

Titanium Dioxide for Biomedical Uses

I. The controlled production of nanoparticles by hydrothermal synthesis moderated by dimedone

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The controlled the solvo-hydro-thermal titanium dioxide synthesis moderated by dimedone from organometallic precursors is approached in order to obtain nanoparticles compatible with the polymeric systems used in the dental technique. The experiments carried out with relation to the production of titanium dioxide nanoparticles using the solvo-hydro-thermal synthesis allowed the production of three types of materials by means of varying the nature of the used solvent: methanol, ethanol and propanol (TiO₂-M, TiO₂-E and TiO₂-P). The characterisation using electron microscopy (SEM and HRTEM), X-ray analysis, FTIR and UV-Vis spectrometry show that the diameter of the produced nanoparticles is less than 15 nm and decreases in the order: $dp_{Methanol} > dp_{Ethanol} > dp_{Propanol}$. The nanoparticles contain trace organic substances which the smaller they are, the bigger the alcohol chain used as a solvent is. The adsorption of a target dye showed increasing values with the increasing number of atoms in the hydrocarbon alcohol chain. The highlighted characteristics suggest the possibility of using the synthesised nanoparticles in the production of hard implants for dental reconstruction.

Keywords: titanium dioxide, solvo-hydro-thermal synthesis, ynthesised nanoparticles

The possibility of substance synthesis in nanometric form led to the re-evaluation of their performances, and particularly of the produced materials based on such substances [1-5].

One of these substances, for which the nanometric size has contributed to the unprecedented expansion of its applications, is the titanium dioxide [6-8].

Known in the past as an excellent white pigment [9,10], the titanium dioxide has come to be a strategic nanomaterial used in: storage of the solar energy [11], purification of the water with organic load [12,13] and, not least, biomedicine [14-16].

The expansion of applications of the titanium dioxide of nanometric size has been favoured by the possibility of the synthesis using multiple methods and experimental techniques, both physical, and chemical: vacuum deposition [17], chemical sol-gel synthesis [18], solvothermal synthesis [19], solid-phase synthesis [20].

Also, the performances of the titanium dioxide nanoparticles have been more poignantly highlighted by modern and ultramodern techniques: spectrophotometry, electron spectroscopy, X-ray diffraction, scanning transmission electron microscopy, nanoscopy, gas adsorption, dye specific adsorption [21-25].

The multitude of synthesis and characterization techniques have had as main objective obtaining the titanium dioxide of nanometric size with predetermined morphology and structure [26-31]

In this piece of work, the controlled the solvo-hydro-thermal titanium dioxide synthesis moderated by dimedone from organometallic precursors is approached in order to obtain nanoparticles compatible with the polymeric systems used in the dental technique.

Experimental part

Materials

The tetrabutylortotitanate, dimedone, methyl alcohol, ethyl alcohol and isopropyl alcohol are purchased from Merck.

The pure water used in experiments is obtained in a Millipore installation for reverse osmosis.

Procedures

Solvo-hydro-thermal titanium dioxide synthesis

In a 500 mL installation flask (type Soxhlet-fig.1) [32,33] 300 mL of the chosen low saturated alcohol (methyl, ethyl or isopropyl alcohol) and 25 mL of tetrabutylortotitanate are placed.

In the regenerated cellulose cartridge of the 100 mL installation extractor 1g dimedone dissolved in 10 mL pure water is placed.

For the synthesis progress, the installation flask is placed on an electric stove provided with a magnetic stirring mechanism underneath, and at the upper part of the extractor a great efficacy condenser is placed.

By heating the flask containing tetrabutylortotitanate in low saturated alcohol under magnetic stirring at 250 rpm, the alcohol evaporates, gets in the side tube of the Soxhlet extractor and comes in the condenser at the upper part. By condensation, the alcohol gets into the extractor body and contacts the content of the cellulosic cartridge (dimedone in water). When the extractor is filled, the alcoholic-water solution containing dimedone at the solubility limit siphons in the flask containing titanium tetrabutryrate. Under powerful stirring (both magnetic, and thermic) the tetrabutylortotitanate hydrothermal solvolysis reaction mediated by dimedone takes place [19] providing a significant instantaneous opalescence. The synthesis

continues by the evaporation of a new portion of alcohol, which provides a thermic quasi-constant regime, and the return of the condensate in the bottom flask will be realised with a quasi-constant content of dimedone and water.

