

Benzoyl Peroxide as a Novel Oxidizing Agent in a Polyaniline Dispersion: Synthesis and Characterization of a Pure Polyaniline–Poly(vinyl pyrrolidone) Composite

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Received 5 July 2007; accepted 27 September 2007

DOI 10.1002/app.27589

Published online 15 January 2008 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: Benzoyl peroxide was used as a novel oxidizing agent in the preparation of a polyaniline (PANI) dispersion. Aniline was oxidized by benzoyl peroxide into a PANI dispersion in the presence of poly(vinyl pyrrolidone) (PVP) as a stabilizer. A pure PANI dispersion in water was prepared by the dispersion of the isolated wet and dry forms of PANI powder. The size of the PANI particles in the water medium was measured for the reaction mixture and wet and dry composites with a particle size analyzer and a zeta sizer. The hydrodynamic diameter of the PANI particles ranged from 435 to 970 nm. The size of

the PANI particles was found to be lower in the wet composite. PANI particles with a lower volume mean diameter (140 nm) and narrow size distribution (100–190 nm) were observed in the PANI–PVP wet composite. The PANI dispersion was characterized with Fourier transform infrared, ultraviolet–visible, differential scanning calorimetry, and scanning electron microscopy measurements. © 2008 Wiley Periodicals, Inc. *J Appl Polym Sci* 108: 825–832, 2008

Key words: composites; conducting polymers; dispersions; FT-IR

INTRODUCTION

A severe constraint in the application area of conducting polymers stems from their general lack of solubility and fusibility. As is evident from the structure of these materials, the molecules are rather rigid and are associated with high cohesive forces. The solubility and fusibility have, however, been improved in some cases by suitable chemical modification of the polymer chains, which increases the chain spacing and reduces the cohesive force.^{1–3}

The preparation of a conducting polymer dispersion is one of the ways of solving the intractability problem because a colloidal dispersion may often be applied in place of a true solution.⁴ A colloidal dispersion can be prepared by the dispersion polymerization technique. The polymerization, when carried out in the presence of certain soluble polymeric stabilizers, yields the desired colloidal dispersion. When polymerization proceeds in the presence of a steric stabilizer, macroscopic precipitation of the polymer can be prevented, and submicrometer dispersion particles are obtained.⁵

Like many electrically conducting polymers, polyaniline (PANI) is difficult to process because it is soluble only in a limited number of organic solvents⁶ because of its highly aromatic nature and the intermolecular hydrogen bonding between amine groups (donors) and imine groups (acceptors) of adjacent chains. On the other hand, many applications require casting the polymers as thin films or thin coatings; therefore, processability is a key issue. Over the last 3 decades, different synthetic routes have been developed to address the problems related to the processability of PANI by the introduction of a polymeric stabilizer. Poly(vinyl pyrrolidone) (PVP) is one of the important stabilizers because PVP is soluble in an aqueous organic medium. The hygroscopic nature of PVP facilitates the redispersion of PANI–PVP composites easily, which can be blended with other water-soluble insulating polymers to make conductive blends. PVP exhibits a unique combination of properties, including solubility in water and in organic solvents, very low toxicity, high complexing ability and good film-forming characteristics, and the ability to adhere to a number of substrates. Several workers have prepared PANI composites with PVP as a stabilizer.^{7–15}

Recently, Murugesan et al.¹⁶ prepared a PANI–PVP dispersion, using potassium persulfate as an oxidizing agent, and studied the specific interaction of PVP in the PANI–PVP blend. Very recently, Dispenza et al.¹⁷ prepared electrically conductive PANI nanoparticles dispersed in a PVP hydrogel by water dispersion polymerization, with ammonium persul-

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Contract grant sponsor: Department of Science & Technology of India; contract grant number: SR/FTP/CS-21/2001 (under the Science and Engineering Research Council (SERC) fast-track scheme).

fate as an oxidizing agent, followed by γ -irradiation-induced crosslinking of the PVP component. Li and Li¹⁸ self-assembled the emeraldine PANI base solution with PVP into aqueous nanocolloids through a rational design of the self-assembly process.

