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पेटेंट प्रमाणपत्र  
PATENT CERTIFICATE  
(Rule 74 Of The Patents Rules)

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पेटेंट सं. / Patent No. : 349961  
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फाइल करने की तारीख / Date of Filing : 27/01/2009  
पेटेंटी / Patentee : INDIAN INSTITUTE OF TECHNOLOGY

प्रमाणित किया जाता है कि पेटेंटी को उपरोक्त आवेदन में यथाप्रकरित A METHOD FOR REMOVING INORGANIC MERCURY FROM DRINKING WATER नामक आविष्कार के लिए, पेटेंट अधिनियम, १९७० के उपबंधों के अनुसार आज तारीख 27th day of January 2009 से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled A METHOD FOR REMOVING INORGANIC MERCURY FROM DRINKING WATER as disclosed in the above mentioned application for the term of 20 years from the 27th day of January 2009 in accordance with the provisions of the Patents Act, 1970.



अनुदान की तारीख : 23/10/2020  
Date of Grant :

पेटेंट नियंत्रक  
Controller of Patent

*OKSupte*

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, 27th day of January 2011 को और उसके पश्चात प्रत्येक वर्ष में उसी दिन देय होगी।

Note. - The fees for renewal of this patent, if it is to be maintained will fall / has fallen due on 27th day of January 2011 and on the same day in every year thereafter.



**FORM – 2**

THE PATENTS ACT, 1970  
(39 of 1970) &  
The Patents Rules 2003

**COMPLETE SPECIFICATION**  
(SECTION 10 & rule 13)

TITLE

**A METHOD FOR REMOVING INORGANIC MERCURY FROM DRINKING WATER**

APPLICANT

We, **INDIAN INSTITUTE OF TECHNOLOGY**, an autonomous body set up by the government of India under an act of parliament, having its office at IIT P.O, Chennai 600 036, Tamil Nadu, India.

The following specifications particularly describes the nature of this invention and the manner in which it is to be performed:-

27 JAN 2009

ORIGINAL

0169/CHE/2009

**FIELD OF INVENTION:**

The present invention relates to the development of a method for removing inorganic mercury from drinking water. More specifically the present invention relates to the complete removal of inorganic mercury from drinking water using gold nanoparticles supported on alumina. This invention includes a setup for decontaminating water contaminated with mercury, suspended matter, pesticides and boron. The setup consists of filter media provided with an inlet and an outlet. The contaminated water is allowed to pass through the filter media while the contaminants are removed by the filter media and decontaminated water flows out through the outlet.

**PRIOR ART:**

Pollution of the biosphere with toxic metals due to anthropogenic sources increased in the 19<sup>th</sup> century and has intensified since then. Sources of toxic metals are diverse including burning of fossil fuels, mining, processing and refining of various ores, municipal and industrial wastes and waste incineration, etc. Removal of toxic persistent pollutants such as heavy metal ions, which are extremely hazardous for environment and living organisms, is one of the biggest challenges in water purification. Mercury is a highly volatile and highly toxic heavy metal present in the environment. It can exist in the environment in elemental, inorganic and organic forms. Once released into the environment, it can undergo complex physical and chemical transformations. Low dose mercury exposure can affect various organ systems of adults and children. In adults, it can lead to memory loss, Alzheimer's like dementia, impairment of hearing and vision, sensory disturbances, decreased muscular strength, decreased overall immunity of the body, decreased rate of fertility, birth of abnormal offspring, etc. In children, the effects include autism, late walking and deficit in memory and language (Zahir, F., Rizwi, S.J., Haq, S.K., Khan, R.H., *Environ. Toxicol. Phar.*, 2005, 20, 351). Due to the severe effects of mercury on human health, World Health Organization (WHO) has set the limit for mercury in drinking water to be 0.001 mg/L (W.H.O., *Guidelines for Drinking Water Quality*, 3rd Ed., 2004, 1). In the developing countries, mercury pollution is indeed a threat to human beings. Technologies like adsorption, ion exchange, amalgamation and chemical precipitation are available for the removal of mercury from contaminated

water. Nanomaterials are highly promising in the water purification process due to their unique properties like higher surface area per unit volume, ease with which they can be anchored onto solid matrices and the ability to functionalize with different functional groups to enhance their affinity towards target molecules (Savage, N., Diallo, M.S., *J. Nanopart. Res.*, 2005, 7, 331). As a result, research efforts are focused on nanotechnology for an efficient, cost effective and eco-friendly method to get rid of water contamination (Dhermendra, K.T., Behari, J., Sen, P., *World Appl. Sci J.*, 2008, 3, 417). The use of gold nanoparticles for the detection and removal of pollutants from water is an emerging field. Gold nanoparticles are effectively utilized for the detection and removal of many toxic chemicals from water. Several prior art exists in this direction. A few are quoted below.

(a) United States patent 2007/0166224 A1, Adsorbent composition, a device and a method for decontaminating water containing pesticides.

(b) Indian patent 200767, A method of preparing purified water from water containing pesticides (chlorpyrifos and malathion) and purified water prepared by the said method.

(c) Indian patent application 1879/CHE/2007 dated 10<sup>th</sup> December, 2007, A method to produce supported noble metal nanoparticles in commercial quantities for drinking water purification.

