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# A novel strategy for tailoring cerium oxide polyaniline nanocomposites for photocatalytic preparation of aniline

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#### Abstract

Cerium oxide polyaniline nanocomposites were synthesized in an effective manner to produce a uniform core-shell structure of the particles. This nanocomposite was then used in the photocatalytic synthesis of aniline. Synthesis conditions, heat treatment, and other factors that affect the structural properties of nanocomposite were studied extensively to optimize the synthesis process. Polyaniline nanospheres (PANI\_NS) were prepared by the microemulsion method. Polyaniline nanoparticles (PANI\_NP) were fabricated through polymerization (chemical oxidative process) of aniline. Specific surface area values of PANI\_NS, CeO<sub>2</sub>@PANI\_NS, PANI\_NP, CeO<sub>2</sub>@PANI\_NP, and CeO<sub>2</sub>\_NS were 200, 260, 40, 110 and 130 m<sup>2</sup>/g respectively. The photo-catalytic effeciency of the nanocomposite was investigated through converting nitrobenzene to aniline via reduction reaction under visible light illumination. CeO<sub>2</sub>@PANI\_NS outperforms CeO<sub>2</sub>@PANI\_NP 1.4 times, PANI\_NS 2.5 times, PANI\_NP 6.6 times, CeO<sub>2</sub>\_NS 14.3 times in terms of photocatalytic reduction of nitrobenzene to aniline.



# Introduction

Polyaniline (PANI) is a conjugated polymer that attracted researcher's attention as it possesses favourable properties towards photocatalysis and other applications. These properties include absorption of light in the visible range, environmental stability, high conductivity, and corrosion resistance [1]. Generally, inorganic nano oxides such as TiO2, ZnO, CeO<sub>2</sub>, WO<sup>-3</sup>, and many others; have been widely used in photocatalytic reactions. Researchers also try to combine inorganic nanomaterials with organic polymers in efforts to prepare catalytic composites with high efficiency. Ameen, et al. synthesized a PANI ZnO composite and used it effectively in methylene blue dye degradation [2]. Sharma, et al. synthesized PANI/CdS nanoflowers and nanorods nanocomposites and used them in photodegradation [3]. Ozbay, et al. reported photo-catalytic efficiencies of polyanilinemodified ZnO and TiO, beneath Vis light [1]. The photocatalytic efficiency of polyaniline sensitized nano-crystallite titania structures has been investigated by Min, et al. [4]. Many researchers studied the various structure of PANI and TiO, composites. These structures include nanotubes [5,6], bionic nanopapilla [7], and A core-shell structure [8]. Agarwal reported the fabrication of polyaniline/ZrO, oxide conductive nano-composite required for many applications such as adsorption of dyes [9]. Patil, et al. developed a sensor for the detection of NH<sub>3</sub> utilizing copper nanoparticle intercalated polyaniline nanocomposite thin films [10]. Salvatierra, *et al.* studied Carbon nanotube/polyaniline nanocomposites [11].

 $\text{CeO}_2$  is known to be a good catalyst for its special redox property and high oxygen storage capacity this catalyst has been studied by numerous researchers [12-14]. PANI and  $\text{CeO}_2$  combination also received some attention. Yongjun He reported the synthesis of polyaniline/nano  $\text{CeO}_2$  arrangement microspheres by means of a solid-stabilized emulsion regime. The synthesized Polyaniline/nano- $\text{CeO}_2$  composite microspheres had an average diameter of 7 mm [15]. Chuang and Yang used  $\text{CeO}_2$  to oxidize aniline for the fabrication of ( $\text{CeO}_2$ /PANI) core-shell nano structures. They reported a polygonal shape of the PANI/CeO<sub>2</sub> nanocomposites [16]. Kumar, *et al.* exploited in-situ polymerization to prepare the PANI/CeO<sub>2</sub> nanocomposite and reported the structure of this composite [17]. Sasikumar, *et al.* reported the use of aniline, HCl, CeO<sub>2</sub> nanoparticles, ammonium persulfate, and

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water to synthesize PANI/CeO<sub>2</sub> composite and used it as a corrosion inhibitor [18]. Da Silva, *et al.* reported the fabrication of poly-aniline ES-PANI Cl-salt in the existence of CeO<sub>2</sub>. They concluded that CeO<sub>2</sub> molecules designing a core-shell arrangement with non-homogeneous shape and size have been coated with a delicate layer of ES-PANI nano-tissues [19].

