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**Title:** HIGH POWER ULTRASOUND REACTOR FOR THE PRODUCTION OF NANO-POWDER MATERIALS

**Abstract:** Ultrasound device comprising a reaction chamber, which comprises a magnetostrictive transducer and a horn transmitting ultrasound radiation substantially uniformly throughout the reaction chamber. The horn is hollow and is constituted by a cylinder having an empty inner chamber at its core defining a resonance chamber, which may be cylindrical and may comprise a plurality of sections of cylindrical shape or a central section of larger diameter and two terminal sections of smaller diameter.
HIGH POWER ULTRASOUND REACTOR FOR THE
PRODUCTION OF NANO-POWDER MATERIALS

Field of the Invention
This invention relates to an improved ultrasound generating and
radiating device for use in an ultrasound reactor, which device comprises
transducers of the magnetostrictive type and horns that transmit
ultrasound radiation to the entire volume of the reactor simultaneously.

Background of the Invention
Ultrasounds have many applications in present-day technology in physical
and chemical processes. Some general references are:
1) K.S. Suslick, Sonochemistry, Science 247, pp. 1439-1445 (23 March
1990);
2) W.E. Buhro et al., Material Science Eng., A204, pp. 193-196 (1995);
3) K.S. Suslick et al., J. Am. Chem. Soc., 105, pp. 5781-5785 (1983);

There are several types of ultrasonic reactors. One of them is the loop
reactor, described e.g. in D. Martin and A.D. Ward, Reactor Design for
3. Inside this reactor, a liquid which is to be subjected to ultrasound
treatment, is caused to flow in a closed loop formed by a vessel provided
with a stirrer and by a conduit in which the ultrasound generator is
housed.

The propagation of ultrasound from a source in an unbounded liquid
medium is illustrated in Figure 2 of the same publication. In this case,
the sonochemically active zone is limited to a frusto-conical space diverging from the radiation face of a transducer.

Also, several transducers may be placed around an elongated enclosure, as in USP 5,658,534 and USP 6,079,508.

This invention relates to a type of reactor in which the reaction occurs in a localized space filled with a material that is generally a liquid phase, which may contain solid particles. By the term "reaction" is meant herein whatever phenomenon is caused or facilitated by the ultrasound radiation, viz. not necessarily a chemical phenomenon, but a physical one or a combination of the two, as well. A reactor of this type is coupled to a transducer, wherein an oscillating, generally alternating, magnetic field is generated by an oscillating, generally alternating, current – hereinafter called “the exciting current” – and a wave guide, generally and hereinafter called “horn”, which receives the ultrasonic vibrations from the transducer and radiates them into the space occluded by the reactor, hereinafter called “the reaction chamber”. The combination of transducer and horn will be called hereinafter, for brevity’s sake, “ultrasound device”. The reactor contains a material to be treated by ultrasound, which will be called hereinafter “reaction material”. The reaction material generally comprises a liquid phase and fills the reaction chamber.

The transducers of ultrasound devices can be of various types. Most common transducers are piezo-electric ones. Therein, the generator of the ultrasound typically consists of a piezo-electric element, often of the sandwich type, coupled with a horn having a generally circular emitting face. Piezo-electric transducers, however, have a maximum power of
about 2 kW and a low maximum oscillation amplitude dictated by the fragility of piezo-electric elements, which tend to break under prolonged working load. They are also not reliable compared to magnetostrictive transducers, to be described hereinafter, because their amplitude drifts with operation, causes breakdowns and lower energy output and has to be manually corrected. Similar properties are also possessed by electrostrictive materials polarized by high electrostatic fields.

Another type of transducer is that based on the use of a magnetostrictive material, viz. a material that changes dimensions when placed in a magnetic field, and conversely, changes the magnetic field within and around it when stressed. When a magnetostrictive material is subjected to a variable magnetic field, the material will change dimensions with the same frequency with which the magnetic field changes.

