer. BSA and MYO were prepared separately in PBS solution to give 10$^{-6}$ M, and TRY

solution was prepared in $5\times10^{-6}$ M using PBS buffer. The calibration curves of all protein solutions were prepared within a range of $1\times10^{-7}$ and $1\times10^{-3}$ M, and the linear region of the curves was selected for extrapolation of unknown concentrations. Plastic syringes (2 m*l* volume; diameter 11 mm) were used to prepare the filtration set-up, and fibers (5 mg) were weighed and placed in the syringes. Approximately 1 m*l* of PBS solution was passed through each syringe to soak the filters and provide easy filtration. After all the PBS solution was drained out of the syringe, 500 μ*l* each of BSA, MYO, and TRY solution was passed through clean filters, and the filtered solution was collected in centrifuge tubes. To calculate the adsorption capacity of the filters, the absorbance of filtered solutions was measured. The adsorption capacity of fibers was then determined with the equation,

$$q = [(c_i - c_f) \cdot V]/m \qquad (1)$$

where $q$ is the adsorption capacity (mg/g); $V$ is the volume (m*l*) of solution passed through the syringe; $c_i$ and $c_f$ are initial and final BSA concentrations (mg/m*l*); and $m$ is the mass of the fiber (mg). Optical absorbance measurements were made using a UV-Vis spectrophotometer (SHIMADZU, UV 2550, Japan). The effect of initial BSA concentration ($10^{-7}$ and $10^{-4}$ M) on adsorption capacity was investigated by filtration of BSA solutions.

## Results and Discussion

### Characterization of Polymer Solutions

Conductivity and viscosity are two important solution parameters of electrospinning process. Table 1 presents the properties of the electrospinning precursor solution. The solution conductivity of the equivolume mixture of DMF: THF was 1.9 μS·cm$^{-1}$. It is reduced to 1.7 for 10 % vir-PS solution and further reduced to 1.2 μS·cm$^{-1}$ with a concentration of 20 wt%. Increasing the amount of non-conductive polymer reduces the conductivity of the solution; i.e. a higher polymer concentration yields a lower conductivity. A similar decrease in conductivity was also seen

**Table 1.** The solution properties (conductivity and viscosity) of PS samples at different concentrations

| Sample name | Conductivity (S·m$^{-1}$) | Viscosity (Pa·s) |
|---|---|---|
| vir-PS-10 | 0.00014 | 0.048 |
| vir-PS-15 | 0.00011 | 0.140 |
| vir-PS-20 | 0.00007 | 0.560 |
| f-PS-10 | 0.00017 | 0.050 |
| f-PS-15 | 0.00016 | 0.134 |
| f-PS-20 | 0.00012 | 0.400 |
| CD-PS-10 | 0.00183 | 0.035 |
| CD-PS-15 | 0.00136 | 0.111 |
| CD-PS-20 | 0.00124 | 0.480 |

for f-PS and CD-PS solutions; although CD-PS solutions have a strictly larger conductivity most probably due to the presence of ionic CaCO$_3$ additive (this point will be given further in the text).

$M_w$ of the PS was found to be 322, 40, and 880 kDa for vir-PS, f-PS, and CD-PS, respectively. CD-PS is composed of General Purpose Polystyrene (GPPS) that has been employed for the fabrication of various goods. It has higher molecular weight compared to other PS samples so that it provides superior mechanical performance due to having high $M_W$ [26].

It is well established that viscosity of polymer solution strongly depends on concentration and molecular weight of the constituent chains. Chain entanglement is the crucial factor; the increase in either of these parameters triggers the increase of viscosity. Three concentrations of the polymer have been prepared: 10, 15, and 20 wt%. Nothing surprise, independent of the PS type, increasing the concentration of the solutions increases the viscosity of solutions. When the viscosity of PS solutions those having the same concentrations were compared, this general rule is not fulfilled. For instance, CD-PS cases have the lowest viscosity although it has the highest molecular weight, which seems against common sense. However, it needs to be noted that they are industrial products, which may potentially have some other additives (for instance lubricants and plasticizers) to facilitate their fabrication process, accordingly change their flow properties [27].