Mostly, ammonium persulfate is being used as the oxidizing agent in the preparation of PANI dispersions. However, ammonium persulfate is unstable when stored; that is, the acidity increases because of moisture absorption, and it undergoes decomposition resulting in a low yield and conductivity.¹⁹ Recently, our group developed a method for the preparation of PANI salt using benzoyl peroxide as a novel oxidizing agent by an emulsion polymerization pathway.²⁰

In this article, we report the results for the dispersion polymerization of aniline in the presence of a PVP stabilizer with benzoyl peroxide as an oxidizing agent in aqueous organic media for the first time. The preparation of a nanosized PANI dispersion, the isolation of a PANI composite in its pure form, and the redispersion procedure are discussed. The size of the PANI particles in the as-prepared dispersion and the change in the size of the particles during the isolation and redispersion of the composite were investigated with a particle size analyzer and a zeta sizer. The size and morphology of the PANI particles were investigated as a function of the stabilizer concentration. The isolated PANI-PVP composite was characterized with thermal, spectral, and conductivity techniques.

EXPERIMENTAL

Materials

PVPs with molecular weights of 360,000 and 40,000, procured from Sigma-Aldrich (Bangalore, India), were used in the polymerization reactions. Benzoyl peroxide (BDH, Mumbai, India) was recrystallized from a chloroform/methanol system. Analar-grade aniline from E. Merck (Mumbai, India) was distilled under reduced pressure. Analar-grade reagents and solvents such as sulfuric acid, acetone, dimethyl sulfide, dimethyl formamide, *N*-methyl pyrrolidone, chloroform, and methanol (S.D. Fine Chemicals, Mumbai, India) were used as received. Deionized water was used for all reactions.

Measurements

Resistance measurements were carried out for the polymer pellet by two probes connected to a Keithley digital multimeter (model 2010, Cleveland, OH). Resistance was calculated on the basis of the average of at least three consistent readings. The polymer sample was dispersed in water by sonication for about 1.5 h and then subjected to particle size measurement. A Master Sizer 2000 (Malvern Instru-

ments, Malvern, United Kingdom) was used to determine the volume mean diameter and particle size distribution of the polymer sample. Dynamic light scattering (DLS) measurements were carried out with a Zetasizer 3000 HS DLS laser light scattering spectrometer (Malvern Instruments). The size measurements of the PANI particles in the reaction mixture and wet and dry composites were carried out by dilution of the dispersion in 1M H₂SO₄ and sonication for 1.5 h before analysis. The Fourier transform infrared (FTIR) spectrum was recorded with a gas chromatography/FTIR spectrometer (model 740, Nicolet, United States). The PANI sample was mixed with KBr powder and compressed into a pellet, in which the sample powder under analysis was evenly dispersed. The electronic absorption spectrum of the polymer sample was recorded at the ambient temperature with a GBC Cintra 10e UV/V spectrophotometer (Dandenong, Australia). The morphology study of the polymer sample was carried out with a Hitachi S520 scanning electron microscope operating at 10 kV. Differential scanning calorimetry (DSC) analysis of the polymer sample was performed on a Mettler-Toledo DSC 821e instrument in the temperature range of 25–400°C at a heating rate of 10°C/min under a nitrogen atmosphere.

PANI dispersion

Dispersion polymerization of aniline in the presence of PVP

The dispersion polymerization of aniline was carried out with PVP as a steric stabilizer. Benzoyl peroxide (1.32 g) was dissolved in 50 mL of acetone placed in a 250-mL, round-bottom flask. A solution of sulfuric acid (2.7 mL) dissolved in 50 mL of water was added to the aforementioned mixture. PVP (2, 5, or 10 g) was added to the mixture, which was stirred for 8 h at 30°C. Finally, 0.5 mL of aniline was introduced into the mixture, and the polymerization was allowed to proceed at 30°C for 24 h. At the end of the reaction, green-colored PANI salt in the form of a dispersion was obtained in the reaction mixture.

Isolation of wet and dry PANI-PVP composites

The PANI-PVP composite was isolated by precipitation of the PANI dispersion in excess acetone. The acetone was removed by filtration and washed with a fresh portion of acetone until no brown color was observed (wet composite). The wet composite was dried at 60°C for 12 h to get the dry composite.

Polymerization of aniline

For a comparative study, aniline was polymerized in the absence of the PVP stabilizer. Benzoyl peroxide

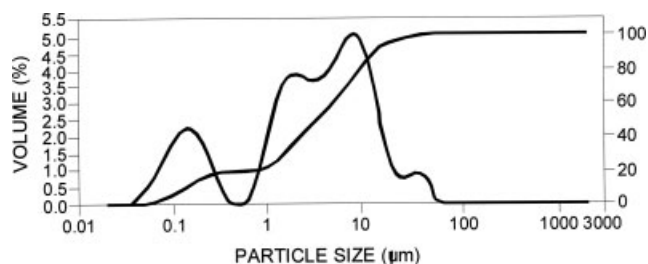


Figure 1 Size distribution analysis of PANI particles in PANI-PVP prepared with 1.2 g of PVP ($M_w = 40,000$).

