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NATURAL AND SYNTHETIC NANOPOWDERED IRON OXIDES AND OXIHYDROXIDES

(57) Abstract: The way of preparation of the nanopowdered iron with the protective iron oxide coat by the reduction of nanopow-
dered crystalline or amorphous precursor of iron oxides and oxihydroxides in the reduction atmosphere, characterized by the fact that
in the course of synchronous exhaust of secondarily originating gas products, nanopowdered crystalline or amorphous iron oxide
or oxihydroxide with particle size smaller than 20 nm is thermally decomposed in the reduction atmosphere at temperature higher
than the minimum decomposition temperature for the given oxide or oxihydroxide and hereby formed nanopowdered iron with the
protective iron oxide coat, for example FeO, is cooled in the inert atmosphere, in the process of which nitrogen, argon or another
inert gas is selected as the inert atmosphere.



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THE METHOD OF SYNTHESIS OF THE IRON NANOPOWDER WITH THE PROTECTIVE OXIDIC COAT FROM NATURAL AND SYNTHETIC NANOPOWDERED IRON OXIDES AND OXIHYDROXIDES

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Field of the Invention

The present invention relates to the method of preparation of the iron nanopowder by the reduction of the nanopowdered crystalline or amorphous precursor of the iron oxides and oxihydroxides with the dimension of particles smaller than 20 nm in the reduction atmosphere.

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State of the Art

For the synthesis of iron nanopowder, many ways are used, for example sonochemical, photochemical or precipitation ways or methods of hydrothermal and thermal decompositions as they are described in the literature. Metal nanoparticles smaller than 100 nm have an extreme ability to oxidize. In the form of powder, metal nanoparticles are pyrophoric, which leads to their spontaneous burning on encountering airy oxide. Self-burning of nanopowdered metal particles can be prevented by their passivation, i.e. creating protective coat on their surface. In the patent CS 237 319 82 (Schrey G., Danninger H., Jangg G.: Způsob výroby železných prášků z jemného volně sypaného práškového oxidu železitého), there is described production of iron powders, usable in powder metallurgy, by the reduction of freely strewn porous powder ferric oxide via freely agitate reduction gases, usually hydrogen, at temperatures between 1200 and 1400°C. Properties of powders prepared with this technology are dominantly shaped by the grain-size of the initial material, temperature and reduction period. Considering only the usage of high temperatures, it is impossible to obtain the final iron powder grain-size smaller than tens of micrometers. Another way of synthesis of metal nanoparticles using thermal decomposition of the mixture of two or more metallic salts and a passivation agent at the temperatures

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higher than the melting point of used metallic salts is described in the patent US 6,974,492 B2 (A. Harutyunyan, L. Grigorian, T. Tokune: Method for synthesis of metal nanoparticles). By this method, metal nanoparticles in the size of units and tens of nanometers are obtained. By the duration of thermal analysis it is possible to control the size of final metal nanoparticles. Preparation of metal powder nanoparticles based on reduction of the initial metallic salts using a suitable reduction agent in a suitable solution of passivation agent is described in the patent US 2003/0190475 A1 (E. Carpenter, V. Hartus: Magnetic nanoparticles having passivated metalloid cores). Another method using reduction of the solution of the initial salt of the appropriate metal by a suitable reduction agent at a suitable high temperature for synthesis of metal nanoparticles is described in the patent WO 2005/118184 A3 (H. Ting, Z. Chuan-Jian, et al.: Metal and alloy nanoparticles and synthesis methods thereof). Another way of preparation of metal nanoparticles with protective passivation oxidic coat is based on mechanical milling of the initial metals with subsequent etching by milling the obtained powder in the solution into the required particle size (WO 2005/013337 A3, P. Dutta: Rapid generation of nanoparticles from bulk solids at room temperature). Stable colloid of dispersed zero-valent iron nanoparticles in water is possible to prepare by milling micrometer-sized iron particles in the presence of adequate passivation agent. This way allows the preparation of colloid of iron nanoparticles of the size smaller than 100 nm (US 2005/0199556 A1. W. Zhang: Disperse zero-valent iron colloids). The US patent proposal 2006/0151398 A1, (M. Uegami, J. Kawano, et al. : Iron composite particles for purifying soil or ground water, process for producing the same, purifying agent containing the same, process for producing the purifying agent and method for purifying soil or ground water) contains the description of creation iron nanoparticles intended for purification soil and ground water. Iron nanoparticles have also been prepared by the thermal reduction of goethite or hematite particles of the size between 50 nm and 500 nm in the temperatures between 350 and 600 °C. After cooling, the particles

