Converting Waste Polystyrene into a Polymer Flocculant for Treating Wastewater

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We have converted waste polystyrene from electrical appliances into sulfonated waste polystyrene (SWP) with various degrees of aqueous viscosity after introducing sulfone bridges in it. We examined the relationship between the degree of flocculation of wastewater and the aqueous viscosity of the SWP and found that medium viscosity SWP is best for flocculating inorganic wastewater from a factory and high viscosity SWP is best for dewatering organic domestic wastewater. How SWP containing sulfone bridges works as a polymer flocculant for treating wastewater is reported.

Introduction

Polystyrene is moderate in price and has excellent mechanical and insulating properties. It is utilized in resin-molded articles such as TV cabinets, video cassette shells and the polystyrene foam used for packing household electric appliances. Unfortunately, most polystyrene after use is disposed of in landfills or by incineration and is hardly ever recycled [1]. This is because polystyrene is relatively low in price and conventional recycling methods [2] turn waste polystyrene into less valuable material such as fuel oil and recycled resin.

Our object was to find a way to convert the waste polystyrene used in household electric appliances into a functional polymer which is more valuable than virgin polystyrene. Concretely, we tried to convert waste polystyrene into a water-soluble polymer, sodium polystyrene sulfonate (SPS).

The author*1 has reported the reclamation of using SWP made from waste polystyrene whose molecular weight ranged from 400,000 to 700,000 as a polymer flocculant for treating inorganic wastewater.[3] We deal here with high molecular weight SWP into which has been deliberately introduced sulfone bridges, as shown in Fig. 1. This SWP has a higher molecular weight than the SPS described above and we report interesting results using the SWP as a polymer flocculant for treating wastewater.

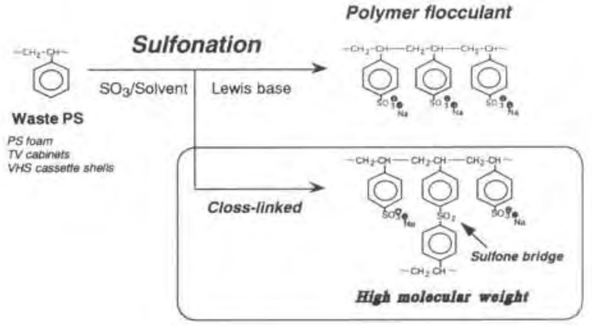

Figure 1. Sulfonated Waste PS containing Sulfone Bridges

Materials and Methods

a) Sulfonation of Waste Polystyrene

Waste polystyrene was obtained from the polystyrene foam (PS foam) used as cushions for packing TV. The waste high-impact polystyrene (HI-PS) from TV cabinets contains butadienes as a comonomer and additives such as carbon black. The molecular weight of the waste polystyrene was measured using gel permeation chromatography (GPC). The SWP was prepared using a method similar to that reported previously [3],[4]. SWP of various aqueous viscosity was obtained by controlling the type and amount of Lewis base to introduce sulfone bridges [5] in it. The percentage of sulfonation of the SWP was calculated by titration with a base and was more than 90 mol%.

Table I. Sulfonation of Waste PS and the Resulting SWP

Run	waste resin	MW [a]	viscosity of SWP[b] (mPa · s, 25℃) no salt	1 M Na_2SO_4
1	PS foam	213,000	3.5	3.0
2	〃	〃	210.0	12.5
3	〃	〃	540.0	10.0
4	〃	〃	690.0	16.0
5	TV cabinet [c]	195,000	3.0	2.2
6	〃	〃	46.0	5.8

[a] Determined by gel permeation chromatography (GPC) in chloroform
[b] Viscosities are for 0.5 % solutions in water at 25°C
[c] Containing butadiene of 4.4 mol % and carbon black 1 wt %.