(1.32 g) was dissolved in 50 mL of acetone placed in a 250-mL, round-bottom flask. To this solution, sulfuric acid (2.7 mL) in 50 mL of water was added. Aniline (0.5 mL) was added to the aforementioned reaction mixture, and the reaction was allowed to proceed at 30°C for 24 h. At the end of the reaction, a dark green precipitate of PANI was obtained. The precipitated PANI was filtered and washed with water and finally with acetone. The PANI powder was dried at 100°C until a constant mass was obtained (PANI).

RESULTS AND DISCUSSION

Yield and conductivity of the PANI-PVP composite

The yield of the PANI-PVP composite was found to be dependent on the amount of PVP used in the dispersion polymerization. The yield of pure PANI salt was found to be 0.3 g, and it was increased to 1.8, 4.5, and 8.5 g with the use of 2, 5, and 10 g of PVP, respectively. The variation in the amount of the PANI-PVP composite isolated and the amount of PVP used in the polymerization was due to the problem associated with the isolation of the composite. The amount of PVP used in the polymerization had a considerable effect on the conductivity of the PANI-PVP composite. The conductivity of pure PANI (51×10^{-3} S/cm) decreased to 2.8×10^{-3} , 1.9×10^{-5} , or 1.7×10^{-5} S/cm when 2, 5, or 10 g of PVP was used in the dispersion polymerization. This was due to the increase in the amount of nonconducting PVP in the composite.

Particle size analysis results for the PANI-PVP dispersion

A preliminary experiment was carried out for the preparation of the PANI-PVP dispersion with different amounts of PVPs of two different molecular weights [weight-average molecular weight (M_w) = 40,000 or 360,000]. The PANI-PVP composite was isolated from the reaction mixture by centrifugation of the dispersion at 10,000 rpm. The isolated com-

posite was redispersed in water by sonication, and particle size analysis was carried out. As a representative system, the size distribution graph of PANI particles in the PANI-PVP composite prepared with 1.2 g of PVP ($M_w = 40,000$) is shown in Figure 1. The distribution pattern shows that 10% of the total number of particles were below 0.14 μm , 50% of the particles were below 3.0 μm , and 90% of the particles were below 13.2 μm . The volume mean diameter of the particles was found to be 6.0 μm . The volume mean diameter and size distribution of the PANI particles in the PANI-PVP composites prepared with PVPs with molecular weights of 40,000 and 360,000 are reported in Table I.

The volume mean diameter of the PANI particles was found to be more or less the same with the use of PVPs of different molecular weights. As a representative system, the volume mean diameter of the PANI particles prepared with PVP (1.2 g) with a molecular weight of 40,000 was 6.0 μm , which was close to that obtained with PVP with a molecular weight of 360,000 (5 μm). The amount of PVP used in the dispersion polymerization had a profound effect on the volume mean diameter and size distribution of the PANI particles. The volume mean diameter of the particles decreased with an increase in the amount of PVP. As a representative system, the volume mean diameter of the PANI particles decreased from 26.0 to 5.0 μm with the increase in the PVP ($M_w = 360,000$) content from 0.3 to 1.2 g. The PANI-PVP composite in the reaction mixture or redispersed form was not stable. The reason for the instability of the dispersion may be the use of a low amount of the stabilizer. The redispersed dispersion was unstable because some portion of the stabilizer was lost during the isolation of the composite by centrifugation. The PANI-PVP composite could not be isolated even by reprecipitation of the dispersion in acetone.