### Preparation of PS Fibers

The PS samples were dissolved in an equivolume mixture of DMF:THF at different concentrations (10, 15, and 20 wt%). Sub-micron PS fibers were fabricated by electrospinning. Figure 1 shows the SEM micrographs of the fibers obtained from vir-PS, f-PS, and CD-PS. Although the three samples can be readily processed by electrospinning and yield sub-micrometer diameter fibers, they differ in the morphology of both the individual electrospun fibers and electrospun fiber mats.

The viscosity of the polymer solution is the dominant parameter involved in the electrospinning process [28]. It is well established that low viscosity yields atomization of the feeding solution (electrospraying) [29], whereas a higher viscosity induces entanglement of the constituent chains, thereby enabling formation of continuous fibers (electrospinning). The influence of viscosity can be remarkably seen for fibers prepared from 10 wt% solution. The electrospun mat obtained from vir-PS-10 and f-PS-10 exhibit straight bead-free fibers. On the other hand, CD-PS-10 presents beads-on-string morphology. It is well established that the beads appear out for electrospinning of low viscosity solutions [30]. Indeed, the viscosity of CD-PS solution is the lowest compared to other two samples (Table 1). These fibers have been used in adsorption of proteins so that the surface
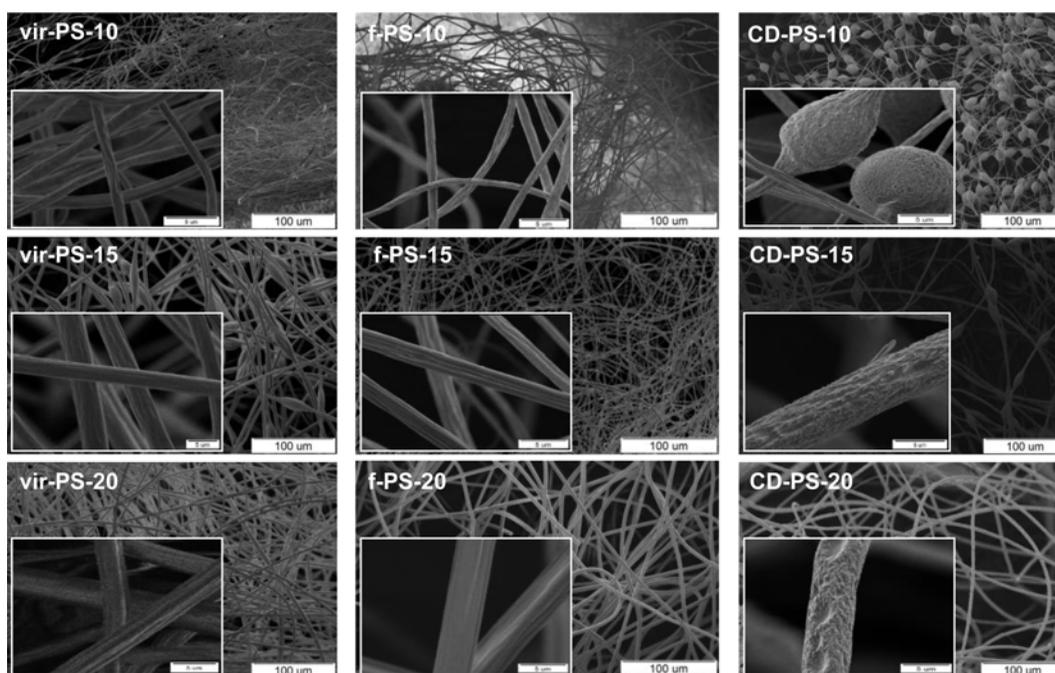
**Figure 1.** SEM micrographs of electrospun fibers fabricated from vir-PS, f-PS and CD-PS from 10, 15 and 20 wt% polymer solutions. Insets show higher magnification image of the electrospun fibers.
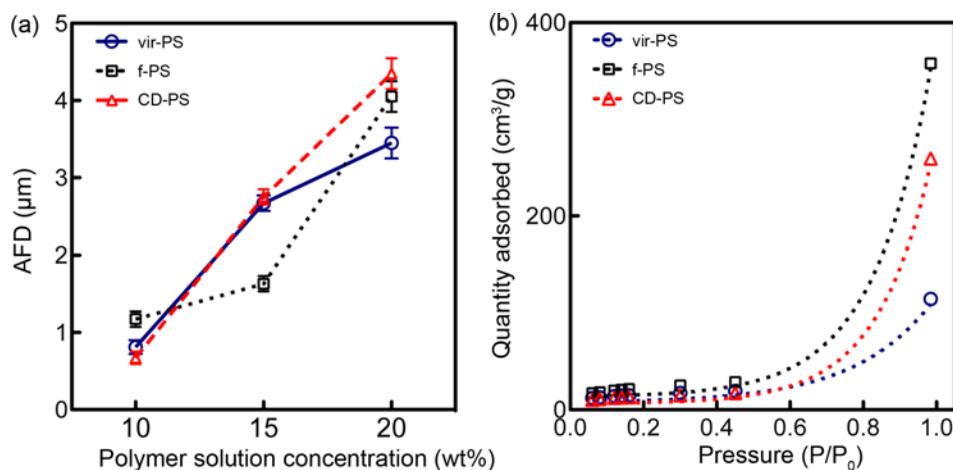