After twenty extraction cycles the heating stops and the stirring of the formed dispersion continues for an extra hour.

The dispersion is vacuum filtered and washed ten times with acetone and ethylic ether 1:1, providing titanium dioxide as white a nanometric powder.

The synthesis se carried out separately, in three working variants, using methanol, ethanol or isopropanol as extraction and dispersing solvents, providing tree types of titanium dioxide denoted with TiO_2 -M, TiO_2 -E and TiO_2 -P.

The attained materials are characterised by: scanning electron microscopy (SEM- scanning electron microscope QUANTA INSPECT F provided with an electron field emission gun - FEG cu 1,2 nm resolution and energy-dispersive X-ray spectrometer - EDAX), transmission electron microscopy (HRTEM - microscope TECNAI F30 G² STWIN), infrared spectrometry (FTIR -Bruker Tensor 27 spectrometer with diamond ATR accessory) and adsorption of a standard dye (UV-Vis with Spectrophotometer CAMSPEC).

Results and discussions

The solvothermal titanium dioxide synthesis using organic precursors of titanium is known [19], but it is still often tackled in research as it is simple, versatile and accessible to the laboratories in various domains: chemistry, material physics, environmental rejuvenation or biomedicine [34, 35].

The control of the solvolysis reaction progress in order to obtain titanium dioxide nanoparticles with predetermined morphology was studied [19], and for this an organic moderator with complexation capacity, dimedone, was used.

The hydrolysis reaction of tetrabutylortotitanate needs a dispersion medium, water, and a reaction moderator in quantities well determined.

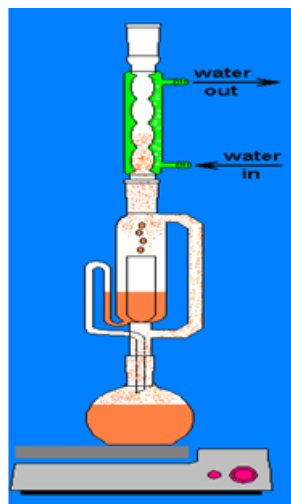


Fig. 1. Installation for titanium dioxide synthesis using the solvo-hydro-thermal method [32, 33]

All these desiderates are achieved by solvo-hydro-thermal synthesis in a Soxhlet extractor (fig.1). Carried out successively in: methanol, ethanol and propanol, the reaction is controlled by means of the constant quantity of dimedone and water which the used solvent brings in the reaction flask in the installation extractor.

The utilisation of a certain saturated low alcohol is intended to cap the solvolysis reaction temperature at the boiling temperature and admit a limited quantity of dimedone and water in the reaction vessel, according to the limit solubility in the chosen solvent.

After the reaction using methanol, ethanol or isopropanol as extraction and dispersion solvents, three types of titanium dioxide are provided, denoted with TiO_2 -M, TiO_2 -E and TiO_2 -P.

The three types of titanium dioxide nanoparticles were morphologically characterised by scanning electron microscopy (fig. 2).

The nanoparticles are produced in smaller and smaller sizes as the low alcohol chain gets bigger (fig 2b). The nanoparticle agglomerations are bigger in case of TiO_2 -M, reaching approximately 300 nm (fig. 3)