To prepare a pure, stable, and nanosized PANI dispersion, a larger amount of PVP with a molecular weight of 360,000 (2, 5, or 10 g) was used. The as-prepared PANI dispersion was impure because it

TABLE I
Volume Mean Diameter (D_V) and Size Distribution of PANI Particles in the Dispersion Prepared with PVP

PVP (g)	PVP ($M_w = 40,000$)				PVP ($M_w = 360,000$)			
	PANI distribution (μm)			D_V (μm)	PANI distribution (μm)			D_V (μm)
	10%	50%	90%		10%	50%	90%	
0.3	5.5	14.0	30.0	16.0	4.0	21.5	53.0	26.0
0.6	4.5	13.5	26.0	14.5	1.5	17.0	34.5	18.0
0.9	0.9	9.6	26.5	12.0	0.15	1.5	13.5	4.0
1.2	0.14	3.0	13.0	6.0	0.2	4.5	11.0	5.0

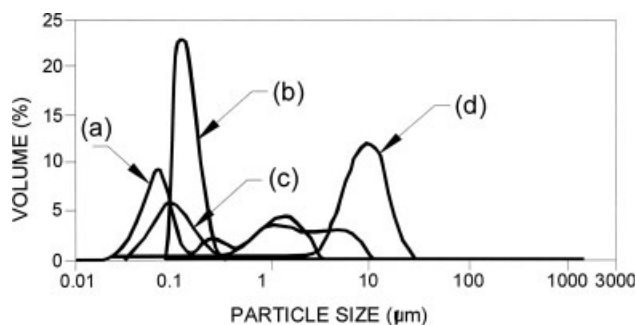


Figure 2 Particle size distribution of PANI particles in (a) PANI-PVP (10) (reaction mixture), (b) PANI-PVP (5) (wet composite), (c) PANI-PVP (2) (dry composite), and (d) PANI.

contained the disintegrated products from the oxidant and oligomers that formed during the polymerization of aniline. Hence, the PANI-PVP composite was isolated in the wet and dry forms and redispersed in water.

The PANI particles in the reaction mixture and wet and dry composites were subjected to particle size analysis. The size distributions of the PANI particles in the mixture and wet and dry composites are shown in Figure 2. It shows that the size of the PANI particles decreased with the use of the PVP stabilizer. The size distribution was found to be narrow in the case of the PANI-PVP (5) wet composite, whereas particles with a broad size distribution were observed in the PANI-PVP (10) reaction mixture and PANI-PVP (2) dry composites.

The size distribution and volume mean diameter of the PANI particles in the mixture and wet and dry composites prepared with different amounts of PVP are reported in Table II. The volume mean diameters of the PANI particles in the PANI-PVP (2) mixture and wet and dry composites are almost the same. The volume mean diameter of the PANI particles in the reaction mixture increased with an

TABLE II
Volume Mean Diameter (D_V) and Size Distribution of the PANI Particles in the Reaction Mixtures and the Corresponding Wet and Dry Composites Prepared with Different Amounts of PVP

Composite	Condition	Particle size distribution			D_V (nm)
		10%	50%	90%	
PANI-PVP (2)	Reaction mixture	40	120	1700	580
	Wet composite	77	181	1500	565
	Dry composite	350	250	1500	510
PANI-PVP (5)	Reaction mixture	70	700	5000	1600
	Wet composite	100	130	190	140
	Dry composite	55	680	1870	830
PANI-PVP (10)	Reaction mixture	480	1300	2800	1500
	Wet composite	50	80	950	260
	Dry composite	50	115	1700	570

increase in the amount of PVP. PANI particles with a narrow size distribution and a lower volume mean diameter were observed in the PANI-PVP (5) wet composite. Although there was an increase in the diameter of the PANI particles in the PANI-PVP (5) dry composite compared to the PANI-PVP (2) and PANI-PVP (10) composites, more particles with a lower diameter were present in the PANI-PVP (5) dry composite.

DLS analysis results for the PANI-PVP dispersion

The zeta average diameter of the PANI particles in the reaction mixture and the corresponding wet and dry composites was determined by DLS. The size distributions of PANI particles in PANI-PVP (10) (reaction mixture), PANI-PVP (5) (wet composite), and PANI-PVP (2) (dry composite) are shown in Figure 3. The zeta average diameter and polydispersity index of the PANI particles in the reaction mixture and the corresponding wet and dry composites are reported in Table III.