are transferred into water, so that a protective oxidic passivation coat is formed on their surface. This coat is formed in water environment and after drying, iron nanoparticles sized between 50 nm and 500 nm with protective oxidic coat, dominantly formed of Fe_3O_4 , are obtained. The disadvantage of this method of iron nanoparticle synthesis is that the protective coat, preventing the particles from self-burning, is formed by Fe_3O_4 , which results in certain limitations in practical utilization of these iron nanoparticles, for example for reduction purification of water. Iron nanoparticles, prepared in this way, have lower reduction ability in spite of the same size.

As described above, none of the mentioned ways, used for the synthesis of iron nanoparticle nanopowders, utilize the reduction of crystalline or amorphous iron oxides and oxihydroxides nanoparticles smaller than 20 nm. Also in none of the above described ways, FeO is used in the function of the protective coat preventing the iron particles from self-burning.

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Summary of the invention

The aim of this invention is to provide a method enabling processing crystalline and amorphous iron oxides and oxihydroxides nanoparticles of the size smaller than 20 nm into iron nanoparticles with protective FeO coat preventing them from self-burning.

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The above mentioned aim is reached via the way of preparation of nanoparticle iron with the protective coat formed of iron oxides by the reduction of nanopowdered crystalline or amorphous precursors of iron oxides and oxihydroxides in the reduction atmosphere, whereby the merits lie in the fact, that in the course of synchronous exhaust of secondarily originating gas products, nanopowdered crystalline or amorphous iron oxide or oxihydroxide with particle size smaller than 20 nm is thermally decomposed in the reduction atmosphere at the temperature higher than the minimum decomposition temperature for the given oxide or oxihydroxide and hereby formed nanopowdered iron with protective iron oxide coat is cooled in

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an inert atmosphere, when nitrogen, argon or another inert gas is selected as an inert atmosphere.

For obtaining particles of the size smaller than 20 nm, it is advantageous to implement the modification of the precursor by drying or dehydration or
5 recrystallization or homogenization or grinding or milling before the thermal decomposition.

For the way of preparation of nanopowdered iron with the protective iron oxide coat, it is advantageous if the precursor is selected from the group of natural and synthetic iron oxides and oxihydroxides.

- 10 For prevention against self-burning of nanopowdered iron with the protective iron oxide coat it is advantageous if the final product is stored in the inert gas atmosphere or in the suitable liquid after the finalization of the synthesis.

The main advantage of the method of preparation of nanopowdered iron with the protective iron oxide coat, for example FeO, according to this invention, is
15 to achieve a new and higher effect due to the fact that this type of thermal decomposition represents a new way of synthesis of nanopowdered iron with the particle-size in the dimension of tens or hundreds of nanometers, in the course of which self-burning is prevented and required chemical purity and size distribution of particles is reached.

- 20 Another indispensable advantage of the method according to this invention is that the protective FeO coat, which forms on the surface of iron nanoparticles, ensures their long-term chemical stability in airy environment, which results in easy manipulation with iron nanoparticles during both their application and their long-term storage.