Here we report, a novel method for the preparation of a uniform core-shell spherical PANI CeO<sub>2</sub> nanocomposite. In the preparation of PANI\_NS, ammonium persulfate was used as an oxidant, ethanol and n-butyl alcohol was utilized as solvents, Na-salt of dodecyl benzene sulfonic acid was used as a surfactant. Poly vinyl pyrrolidine was used in the preparation of CeO<sub>2</sub>@PANI nanocomposites.

#### Chemicals and experimental procedures

#### Chemicals

Monomers of aniline (purity of 99 %, Aldrich), cerium isopropoxide, poly vinyl pyrrolidine (PVP), ammonium persulfate (APS), sodium dodecylbenzene sulfonate (SDBS), ethanol (99.8%), n-butyl alcohol (BA), and hydrochloric acid (HCl, 37%) have been utilized without any further purification.

## Fabrication of polyaniline nanospheres

The microemulsion method was employed to prepare polyaniline nanospheres (PANI\_NS). In this procedure, 6.0 g of sodium dodecyl benzene sulfonate (SDBS) was dissolved in 100 mL of distilled water while maintaining the pH=0.3 with the use of HCl solution. 1.3 mL of aniline monomer was added to the mixture. After stirring for 60 min 4 mL of n-butyl alcohol (BA) was drop-wisely introduced to the mixture. The system temperature was adjusted at 25 °C, and 33 mL of 10% ammonium persulfate (APS) solution was introduced to the reaction medium and the resultant system was agitated for additional 5 h to achieve polymerization of the aniline monomer. A change of colour from brown-yellow to dark-green was observed during the stirring process. The mixture was cleaned several times via ethanol and distilled water and then left to dry for 12 h at 70°C using a vacuum oven to collect PANI\_NS.

#### Preparation of polyaniline nanoparticles

Polymerization of aniline was performed to fabricate poly-aniline nanoparticles (PANI\_NP) adopting the chemical oxidation route. In this procedure, 1.3 mL of aniline monomer was added to 100 mL of HCl aqueous solution under vigorous stirring at 1°C. A 33 mL portion 10% APS solution was introduced to the system which was agitated for 5h. The mixture was cleaned many intervals with ethyl alcohol and distilled water under vacuum. The resultant yield was kept to dry for 30 h at 70°C using a vacuum oven and PANI\_NP for further use.

#### Preparation of CeO<sub>2</sub>@PANI nanocomposites

A mixture of 0.3 g of PVP and 1.6 g of PANI\_ NS or PANI\_NP were dispersed in 30 mL of ethanol using Ultrasonic Cleaner for 60 min. Then, cerium isopropoxide solution (100 mL of 0.3 mol/L) was added to the mixture with further dispersion in the ultrasonic bath for 3 hrs. The mixture was cleaned many intervals with distilled water and ethanol under vacuum distillation. After drying overnight at 100°C, the product material was calcined for 4 h at 350°C. Both CeO<sub>2</sub>@PANI\_NS and CeO<sub>2</sub>@PANI\_NP were synthesized by this mannar. For comparison purposes, pure CeO<sub>2</sub> nanospheres were prepared by the above-mentioned procedures without the use of PANI\_NS or PANI\_NP.

#### Characterization

JEOL-JEM-1230 transmission electron microscope was used to observe the morphology and sample dimensions of the prepared materials. To get the TEM images, samples were ultrasonicated for 30 m after suspension in ethanol. A small portion of the suspended sample was left to dry on the carbon covered Cu grid and introduced to the spectrometer.

The surface area was determined via  $N_2$ -adsorption evaluations of the specimen adopting Chromatech instrument (Nova 2000 series) at 77 K. specimens were heated at 100°C beneath vacuum for 2 h to complete this measurement.

Bruker axis D8 XRD system was utilized to observe the crystallite points of the nanocomposites. XRD was observed employing Cu Ka radiation ( $\lambda$ =1.540 Å) at ambient temperature.