Magnetostrictive materials, to be quite suitable, must present a sufficiently large magnetic stricture at the temperature at which the ultrasonic reactor is intended to be used. To achieve this, proposals have been made to use special magnetostrictive materials, for example, alloys containing rare earths: see, e.g., USPs 4,308,474; 4,378,258 and 4,763,030. Such alloys are expensive, and, in spite of their better elastic properties, they suffer major drawbacks, one of them being that they will brake if subjected to relatively high power, e.g. 5 Kw, and at lower powers they do not transduce enough electromagnetic energy to acoustic energy.

A magnetostrictive transducer must comprise a magnetostrictive element, e.g. a rod or another elongated element, located in a space in which an oscillating magnetic field is produced. In its simplest form, such a
transducer would comprise a nucleus of magnetostrictive element and a coil disposed around said element and connected to a generator of oscillating electric current. However, different forms of transducers can be devised to satisfy particular requirements: for instance, USP 4,158,368 discloses a toroidal-shaped core of magnetic metal, about which a coil is wound, which toroid defines with its ends an air gap in which a magnetostrictive rod is located.

The magnetostrictive transducer transduces the electromagnetic power it receives into ultrasonic power, which it transmits to an irradiating device — the wave guide or horn. It will be said hereinafter that the horn irradiates the ultrasound into a reactor chamber, but no limitation is intended by said expression, which is used only for the sake of brevity. Generally, the horns of the prior art have a slim frusto-conical shape or a stepped or exponential shape. In every case, they concentrate the ultrasonic vibrations and irradiate them from their tip, which is generally circular and anyway of reduced dimensions. The ultrasonic waves have therefore a high intensity only at the tip of the horn and spread out from it in a conical configuration, so that they reach only a part of the reactor chamber and at any point of said chamber their intensity is reduced, generally proportionally to the square of the distance from the horn tip. At their region of maximum intensity various phenomena occur, including heating, cavitation, evaporation, and so on, which absorb and waste a large portion of the ultrasound energy, resulting in a limited efficiency, which is generally in the order of 20-30%. Additionally, some desired phenomena that are produced by the high energy density at the tip of the horn may become reversed at a distance from said tip: for instance, if it is desired to fragment solid particles, contained in a liquid phase, into
smaller ones, such smaller particles may be produced at the tip of the horn, but then migrate through the liquid phase and coalesce to some extent at a distance from said tip, so that the particles finally obtained are not as small as desired.

It is a purpose of this invention, therefore, to provide an ultrasound device that is free from the drawbacks of the prior art ultrasound devices.

It is another purpose of the invention to provide such an ultrasound device which has a higher power than the prior art devices, e.g. those of the piezo-electric type.

It is a further purpose of the invention to provide such an ultrasound device comprising a transducer that is inexpensive and durable and has a high oscillation amplitude, up to 45 microns.

It is a still further purpose of this invention to provide an ultrasound device which irradiates ultrasonic energy to all the volume of the reactor chamber simultaneously and substantially uniformly.

It is a still further purpose of this invention to provide a sonochemical reactor of high power, e.g., up to 6 Kw.

It is a still further purpose of this invention to provide such an ultrasound device which has at least 60% efficiency, e.g., 60-80%.

It is a still further purpose of this invention to provide a reactor including such an ultrasound device.
It is a still further purpose of this invention to provide a reactor in which there is no occurrence of undesired phenomena at a distance from the horn.

It is a still further purpose of this invention to provide a reactor for the effective and high throughput production of nano-scale materials.

It is a still further purpose of this invention to provide a reactor for the production of nano-powder materials.

It is a still further purpose of this invention to provide a reactor for the production of nano-structured metal powders.

It is a still further purpose of this invention to provide a reactor for the production of nano-powder of metal oxides.

It is a still further purpose of this invention to provide a reactor for the production of nano-metal hydroxides.

It is a still further purpose of this invention to provide a reactor for treating agglomerated materials and effectively cause de-agglomeration.

It is a still further purpose of this invention to provide means for the acceleration of chemical reactions.