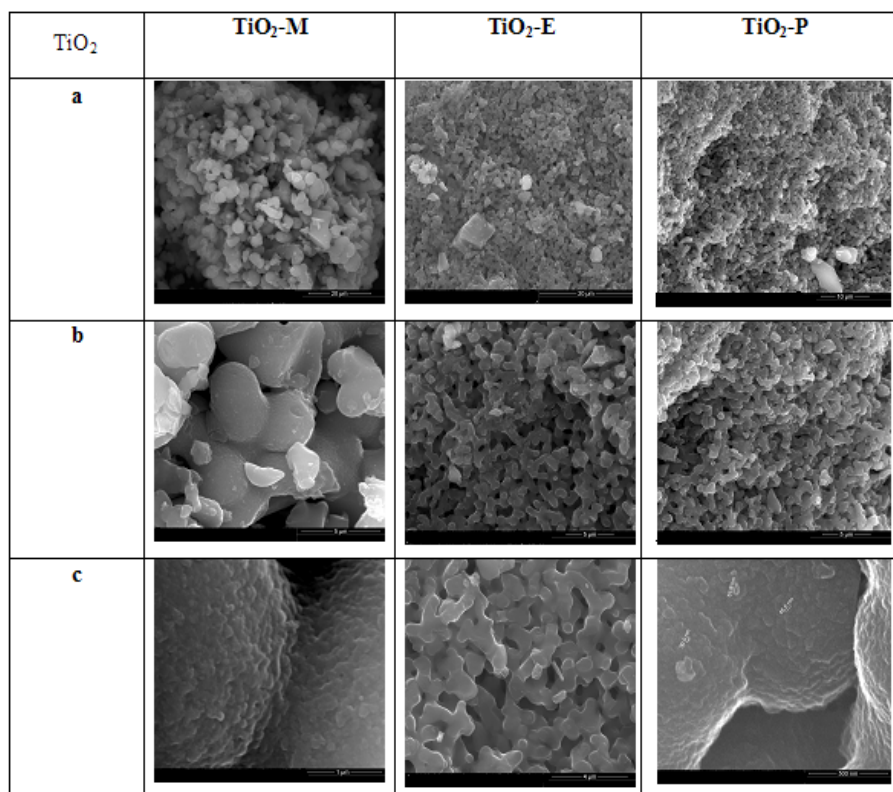


Fig. 2. Scanning electron microscopy for nanoparticles of TiO_2 -M, TiO_2 -E and TiO_2 -P at three magnitudes (a: nanoparticles assembly, b: aggregates and c: details)

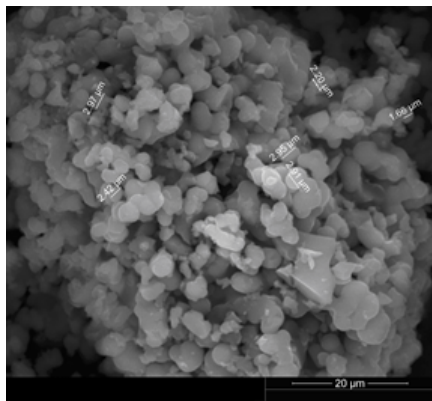


Fig. 3. Sizes of TiO₂-M nanoparticle agglomeration (1-3 μm)

The nanometric morphology of the three types of nanoparticles is highlighted in the details in figure 2 c, the best highlighted being the ones of approx. 50 nm for TiO₂-P.

The study using transmission electron microscopy was carried out by means of a high resolution transmission electron microscope (HRTEM) type TECNAI F30 G² STWIN

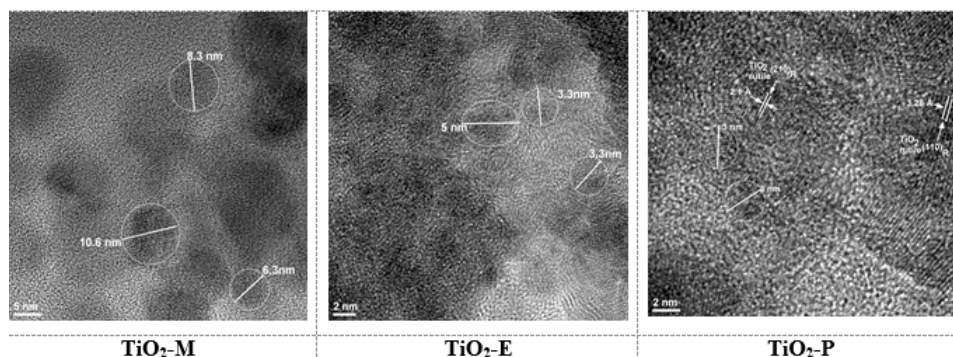


Fig. 4. Image of high resolution transmission electron microscopy (HRTEM) highlighting TiO₂ nanoparticles with a structure mostly rutile