(d) PCT application, PCT/IN05/0002, Extraction of malathion and chlorpyrifos from drinking water by nanoparticles adsorbent composition, a device and a method for decontaminating water containing pesticides.

An anisotropic gold nanoparticle-based mercury sensor and water remediation method exists (United States patent 20080081376 A1). The variation in the absorption, reflectance or scattering of the solution due to gold amalgam formation is utilized in sensing.

#### **OBJECT OF THE INVENTION:**

The object of the present invention is to remove inorganic mercury from drinking water.

Another object of the present invention is to construct a filter system to remove

impurities from drinking water.

Yet another object of the present invention is to use gold nanoparticle-coated alumina as a filtering medium for removing mercury.

Further object of the present invention is to utilize the constructed filter system for removal of mercury from industrial solvents, waste water, effluents and pesticides.

These and other objects, advantages of the present invention will be apparent by the forthcoming description.

Description with reference to drawing:

The column used for the study was 1.5 cm in diameter and 30 cm in height. The sorbent was packed in the column and the flow rate through the column was controlled by a peristaltic pump. The sorbent used was gold nanoparticle-coated alumina. Figure 1. Schematic representation of the setup used to study the mercury uptake from water using gold nanoparticle-coated alumina. Additional filter media are also shown. In a preferred experiment, 2 g of gold nanoparticle-coated alumina was packed over the first additional filter medium of glass wool in the column and the mercury contaminated water was passed through it and the eluent was collected for analysis. In case of removal of suspended matter and other contaminants, such as boron, which in this case is due to the process of reduction of Hg(II), other additional filter media may be added. Second additional filter medium of sand and third additional filter medium of magnesium oxide were used as additional filter media for the removal of suspended matter and boron, respectively. Finally the fourth additional filter medium of glass wool was packed in the column.

Specific example of the working of the system:

Detection of mercury

Detection of mercury in the concentration range of 0.2 mg/L to 2 mg/L was done using rhodamine 6G based UV-vis spectrometric method. Figure 2. UV-vis absorption spectra of blank and mercury containing samples, for rhodamine 6G based detection. In FIG. 2 trace 'a' is the absorption spectrum of rhodamine 6G which shows the characteristic absorption at 527 nm. Traces 'b-o' are the absorption spectra of 0.20, 0.25, 0.30, 0.40, 0.50, 0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95 and 1.00 mg/L Hg(II) ion concentrations, respectively. As the concentration of Hg(II) increases, the intensity of the absorption maximum of rhodamine 6G centered

at 527 nm decreases and another absorption feature at 570 nm emerges. Also observed is the color change of the solution from orange to pink as the concentration of mercury is increased. The absorbance at 570 nm is due to the complex formed between tetraiodomercurate and rhodamine 6G (Ramakrishna, T.V., Aravamudan, G., Vijayakumar, M., *Anal. Chim. Acta*, 1976, 84, 369). The inset is the plot of this absorbance intensity at 570 nm versus mercury concentration for traces 'b-o'. The red line in the inset shows a linear fit of absorbance with mercury concentration. The fit is excellent as suggested by the  $R^2$  value (0.9998). The data shows that mercury concentration down to 0.2 mg/L can be detected using this method and in the 0.2 to 2.0 mg/L concentration window, the colorimetric method is effective.

#### Uptake of mercury by gold nanoparticle-coated alumina

The eluent collected after passing 10 L of 0.2 mg/L Hg(0) through 4 g gold nanoparticle-coated alumina in the column, showed its complete removal.

The UV-vis absorption spectra for the elution of 1 mg/L and 2mg/L Hg(0) through a column containing 2 g of gold nanoparticle-coated alumina were studied.

Figure 3. (A)UV-vis absorption spectra of the solution as 1.0 and (B) 2.0 mg/L Hg(0) were passed through the column.

In FIG. 3A traces 'a-f' are the absorption spectra for the first 6 L of 1.0 mg/L Hg(0) containing water passed through gold nanoparticle-coated alumina. There is no absorbance at 570 nm in these spectra which is the indication of the absence of mercury in the eluent. Trace 'g' and trace 'h' are the absorption spectra for 7 and 8 L, respectively. The absorbance at 570 nm in these spectra is due to mercury and the concentration is 0.356 and 0.419 mg/L, respectively. The inset is the plot of mercury concentration versus the bed volume. In FIG. 3B traces 'a-e' are the absorption spectra of 0.5, 1.0, 1.5, 2.0 and 2.5 L, respectively for 2.0 mg/L Hg(0) containing water passed through gold nanoparticle-coated alumina. There is no absorbance at 570 nm in these spectra which is a clear evidence of the absence of mercury. Traces f, g, h are for 3.0, 3.5, 4L, respectively and the absorbance at 570 nm is very clear which is an indication of the presence of mercury. From these experiments the

loading capacity of Hg(0) is 3.388 gm per gm of gold nanoparticle. The loading capacity of Hg(0) expressed in terms of gold coated alumina is 2500 mg/kg. The extremely high capacity for incorporation on gold nanoparticle surface is due to gold-mercury amalgam formation and the amorphous mercury layer formation over gold nanoparticle surface (see below). Inset is the plot of mercury concentration versus bed volume.

