O NOUĂ METODĂ DE SINTEZĂ A SILICEI NANOPOROASE
A NOVEL METHOD OF SYNTHESIS FOR NANOPOROUS SILICA MATERIALS

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The scope of the present study is the synthesis and characterization of mesoporous silica. using two different methods, the classic sol-gel and a novel microwave- hydrothermal process. There were synthesized nanostructured mesoporous silica materials with average particle size dimensions between 87-500 nm presenting a structure with symmetrical hexagonal pores with the average size of 4 nm.

In order to obtain mesoporous silica, the precursor has been characterized using TG-DSC analysis. Nanoporous silica materials, MCM-41, have been characterized using different techniques as X- ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), high resolution transmission electron microscopy (HRTEM) and the Brunauer– Emmett–Teller (BET) analysis.

Scopul acestui studiu este sinteza și caracterizarea silicei mezoporoase, utilizându-se două metode diferite, clasicul sol-gel și o nouă metodă hidrotermală asistată în câmp de microunde. A fost obținută silice mezoporoasă nanostructurată, cu dimensiunea particulei între 87 și 500 de nm conținând în structură pori hexagonali, simetrici cu dimensiuni de aproximativ 4 nm.

Pentru obținerea silicei mezoporoase, precursorul a fost caracterizat utilizând analizele termice TG-DSC. Silicea nanoporoasă obținută a fost caracterizată folosind diferite tehnici precum difracția de raze X (XRD), microscopie electronică de baleiaj (SEM), microscopie electronică de transmisie (TEM), microscopie electronică de transmisie de înaltă rezoluție (HRTEM) și Brunauer–Emmett–Teller (BET).

Keywords: *MCM, mesoporous silica, hexagonal, mesostructured, biomaterials*

1. Introduction

In the recent years there has been an increasing interest in the research of mesoporous materials used as support in controlled drug delivery systems [1]. Among these supports, those based on mesostructured silica have an important contribution due to their biocompatibility, large specific surface area, possibility of controlling the morphology and pore size for absorption of high concentrations of biologically active substances, chemical and thermal stability [2,3]. The most used mesoporous SiO_2 based material in medical field is MCM-41, due to its structure with unidimensional, uniform ordered in a hexagonal honeycomb [4-8].

Regarding its biocompatibility, the viability of primary immune cells from the spleen is not affected in relevant concentrations when functionalized mesoporous silica nanoparticles is used. It is known that using mesoporous silica, cell viability or plasma membrane are not affected [9-14]. Different studies show that silicon nanoparticles do not produce toxicity when administrated, even if the largest amount of silicon nanoparticles are excreted in urine and feces regardless administration type [6-14].

Generally, most preparation techniques of mesoporous materials are based on organic molecules used in different assembling processes as template that condenses with inorganic precursor (alkoxysilanes, sodium silicate solution and tetramethylammonium silicate). Kresge et al. [8] study results show toxic effects due to the large amount of surfactant - alkyl trimethylammonium used for silicon nanoparticles synthesis. To form the hexagonal mesostructured, MCM-41, Beck et al. [9, 15-20] showed a crystal – liquid templated mechanism in 2 possible ways. Another traditional method of synthesis of mesoporous materials is hydrothermal synthesis. This method involves the simultaneous application of pressure and temperature of a chamber containing the reaction mixture [10, 11].

Comparing the conventional hydrothermal method with microwave-assisted hydrothermal method, the second leads to a significant decrease of the reaction time [12]. With the decrease in synthesis time, the application of microwave leads to controlling the morphology and crystallinity easier samples. In order to be used in biomedical applications, as drug delivery systems, mesoporous materials are functionalized.

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Mesoporous silica nanoparticles have been proposed as drug delivery systems about 15 years ago. In vitro studies have been promising and have demonstrated the capacity of the controlled release, good absorption at the cellular level, specific target cell and ability of carrying a variety of substances, as drug molecules or imaging agents [14-16]. Active area allows functionalization by binding therapeutic molecules and mesopores structure and size allow the incorporation of different classes of molecules such as some anti-inflammatory drugs, but many chemotherapies such as doxorubicin and irinotecan. It is also possible to use functionalized and various essential oils such as thyme oil, lavender and rosemary which is promising anti-tumor activity.