A spectrometer (Thermo-Scientific K-ALPHA) has been utilized in order to attain x-ray photoelectron spectroscopy (XPS) measurements. Whereas, a spectrophotometer (Jasco, Japan) was adopted to attain UV-Vis-DRS spectra that were recognized at ambient temperature in the absorption space from 200 up to 800 nm. Band gap performance has been determined by applying the observed UV-Vis-DRS. In addition, a fluorescence spectrophotometer of Shimadzu type has been utilized to record photoluminescence emission spectra (PL). A transmittance mode FTIR spectrum was documented for a powdered sample and KBr applying a JASCO-type spectrometer keeping the spectral resolution of 2 cm<sup>-1</sup> at ambient temperature.

#### Photo-catalytic tests

The efficiency of the prepared nanocomposites was tested on the reduction of nitrobenzene into aniline. For this purpose, a known weight of the photocatalyst was scattered by means of ultrasonic in a 10 mL nitrobenzene-CH3OH solution (1/99, v/v) with starting dose of nitrobenzene (NB) at 8.13×10<sup>-4</sup> molL<sup>-1</sup>. The reaction mixture was illuminated under artificial visible light produced from Xenon lamp mounted on a photocatalytic reactor. A  $\lambda$ >420 nm cutoff filter was used and a running water tube was exploited to prevent heating which allowed the reaction solution to be kept at about 30 °C. The fixed container, made of quartz, was placed at 11 cm from the origin of illumination. Before starting, dissolute O, is flushed from the solution by nitrogen for 0.5 h. Illumination time was set at 2.5 h for each experiment. After exposure specimens were removed from the reactor, centrifuged for 20 min (7000 rpm). Finally, the solution was filtered via a filter of 0.2µm pore size in order to get rid of any remaining molecules. Agilent Gas Chromatograph (GC 7890A model) was applied to analyze the resulting aniline from the reduction process.

#### **Results and discussion**

#### Characterizations of materials

Figure 1 shows XRD diffractograms of PANI\_NP, PANI\_NS, CeO<sub>2</sub>-NS, CeO<sub>2</sub>@PANI\_NP, and CeO<sub>2</sub>@PANI\_NS samples. The broad peak at ~ 15- 25°C suggests polyaniline phase structure for PANI\_NP, PANI\_NS. On the other hand, CeO<sub>2</sub>\_NS, CeO<sub>2</sub>@PANI\_NP, and CeO<sub>2</sub>@PANI\_NS are composed of CeO<sub>2</sub> phase as characteristic peaks of polyaniline disappeared in the spectra of CeO<sub>2</sub>@PANI\_NP and CeO<sub>2</sub>@PANI\_NS. Also, the decrease in the intensity of the characteristic peaks of CeO<sub>2</sub> phase in the spectra of CeO<sub>2</sub>@PANI\_NP and CeO<sub>2</sub>@PANI\_NS suggests that doping of polyaniline decrease crystallite sizes of both composites.



Figure 1. XRD patterns of PANI\_NP, PANI\_NS,  $\rm CeO_2NS, CeO_2@PANI_NP,$  and  $\rm CeO_3@PANI_NS$ 

Figure 2 exhibits TEM pictures of PANI\_NP, PANI\_NS, CeO<sub>2</sub>-NS, CeO<sub>2</sub>@PANI\_NP, and CeO<sub>2</sub>@PANI\_NS samples. PANI\_NP and CeO<sub>2</sub>@PANI\_NP are nanoparticle shape with sizes of 60 and 75 nm, respectively. However, CeO<sub>2</sub>\_NS, PANI\_NS, and CeO<sub>2</sub>@PANI\_NS are nanospherical in shape with shell diameters of 20-40, 22-44 and 25-50 nm, respectively and core diameter of 150, 170 and 190 nm, respectively. It is obvious that the addition of polyaniline increases the size of CeO<sub>2</sub>@PANI\_NS particles.

XPS spectra of Ce3d (A), O1s (B), N 1s (C) and C 1s (D) for CeO<sub>2</sub>@ PANI\_NS sample is illustrated in Figure 3 The existence of double binding peaks for Ce3d5/2 and Ce3d5/2 at 882 and 916 eV indicate that the cerium ion is Ce(IV) (Figure 3A). The presence of one binding peak for O 1s at 531.6 eV (Figure 3B) indicates that oxygen ion was present as  $O^{2^{\circ}}$ . Therefore, The XPS results for O 1s and Ce3d confirm the presence of CeO<sub>2</sub>. XPS spectra for N 1s and C 1s assure the existence of aniline in CeO<sub>2</sub>@PANI\_NS sample, due to the presence of the binding peaks for N 1s and C 1s at 400 and 284.7 eV (Figures 3C and D, respectively).