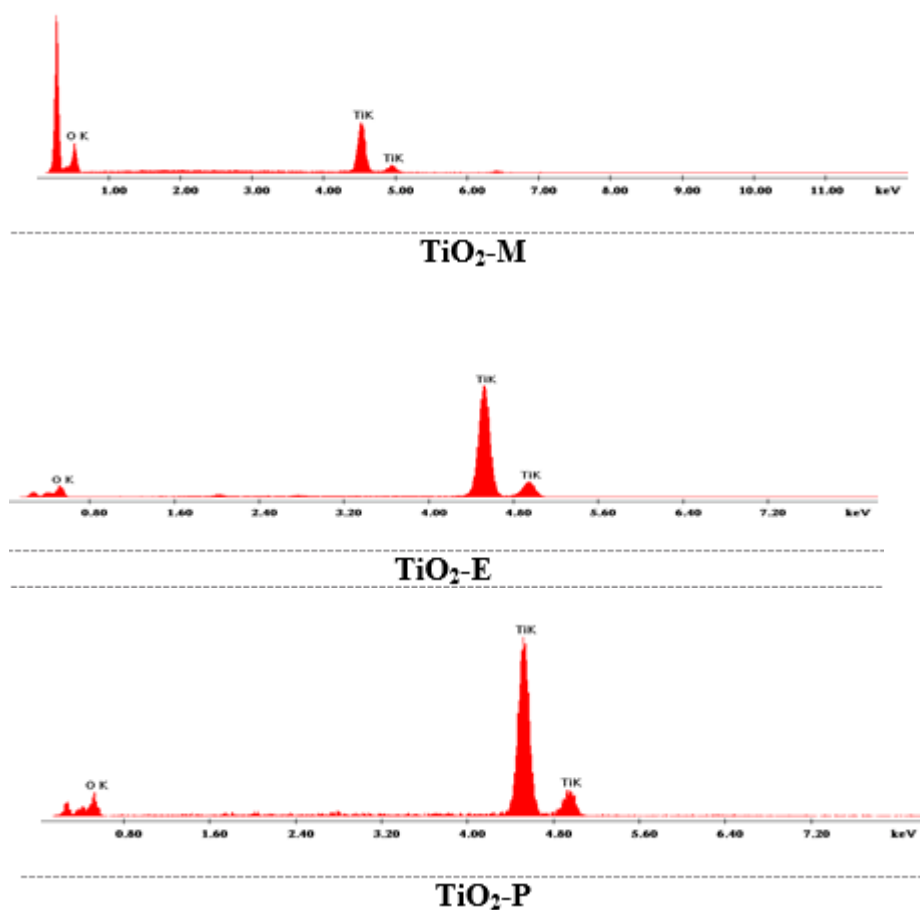


Fig. 5. EDAX spectra of the three types of titanium dioxide nanoparticles

with linear resolution of 1 Å and a punctual resolution of 1.4 Å.

The high resolution transmission electron microscopy show, for all the three types of titanium dioxide produced nanoparticles, the specific structure mostly rutile (fig. 4).

The data provided by the two microscopy techniques outline the size, morphology and structure of titanium dioxide nanoparticles and of their aggregates. The sizes of the produced nanoparticles (*dp*) depend on the used solvent, decreasing in the order:

$$dp_{Methanol} > dp_{Ethanol} > dp_{Propanol}$$

In order to be used in biomedical applications, the titanium dioxide nanoparticles must not be contaminated with organic substances, especially with metal cations.

The demonstration of the purity of the produced nanoparticle was carried out using X-ray analysis. The energy dispersive X-ray Spectrometer - EDAX confirms the rutile structure of titanium dioxide produced in the three solvents, the titanium and oxygen peaks being predominant (fig.5).