The UV-vis absorption spectra of samples at various intervals were collected from a batch reaction using 1.5 mg/L Hg(0) and 1 g gold nanoparticle-coated alumina.

Figure 4. UV-vis absorption spectra of samples collected at different time intervals in a batch reaction using 1.5 mg/L Hg(0).

In FIG. 4 trace 'a' is the absorption spectrum of the supernatant collected after 30 minutes. It shows the intense absorption at 570 nm. Traces 'b-f' are the absorption spectra collected at 1, 2, 3, 4 and 5 h, respectively. Inset in the figure shows a plot of absorbance versus time. It shows a gradual reduction in the absorption at 570 nm and by the fifth hour, complete disappearance occurs. This reduced kinetics may be due to the slow incorporation of mercury on gold nanoparticles under vigorous stirring.

#### Detection and removal of boron

As Hg(II) is reduced to Hg(0) using  $\text{NaBH}_4$ , boron is present in the water. Concentrations of boron in the eluent were recorded using UV-vis spectrometer. Figure 5. UV-vis absorption spectra of boron samples for (A) calibration and (B) eluents collected from columns tested with 1.0 and 2.0 mg/L mercury.

In FIG. 5A trace 'a' is the absorption spectrum for the blank. Traces 'b-h' are the absorption spectra of 0.25, 0.50, 0.60, 0.70, 0.80, 0.90 and 1.0 mg/L boron, respectively. From trace 'b' onwards, a characteristic absorption at 425 nm started originating and its intensity increased with increase in boron concentration. The characteristic absorption at 425 nm is due to the formation of 1:1 bischelate complex of azomethine-H and boron (Matsuo, H., Miyazaki, Y., Takemura, H., Matsuoka, S., Sakashita, H., Yoshimura, K., *Polyhedron*, 2004, 23, 955). Inset is the plot of

absorbance versus boron concentration. It shows a linear relation. In FIG. 5B traces 'a' and 'b' are for the eluent collected after passing 1 L of 1.0 mg/L and 2.0 mg/L Hg(0) through the column. These spectra do not have the absorbance of boron complex at 425 nm and it exactly matches with the blank spectrum. This shows that the boron concentration is below 0.50 mg/L (permissible limit by World Health Organization) in these samples.

Through the use of NaBH<sub>4</sub> as the reducing agent for toxic heavy metal ions such as mercury, boron gets added to the water and if its concentration is above the permissible limit it can be removed using magnesium oxide. Figure 6. gives the UV-vis absorption spectra of the supernatant collected from magnesium oxide as an adsorbent. In FIG. 6 trace 'a' is the absorption spectrum due to the sample taken for the experiment. Trace 'b' is the absorption spectrum corresponding to the supernatant collected after one hour, traces 'c-g' are the spectra collected for samples at 2, 3, 4, 5 and 6 h, respectively. Traces 'h' and 'i' are for those collected after 12 and 24 h, respectively. Inset is the plot of absorbance versus time.

#### Characterization of the system

Figure 7. TEM images of gold nanoparticles before and after mercury treatment. FIG. 7A shows the large area TEM image of the as prepared gold nanoparticles. The nanoparticles are spherical in shape and are uniformly distributed as typical of citrate-based gold nanoparticle synthesis. Their size distribution is remarkably narrow and is within  $16 \pm 2$  nm. Lattice resolved image of an individual gold nanoparticle is given in FIG. 7B. A lattice spacing of 2.35 Å is seen, which corresponds to the (111) plane of gold. Multiple twinning is evident. FIG. 7C shows a large area image of mercury treated gold nanoparticles. The nanoparticles are of varying sizes and there is a broad size distribution. The image shows several larger particles being surrounded by smaller particles. It appears that the larger particles are undergoing Ostwald ripening. FIG. 7D shows the lattice resolved image of an individual mercury treated gold nanoparticle. The nanoparticle exhibits a lattice spacing of 2.24 Å, which corresponds to the (101) plane of Au<sub>3</sub>Hg alloy. No core-shell morphology is seen and it appears that the product formed is a continuous phase. It is clear that the ionic shell formed by the protecting group is disturbed due to Hg uptake, which contributes to the fusion of the particles.



Figure 8. SEM image, elemental map and EDAX spectrum of mercury treated gold nanoparticles. FIG. 8A and FIG. 8B are the large area SEM images of mercury treated gold nanoparticles. The image shows that some particles are very large in size and are distributed randomly. The morphology of the particles is different and they possess a thin surface layer which may be due to the presence of mercury. Elemental maps of Au and Hg overlaid on Si (from the glass substrate) are shown in FIG. 8C and 8D, respectively. From the elemental analysis, it is clear that gold and mercury are uniformly distributed in the particles. The uniform distribution of gold and mercury may be due to the amalgam formation. FIG. 8E shows the EDAX spectrum of the particles. Inset gives the composition. From the figure, it is clear that the nanoparticles formed are gold-mercury bimetallic alloys and their distribution is nearly uniform. Si and Sn are due to the substrate used.