**Figure 2.** (a) AFD of the electrospun fibers obtained at different polymer solution concentration and (b) BET nitrogen adsorption results of vir-PS-10, f-PS-10 and CD-PS-10 electrospun fibers.

feature is extremely important. Vir-PS and f-PS fibers have smooth surface; however, the inset of CD-PS fibers shows remarkable surface roughness at high magnifications. This roughness may be originated from the presence of $CaCO_3$ domains on fiber surface.

Figure 2(a) shows the effect of polymer solution concentration, namely viscosity, on average fiber diameter (AFD). An increase in concentration from 10 to 20 wt% enhances the AFD up to 6 times, most probably due to the increase in viscoelastic forces that makes stretching of jet difficult [28]. Fiber diameter distributions were obtained from SEM

micrographs and measured by Image J [31] (Figure S1). The solution of CD-PS provides the thinnest electrospun fibers with beads; this is because it has the lowest viscosity out of all solutions prepared from other PS sources.

Nitrogen adsorption/desorption measurements were conducted to determine the BET surface area of electrospun fibers. Figure 2(b) shows the nitrogen adsorption isotherms used to calculate surface area of the fibers obtained from vir-PS-10, f-PS-10, and CD-PS-10. The amount of gas adsorbed onto vir-PS and CD-PS is 110 $cm^3$/g (surface area: 42 $m^2$/g) and 254 $cm^3$/g (surface area: 35 $m^2$/g), respectively. Isotherms

of f-PS-10 fibers have the largest surface area out of all other samples (67 $m^2 \cdot g^{-1}$). AFD seems to be the strongest parameter in determination of surface area. BET results also indicate that the increase in AFD reduces the surface area of fibers (Table S1).

To determine the inorganic content, a thermogravimetric analysis was conducted for all PS systems under identical conditions. Regardless of the source of PS, Figure 3(a) shows that all fiber mats were decomposed at nearly 400 $^o$C. This one-stage decomposition of fibers may be attributed to scission of the backbone. Although both fibers undergo almost complete degradation, it can be seen that CD-PS fibers with 10 % inorganic inclusion remain and resist higher temperatures than parent PS, and this result validates the presence of inorganic species in CD-PS fibers.