**Summary of the Invention**
The ultrasound device of this invention comprises a transducer and a horn, which are different from, and improved with respect to, the prior art, as will be explained hereinafter. While the aforesaid improved transducer and horn, in combination, characterize the device of the invention, each of them separately considered is also a part of the invention. The horn of this invention is mostly intended to be immersed in the reaction material. In the following description the reactor will be assumed to have an axis of symmetry and the horn also to have an axis of symmetry coinciding with the axis of symmetry of the reactor, however this is not to be construed as a limitation, since the invention covers an ultrasound device as hereinafter defined and is not limited to the reactor with which said device is used, nor to the position in which said device is located with respect to the reactor, nor to the properties of the reaction material.

The transducer comprises a magnetostrictive element of a special alloy, which alloy comprises iron, cobalt, and rare earth elements, such, but not only, nickel, vanadium, dysprosium, terbium, etc. The prior art discloses alloys of iron and rare earth, but teaches that very high contents of rare earth metals are needed to obtain satisfactory magnetostriction properties. For instance, USP 4,308,474 discloses alloys of iron and rare earths (terbium, dysprosium, holmium, samarium) wherein the atomic ratio of rare earths to iron is 1:2, viz. the alloy weight content of rare earths is higher than 50%. USP 4,378,258 discloses alloys of iron and terbium, in which the content of iron varies from 15 wt% to 91 wt%, but while the magnetostriction of the alloy with 30 wt% iron is $2380 \times 10^{-8}$, that of the alloy with 91 wt% iron is only $16 \times 10^{-6}$, viz. such an alloy cannot be used in an ultrasound transducer. Among the alloys disclosed, alloy TbFe3, containing less than 44 wt% of iron, with a magnetostriction of
1040×10⁻⁶, appears to be the alloy with the highest iron content that is usable, though not very good. It is surprising that the alloys of this invention, as hereinbefore defined, have high magnetostrictive properties, in spite of the relatively low content of rare earth metals; additionally, they are less expensive than prior art ones and have better mechanical properties which allow them to work in high power ultrasound generators.

The shape of the magnetostrictive element may vary to satisfy particular requirements. Preferred forms will be described hereinafter. The dimensions of any such element is calculated to resist metal fatigue and to give maximum oscillation amplitude. All the electromagnetically relevant parameters of the transducer, for instance the dimensions of the coil that generates the magnetic field, the intensity and frequency of the alternating current fed to said coil, and the like, must be determined to produce the desired magnetic field, and persons skilled in the art will have no difficulty in doing so. For purposes that will be described hereinafter, the ultrasound device of the invention may be combined with a source of exciting current the frequency of which can be gradually varied. However, the optimum frequency for each specific device to be used for a specific process is generally determined and fixed once and for all. For example, such frequencies may be in the range of 15 to 40 KHz.

The horn of this invention, contrary to prior art horns, is a hollow type (see Fig. 2). It is characterized in that it contains an inner resonance chamber, which has several functions: 1) to make the walls of the horn thinner, so that their motions are easier and their amplitude under a given driving force is increased; 2) to cause the transducer power to be transmitted to the horn in an uneven manner and form a standing wave.
forcing the horn walls to vibrate; 3) to increase the horn vibrations through resonance that is the result of interaction between parallel vibrating walls. In view of its function, the inner chamber could also be called “resonance chamber”. In a form of the invention, the shape of said chamber matches the outer shape of the horn, to determine, as desirable, a thickness of the horn wall that is peripherally uniform. Therefore, since the horn is preferably cylindrical, the resonance chamber has preferably a cylindrical shape. In another form of the invention, it comprises a plurality of sections of cylindrical shape, to provide other advantages that will be explained hereinafter, while being preferably, substantially symmetric with reference to a plane transverse to the chamber.