FT-IR spectral lines for PANI\_NS and CeO<sub>2</sub>@PANI\_NS samples are exhibited in Figure 4. The characteristic peaks at 1567, 1492, 1297, 1245, 1147 and 815 cm<sup>-1</sup> for polyaniline are present in PANI\_NS and CeO<sub>2</sub>@PANI\_NS samples, which confirm the presence of polyaniline in CeO<sub>2</sub>@PANI\_NS samples.

Figure 5 exhibits adsorption-desorption isotherms of  $CeO_2$ \_NS,  $CeO_2@PANI_NP$ , and  $CeO_2@PANI_NS$  respectively. Type II isotherm is present for PANI\_NP sample as shown in Figure 5B. While type IV isotherm was present for  $CeO_2$ \_NS and  $CeO_2@PANI_NS$  samples as shown in Figure 5. Therefore,  $CeO_2$ \_NS and  $CeO_2@PANI_NS$  samples are mesoporous materials.

The pore size distribution of CeO<sub>2</sub>@PANI\_NS specimen is illustrated in Figure 6. A narrow distribution of pore size around 3.5 is obvious. This explains that the core-shell structure has a large surface area. The values of the specific surface area of PANI\_NS, CeO<sub>2</sub>@ PANI\_NS, PANI\_NP, CeO<sub>2</sub>@PANI\_NP and CeO<sub>2</sub>\_NS as calculated from desorption measurements are 200, 260, 40, 110 and 130 m<sup>2</sup>/g, respectively.

Figure 7 shows UV-Vis spectra of CeO<sub>2</sub>\_NS, CeO<sub>2</sub>@PANI\_NP, and CeO<sub>2</sub>@PANI\_NS samples. The curve shows that CeO<sub>2</sub>\_NS absorbs in the UV zone, the existence of polyaniline within the nanoparticles and within the nanospheres results in a displacement of the absorption edge of cerium dioxide in the UV visible zone. Furthermore, the shift is greater in the case of polyaniline nanospheres. The values of band gap energies as calculated from UV-Vis spectra of CeO<sub>2</sub>\_NS, CeO<sub>2</sub>@PANI\_NP, and CeO<sub>2</sub>@PANI\_NS, are 3.21, 2.38 and 1.91 eV, respectively.

Figure 8 show Pl spectra of  $CeO_2$ \_NS,  $CeO_2@PANI_NP$  and  $CeO_2@PANI_NS$  samples.  $CeO_2\_NS$  shows high Pl peak intensity, the addition of polyaniline to the nanoparticles and nanospheres decreases the Pl peak intensity. Furthermore, the decrease in the case of polyaniline nanospheres is greater than that of polyaniline nanoparticles. The values of band gap energies of  $CeO_2\_NS$ ,  $CeO_2@PANI\_NP$  and  $CeO_2@PANI\_NS$  samples as determined from their Pl emission spectra are 3.20, 2.37 and 1.90 eV, respectively. These values are very close to those obtained from UV-Vis spectra as discussed in the previous paragraph.

### Photocatalytic performance

Conversion of nitrobenzene into aniline reaction was utilized to test the synthesized photocatalyst. A comparison between various prepared



Figure 2. TEM images of PANI\_NP (A), PANI\_NS (B), CeO\_\_NS (C), CeO\_@PANI\_NP (D) and CeO\_@PANI\_NS (E)



Figure 3. XPS spectra of Ce3d (A), O1s (B), N1s (C) and C1s (D) for CeO2@PANI\_NS sample



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Figure 5. Adsorption-desorption isotherms of CeO<sub>2</sub> NS (A), CeO<sub>2</sub>@PANI\_NP (B) and CeO<sub>2</sub>@PANI\_NS (C)