X-ray Photoelectron Spectra (XPS) demonstrate the presence of calcium carbonate ($CaCO_3$) domains in CD-PS fibers (Figure 3(b)). The Ca (2p) signals with binding energies between 345-355 eV can be assigned to $CaCO_3$ molecules found in the CD-PS fibers, and the atomic percentage of $CaCO_3$ was estimated 4.2 % from the area under the signal. When EDX (Table S2) and XPS results were considered, the residual 10 % mass of CD-PS fibers in TGA thermogram can be attributed to the presence of $CaCO_3$ inclusions. It is

well established that inorganic fillers have a wide range of applications in the plastic industry for improving mechanical and optical properties [32]. As it is globally abundant, $CaCO_3$ is one of the most commonly used inorganic fillers for polymers [33]. FTIR-ATR spectra show remarkable vibrational signals at around 1390 $cm^{-1}$ and 1680 $cm^{-1}$, indicating the presence of C=O stretching bands (Figure S2). Both spectroscopic techniques validate the presence of $CaCO_3$ in the CD-PS unlike to the other sources of PS.

**Adsorption Experiments**

The main objective of this work is to use electrospun mats from waste PS as a separation tool for medical wastes disposal. Protein adsorption capacities of fibers were examined using Bovine Serum Albumin (BSA), Myoglobin (MYO), and Trypsin (TRY) as model proteins, and results are given in moles ($\times 10^8$) of adsorbed analyte per gram fiber (Figure 4). For the quantitative determination of adsorbed amounts, calibration graphs of these solutions were generated and used for further calculations (Figure S3). Results show that irrespective of the PS source, electrospun fibers enable the adsorption of BSA molecules in larger amounts than MYO and TRY. Figure 4(a) shows that thin fibers have the highest BSA adsorption capacity, i.e., the
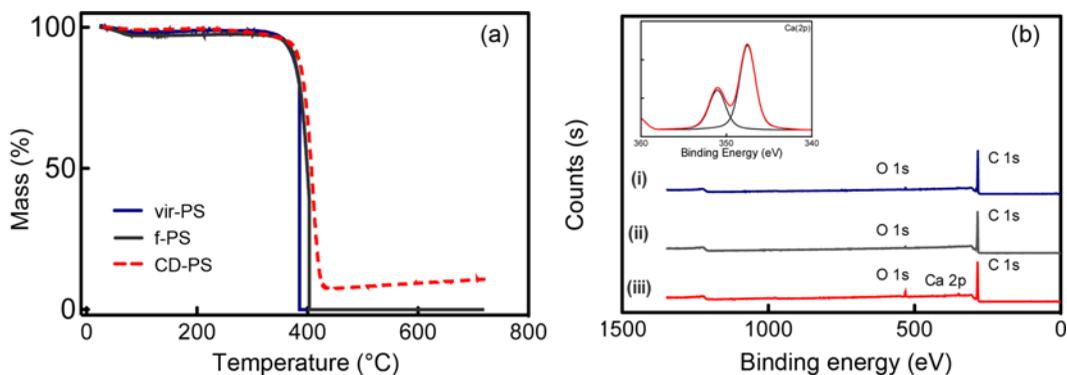