Figure 9. XRD pattern of mercury treated gold nanoparticles. FIG. 9A shows the XRD pattern of gold nanoparticles which exhibits all the peaks expected for gold at  $38.17^\circ$ ,  $44.38^\circ$ ,  $64.57^\circ$ ,  $77.56^\circ$  and  $81.72^\circ$  in  $2\theta$  (JCPDS Data File No. [04-0784]). The peaks correspond to gold (111), (200), (220), (311) and (222) planes, respectively. FIG. 9B is the XRD pattern of mercury treated gold nanoparticles. It shows peaks at  $35.62^\circ$ ,  $37.47^\circ$ ,  $40.44^\circ$ ,  $52.59^\circ$ ,  $63.74^\circ$ ,  $69.64^\circ$ ,  $76.51^\circ$ ,  $78.37^\circ$  and  $79.94^\circ$  in  $2\theta$ . The peaks correspond to (100), (002), (101), (102), (110), (103), (112), (201) and (004) planes of  $\text{Au}_3\text{Hg}$  (JCPDS Data File No. [040808]). The peaks observed at  $31.64^\circ$ ,  $39.01^\circ$ ,  $66.09^\circ$  and  $83.81^\circ$  in  $2\theta$  correspond to the (110), (101), (220) and (202) planes of Hg-tetragonal (JCPDS Data File No. [89-3711]). The inconsistency between the EDAX and XRD data appear to be because XRD samples a much larger area.

#### **DETAILED DESCRIPTION OF INVENTION:**

The present invention describes a method to use the gold nanoparticle-coated alumina as a sorbent for the removal of inorganic mercury from drinking water. A filter for the remediation of mercury pollution has been proposed, in which the contaminated water is passed through a grid having a reducing material and then through a grid including a surface comprising amalgamating materials which are the gold nanoparticles. Although anisotropic particles are better sensors in comparison

to spherical particles, they are more expensive to make and a remediation strategy using these particles is expensive.

The present invention demonstrates a method for the development of a domestic water filter for removing mercury from drinking water using supported gold nanoparticles as a sorbent. The gold nanoparticle-coated alumina can act as a cost-effective, efficient and long lasting sorbent composition for mercury uptake from drinking water. The sorbent can work in either a packed bed configuration or as a stirred vessel batch reactor design. The nanoparticles may be impregnated on membranes, polymers, cloth, magnesium oxide, silica, clays, zeolites, polymers or activated carbon. The use of gold nanoparticle-coated alumina for the decontamination of water containing pesticides has already been explored. This makes the gold nanoparticle-coated alumina based filter as a highly efficient system for producing clean water by removing both pesticides and mercury from contaminated water. Spherical nanoparticles are much simpler to make, requiring fewer and inexpensive chemicals than anisotropic nanoparticles. Gold nanoparticles supported on alumina are easier to manufacture in large scale. The materials involved can be made in the field and as a result the technology is easier to implement, especially in the rural environment. Our method involves the conversion of  $\text{Hg(II)}$  to  $\text{Hg(0)}$ , which is taken up by nanoparticles. Other contaminants during the course of this chemistry are also removed subsequently, if their concentrations are higher than the limits prescribed.

The method herein proposes to develop a filter containing gold nanoparticle-coated alumina for the removal of inorganic mercury from drinking water.

In one of the preferred embodiment, the invention shall describe a filter system for filtering water, such that the filter system comprises of a filter assembly in which metal nanoparticles have been disposed in the flow path for the removal of impurities from water by incorporating the impurities such as mercury on the metal nanoparticles. The metal nanoparticles that has been disposed in the flow path shall be gold nanoparticles or plurality of metal nanoparticles with at least one metal being gold nanoparticles selectively with a combination of another metal nanoparticles

selected from a group comprising of silver, platinum, palladium, nickel, iron and copper.

Further the metal nanoparticles disposed in the flow pathway shall be alumina coated with gold nanoparticles or plurality of metal nanoparticles with at least one metal being gold nanoparticle selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper. Further, the filter system shall also include a reducing agent selected from the group comprising of sodium borohydride, stannous chloride, hydrazine or hydrogen for reducing the mercury from Hg(II) to Hg(0) form, prior to the incorporation onto the nanoparticles.

Thus the present invention which describes a filter system specifically for filtering water shall include all the features which have been described in the previous paragraph. The water filter system described shall be a drinking water filter system which accompanies all the features disclosed in the previous paragraph.

In another preferred embodiment, the filter assembly of the filter system for filtering water shall comprise an enclosed space which form a flow path for the water with two ends namely an inlet source end to receive the water to be filtered into the enclosed space and an outlet exit end to exit the filtered water from the enclosed space. Further the said filter assembly shall also include plurality of additional filters and nanoparticle filter which are arranged along the flow path for capturing plurality of impurities in the flow path. The plurality of impurities as per the invention shall include at least mercury.

As per the invention, at least some of the additional filters shall be arranged either before or after the nanoparticle filter in the flow path.

As per the invention, at least some of the additional filters shall be arranged both before and after the nanoparticle filter in the flow path.

In another preferred embodiment, the arrangement of additional filter medium in the filter assembly of the filter system for filtering the water is disclosed. The

arrangement of additional filters shall have a first additional filter medium which have been disposed closest to the inlet for capturing large particles in the water flowing within the enclosed space from inlet end to create a first strained flow along the flow path, a second additional filter medium shall be arranged thereafter for capturing suspended particles from the first strained flow to create a second strained flow along the flow path, metal nanoparticle filters shall be arranged thereafter for capturing mercury from the second strained flow to create a third strained flow along the flow path, a third additional filter medium shall be disposed next for capturing boron from the third strained flow to create a fourth strained flow along the flow path, and a fourth additional filter medium shall be arranged thereafter to create a fifth strained flow towards the outlet exit end of the enclosed space.