In a preferred embodiment, the resonance chamber comprises a central section of larger diameter and two symmetrical, extreme or terminal sections of smaller diameter. In a form of said preferred embodiment, the horn comprises a body, which defines the central section of the resonance chamber and one of its extreme sections, and a plug which defines the other extreme section of the resonance chamber and which is connected to the body, preferably screwed into it, at one end thereof. Preferably, the two extreme sections are symmetric to one another with respect to the central section.

Horns are generally made, in the art, of a titanium alloy, e.g. Ti-4V-6Al, but for the purposes of this invention the horn and the aforesaid plug are preferably made of stainless steel (316L/302 ASTM. The transducer is connected to one of the ends of the horn, preferably the end into which the plug, if any, is inserted, e.g. by a connecting insert, screwed into both the said plug of the horn and into the transducer.
The ultrasonic power generated by the transducer of the invention is irradiated from the entire surface of the horn, comprising its sides, and not merely from an extremity of it, as in prior art horns. In the prior art horns, the only irradiating surface is a narrow tip and the ultrasonic waves spread out from it in conical configuration; therefore the ultrasound has a high intensity at said tip and becomes weaker as it spreads out from it, roughly inversely proportional to the square of the distance from said tip. In the horn of the invention the irradiating surface is practically the whole outer surface of the horn and the ultrasound intensity is substantially uniform throughout the reaction space, although it is still somewhat higher at the horn tip, as will be explained hereinafter. This leads to a greatly increased efficiency, in the order of 60-80%, as has been said.

**Brief Description of the Drawings**

In the drawings:

- Fig. 1 represents in schematic perspective view a transducer, coupled with a horn, according to an embodiment of the invention;

- Fig. 2 is an axial cross-section of a horn according to an embodiment of the invention;

- Fig. 3 is an axial cross-section of a horn according to a second embodiment of the invention;

- Fig. 4 is an axial cross-section of a horn according to a third embodiment of the invention;

- Fig. 5 an enlarged view of a detail of Fig. 4, particularly illustrating the screw connection between the body and the plug of the horn; and
- Fig. 6 is a schematic illustration of an embodiment of a reactor in which the transducer and horn of this invention are used.

**Detailed Description of Preferred Embodiments**

Fig. 1 illustrates a transducer according to an embodiment of the invention and its connection to the horn. The transducer generally indicated at 1 is supported by a base 5 to which it is welded or in any other convenient way. The transducer comprises a magnetostrictive element 2, which in this embodiment comprises two vertical branches 3 and 3'and two horizontal branches 4 and 4' connecting said vertical branches, the lower branch 4' being welded to the base 5.

Numeral 6 generally indicates a coil, which comprises two branches 7 and 7' wound about the vertical branches 3 and 3' of the magnetostrictive element and connected at both ends, as indicated at 8 and 8' in the drawing, to an AC power generator (not shown). The same electric current flows through both branches of coil 6 and, generates the same magnetic field about the branches 3 and 3' of the magnetostrictive element.

The base 5 has a height or length which measures a whole number of half-wavelengths, preferably one wavelength, of the ultrasound generated by the transducer, which corresponds to the frequency of the current flowing through coil 6. A connecting insert 9, shown in a section detail of Fig. 1, is screwed into the horn 10 and into base 5, and the screw connections must be wound tight to effect a strong mechanical coupling between the transducer 1 and the horn 10. The horn, in this embodiment, has a length or height equal to a whole number “n” of half-wavelengths.
Fig. 2 is an axial (generally vertical) cross-section of a horn 11, which is cylindrical, except for a short, frusto-conical, bottom portion cut-off 13 of its bottom plate 12. The connecting insert 9 is shown mounted on the top of the horn and threadedly connected to its top plate 14. Horn 11 is hollows and defines a cylindrical resonance chamber 15, coaxial with the horn outer surface, so that the longitudinal (generally vertical) walls of the horn have the same thickness throughout. Under the ultrasonic vibrations produced by the transducer, the horn walls oscillate elastically, expanding an contracting periodically. At the top and bottom, they are retained by the top and bottom plates, so that the amplitude of the oscillations at those points is practically zero, while it is a maximum practically half-way between said plates. Its diagram resembles therefore one half of a sinusoidal wave. When the horn is mounted in a reactor within a fluid medium, said elastic oscillations will produce alternate compression and decompression on said medium, acting in a way that may be roughly described as “push-pull”. This and all the horns illustrated herein preferably have a length or height equal to a whole number of half-wavelengths, as shown in Fig. 1.