The viscosity of the SPS for a 0.5 % solution in water at 25 ℃ was measured using a rotational viscometer. Details on the sulfonation of the waste PS are shown in Table I.

b) Flocculation of Wastewater Using SWP

In order to evaluate the flocculating effectiveness of SWP, we used two types of inorganic wastewater and one type of organic wastewater. One type of inorganic wastewater was made of kaolin/ water = 4.0/ 96.0: weight % and the pH of its suspension was 4.22. The kaolin was obtained commercially. The other type of inorganic wastewater was obtained from a semiconductor plant. This wastewater was first strongly acidic, so it had to be neutralized with a calcium-hydroxide. Next, the wastewater was coagulated using an inorganic flocculant, $Al_2(SO_4)_3$. The coagulated wastewater was used for the flocculation test. The flocculating effectiveness of SWP on the inorganic wastewater was evaluated by measuring the sedimentation rate of the wastewater in the manner described by previous researchers.[6]-[8] The results are shown in Figs. 2 and 3. ( ) in Figures 2 to 4 shows viscosity of SWP for 0.5 % solution in water at 25 ℃. EPS was made from expanded polystyrene and HIPS was made from TV cabinet.

As organic wastewater, returned sludge aerated in an aeration tank was obtained from household wastewater. The pH of the sludge, the concentration of suspended solids in the sludge and electric conductivity were 6.6, 1.31 % and 2.2 mS/cm, respectively. Several kinds of polymers were used for treating the organic wastewater. Conventional poly (trimethyl aminoethylacrylate) ammonium chloride was used as a cation polymeric flocculant. The SWP, a commercial reagent SPS whose molecular weight was 2.6×10^6, conventional poly (acrylic acid, sodium salt): PAS, and partially hydrolyzed polyacrylate (PAA: hydrolyzed to about 20 mol %) were used as anion polymer flocculants.

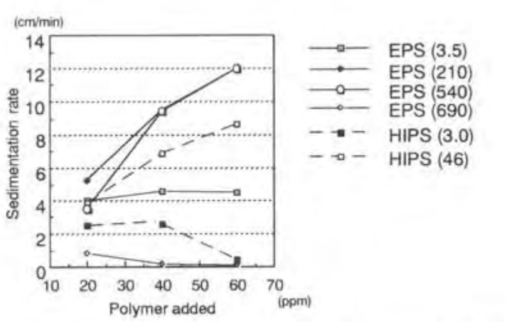

Figure 2. Sedimentation rate versus concentration of SWP in kaolin suspension using various SPS aqueous viscosities

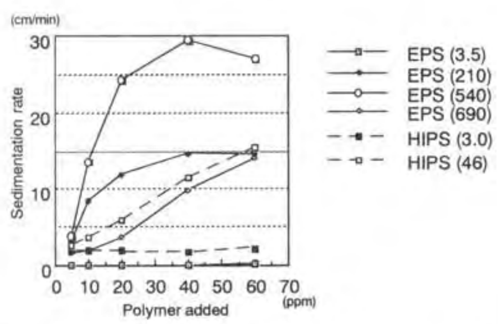

Figure 3. Sedimentation rate versus concentration of SWP in wastewater from semiconductor plant using various SWP aqueous viscosities

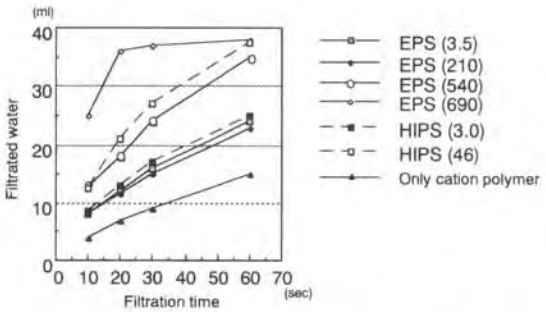

Figure 4. Effect of aqueous viscosities of SWP on filtration rate when SWP is used for dewatering a domestic wastewater

A table-top flocculation and dewatering test was performed as follows. After adding 20 ppm of the cation polymer to the sludge, the sludge was immediately stirred using a hand-held mixer at 800 rpm for 30 s, after which an anion polymer was added, and flocculation was facilitated by stirring the sludge at 120 rpm for 30 s using a spatula. The flocculated sludge was then placed on a polypropylene filter set on top of a Buchner funnel and subjected to gravity filtration so that excess water dripped into a cylinder. The amount of filtrate in the cylinder was measured as shown in Figs. 4. After pressing the gravity-filtered cake to dewater it, the resulting dewatered sludge cake was separated from the filter cloth to measure its moisture content.