The said first additional filter medium shall be a glass wool. The said second additional filter medium shall be sand. The said third additional filter medium arranged shall be magnesium oxide. The said fourth additional filter medium arranged shall be of glass wool.

In another embodiment, the present invention describes a method for filtering water which involves the step of passing the water through a filter formed with metal nanoparticles or plurality of metal nanoparticles with at least one metal being gold, selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper or alumina coated with a plurality of metal nanoparticles with at least one metal being gold, selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper and arranged with additional filters in the flow path of the water to be filtered. Further the method shall also include the step of firstly introducing reducing agent selected from the group comprising of sodium borohydride, stannous chloride, hydrazine or hydrogen to reduce the mercury from Hg(II) to Hg(0) form contained in the water, and then passing the water containing the reduced mercury through a filter formed with nanoparticles for removing mercury.

The size of the said nanoparticles as per the invention shall range from 1 to 100 nm and further the shape of the said nanoparticles shall be of the form of nanospheres,

nanostars, nanowires, nanocubes or nanoplates. The said nanoparticles are impregnated on membranes, polymers, paper, cloth, magnesium oxide, silica, clays, zeolites, polymers or activated carbon. The concentration of mercury in the method for filtering water using a filter assembly shall be below 2 mg/L in the water to be filtered.

Studies have shown that inorganic mercury, existing principally as Hg(II) in water has to be reduced to Hg(0) for it to get captured on gold nanoparticles. Thus the present method involves the conversion of inorganic mercury in water to Hg(0) and then its incorporation on gold nanoparticles supported on suitable substrates. The chemical added to the water due to the action of reducing agent, used for the conversion of Hg(II) to Hg(0), can be removed from water whenever its concentration is above the permissible limits. Methods were developed for all these so as to produce clean drinking water.

The nanoparticles of gold, stabilized by citrate groups were synthesized by a procedure reported in the literature (Turkevich, J., Stevenson, P.L., Hiller, J., *Discuss. Faraday Soc.* 1951, 11, 55). The typical size of the particles synthesized by this method is  $16 \pm 2$  nm in diameter. Gold nanoparticle-coated alumina was prepared by the following procedure. 10 g of neutral activated alumina were soaked in 25 mL of gold nanoparticles and allowed to stand for 30 minutes. Once the supernatant became colorless, it was replaced with another fresh 25 mL suspension. This procedure was repeated until there was no color change for the supernatant. After decanting the supernatant, gold nanoparticle-coated alumina were washed thoroughly with distilled water and dried under ambient condition. The size of the nanoparticles ranges from 1 to 100 nm. The intake of gold nanoparticle was about 738 mg per 1 kg alumina.

For detection of Hg(II) ions in water by UV-vis spectroscopy, a standard procedure was followed (Ramakrishna, T.V., Aravamudan, G., Vijayakumar, M., *Anal. Chim. Acta*, 1976, 84, 369). For the uptake of mercury, a down-flow column apparatus was used, the details of the instrumental setup is given below. For removing mercury from water, 1.0 mg/L Hg(II) was first reduced with dilute aqueous NaBH<sub>4</sub> (10 times the mercury concentration) and allowed to stand for 1 h. Afterwards, the solution was



passed through a column containing 2 g of gold nanoparticle-coated alumina. 5 mL of the eluent was collected at an interval of 100 mL. Before analysis, the eluent collected was treated with concentrated HCl for the oxidation of Hg and the pH of the solution was adjusted to six by adding NaOH. Afterwards the detection of mercury was carried out. The experiment was continued till mercury was detected in the eluent. Same experiment was repeated with 2.0 mg/L Hg(II) also. A study was done with 0.2 mg/L mercury for understanding the interaction of low concentrations of mercury with gold nanoparticle-coated alumina. 4 g of gold nanoparticle-coated alumina was taken in the column and mercury solution was passed through it. 50 mL of the eluent was collected at an interval of 1 L. Mercury concentration in the solution was detected using a Mercury Analyzer. Batch experiments were done for finding the time-dependent removal of mercury using gold nanoparticle-coated alumina. For the study, 1 g of gold nanoparticle-coated alumina was transferred to NaBH<sub>4</sub> treated 500 mL of 1.5 mg/L Hg(II) in a conical flask, and stirred continuously. 5 mL of the sample was collected at different time intervals and centrifuged at 10,000 rpm for 15 minutes to remove the suspended gold particles. Supernatant was collected for mercury measurement. Boron concentrations in the 1 mg/L and 2mg/L Hg(0) solutions passed through the column were detected by a reported procedure (Lopez, F.J., Gimenez, E., Hernandez, F., *Fresen. J. Anal. Chem.*, 1993, 346, 984). In order to have a larger boron concentration in the eluent, a column study was done with 2.0 mg/L Hg(II) reduced with 20 times excess NaBH<sub>4</sub>. The eluent was collected and boron concentration was detected. Performance of magnesium oxide as a boron adsorbent was tested (Soto, M.M.F.G., Camacho, E.M., *Sep. Purif. Technol.*, 2006, 48, 36). 250 mg of magnesium oxide was transferred to 50 mL of the eluent in a conical flask and stirred continuously. 2.5 mL of the sample was taken at different time intervals and centrifuged at 10,000 rpm for 15 minutes. The supernatant was collected and analyzed for boron.