According to recent research, the scope of this study is to propose a novel method of synthesis for nanoporous silica materials using both traditional and unconventional methods (sol-gel and personalized microwave- hydrothermal method). Moreover, in the present study, the obtained mesoporous silica MCM-41 were characterized using different techniques in order to confirm the obtained properties are suitable for a potential drug delivery system support.

2. Experimental

2.1.Materials

In order to obtain mesoporous silica, there have been proposed two methods of synthesis. The first method was considered conventional sol-gel method and the second method was microwave - assisted hydrothermal. Both methods are based on tetraethyl orthosilicate (TEOS - Aldrich 99 %), distilled water and absolute ethanol (Sigma-Aldrich). To achieve mesoporous structure, cetyl trimethylammonium bromide (CTAB -Fluka ,96 %) was used as surfactant and basic environment was ensured by adding ammonium hydroxide solution (Sigma-Aldrich, 25 % NH_4OH).

2.2. Synthesis of mesoporous silica

Using a Berzelius glass, 2,6 g CTAB were solubilized in a solution of 120 mL distilled water and 50 mL ethanol (molar ratio H_2O: EtOH=7,7). After surfactant complete solubilization were added 12 mL NH_4OH and then 3,6 mL TEOS (molar ratio CTAB:TEOS=0,43), as can see in Figure 1.

In order to obtain the powder P1, reaction mixture was gelled for 12 hours at room temperature, then was washed using purified water and ethyl alcohol, dried at 95°C.

Analyzing the TG - DSC performed on precursor obtained (Fig. 2) it can be observed that after 550°C no changes or significant mass losses occur, the surfactant is removed completely, therefore the powder suffered heat treatment for 6 hours at this temperature. The exothermic effect from 300°C accompanied by the mass loss shows

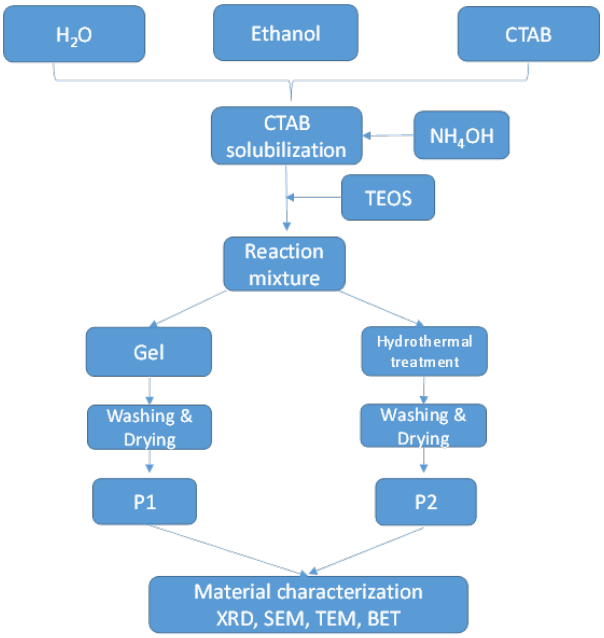


Fig. 1 - Synthesis flux of mesoporous silica using sol-gel method (P1) and microwave assisted hydrothermal method (P2) / *Schema de obținere a silicei mezoporoase folosind metoda sol-gel (P1) și metoda hidrotermală cuplată cu microunde (P2).*

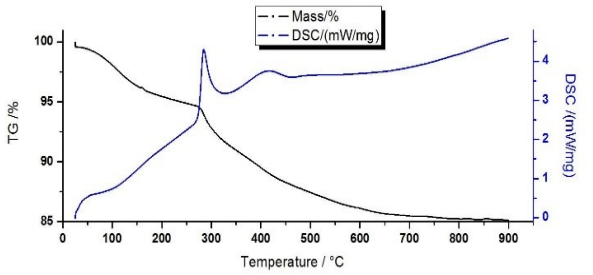


Fig. 2- TG-DSC analysis of silica precursor obtained using sol-gel method / *Analiza TG-DSC a prescursorului silicei obținut folosind metoda sol-gel.*

the combustion process of the organic component.

P2 sample was obtained using a hydrothermal treatment at 100° C temperature and 20 de bars pressure for 1,5 h using an assisted microwave synthesis equipment (Synthwave Milestone). To compare the obtained powders there were used different techniques as: X-ray diffraction, scanning electron microscopy and transmission electron microscopy.