The applicant has found, however, that it is advantageous to provide essentially cylindrical horns the walls of which have portions of different thicknesses. In this case, elastic oscillations will be produced having different amplitudes along the horn, greater in horn sections of equal lengths where the horn walls are thinner. The applicant has found that, in this case, the ultrasound energy produced and transferred to the reactor medium – “the output energy” – is greater than when the horn resonance chamber is cylindrical, all other things being equal. Such an embodiment
is shown in Fig. 3. The horn 16 has the same outer shape as the horn 11, but the resonance chamber comprises a central section 17 and two symmetric sections 18 and 18' of smaller diameter than said central section 17 and connected thereto by curved annular surfaces 19 and 19'. The whole resonance chamber is symmetric with respect to a transversal plane passing through the center of section 17. The walls of the horn are thinner where they define said section 17.

However, making a horn as shown in Fig. 3 would require providing at least two halves or unequal portions, boring them to define the various parts of the resonance chamber, and then connecting them by welding or the like. Such a connection would not adequately resist the stresses caused by ultrasonic, elastic oscillations. Therefore, a preferred embodiment of a horn, having a resonance chamber comprising the same sections shown in Fig. 3, is illustrated in Figs. 4 and 5.

Figs. 4, and Fig. 5, which is a detail of the part of Fig. 4 indicated as “T”, illustrate a horn 20 which comprises a body 21, defining the central portion of the resonance chamber 22 and one of the terminal sections 23 of said resonance chamber 22. The horn further comprises a plug 24 screwed into body 21, which defines a second terminal section 25 of the resonance chamber. The two terminal sections 23 and 25 have the same length and diameter. Connection insert 9 is screwed into said plug 24 and extends outwardly from said plug, preferably by one-half its length, to provide an external section onto which the base 5 can be screwed firmly to connect the horn to the transducer, as shown in Fig. 1. Central section 22 of the resonance chamber blends with the terminal sections 23 and 25 through annular sections 27.
For example, in the embodiment illustrated, the sections of the resonance chamber may have the following dimensions: the central section may have a diameter of from 15 to 45 mm and a length of 60 to 105 mm, and the terminal sections may have a diameter of 8 to 28 mm and a length of 20 to 90 mm.

In the embodiment illustrated, the body 21 of the horn is connected with the plug 24 by means of a square screw thread 28 (see Fig. 5). The ultrasonic radiation intensity should be high and be distributed throughout the reactor chamber as evenly as possible. The energy levels should preferably be from 3 to 7 W per square centimeter of the horn outer surface. When the reactor chamber is filled with liquid, said even intensity distribution can be achieved by the ultrasonic resonance of the liquid. For example, the energy intensity may reach high levels, such as 0.2 \( \div \) 0.6 W per cubic centimeter of the horn volume.

In a preferred design, the length of the horn should be equal to a whole number of ultrasonic radiation half-waves. The wavelength \( \lambda \) of the ultrasonic radiation is given by \( \lambda = v/\gamma \), wherein \( \gamma \) is the ultrasound frequency and \( v \) is the velocity of the ultrasound propagation in the material of which the horn is made. The intensity \( I \) of the ultrasound radiation corresponding to an energy \( W \), assumed to be uniformly distributed, is \( I = W/S \), wherein \( S \) is the area from which the ultrasound is irradiated.

In ideal cases, the intensity \( I \) can be calculated from the formula
I = \nu \rho \gamma A^2$, wherein \( \nu \) is the ultrasound velocity in the environment, \( \rho \) is the density of the environment, \( \gamma \) is the ultrasound frequency and \( A \) the ultrasound amplitude.