**Figure 3.** (a) TGA curves of virgin and waste PS fibers and (b) XPS spectra of (i) vir-PS, (ii) f-PS and (iii) CD-PS electrospun fibers. Inset indicates Ca (2p) spectra of CD-PS fibers.
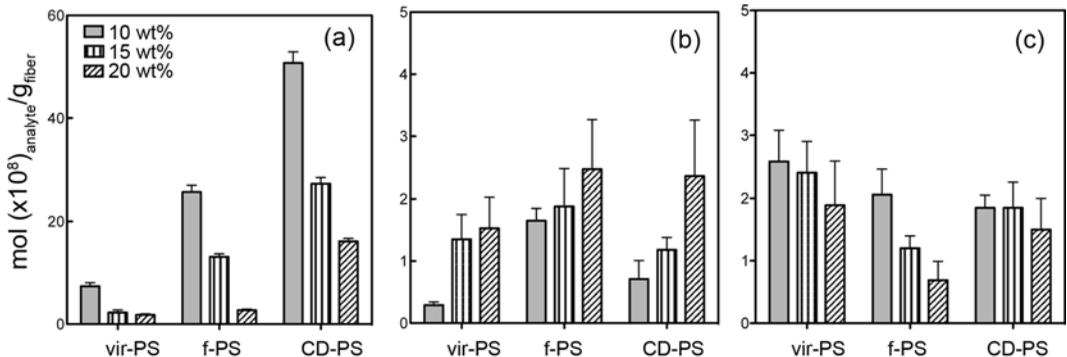


**Figure 4.** Quantity of adsorbed (a) BSA, (b) MYO, and (c) TRY molecules on vir-PS, f-PS, and CD-PS electrospun fibers fabricated at different PS concentration in DMF:THF.

high surface area of the fibers with thin AFD enhances the BSA adsorption. The source of PS waste also has an effect on the adsorption performance. The BSA adsorption capacity of CD-PS fibers was strikingly larger than that of vir-PS and f-PS fibers, although the BET surface area of CD-PS fibers was smaller than the other ones. It is considered that the high affinity of BSA molecules to CD-PS surfaces most probably originates from the interaction between $CaCO_3$ domains, which are found originally as an additive in CD case wastes. Isoelectric point of BSA is around 4.8; at pH=7.4 the charge of the molecule is negative. The electrostatic interaction between positively-charged $Ca^{2+}$ ions and negatively-charged BSA (at pH 7.4) may thus be the driving force for the enhanced adsorption capacity of CD-PS fibers [34].

MYO was used as another blood protein to investigate the adsorption capacity of PS fibers. In contrast to BSA, MYO demonstrated almost non-binding behavior toward the PS fibers from all samples (Figure 4(b)). CD-PS-10 and f-PS-10 fibers have nearly 70 and 25 folds lower adsorption capacity for MYO, respectively. Similarly, fabricated PS fibers do not have tendency to hold TRY. CD-PS-10 and f-PS-10 fibers have ≈15 times less adsorption of TRY compared to one of BSA. Consequently, PS fibers were found to be more selective to BSA than the other model proteins. There may be both physical and chemical reasons. BSA has hydrophobic groups that may improve the interaction with PS. Moreover, the presence of $CaCO_3$ may arise electrostatic interaction between $Ca^{2+}$ and negatively charged groups of BSA. From the physical point of view, the reason could also be the sieving effect of electrospun fibers because BSA has higher molecular weight accordingly larger size than other two proteins. Thus, it can readily be stuck into interfibrillar spacing.

Adsorption experiments were conducted to reveal the effect of the initial concentration on the adsorption of BSA by the fibers obtained from waste PS. Throughout these experiments, a fixed amount of adsorbent (5.0 mg of PS fibers) was employed, and the initial concentration of BSA solution varied in the range of 6 to 6500 ppm at a fixed pH of 7.4. Figure 5 shows BSA adsorption as a function of initial concentration. An increasing concentration of BSA results in a gradual increase in the adsorption capacity up to a plateau, which implies that there are available sites to adsorb BSA molecules up to that value. However, the adsorption sites reach saturation state at higher initial concentrations of BSA when all sites are occupied. Out of all the waste samples, the largest BSA adsorption capacity (81.5 mg·g$^{-1}$) was ascertained for CD-PS-10 sample.