Generally, the zeta average diameter of PANI particles in the dispersion and the corresponding wet and dry composites was increased with an increase in the amount of PVP. As a representative system,

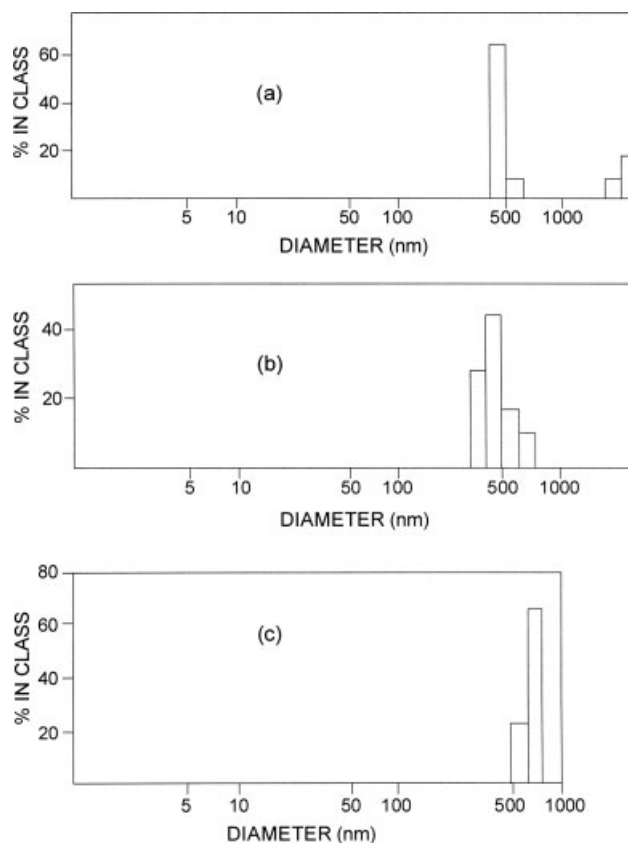


Figure 3 Size distribution of PANI particles in (a) PANI-PVP (10) (reaction mixture), (b) PANI-PVP (5) (wet composite), and (c) PANI-PVP (2) (dry composite).

TABLE III
Zeta Average Diameter (D_z) and Polydispersity Index (σ^2) of PANI-PVP Composites Prepared Under Different Conditions

Composite	D_z (nm)			σ^2		
	Reaction mixture	Wet composite	Dry composite	Reaction mixture	Wet composite	Dry composite
PANI-PVP (2)	900	435	580	0.27	0.34	— ^a
PANI-PVP (5)	915	560	630	0.63	0.69	0.32
PANI-PVP (10)	970	870	970	— ^a	0.44	— ^a

^a Above the instrument range (i.e., >0.75).

the diameter of PANI particles in the PANI-PVP (2) dry composite (580 nm) increased to 970 nm when the amount of PVP was raised to 10 g. However, the value of conductivity decreased with the amount of PVP increasing from 2 (2.8×10^{-3} S/cm) to 10 g (1.7×10^{-5} S/cm). This result indicates that no correlation exists between the particle size of the PANI-PVP composite and its conductivity. PANI particles with a lower diameter were observed in the wet composite. There was a marginal change in the zeta average diameter of the PANI particles with an increase in the amount of PVP from 2 to 5 g, but it had a considerable effect when the amount of PVP in the dispersion polymerization was raised to 10 g. The value of the polydispersity index is a measure of the nonuniformity of particles. Generally, the nonuniformity parameter or polydispersity index varies from 0 for monodisperse particles to 1 for extremely polydisperse ones.²¹ The polydispersity indices of the particles in the dispersion and the corresponding wet and dry composites are reported in Table III. An analysis of the polydispersity index of the size analysis report indicates the formation of polydisperse PANI particles. A similar observation was reported by Stejskal et al.¹¹ for PANI particles prepared with PVP and PVA stabilizers with ammonium persulfate. The PANI particles were polydisperse (0.15–0.35) in nature, and their hydrodynamic diameter ranged from 300 to 600 nm.

The increase in the size of the PANI particles with an increasing concentration of the stabilizer may be due to the insufficient coverage of PANI particles by the stabilizer. The viscosity of the polymerization medium increased as the amount of stabilizer was increased. This resulted in the nonuniform distribution of aniline in the polymerization medium, and polymerization took place in local regions; this resulted in the agglomeration of PANI particles. The size of the PANI particles in the redispersed wet and dry composites was low compared to that of the PANI particles produced in the dispersion. This may be due to the disintegration of agglomerates by sonication. The hygroscopic nature of PVP made the redispersion of isolated wet and dry PANI-PVP composites easy. However, complete redispersion was not achieved in the case of 100% dry (moisture-

free) PANI-PVP composites. A moisture level of 25% was maintained in PANI-PVP composites to facilitate complete redispersion in water.