2.3. Characterization

Diffraction techniques are the most used methods to reveal materials crystallinity. X-ray diffraction provides evidence of crystallinity degree, phases structure and composition, crystallites dimensions, and for mesoporous materials information about pores dimensions and order. Synthesized powders using different methods were analyzed with X-ray diffraction at small angles using a PAN analytical Empyrean with CuKα radiation (λ= 1.541874A), equipped with hybrid monochromator.

Electron microscopy is one of the traditional characterization techniques that allows direct observation of the morphology and size of micro and nanostructured systems. SEM images used in this paper were performed with a microscope FEI Inspect F50 and TEM using an electron microscope TecnaiTM G2 F30 S -Twin equipped with STEM / HAADF detector, EDX (Energy dispersive X - ray Analysis) and spectrometer EFTEM - EELS (electron energy loss spectroscopy).

The BET analysis was obtained on a Micrometrics Gemini V2 model 2380-surface area and pore size analyzer. The adsorption-desorbtion isotherms were obtained by measuring the amount of N_2 adsorbed across a wide range of relative pressures between 780 and 7.8 mmHg at a constant temperature of 77K and then measuring the gas removed as pressure was reduced.

3.Results and discussion

3.1.X-ray diffraction for mesoporous silica support

Comparing data with ASTM was identified hexagonal structure of MCM-41 silica (MCM-41, 00-051-1591). Moving diffraction interference specific plan (100) to lower values indicates different orientations of lattice planes (Fig. 3 and Fig.4).

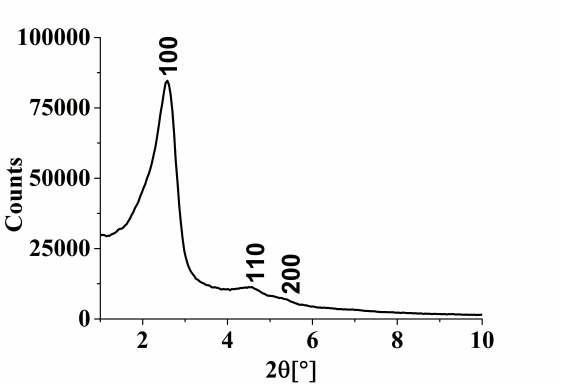
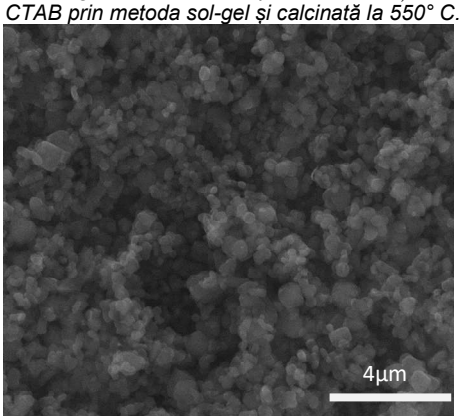


Fig. 3 - X- ray diffraction for P1 powder obtained with CTAB using sol-gel method and calcinated at 550° C / *Difractogramele de raze X pentru P1 – obținută folosind CTAB prin metoda sol-gel și calcinată la 550° C.*



a

The presence of hexagonal pores, according to the specialized literature [12] is highlighted by XRD analysis through the characteristic silica interface registered between 2-3 degrees, corresponding to the crystallization plane (100).

3.2.Scanning electron microscopy (SEM)

SEM images realized on MCM -41 support obtained by sol-gel method starting with TEOS – Aldrich 99%, distilled water and absolute ethyl alcohol (Sigma-Aldrich), surfactant CTAB (Fluka, 96%) in basic pH medium with an ammonium hydroxide solution (Sigma-Aldrich, 25% NH_3) (P1) are presented in Figure 5.

As can be seen in Figure 5 a and b the sample is formed of particles and clusters of various sizes between 87 and 500 nm. The morphology is different, spherical particles are observed as well as clusters of interconnected particles (Fig. 5 c and d).

In the case of the sample obtained from the same precursors but applying microwave assisted hydrothermal treatment (P2) the formation of interconnected spherical clusters is observed in Figure 6. Unlike sample P1, P2 cluster sizes are much larger, with average size particle dimension of 500 nm.