To get further insight about the role of $CaCO_3$ domains of waste PS-CD cases in protein adsorption, PS/$CaCO_3$ composite fibers were prepared for comparison from virgin PS and commercial $CaCO_3$ powder. The concentration of $CaCO_3$ was fixed to 10 % as in the case of CD cover. No surface
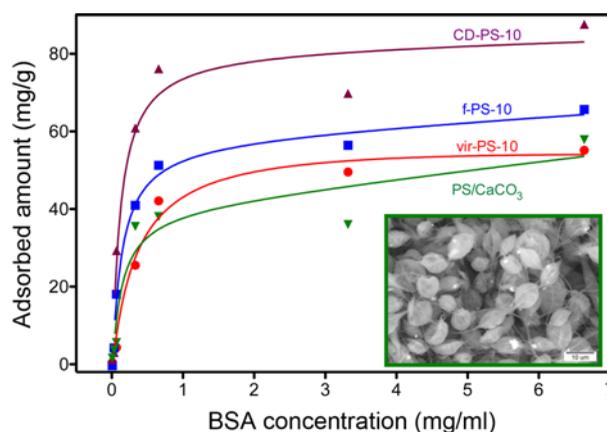


**Figure 5.** BSA adsorption at various concentrations on the adsorption capacity of the PS fibers. Inset shows the SEM micrograph of PS/$CaCO_3$ fibers prepared in the lab for comparison.

modification was applied to $CaCO_3$ to increase the compatibility with PS matrix. Its adsorption capacity was then compared with that of CD-PS-10. The inset shows the beady nature of the resulting PS/$CaCO_3$ fibers prepared at identical conditions. Although vir-PS-10 has smooth fibers, the composite sample shows beads-on-string morphology consisting of an excess amount of beads (≈5.5 μm) and thin fibers with diameters of 0.4 μm connecting the beads (Figure S4(a)-(b)). A maximum BSA adsorption capacity (53.9 mg·g$^{-1}$) occurred that was nearly the same as that of vir-PS fibers (without $CaCO_3$). It may be reason that the formation of beads reduces the effective surface area of the fibers, i.e. the less surface area, the less sorption capacity is. On the other hand, $CaCO_3$ may have positive effect for adsorption because of electrostatic interaction between $Ca^{2+}$ and negatively charged BSA. Both effect may be balanced and the similar adsorption of protein is observed from both virgin PS and PS/$CaCO_3$ composite fibers prepared in the lab for comparison with CD-PS. The higher adsorption capacity of CD-PS can be attributed to the homogeneous dispersion of $CaCO_3$ moiety compared to PS/$CaCO_3$, even though they contain identical amounts of $CaCO_3$.

## Conclusion

Two sources of urban PS waste (CD cover and styrofoam) are converted into a protein adsorbent via electrospinning that can be used to filter solid content of the medical wastes before their disposal. Although they may contain some ingredients employed during their production such as lubricants and plasticizers, they can readily be processed by electrospinning. Electrospun mats obtained from the PS wastes show remarkable adsorption capacity for three model proteins as following order: BSA >> MYO > TRY. The mats consisting of thin fibers show higher adsorption capacity due

to both having large surface area that increases the available binding sites for the protein and sieving effect of interfibrillar spacing. Although f-PS fibers have the largest BET surface area, the BSA adsorption capacity is highest in CD-PS. The presence of $CaCO_3$ already dispersed in the PS volume most probably to increase final product features and may show high affinity to the proteins. The electrostatic interactions between the $Ca^{2+}$ and negatively charged BSA may override the high adsorption capacity. To approve the role of $CaCO_3$ on adsorption study, PS/$CaCO_3$ composite fibers were fabricated synthetically for comparison. The inclusion of $CaCO_3$ improves the adsorption of proteins compared to parent PS; however, the result appears worse than the one obtained from CD-PS probably having better dispersion of $CaCO_3$ domains. In conclusion, the approach presented in this study may represent a successful way of making valuable products from waste PS to get rid of protein-rich solid content of the body fluid wastes accumulated from hospitals. There have been other researches about the adsorption application of waste polymers but this study is the first that aims the protein adsorption application of polystyrene wastes. Future studies will be focused on using same approach to process other commodity waste plastics produced in larger volumes.

## Acknowledgement

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