Figure 6. Pore size distribution of CeO<sub>2</sub>@PANI\_NS sample



Figure 7. UV-Vis spectra of CeO, NS, CeO,@PANI\_NP, and CeO,@PANI\_NS samples



Figure 8. Pl spectra of CeO<sub>2</sub> NS, CeO<sub>2</sub>@PANI\_NP, and CeO<sub>2</sub>@PANI\_NS samples

structures was performed. Figure 9 illustrates the photocatalyst type effect on the conversion of nitrobenzene to aniline. Photocatalytic nitrobenzene-aniline transformation with the use of CeO, NS is very small (7%), this can be explained by the fact that CeO<sub>2</sub> NS absorbs only in the UV region while the light source used is in the visible region. Nitrobenzene-aniline transformation, photocatalytically, with the use of PANI\_NP and PANI\_NS was at 15% and 40%, respectively. While the photocatalytic conversion with the use of CeO,@PANI\_NP and CeO,@PANI\_NS as photocatalysts was at 70% and 100% respectively. It is clear that the addition of polyaniline nanoparticles and nanospheres photocatalytic increases nitrobenzene-aniline transformation considerably. Polyaniline nanospheres in the form of CeO<sub>2</sub>@PANI\_NS exhibit superior efficiency at about 100% conversion.

The effect of the amount of added catalyst to the reaction was also studied. Figure 10 illustrates the consequence of the dose of CeO,@

PANI\_NS photocatalyst on the nitrobenzene aniline transformation. The photocatalytic transformation has been enhanced from 75 to 100% by increasing the catalyst amount from 0.3 to 0.6 g/L, respectively. The time needed for a complete nitrobenzene-aniline transformation has been reduced from 150 to 90 min by increasing the amount of  $CeO_2@$  PANI\_NS from 0.6 to 1.2 g/L, respectively. This may be attributed to the improved amount of accessible active sites by the increase in the dose of the photocatalyst. If the dose was raised above 1.2 g/L to a value of 1.5 g/L the nitrobenzene – aniline, photocatalytically, decreases from 100 to 98 % and reaction time increases from 90 to 150 min. the higher dose of photocatalyst beyond a certain point may result in hindering penetration of light to reach all active sites of the photocatalyst.

A test on the possibility of the reuse of the catalyst was also performed. Figure 11 shows recycling and reuse of CeO<sub>2</sub>@PANI\_NS photo-catalyst on nitrobenzene-aniline transformation. The figure shows that the transformation remains constant even if the catalyst was reused for five times showing great stability of the CeO<sub>2</sub>@PANI\_NS photocatalyst.



Figure 9. Effect of type of photocatalyst on the conversion of Nitrobenzene to Aniline



Figure 10. Effect of dose of CeO<sub>2</sub>@PANI\_NS photocatalyst on the conversion of Nitrobenzene to Aniline



Figure 11. Recycling and reuse of CeO\_2@PANI\_NS photocatalyst on conversion of Nitrobenzene to Aniline

#### Conclusion

Polyaniline nanospheres were fabricated by the microemulsion method. Polyaniline nanoparticles were fabricated through polymerization of aniline (chemical oxidation type). CeO,@PANI\_NS was prepared by a method that ensures the production of a uniform spherical core-shell structure. The photocatalytic efficiency of the nanocomposites was investigated by the photocatalytic reduction of nitrobenzene to aniline beneath Vis light. The values of the specific surface area of PANI\_NS, CeO\_@PANI\_NS, PANI\_NP, CeO\_@PANI\_ NP, and CeO<sub>2</sub>NS are 200, 260, 40, 110 and 130 m<sup>2</sup>/g, respectively, which means the NS structure has a high specific surface area. The shapes of PANI\_NS (nanospheres), CeO,@PANI\_NS (core-shell nanospheres), PANI\_NP (nanoparticles), CeO,@PANI\_NP (nanoparticles), CeO,\_ NS (nanospheres); were determined by TEM. The photocatalytic performance of CeO,@PANI\_NS for reduction of nitrobenzene to aniline under visible light is 1.4, 2.5, 6.6 and 14.3 times more than that of CeO,@PANI\_NP, PANI\_NS, PANI\_NP, and CeO,\_NS, respectively.

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# Highlights

- A cerium oxide polyaniline nanocomposite was prepared.
- The photocatalytic properties were studied upon visible irradiation.
- A new cerium oxide polyaniline nanocomposite showed superior photocatalytic activity.

A new cerium oxide polyaniline nanocomposite remains effective and active after five cycles.