Infrared spectral analysis of the PANI-PVP composite

The infrared spectra of PANI, PVP, and the PANI-PVP (2) dry composite are shown in Figure 4. The vibrational bands observed for PANI are explained on the basis of the normal modes of aniline and benzene.²² The 1565- and 1490- cm^{-1} bands are due to the quinonoid ring (Q) and/or the benzenoid ring (B). The band around 1450 cm^{-1} is due to the stretching of the benzene ring. Bands at 1300 cm^{-1} are assigned to the C–N stretching vibration in

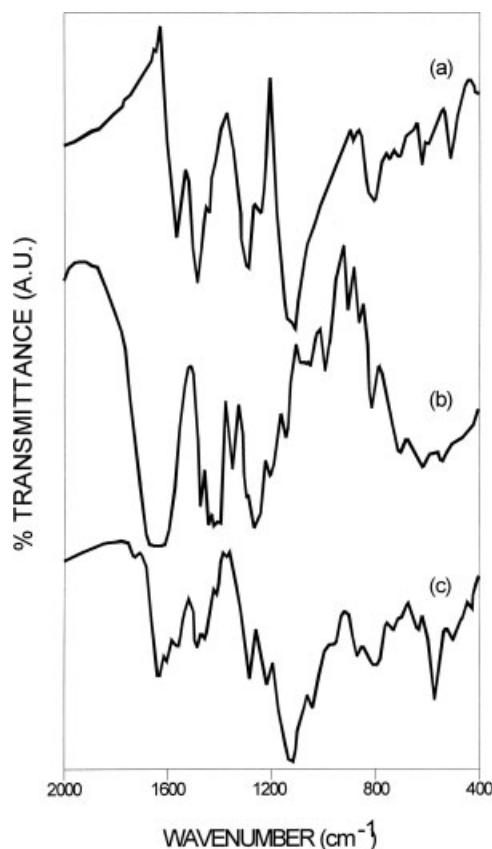


Figure 4 Infrared spectra of (a) PANI, (b) PVP, and (c) PANI-PVP (2) (dry composite).

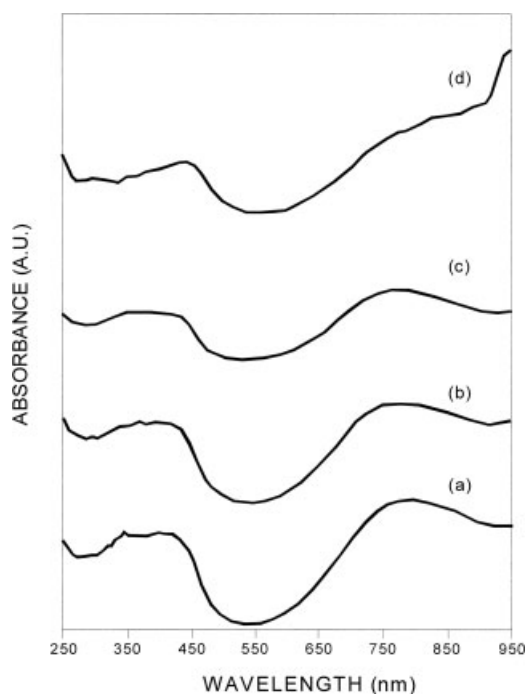


Figure 5 UV-vis spectra of (a) PANI-PVP (2), (b) PANI-PVP (5), (c) PANI-PVP (10), and (d) PANI in water.

QBQ, QBB, and BBQ; a 1245-cm^{-1} band is assigned to the C—N stretching vibration of aromatic amine. For PANI, a characteristic strong band appears at 1140 cm^{-1} , which has been explained as an electronic band or vibrational band of nitrogen quinone. A band at 710 cm^{-1} is assigned to a ring C—C bending vibration, and the band at 580 cm^{-1} is due to ring in-plane deformation. The C—H out-of-plane bending mode has been used as a key to identifying the type of substituted benzene. The infrared spectrum of PVP [Fig. 4(b)] shows an absorption band around 1660 cm^{-1} which is called amide I and is attributed to the combination of $>\text{C}=\text{O}$ and C—N stretching. Because of this combination mode, this band occurred at a lower wave number than expected for a pure ester carbonyl band ($1750\text{--}1700\text{ cm}^{-1}$).^{23,24}

The carbonyl absorption band at 1660 cm^{-1} in PVP shifted to 1630 cm^{-1} in the PANI-PVP composite. The shift in the carbonyl absorption band to a lower frequency is attributed to the hydrogen bonding between the $>\text{C}=\text{O}$ group of PVP and N-hydrogen of PANI. The shift in the carbonyl absorption band was reported by Lau and Mi²⁴ in their studies on poly(acrylic acid)/PVP blends and was attributed to the hydrogen bonding between the carbonyl group of PVP and hydroxyl groups of poly(acrylic acid).