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Brief Description of the Figures on Drawings

The way of preparation of nanopowdered iron with the protective FeO coat by the reduction of nanopowdered crystalline or amorphous precursor of iron oxides and oxihydroxides in the reduction atmosphere according to this
30 invention will be explained more closely with the help of a drawing, on which figure 1 represents the X-ray diffraction pattern of the initial ferrihydrite,

figure 2 is TEM images of the initial natural ferrihydrite , figure 3 depicts the X-ray diffraction pattern of the final nanopowdered iron with the protective FeO coat , figure 4 displays Mössbauer spectrum of the final nanopartical iron with the protective coat and figure 5 is TEM image of the final nanopartical iron with the protective FeO coat .

Examples of the implementation of the invention

The way of preparation of the nanopowdered iron with the protective iron oxide coat by the reduction of nanopowdered crystalline or amorphous precursor of iron oxides and oxihydroxides in the reduction atmosphere according to the invention will be explained with the help of a useful example of the preparation of the iron nanopowder with the protective FeO coat.

For the preparation of the iron nanopowder with the protective FeO coat by the thermal decomposition in the reduction atmosphere, a nanopowder iron oxide or oxihydroxide is selected as the precursor. Subsequently, the precursor is dried in the dehydrating furnace before the reduction. Dried precursor is set into a suitable container, for example porcelain bowl, and then placed into the reduction furnace securing both stability of the selected reaction temperature for the whole synthesis period and the supply of the reduction gas as well as exhaust of gas products. The synthesis temperature is 650 °C or higher. The reaction temperature value then influences the size distribution of product particles. Synthesis of the precursor proceeds in a selected reaction temperature for a selected reaction period, the length of which influences the degree of the precursor conversion and simultaneously co-designates the size distribution of the final nanopowdered iron particles with the protective FeO coat. The synthesis itself is terminated by gradual lowering of the temperature and substitution of the reduction gas for inert gas, which cools the final product. After cooling, the final product is transferred into a container with inert gas or with a suitable liquid in a way that prevents self-burning of the nanopowdered iron.

As an illustrative example of verification of practical results of the proposed invention, preparation of iron nanopowder from natural ferrihydrite nanopowder by thermal analysis in hydrogen reduction atmosphere is presented.

5 Chemical composition, structural constitution and particle size of the initial material were identified with the methods of X-ray diffraction analysis (XRD), transmission electron microscopy (TEM) and chemical element analysis. X-ray diffraction analysis pattern is illustrated in figure 1 and it demonstrates the nanoparticle character of the initial ferrihydrite and imperceptible admixtures
10 of goethite and quartz. Simultaneously, transmission electron microscopy shows that the particle size is smaller than 10 nm as visible from figure 2. Chemical element composition is presented in table 1 and it shows that as trace elements silicone, calcium and aluminium are present.

Chemical and structural composition and the size of the synthesized product
15 particles were analyzed with the methods of X-ray diffraction analysis (XRD), Mössbauer spectroscopy on ^{57}Fe and transmission electron microscopy (TEM). X-ray diffraction analysis shows that the final product dominantly consists of pure iron, as visible from figure 3. The X-ray diffraction pattern further shows that minority amount of wustite and trace amount of quartz (the
20 same amount as in the initial material) is present in the final product. Mössbauer spectrum measured in the room temperature, as illustrated in figure 4, consists of a sextet with hyperfine parameters of pure α -iron ($IS=0$ mm/s, $QS=0$ mm/s, $B=33$ T) and a minority doublet corresponding with wustite ($IS=0.77$ mm/s, $QS=0.99$ mm/s). The particle size of the final iron
25 nanopowder is evident from TEM image (see figure 5), the particle size is c. 300 – 400 nm. In figure 6, the protective FeO coat is visible on the surface of iron particles.

Industrial Applicability

30 The method of preparation of the nanoparticle iron with the protective FeO coat according to the invention is advantageously usable in the production of

nanosized iron used in the surface and ground water purification and in soil purification. The invention is also usable for purifying water for industrial use.

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(hm.%)	
SiO ₂	3,99
Al ₂ O ₃	1,06
Železa ₂ O ₃	68,63
MgO	0,26
CaO	2,63
Na ₂ O	0,61
K ₂ O	<.04
TiO ₂	<.01
P ₂ O ₅	0,17
MnO	0,07
Cr ₂ O ₃	0,002
LOI	22,4
TOT/C	0,85
TOT/S	0,84
SUM	99,86

Table 1. Element composition of the initial material – ferrihydrite.