Results and Discussion

(1) Sulfonation of Waste Polystyrene

The waste polystyrene as a starting material and the resulting SWP are summarized in Table I. SWP with various degrees of aqueous viscosity was obtained by controlling the type and amount of Lewis base to introduce sulfone bridges. Of course, the more Lewis base was used under sulfonation, the fewer sulfone bridges were introduced into the SWP. Even if the TV cabinet contained a rubber component such as butadiene and a coloring agent such as carbon black, the waste polystyrene could be converted into SWP with various degrees of aqueous viscosity. Using PS foam as a starting material, we could obtain SWP whose aqueous viscosity for a 0.5 % solution in water at 25 ℃ ranged from 3.5 to 690 mPa・s. The viscosity of SWP containing a salt such as a Na_2SO_4 was lower than the SWP without salt. It was confirmed that viscosity of the SWP without salt was generally related to the viscosity of the SWP with salt.

(2) Flocculating of Inorganic Wastewater Using SWP

The result of flocculation of a kaolin suspension using SWP with various degrees of aqueous viscosity, prepared from PS foam and TV cabinets, is shown in Fig. 2. In the SWP made from PS foam (EPS), medium viscosity SWP was best for flocculating this suspension. In the SWP made from TV cabinet (HIPS), the higher viscosity SWP was best for the flocculation.

Figure 3 shows the result of flocculation of actual wastewater from a semiconductor plant using SWP with various degrees of aqueous viscosity. This test showed the same tendency as the above test using kaolin suspension. We think this is because (i) since the lowest viscosity SWP has the weakest electrostatic property, it is difficult for the SWP to flocculate inorganic particles in the wastewater effectively and because (ii) although the highest viscosity SWP has strongest electrostatic property, the hydrophobic area generated by the sulfone bridges in the SWP makes adsorption of the SWP onto the hydrophilic surface of inorganic particles difficult.

At any case, these results indicate that there are optimum degrees of viscosity for SWP in flocculating inorganic wastewater.

(3) Flocculating of Organic Wastewater Using SWP

A returned sludge aerated in an aeration tank obtained from household wastewater was used for flocculation and dewatering of organic wastewater using SWP.

Figure 4 shows the effect of the viscosity of SWP on the filtration rate of the organic wastewater. The filtration rate of the wastewater was increased by adding an anion polymer after adding a cation polymer to the wastewater. When SWP was added to the wastewater, the filtration rate of the wastewater rose as the viscosity of the SWP rose. The highest viscosity EPS had fastest filtration rate in all EPSs. In the case of HIPS, higher viscosity HIPS was also better for filtration. These results suggest that the hydrophobic area generated by the sulfone bridges in SWP makes adsorption of the SWP onto hydrophobic area in organic wastewater easy.

Flocculation and dewatering of the same organic wastewater using SWP and the other anion polymers such as the reagent SPS, PAS and PAA were evaluated. It was found that the high viscosity EPS and HIPS with the most sulfone bridges had the fastest filtration rate and using them produced a dewatered sludge cake with a moisture content 1-2.5 % lower than the other anion polymers. We think that this is because the highest viscosity EPS and HIPS have a hydrophobic nature derived from sulfone bridges and a strong electrolyte such as the sulfate group.

Conclusions

1. Sulfonated waste polystyrene having various degrees of aqueous viscosity can be obtained by introducing sulfone bridges.
2. There are optimum points of viscosity of SWP for treating wastewater
   a) Medium viscosity SWP is best for flocculating inorganic wastewater.
   b) High viscosity SWP is best for flocculating organic wastewater.

A polymer flocculant suitable for use with various types of wastewater can be obtained from waste polystyrene by controlling the viscosity of SWP by introducing sulfone bridges into the SWP.

We believe this technology will help to effectively utilize limited resources, clean the environment, and reduce waste.

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