Ultraviolet-visible (UV-vis) spectral analysis of the PANI-PVP dispersions

The UV-vis spectra of PANI and PANI-PVP composites prepared with different amounts of PVP are

shown in Figure 5. The sample for UV-vis analysis was prepared by redispersion of the dry PANI-PVP composites and pure PANI in water. The UV-vis spectrum of PANI shows three peaks at 350, 440, and 840 nm [Fig. 5(d)]. The peak positions are in accordance with the literature reports on PANI salts.^{22,25} The UV-vis spectra of PANI-PVP composites [Fig. 5(a–c)] show three peaks in the region of 310–360, 380–450, and 750–800 nm. The peak positions are in good agreement with literature reports on PANI dispersions.²⁶ The UV-vis spectral analysis supports the formation of PANI salt during the dispersion polymerization of aniline in the presence of the PVP stabilizer.

Scanning electron microscopy (SEM) analysis of the PANI-PVP composites

Scanning electron micrographs of PANI and PANI-PVP composites are shown in Figure 6. Samples for SEM analysis were prepared by redispersion of the PANI-PVP dry composites in water. The PANI prepared in the absence of a stabilizer showed an aggregated, irregular morphology. The shape of the chemically polymerized PANI particles is commonly

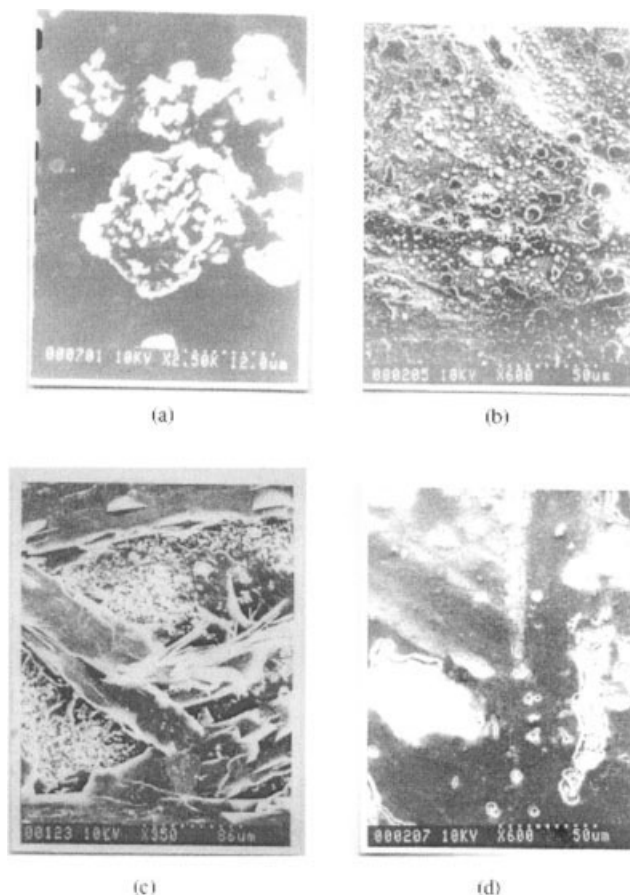


Figure 6 Scanning electron micrographs of (a) PANI, (b) PANI-PVP (2), (c) PANI-PVP (5), and (d) PANI-PVP (10).

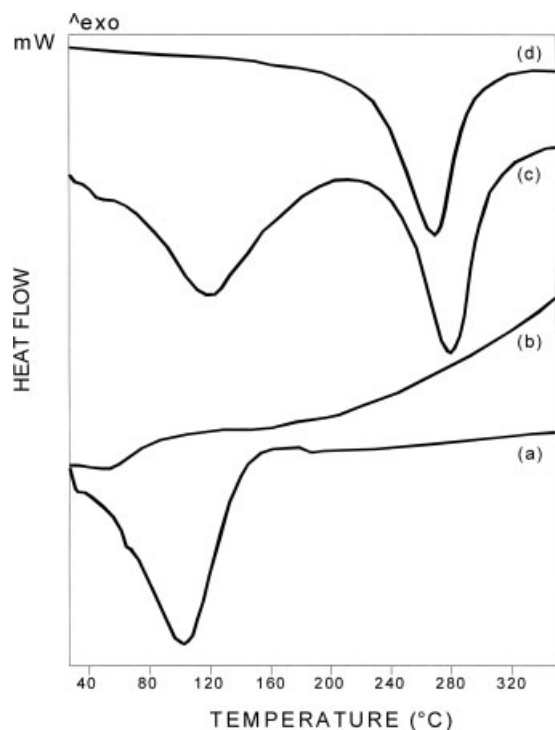


Figure 7 DSC thermograms of (a) PVP, (b) PANI, (c) PANI-PVP (2), and (d) PANI-PVP (2) heated at 100°C.