CLAIMS

- 5 1. The method of preparation of nanopowdered iron with the protective iron oxide coat by the reduction of nanopowdered crystalline or amorphous precursor of iron oxides and oxihydroxides in the reduction atmosphere, characterized by the fact that in the course of synchronous exhaust of secondarily originating gas products, nanopowdered crystalline or amorphous iron oxide or oxihydroxide
10 with particle size smaller than 20 nm is thermally decomposed in the reduction atmosphere at temperature higher than the minimum decomposition temperature for the given oxide or oxihydroxide and hereby formed nanopowdered iron with the protective iron oxide coat, for example FeO, is cooled in an inert atmosphere, in the process of
15 which nitrogen, argon or another inert gas is selected as the inert atmosphere.
- 20 2. The method of preparation of nanopowdered iron with the protective iron oxide coat by the reduction of nanopowdered crystalline or amorphous precursor of iron oxides and oxihydroxides in the reduction atmosphere according to claim 1, characterized by the fact that the final product is stored in the inert gas atmosphere or in a suitable liquid after the finalization of the synthesis.
- 25 3. The method of preparation of nanopowdered iron with the protective iron oxide coat by the reduction of nanopowdered crystalline or amorphous precursor of iron oxides and oxihydroxides in the reduction atmosphere according to claim 1 and 2, characterized by the fact that before the thermal decomposition itself, the precursor is modified with
30 drying or dehydration or recrystallization or homogenization or grinding

or milling and then, the modified precursor is placed into a suitable container and subsequently, it is placed into the reduction furnace.

- 5 4. The method of preparation of nanopowdered iron with the protective iron oxide coat by the reduction of nanopowdered crystalline or amorphous antecedent of iron oxides and oxihydroxides in the reduction atmosphere, characterized by the fact that nanoparticles of natural or synthetic ferrihydrite are used for the preparation of iron nanoparticles with the protective FeO coat.

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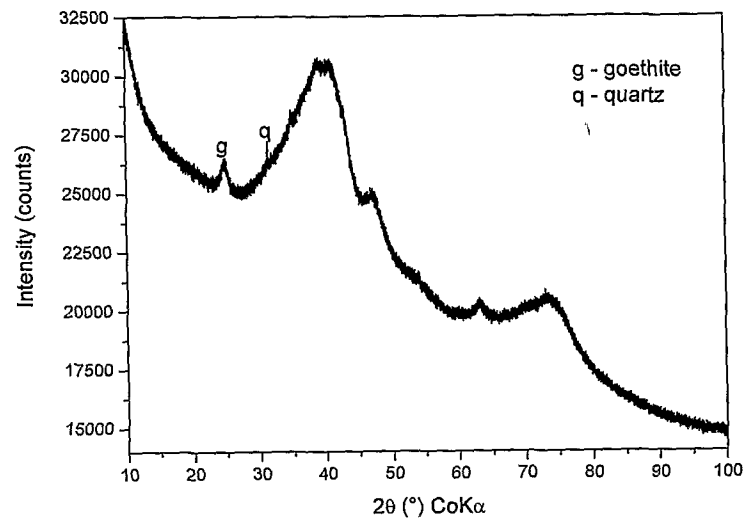