For TEM image, 25 mL of gold nanoparticles was added to 25 mL of NaBH<sub>4</sub> treated 2 mg/L Hg(II) and kept for 1 h. Then the solution was centrifuged at 20,000 rpm for 30 minutes. The residue was collected and dropped on amorphous carbon films supported on a copper grid and dried in ambience. For scanning electron microscopy (SEM) and energy dispersive analysis of X-rays (EDAX), the residue collected in the above procedure was drop-casted on an indium tin oxide (ITO) conducting glass and

dried. For X-ray diffraction (XRD) analysis, the residue collected in the above procedure was casted on a glass plate and air-dried. Nanoparticle samples without Hg(0) uptake were also studied.

## **WE CLAIM :**

1. A filter system for filtering water comprising a filter assembly of metal nanoparticles disposed in the flow path for the removal of impurities from the water by incorporating the impurities on the metal nanoparticles, the said impurities including at least mercury.
2. A filter system for filtering water as claimed in claim 1 wherein the filter assembly is plurality of metal nanoparticles with at least one metal being gold selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper, disposed in the flow path for removal of impurities from the water by incorporating the impurities on the nanoparticles, the said impurities including at least mercury
3. A filter system for filtering water as claimed in claim 1 wherein the filter assembly having alumina coated with plurality of metal nanoparticles with at least one metal being gold nanoparticle selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper disposed in the flow pathway for removal of mercury from the water by incorporating mercury on the nanoparticles.
4. A filter system for filtering water as claimed in claim 1-3 wherein a reducing agent is disposed for reducing the mercury from  $\text{Hg(II)}$  to  $\text{Hg(0)}$  form in the flow path ahead of the said filter assembly, wherein the said reducing agent selected from the group comprising of sodium borohydride, stannous chloride, hydrazine or hydrogen.
5. A water filter system comprising of a filter assembly for filtering the said water, the filter assembly having metal nanoparticles disposed in the flow path for removal of impurities from the water by incorporating the impurities on the metal nanoparticles, the said impurities including at least mercury

6. A water filter system as claimed in claim 5 wherein the filter assembly is plurality of metal nanoparticles with at least one metal being gold nanoparticles selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper disposed in the flow path for removal of impurities from the water by incorporating the impurities on the nanoparticles, the said impurities including at least mercury
7. A water filter system as claimed in claim 5 wherein the filter assembly having alumina coated with plurality of metal nanoparticles with at least one metal being gold nanoparticles selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper, disposed in the flow path for removal of mercury from the water by incorporating the mercury on the nanoparticles.
8. A water filter system as claimed in claim 5-7 wherein a reducing agent is disposed for removal of mercury from water by reducing the mercury from  $\text{Hg(II)}$  to  $\text{Hg(0)}$  form in the flow path ahead of the said filter assembly, wherein the said reducing agent selected from the group comprising of sodium borohydride, stannous chloride, hydrazine or hydrogen.
9. A drinking water filter system comprising of a filter assembly for filtering the said water, the filter assembly having metal nanoparticles disposed in the flow path for removal of impurities from the water by incorporating the impurities on the metal nanoparticles, the said impurities including at least mercury.
10. A drinking water filter system as claimed in claim 9 wherein the filter assembly is plurality of metal nanoparticles with at least one metal being gold nanoparticles selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper, disposed in the flow path for removal of impurities from the water by incorporating the impurities on the nanoparticles, the said impurities including at least mercury

11. A drinking water filter system as claimed in claim 9 wherein the filter assembly having alumina coated with plurality of metal nanoparticles with at least one metal being gold nanoparticles selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper, disposed in the flow path for removal of mercury from the water by incorporating the mercury on the nanoparticles.
12. A drinking water filter system as claimed in claim 9-11 wherein a reducing agent is disposed for reducing the mercury from Hg(II) to Hg(0) form in the flow path ahead of the said filter assembly, wherein the said reducing agent selected from the group comprising of sodium borohydride, stannous chloride, hydrazine or hydrogen.
13. The filter system for filtering water, as claimed in claim 1-12, the filter assembly further comprising:
  - a. an enclosed space which forms a flow path for the water, the flow path having two ends;
  - b. an inlet source end formed at one end of the flow path to receive the water to be filtered into the enclosed space;
  - c. an outlet exit end formed at the other end of the flow path to exit the filtered water from the enclosed space, and
  - d. a filter assembly including plurality of additional filters and nanoparticle filter arranged along the flow path for capturing plurality of impurities in the flow path, including at least mercury from the water to be filtered.
14. The filter system for filtering water, as claimed in claim 1-12, the filter assembly further comprising:
  - a. an enclosed space which forms a flow path for the water, the flow path having two ends;
  - b. an inlet source end formed at one end of the flow path to receive the water to be filtered into the enclosed space;
  - c. an outlet exit end formed at the other end of the flow path to exit the filtered water from the enclosed space, and