#### References

- Ozbay B, Genc N, Ozbay I, Baghaki B, Zor S (2016) Photocatalytic activities of polyaniline-modified TiO<sub>2</sub> and ZnO under visible light: an experimental and modeling study. *Clean Techn Environ Policy* 18: 2591-2601.
- Ameen S, Akhtar MS, Kim YS, Yang OB, Shin HS (2011) An effective nanocomposite of polyaniline and ZnO: preparation, characterizations, and its photocatalytic activity. *Colloid Polym Sci* 289: 415-421.
- Sharma S, Singh S, Khare N (2016) Synthesis of polyaniline/CdS (nanoflowers and nanorods) nanocomposites: a comparative study towards enhanced photocatalytic activity for degradation of organic dye. *Colloid Polym Sci* 294: 917-926.
- Min S, Wang F, Han Y (2007) An investigation on synthesis and photocatalytic activity of polyaniline sensitized nanocrystalline TiO, composites. J Mater Sci 42: 9966-9972.
- Olad A, Nosrati R (2013) Preparation, characterization, and photocatalytic activity of polyaniline/ZnO nanocomposite. *Res Chem Intermed* 39: 3969-3979.
- Cheng Y, An L, Zhao Z, Wang G (2014) Preparation of polyaniline/TiO<sub>2</sub> composite nanotubes for photodegradation of AZO dyes. *Journal of Wuhan University of Technology-Mater Sci Ed* 29: 468-472.
- Wei J, Zhang Q, Liu Y, Xiong R, Pan C, et al. (2011) Synthesis and photocatalytic activity of polyaniline–TiO<sub>2</sub> composites with bionic nanopapilla structure. *J Nanopart Res* 13: 3157-3165.
- Olad A, Behboudi S, Entezami AA (2012) Preparation, characterization and photocatalytic activity of TiO<sub>2</sub>/polyaniline core-shell nanocomposite. *Bull Mater Sci* 35: 801-809.
- Agarwal S, Tyagi I, Gupta VK, Golbaz F, Golikand AN (2016) Synthesis and characteristics of polyaniline/zirconium oxide conductive nanocomposite for dye adsorption application. *Journal of Molecular Liquids* 218: 494-498.
- Patil UV, Ramgir NS, Karmakar N, Bhogale A, Debnath AK, et al. (2015) Room temperature ammonia sensor based on copper nanoparticle intercalated polyaniline nanocomposite thin films. *Applied Surface Science* 339: 69-74.
- Salvatierra RV, Zitzer G, Savu SA, PAlves A, Zarbin AJG, et al. (2015) Carbon nanotube/polyaniline nanocomposites: Electronic structure, doping level and morphology investigations. *Synthetic Metals* 203: 16-21.
- Onn TM, Ramirez LA, Monai M, Soh T, Talati M, et al. (2016) Modification of Pd/ CeO<sub>2</sub> catalyst by atomic layer deposition of ZrO<sub>2</sub>. *Applied Catalysis B: Environmental* 197: 280-285.
- Tang C, Sun B, Sun J, Hong X, Deng Y, et al. (2016) Solid state preparation of NiO-CeO, catalyst for NO reduction. *Catal Today* 281: 575-582.
- Kim TH, Seon H, Park DW (2016) Synthesis of CeO<sub>2</sub> nanocrystalline powders using DC non-transferred thermal plasma at atmospheric pressure. J Sol-Gel Sci Technol 27: 2012-2018.
- He Y (2005) Synthesis of polyaniline/nano-CeO<sub>2</sub> composite microspheres via a solidstabilized emulsion route. *Materials Chemistry and Physics* 92: 134-137.
- Chuang FY, Yang SM (2008) Cerium dioxide/polyaniline core-shell nanocomposites. Journal of Colloid and Interface Science 320: 194-201.
- Kumar E, Selvarajan P, Muthuraj D (2012) Preparation and characterization of polyaniline/cerium dioxide (CeO<sub>2</sub>) nanocomposite via in situ polymerization. *J Mater Sci* 47: 7148-7156.
- Sasikumar Y, Madhan AK, Gasem ZM, Ebenso EE (2015) Hybrid nanocomposite from aniline and CeO<sub>2</sub> nanoparticles: Surface protective performance on mild steel in acidic environment. *Applied Surface Science* 330: 207-215.
- da Silva JSM, de Souza SM, Trovati G, Sanches EA (2017) Chloride salt of conducting polyaniline synthesized in the presence of CeO<sub>2</sub>: Structural analysis of the core-shell nanocomposite. *Journal of Molecular Structure* 1127: 337-344.

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