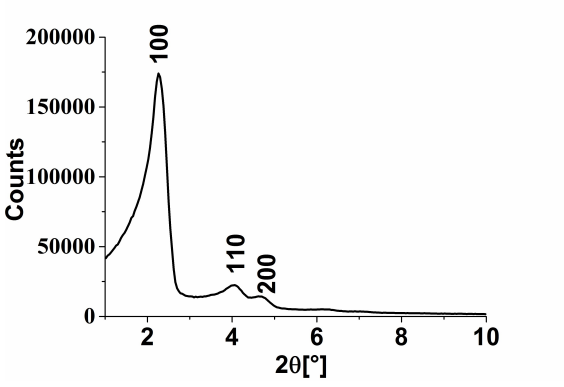
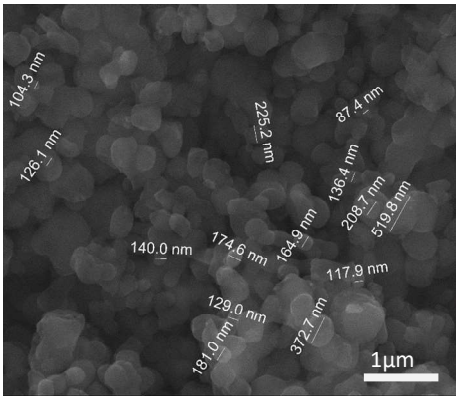
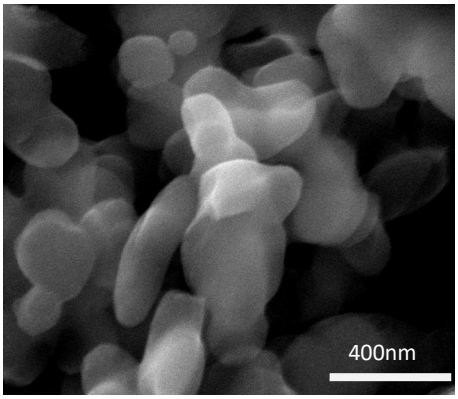


Fig. 4 - X- ray diffraction for P2 powder obtained with CTAB using hydrothermal method/ *Difractogramele de raze X pentru P2- obținută folosind CTAB prin metoda hidrotermală.*



b

Fig. 5 continues on next page



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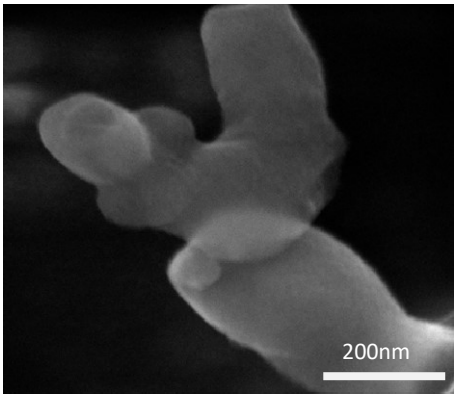
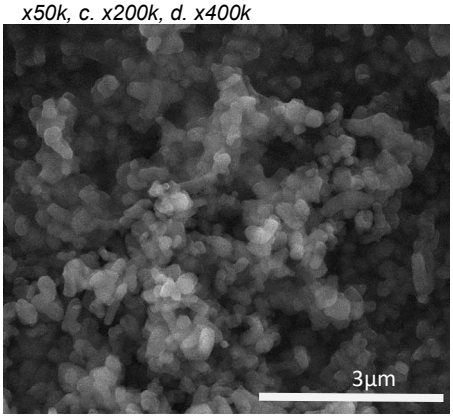


d

Fig. 5. - Scanning Electron Microscopy for sol-gel obtained powder, with CTAB calcinated at 550° C: a. x20k, b. x50k, c. x200k, d. x400k / *Microscopie electronică de baleiaj pentru probele obținute folosind CTAB prin metoda sol-gel, calcinate la 550° C: a. x20k, b. x50k, c. x200k, d. x400k*



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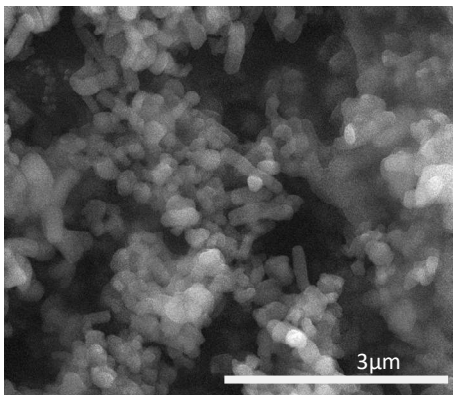