In any design of solid horns according to the prior art it is possible to observe weak oscillation and cavitation on the side surface of the horn. Those weak radial oscillations constitute the manifestation of the Poisson effect, according to the formula: \( \chi = - \varepsilon^r / \varepsilon \), wherein \( \chi \) is the Poisson coefficient and \( \varepsilon^r \) and \( \varepsilon \) are respectively the radial and the longitudinal modules. In ultrasound oscillations the speed of the deformations is very high, and the material of the horn can be considered as incompressible.

The amplitude of the of radial elastic oscillations can be calculated by the formulae:

\[
G = \frac{E}{2(1+\chi)}; \quad E = \frac{K}{3(1+2\chi)}; \quad \sigma = K\varepsilon
\]

wherein \( E \) is the Young modulus, \( K \) is the volume elasticity module; \( G \) is the module displacement, \( \chi \) is the Poisson coefficient, \( \sigma \) is the stress and \( \varepsilon \) is the strain.

In massive horns, radial oscillations are small because of tangent stress relaxation in whole metal volume. For exclusion relaxation phenomena, the horn metal volume has to be reduced and keeping the surface size in such a way the horn design should be tubular. So in relatively thin walls, the radial amplitude can reach 0.5 of the longitudinal amplitude. Therefore the parameters of the horn should be determined according to the radial oscillations desired, the ultrasound power to be irradiated the desired uniformity of said power on the horn outer surface, the radiating surface area that will provide the desired ultrasound intensity account,
and the resistance of the horn material to the stresses generated by the ultrasound.

Fig. 6 schematically illustrates a reactor which can be used in various processes in which an ultrasonic irradiation is employed. The reactor, generally indicated at 30, and which may be made, e.g. of pyrex glass, is mounted in a housing 31, which is broken off to show the inner components of the reactor, and comprises upper flange 43 and lower flange 42. The ultrasound device 33 is supported by flange 32. 44 is the transducer and 45 is the horn. 16 is the connecting insert. 34 indicates a thermometer; and 35, in flange 42, and 35', in flange 43, indicate an inlet and an outlet of a cooling liquid. 37 is an optional stirrer. All said flanges may be e.g. of polypropylene. A circuit for the protection of the horn against chemical corrosion, not shown, has terminals indicated at 40 and 41. The means for feeding the exciting current to the transducer are not shown. 46 indicates a connection to pumps. Means for feeding electric power to the coil are not shown, and means for feeding material to be treated by ultrasound are likewise not shown, as they change from case to case.

To produce nano-metal oxides or hydrates, a solution of a salt of the metal (generally a chloride) in a suitable solvent is subjected to the extremely high US energy in the presence of a base, such as e.g. an alkali hydroxide. A 10-liter reactor as hereinbefore described, capable of producing energy up to 0.6 W/cm³, is suitable for this purpose. Under such conditions, highly active radicals are rapidly created inside cavitation bubbles, that explode rapidly, leaving nuclei of nano-particles. In such a sono-reaction, a solution of one mole of metal salt yields up to several hundred grams of
nano-products, having dimensions in the nano-scale of 5 to 60 nm, in a remarkably short reaction time, e.g. 3-6, minutes.

Examples of compounds, nano-particles of which can be produced in this way, are oxides FeO, Fe₂O₃, Fe₃O₄, NiO, Ni₂O₃, CuO, Cu₂O, Ag₂O, CoO, Co₂O₃ and hydroxy crystal hydrates Fe(OH)₃, Co(OH)₃, NiO(OH). Another compound is BaTiO₃.

Metals nano-particles can also be produced in this way, for example, nanoparticles of Fe, Co, Cu, Ag, Ni, Pd, etc.