Fig.1

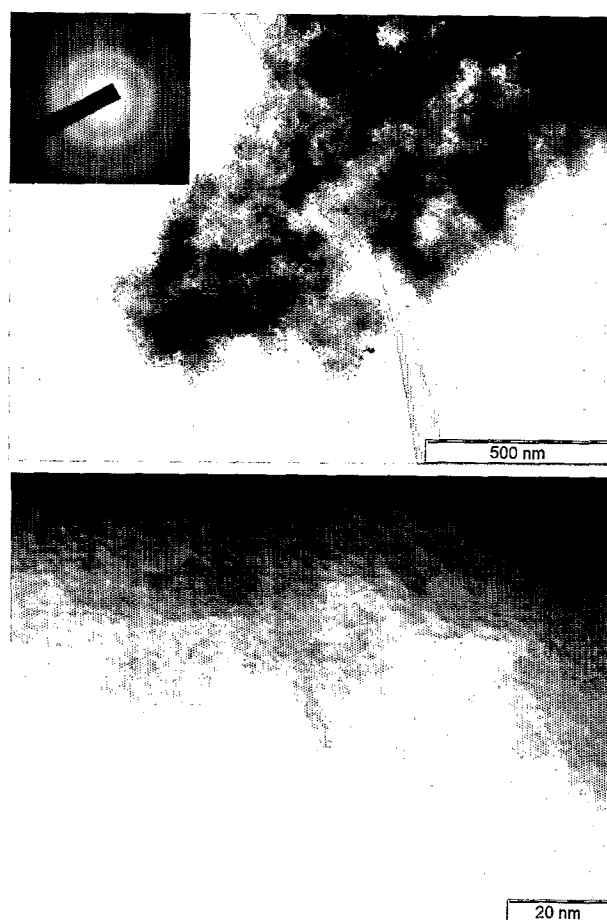


Fig.2.