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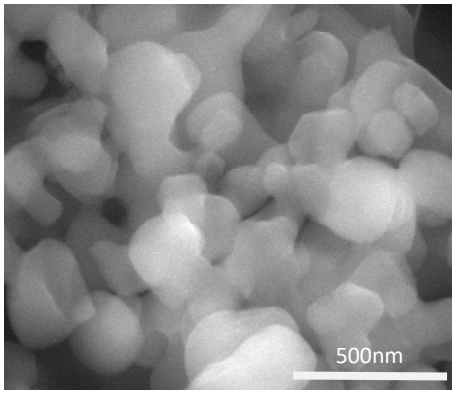

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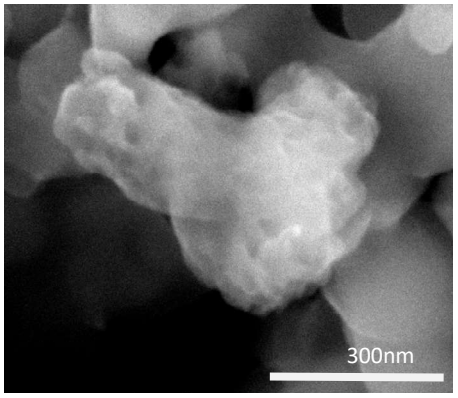


d

Fig.6. - Scanning Electron Microscopy for hydrothermal obtained powder, with CTAB calcinated at 550° C: a. x40k, b. x50k, c. x200k, d. x400k / *Microscopie electronică de baleiaj pentru probele obținute prin metoda hidrotermală cu CTAB calcinate la 550° C: a. x40k, b. x50k, c. x200k, d. x400k.*

3.3.Transmission Electron Microscopy for mesoporous silica support

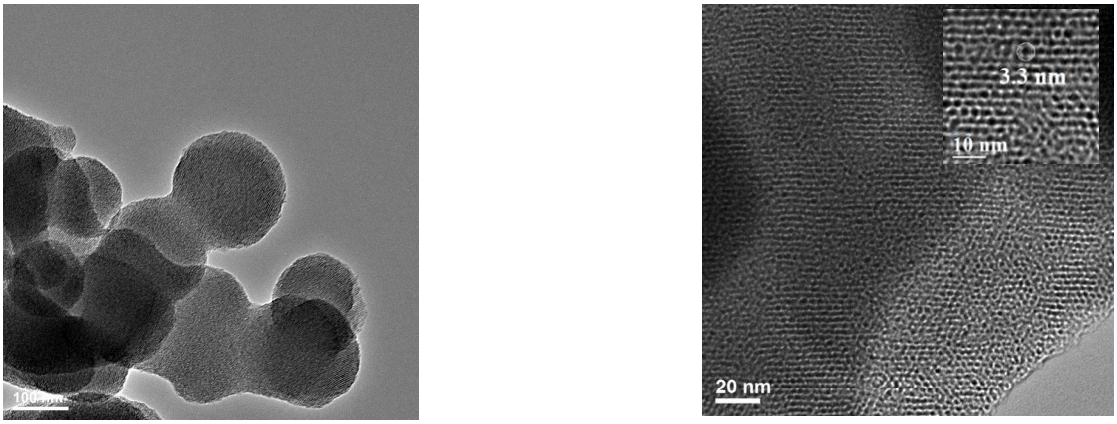
The orderly arrangement of pores and specific mesostructured materials MCM - 41 are confirmed for both versions sample P1 (Fig.7 a and b) and sample P2 (Fig. 8 a and b).

An increase can be seen for the sample obtained by hydrothermal treatment (P2) in pore size from 3.3 nm for sample synthesized by sol-gel method at about 4 nm. These dimensions are correlated with X-ray diffraction at small angles (Fig.7b and Fig. 8b).