The reactor of the invention is an effective unit for acceleration of chemical reactions. For example, the reduction of metal salts or oxides to a metallic powder, in relatively high amounts (1 mole) is completed in 5-10 minutes. Such powders consist of ultrafine metallic or non-metallic particles in the nano-scale range (5-100 nm). The resulting products may be used in a wide range of applications, including pigments, catalysts, magnetic media, optoelectronic materials, cosmetics, chemical polishes, abrasives, composites and coatings.

The following, non-limitative Examples illustrate embodiments of such processes.

**Example 1**

**Production of Nano iron hydroxide powder**

The iron hydroxide is produced from an iron salt, in this example iron chloride, and a base, particularly an alkali hydroxide, in this example sodium hydroxide, according to the following reaction:
\[2\text{FeCl}_3 + 6\text{NaOH} \rightarrow 2\text{Fe(OH)}_3 + 6\text{NaCl}\]

The reagents are prepared by weighting with an analytical balance and preparing water solutions of iron chloride and sodium hydroxide. The reaction is carried out under high power ultrasound according to the following parameters:

Reaction composition:  
- sodium hydroxide – 60 gr.  
- distilled water – 950 gr.

Time of reaction – 5 minutes

The product is Nano iron hydroxide powder, having particle size below 100 nm.

**Example 2**  
**Production of Nanoamorphous nickel hydroxide Ni(OH)$_2$**

The nickel hydroxide is produced from a nickel salt, in this example nickel chloride, and a base, in this example sodium hydroxide, according to the following reaction:

\[\text{NiCl}_2 + 2\text{NaOH} \rightarrow \text{Ni(OH)}_2 + 2\text{NaCl}\]

The reagents are prepared by weighting with analytical balance and preparing water solutions of nickel chloride and sodium hydroxide. The reaction is carried out according to the following parameters:

Reaction volume – 1 liter  
Reaction composition:  
- nickel chloride – 70 g  
- sodium hydroxide – 25 g  
- distilled water – 900 ml

Time of reaction – 5 minutes
The product nickel hydroxide is a green amorphous material having surface area (BET) > 350 m²/gr and particle size (HRSEM) of 20-60 mm.

**Example 3**

**Production of Nanocrystalline cobalt powder**

The cobalt is produced from a cobalt salt, in this example cobalt chloride, and a powder of a metal capable of reducing said salt to cobalt metal (hereinafter indicated by “M”), according to the following reaction:

\[ \text{CoCl}_2 + M \rightarrow \text{Co} + \text{MCl}_2 \]

The reaction is carried out according to the following parameters:

Reaction volume – 1 liter

Reaction composition:
- cobalt chloride – 240 g
- M – reducing metal
- suitable solvent – 1 liter

Time of reaction – 5 minutes

The product is hexagonal cobalt powder, having a specific weight of 8.9 g/cc and a black color, and particle size 10-40 nm.

Other metals can be produced by similar reactions.

**Example 4**

**Production of Nanocrystalline iron oxide powder Fe₂O₃**

80 g of FeCl₃ anhydrous were dissolved in 800 ml of water. 60 g of NaOH were added to 100 ml of water at room temperature. The solution of FeCl₃ was mixed with the solution of NaOH under ultrasound and a gelled solution of precipitates was obtained.

The gelled solution was filtrated with suction and washed thoroughly with distilled water until a test with AgNO₃ reagent is negative, to remove any residual free chlorine. The dried precipitates were then placed into a high
temperature oven for the heat treatment, and the temperature of the oven was increased at a rate of 5°C/min to 600°C to calcine the precipitates for 1 hour and then they were cooled at room temperature to obtain red hematite iron oxide Fe₂O₃ nano-powder, with particle size 20-100 nm.

While embodiments of the invention have been described for the purpose of illustration, it will be understood that the invention may be carried into practice with many modifications, adaptations and variations, without exceeding the scope of the claims.
CLAIMS

1. Ultrasound device comprising a reaction chamber, which comprises a magnetostrictive transducer and a horn transmitting ultrasound radiation substantially uniformly throughout said reaction chamber.