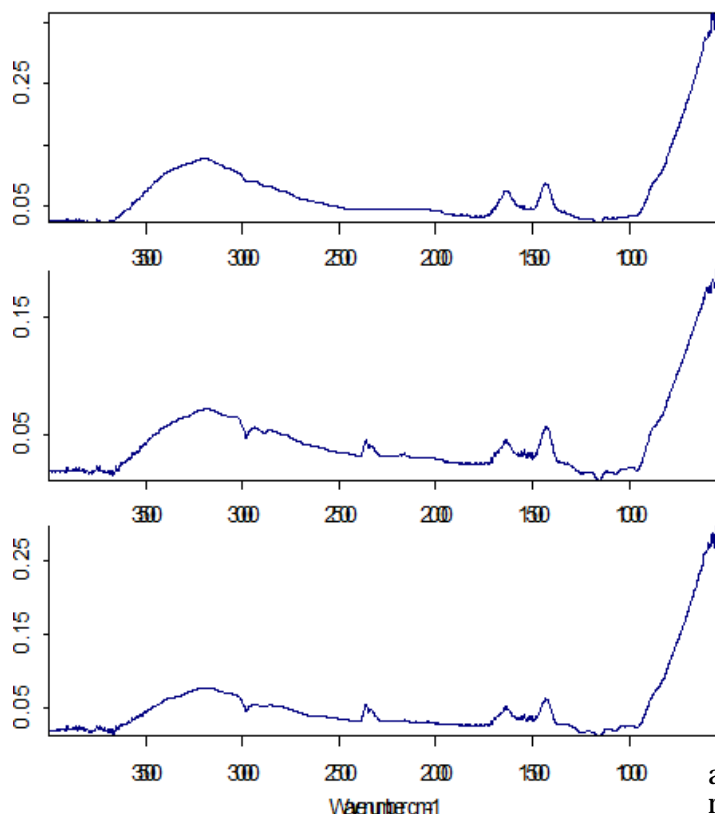


Fig. 6. Spectra FTIR of nanoparticles: TiO₂-M, TiO₂-E and TiO₂-P

The presence of a residual peak in the carbon atom area shows that the titanium dioxide nanoparticles are covered with traces of an organic compound, most probably dimedone which complexes the titanium atoms in the solvolysis process.

In order to confirm this hypothesis analyses in infrared were carried out, providing information on the residual organic compound, and also on its quantity on the titanium dioxide nanoparticle surface (fig. 6).

The spectrum bands (ν) from 1460, 1580, 2370 and 2930-3600 cm⁻¹, specific to the organic compounds, especially to complexant dimedone, decrease progressively in the order:

$$\nu_{\text{Propanol}} > \nu_{\text{Ethanol}} > \nu_{\text{Methanol}}$$

Most probably in case of propanol the quantity of dimedone brought, at reflux, at the bottom of the synthesis installation is significantly bigger than in case of ethanol or methanol.

However, the quantity of organic compounds on the titanium dioxide nanoparticle surface is extremely small, needing the adjustment of the FTIR spectrometer to very low sensitivities, in order to allow trace detection (fig. 6).

Although the size of the titanium dioxide particles show how efficient they can be in case of organic compound adsorption, for the quantification of this characteristic, which may be essential in case of biomedical applications, such as their inclusion in a polymeric mass, methyl blue adsorption tests were carried out (fig. 7).

For the methyl blue adsorption monitoring on three types of titanium dioxide (TiO₂-M, TiO₂-E and TiO₂-P) the wavelength of $\lambda=625$ nm was selected. The obtained results show that the relative adsorption of the methyl blue relative to the standard nanoparticles of titanium dioxide with the mean diameter of 20 nm is continuously increasing with the increasing number of atoms in the hydrocarbon alcohol chain used as a synthesis solvent (fig. 8)

The characterisation of the titanium dioxide nanoparticles (TiO₂-M, TiO₂-E and TiO₂-P) allows the test

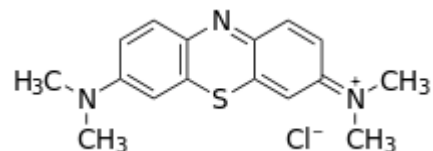


Fig. 7. Chemical structure of the chosen target dye

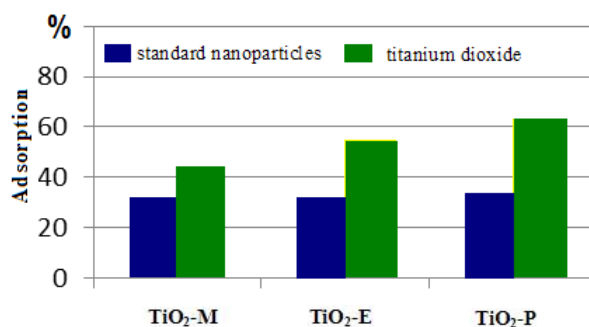


Fig. 8. Relative adsorption of methyl blue on the titanium dioxide nanoparticles (TiO₂-M, TiO₂-E and TiO₂-P)

approach with relation to their compatibility and efficacy regarding the entrainment in polymer matrixes used in biomedicine involving the attaining of hard implants for dental reconstruction.

Conclusions

The experiments carried out with relation to the production of titanium dioxide nanoparticles using the solvo-thermal synthesis allowed the production of three types of materials by means of varying the nature of the used solvent: methanol, ethanol and propanol (TiO₂-M, TiO₂-E and TiO₂-P).

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