3.4.BET analyses for mesoporous silica

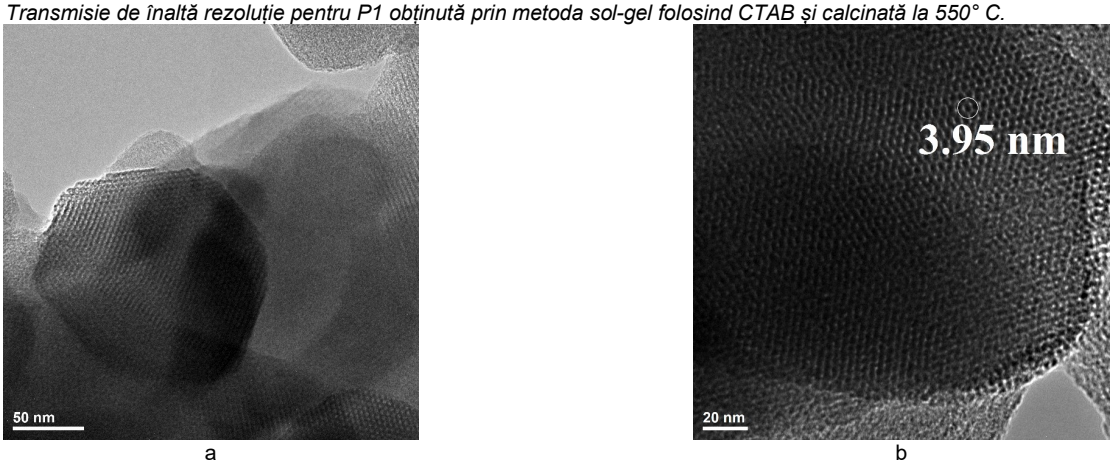
Adsorbtion-desorbtion isotherms were recorded at liquid nitrogen temperature and present a type IV graph specific for mesoporous materials, in IUPAC classification.

For the sample synthesized by the sol –gel, adsorption - desorption isotherm (Fig.9) confirms that the obtained materials have a surface area of 2195.37 m^2/g. Pore size distribution, shown in Figure 10, is mainly in the range of 1.5 - 2.5 nm but the presence of a smaller fraction of larger pores around 3.5 nm is also observed.



a b

Fig 7. a. Transmission Electron Microscopy, b. High resolution Transmission Electron Microscopy -for P1 powder synthesised by sol-gel method using CTAB and calcinated at 550° C / a.*Microscopie Electronică de Transmisie, b. Microscopie Electronică de Transmisie de înaltă rezoluție pentru P1 obținută prin metoda sol-gel folosind CTAB și calcinată la 550° C.*



a b

Fig. 8 a. Transmission Electron Microscopy, b. High resolution Transmission Electron Microscopy -for P2 powder synthesised by hydrothermal method using CTAB/ a.*Microscopie Electronică de Transmisie, b. Microscopie Electronică de Transmisie de înaltă rezoluție pentru P2 sintetizată prin metoda hidrotermală folosind CTAB.*

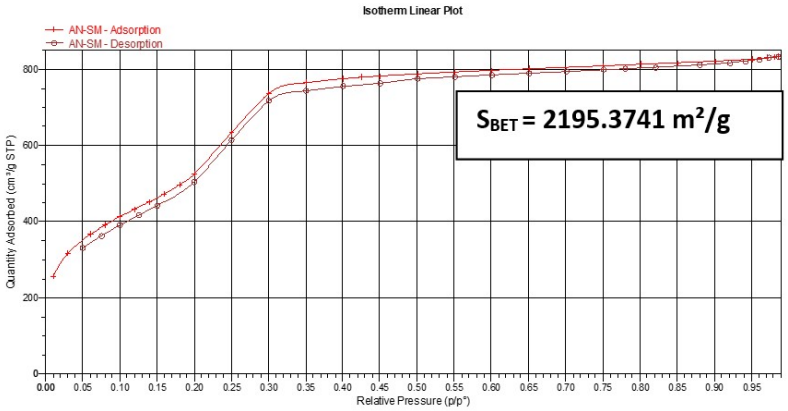


Fig 9 - Adsorbtion-desorbtion analyses for syhtesised powder by sol-gel method using CTAB and calcinated at 550° C / *Analize BET pentru pulberea sintetizată prin metoda sol-gel folosind CTAB și calcinată la* 550° C.

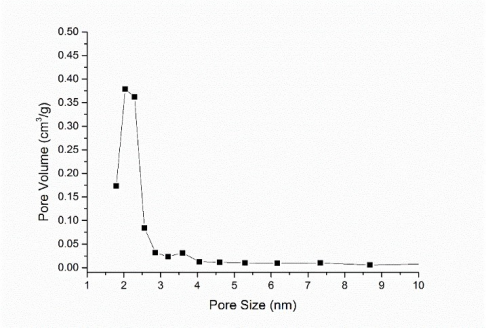


Fig 10 - Pore size distribution for P1 synthesised silica/ *Distrubuția porilor pentru silicea sintetizată P1.*

In the case of the sample synthesized by the hydrothermal method the adsorption - desorption isotherm, shown in Figure 11, is fully reversible and is also characteristic for mesoporous materials.