2. Ultrasound device according to claim 1, wherein the horn is hollow.

3. Ultrasound device according to claim 1, wherein the horn is constituted by a cylinder having an empty inner chamber at its core defining a resonance chamber.

3. Ultrasound device according to claim 3, wherein the inner chamber has a cylindrical shape.

4. Ultrasound device according to claim 3, wherein the inner chamber comprises a plurality of sections of cylindrical shape.

5. Ultrasound device according to claim 3, wherein the inner chamber comprises a central section of larger diameter and two terminal sections of smaller diameter.

6. Ultrasound device according to claim 6, wherein the horn comprises a body, which defines a central section of the inner chamber and
one of its terminal sections, and a plug which defines the other terminal section and which is connected to the body at one end thereof.

7. Ultrasound device according to claim 7, wherein the plug is screwed into the body at one end thereof.

8. Ultrasound device according to claims 5 to 10, wherein the horn is made of Stainless steel 316L/302.

9. Ultrasound device according to claim 6, wherein the central section of the inner chamber has a diameter of from 15 to 45 mm and a length of 60 to 105 mm, and the terminal sections of said chamber have a diameter of 8 to 28 mm and a length of 20 to 90 mm.

10. Ultrasound device according to claim 9, wherein the transducer is connected to one of the ends of the horn.

11. Horn for an ultrasound device, which contains an empty, inner chamber.

12. Horn according to claim 14, wherein the inner chamber has a cylindrical shape.

13. Horn according to claim 14, wherein the inner chamber comprises a plurality of sections of cylindrical shape.
14. Horn according to claim 14, wherein the inner chamber comprises a central section of larger diameter and two terminal sections of smaller diameter.

15. Horn according to claim 15, wherein the horn comprises a body, which defines a central section of the inner chamber and one of its terminal sections, and a plug which defines the other terminal section and which is connected to the body at one end thereof.

16. Horn according to claim 18, wherein the plug is screwed into the body at one end thereof.

17. Horn according to claims 12 to 17, made of Stainless steel.

18. Horn according to claim 17, wherein the central section of the inner chamber has a diameter from 15 to 45 mm and a length of 60 to 105 mm and the terminal sections of said chamber have a diameter of 8 to 28 mm and a length of 20 to 90 mm.

19. Process for the production of nano-products, which process comprises subjected a starting material to ultrasound waves in an ultrasound device according to one or more of claims 1 to 10.

20. Process according to claim 19, wherein the starting material comprises a solution of a metal salt, which process further comprises precipitating from said solution a nano-powder material.
21. Process according to claim 19, wherein the nano-powder material is a metal.

22. Process according to claim 19, wherein the nano-powder material is a metal oxide or a metal hydroxide or a metal.

23. Process according to claim 19, wherein the nano-powder material is chosen in the group consisting of FeO, Fe$_2$O$_3$, Fe$_3$O$_4$, NiO, Ni$_2$O$_3$, CuO, Cu$_2$O, Ag$_2$O, CoO, Co$_2$O$_3$, Fe(OH)$_3$, Co(OH)$_3$, NiO(OH) and BaTiO$_3$.

24. Process according to claim 19, wherein the nano-powder material is chosen in the group consisting of Fe, Co, Cu, Ag, Ni, and Pd.

25. Process according to claim 20, wherein the starting material additionally comprises a reagent chosen from the group consisting of alkali hydroxides and metals.

26. Use of a ultrasound device according to any one of claims 1 to 10 to accelerate chemical reaction.

27. Use according to claim 26, wherein the reaction is the formation of a metal oxide or hydroxide from a corresponding metal salt.

28. Use according to claim 25, wherein the reaction is the formation of a metal from a corresponding metal salt or oxide.

29. High power ultrasound device, up to 7 Kilowatt, for use in a sonochemical reactor, substantially as described in the specification.
30. Ultrasound device, substantially as described and illustrated.

31. Horn for an ultrasound device, substantially as described and illustrated.

32. Process for the production of nano-products, substantially as described.

33. Use of a ultrasound device, substantially as described.