- d. a filter assembly including plurality of additional filters and nanoparticle filter arranged along the flow path for capturing plurality of impurities in the flow path, including at least mercury from the water to be filtered, wherein at least some of the additional filters arranged before the nanoparticle filter in the flow path.
15. The filter system for filtering water, as claimed in claim 1-12, the filter assembly further comprising:
- a. an enclosed space which forms a flow path for the water, the flow path having two ends;
  - b. an inlet source end formed at one end of the flow path to receive the water to be filtered into the enclosed space;
  - c. an outlet exit end formed at the other end of the flow path to exit the filtered water from the enclosed space, and
  - d. a filter assembly including plurality of additional filters and nanoparticle filters arranged along the flow path for capturing plurality of impurities in the flow path, including at least mercury from the water to be filtered, wherein at least some of the additional filters arranged after the nanoparticle filter in the flow path.
16. The filter system for filtering water, as claimed in claim 1-12, the filter assembly further comprising:
- a. an enclosed space which forms a flow path for the water, the flow path having two ends;
  - b. an inlet source end formed at one end of the flow path to receive the water to be filtered into the enclosed space;
  - c. an outlet exit end formed at the other end of the flow path to exit the filtered water from the enclosed space, and
  - d. a filter assembly including plurality of additional filters and nanoparticle filter arranged along the flow path for capturing plurality of impurities in the flow path, including at least mercury from the water to be filtered, wherein at least some of the additional filters arranged before the nanoparticles and at least some of the additional filters arranged after the nanoparticles in the flow path.

17. The filter system for filtering the water as claimed in claim 16 wherein the filter assembly includes additional filters arranged as:-
  - a. a first additional filter medium of glass wool disposed closest to the inlet for capturing large particles in the water flowing within the enclosed space from inlet end to create a first strained flow along the flow path,
  - b. a second additional filter medium arranged thereafter comprising of sand for capturing suspended particles from the first strained flow to create a second strained flow along the flow path,
  - c. said metal nanoparticles filter arranged thereafter for capturing mercury from the second strained flow to create a third strained flow along the flow path,
  - d. a third additional filter medium arranged thereafter comprising of magnesium oxide for capturing boron from the third strained flow to create a fourth strained flow along the flow path, and
  - e. a fourth additional filter medium arranged thereafter comprising of glass wool to create a fifth strained flow towards the outlet exit end of the enclosed space.
18. A method for filtering water comprising of passing the water through a filter formed with metal nanoparticles.
19. A method for filtering water comprising of passing the water through a filter formed with plurality of metal nanoparticles with at least one metal being gold, selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper.
20. A method for filtering water comprising of passing the water through a filter formed with alumina coated with a plurality of metal nanoparticles with at least one metal being gold, selectively with a combination of another metal nanoparticles selected from a group comprising of silver, platinum, palladium, nickel, iron and copper.

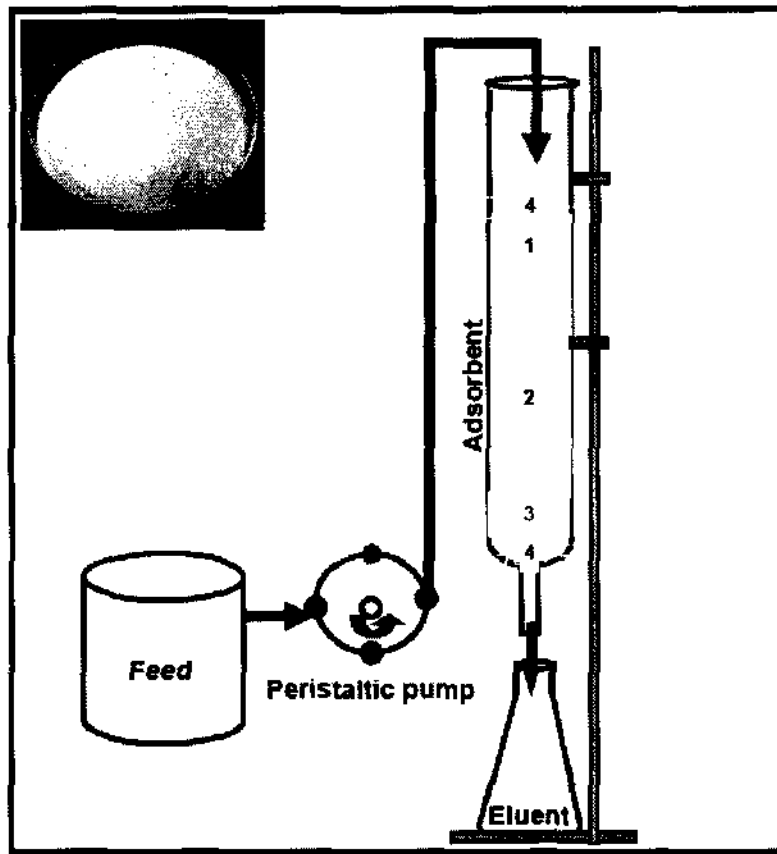
21. A method for filtering water as claimed in claim 18-20 further comprising of passing the water through the additional filters arranged in the flow path of the water to be filtered.
22. A method for filtering water as claimed in claim 18 to 21 comprising of introducing a reducing agent to reduce the mercury from Hg(II) to Hg(0) form contained in the water, and passing the water containing reduced mercury through a filter formed with nanoparticles for removing mercury wherein the said reducing agent selected from the group comprising of sodium borohydride, stannous chloride, hydrazine or hydrogen.
23. The nanoparticles of claim 1 to 22 are such that the size of the said nanoparticles ranges from 1 to 100 nm.
24. The nanoparticles of claims 1 to 22 is such that the shape of the said nanoparticles is nanospheres, nanostars, nanocubes, nanowires or nanoplates or other shapes.
25. The nanoparticles of claims 1 to 22 is such that the nanoparticles are impregnated on membranes, polymers, cloth, magnesium oxide, silica, clays, zeolites, polymers or activated carbon.
26. The filter system as claimed in claims 1 to 17 is such that the concentration of mercury is below 2 mg/L in the water to be filtered.
27. The method for filtering water claimed in claims 18 to 21 wherein the concentration of the mercury is below 2 mg/L in the water to be filtered.