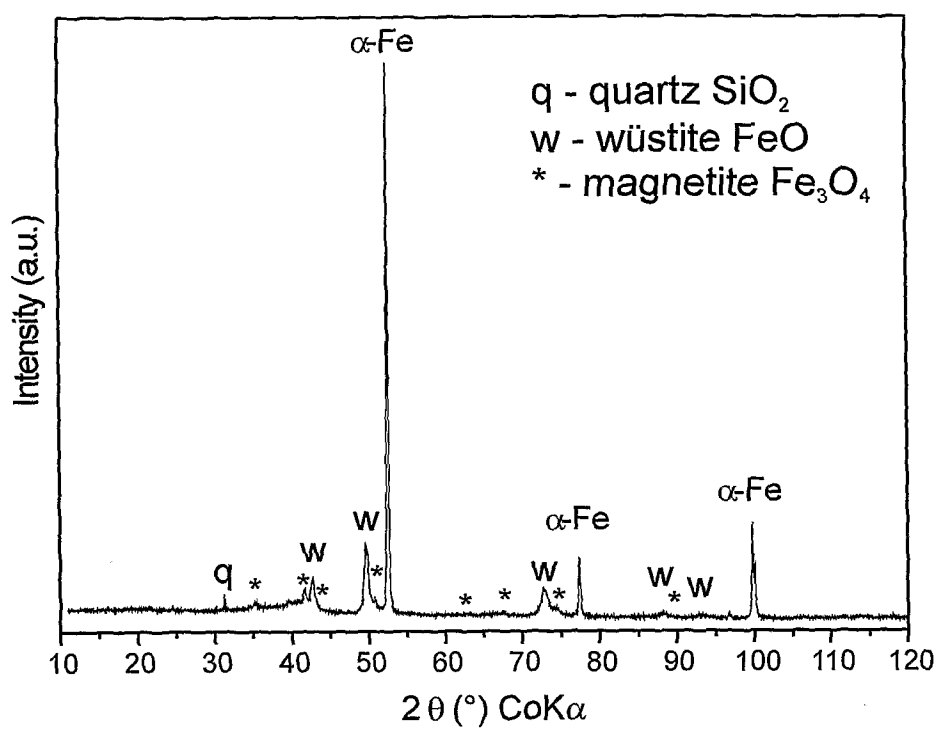


Fig.3

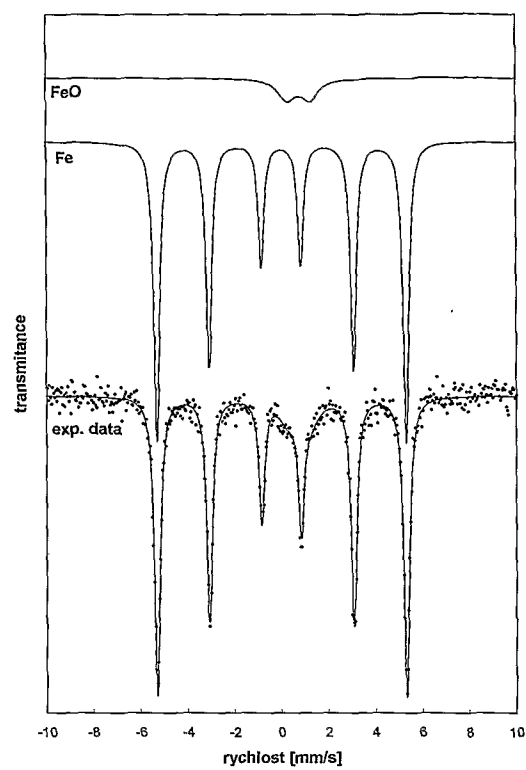


Fig. 4.

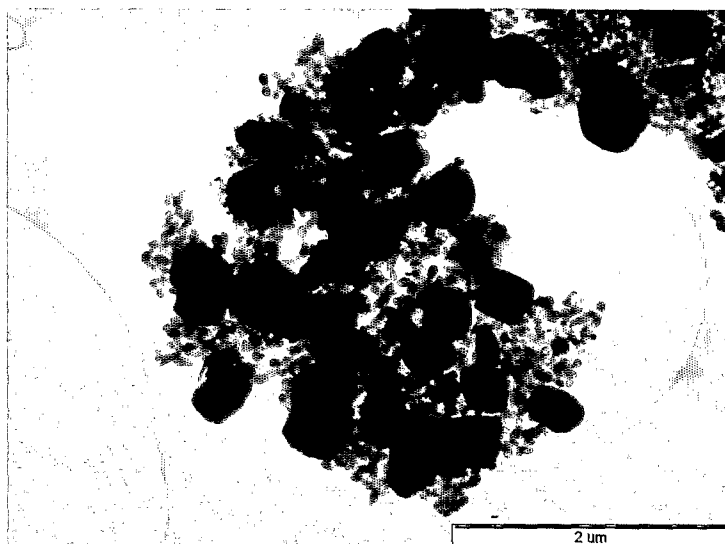


Fig.5

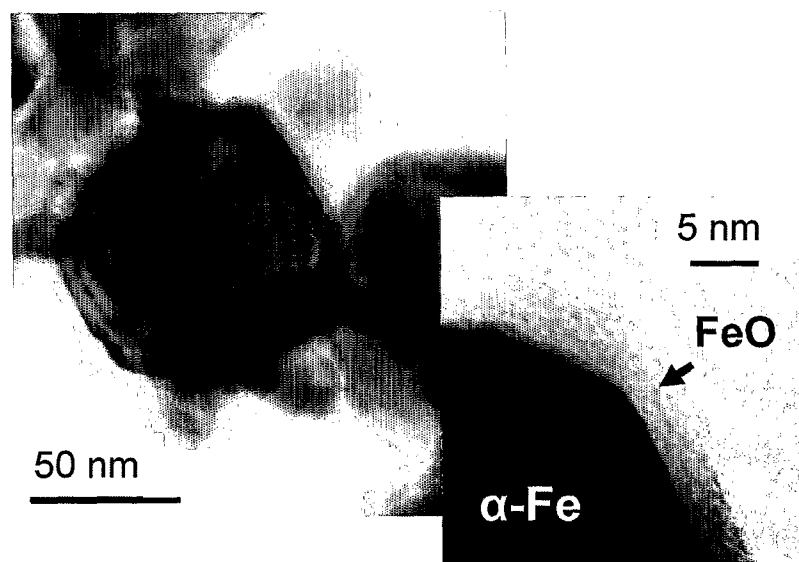


Fig. 6