On the other hand, the specific surface is much lower than in the case of the sample synthesized by sol- gel method. This difference can be explained by the particle size of the sample, which in this case is greater, as shown by electron microscopy analysis.

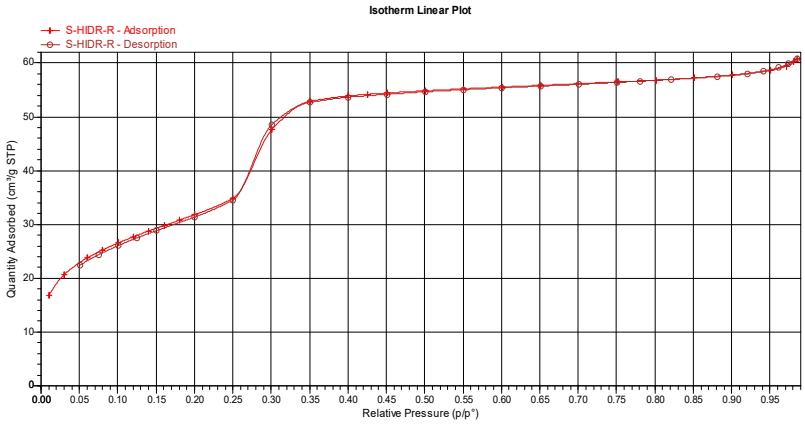


Fig. 11 - Adsorbtion-desorbtion analyses for syhtesised powder by hydrothermal method using CTAB and calcinated at 550° C/ *Analize BET pentru pulberea sintetizată prin metoda hidrotermală folosind CTAB și calcinată la* 550° C.

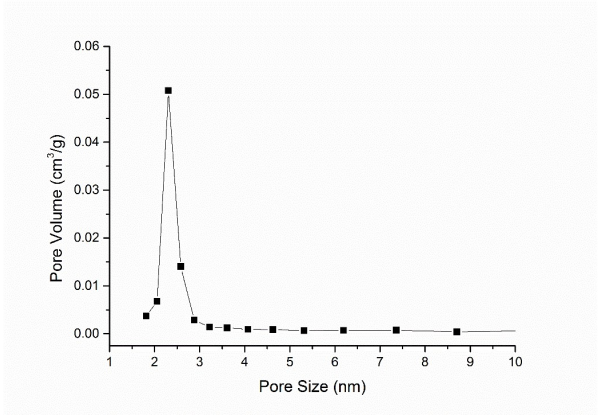


Fig. 12 - Pore size distribution for P2 synthesised silica / *Distrubuția porilor pentru silicea sintetizată P2.*

Analyzing pore size distribution for P2, a monomodal distribution is observed in the range of 2 - 3 nm with a maximum of 2.5 nm. Comparing pores distribution for both probes, P2 presents a uniform distribution of pores with dimension of 2.5 mm, not like P1 which has different pore sizes between 1.5-2.5 nm.

4. Conclusions

In this work, a mesoporous nanostructured material type SiO_2 was synthesized and characterized, showing pores with hexagonal symmetry by sol - gel and the microwave- assisted hydrothermal methods, which can be used to obtain drug delivery systems with controlled release for biological active substances with potential application in the treatment of cancer. Samples synthesized on the two routes sol- gel and respectively microwave- assisted hydrothermal method were characterized by XRD, SEM and TEM.

Comparing the X-ray diffraction patterns performed on the two powders produced by two routes SiO_2 formation was identified. Also, it was found moving pick for sample hydrothermal treated to smaller angles, which can be attributed to the influence of reaction parameters (pressure, temperature) on SiO_2 structure. Transmission electron microscopy showed a pore size of about 1.5-3 nm. SEM analysis indicates a similar morphology to the two samples, consisting of large spherical shape particles and clusters interconnected, approximately 500 nm in the case of the sample obtained by the hydrothermal treatment. This size increase leads to specific surfaces lower than the sample obtained by sol-gel whose surface area is 2195 m^2/g, as demonstrated by the adsorption-desorption isotherms of nitrogen.

In conclusion, a new method has been developed with new parameters to obtain a mesoporous silica material, which was analyzed in order to continue the study being used as substrate in a controlled release system for cancer treatment.

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