difficult to control and is most often granular rather than fibrillar. Spherical PANI particles of a nonuniform size were observed in the PANI-PVP (2) composite. PANI particles in the PANI-PVP (5, 10) composites formed aggregates compared to PANI-PVP (2) and were not distributed evenly because of the high concentration of PVP. However, the aggregation of PANI particles in the PANI-PVP (5, 10) composites was less compared to that of PANI synthesized in the absence of a stabilizer. The aggregates formed because of the close approach of individual spherical particles. Generally, submicrometer-size PANI particles are obtained by the dispersion polymerization of aniline in the presence of a suitable steric stabilizer. The particles are protected from aggregation by a surface layer of the attached stabilizer. The DLS results for the PANI reaction mixture and wet and dry composites indicated the formation of polydisperse particles and agglomeration. Aggregation of some of the particles occurred during the isolation and drying process and also during the preparation of samples for SEM analysis. The observed nonuniform PANI particles from DLS were in accordance with the aggregated morphology of the PANI particles (SEM pictures), and this may be due to the insufficient coverage of particles by PVP. Stejskal et al.¹¹ in their studies on PANI-PVP dispersions reported the formation of spherical PANI particles. Ghosh et al.¹³ in their studies on PANI-PVP composites reported the variation in the morphology

of PVP-supported PANI microparticles from a finer, grainlike morphology to a somewhat larger spherical or oblong morphology.

DSC analysis of the PANI-PVP composites

DSC thermograms of PVP, PANI, and the PANI-PVP (2) dry composite are shown in Figure 7. The DSC thermogram of PVP [Fig. 7(a)] shows a broad endotherm in the region of 40–140°C due to the loss of moisture present in PVP and a glass-transition temperature for PVP around 180°C. The thermogram of PANI [Fig. 7(b)] shows an endotherm in the temperature zone of 50–100°C due to the release of moisture.^{27,28} A weak endotherm appearing in the region of 155–290°C is attributed to the release of dopant and morphological changes in PANI on heating. The PANI-PVP composite shows two broad endotherms in the regions of 50–200 and 220–295°C. The endotherm appearing in the region of 50–200°C arose because of the release of moisture present in the PANI-PVP (2) composite. The other endotherm appearing in the region of 220–295°C may be due to the morphological changes in the PANI-PVP (2) composite. The glass transition of PVP in the composite overlapped with the moisture release endotherm in the region of 50–200°C, and this was evidenced when the composite sample was heated at 100°C for 6 h and subjected to DSC analysis [Fig. 7(d)].

CONCLUSIONS

A PANI dispersion was prepared with PVPs with molecular weights of 40,000 and 360,000 with a novel oxidizing agent, benzoyl peroxide. A nano-sized PANI dispersion was prepared at a fixed concentration of aniline and with various amounts of PVP (from 2 to 10 g). The size of the PANI particles was measured for the reaction mixture and wet and dry composites. The PANI particles in the reaction mixture were large in size compared to those of the wet and dry systems. The size of the PANI particles was found to be lower in the wet composites. PANI particles with a lower volume mean diameter (140 nm) and narrow size distribution (100–190 nm) were observed in the PANI-PVP (5) wet composite. The hydrodynamic diameter of the PANI particles ranged from 435 to 970 nm. The polydispersity index indicated the nonuniform nature of the particles. Spherical PANI particles of a nonuniform size were observed in the PANI-PVP (2) composite, and an aggregated spherical morphology was observed in the PANI-PVP (5) and PANI-PVP (10) composites. The UV-vis spectral analysis of the PANI-PVP composites supports the formation of PANI. The infrared spectra of the PANI-PVP composites show the formation of hydrogen bonding between PANI and

PVP. From these results, it is difficult to determine the amount of PANI present in the PANI-PVP composite and also the nature of the composite; that is, PVP is completely or partially covered by the PANI particles in the composite.

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