Dated on this 27<sup>th</sup> day of January, 2009.

For **INDIAN INSTITUTE OF TECHNOLOGY**,  
By its attorney,

  
(**ARUNACHALAM APPAJI MOHAN**)  
(**BRINDA MOHAN**)

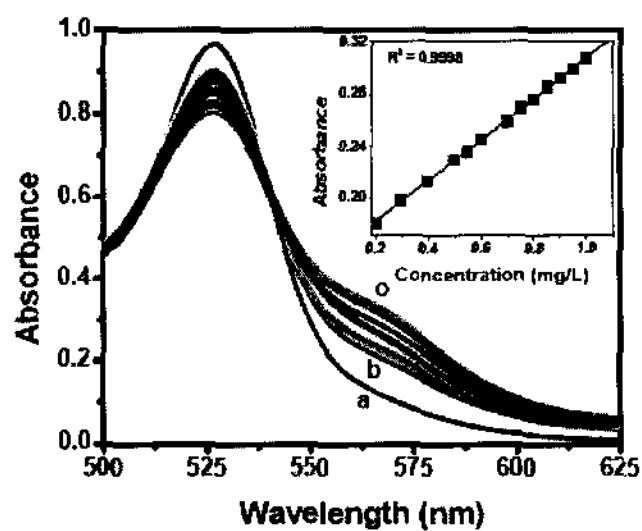
FIG 1



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**FIG 2**



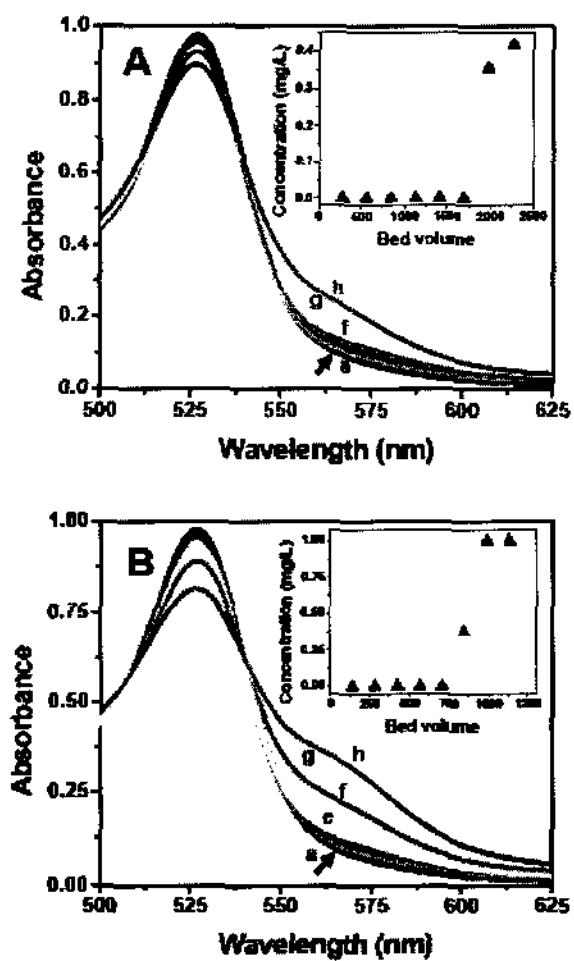
For **INDIAN INSTITUTE OF TECHNOLOGY**,  
By its attorney,

*Brinda Mohan*

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FIG 3

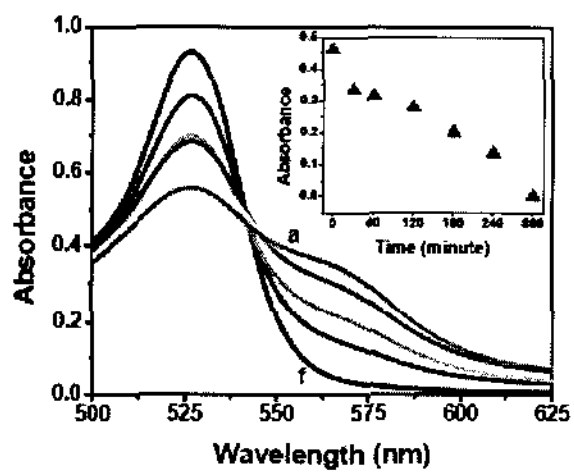


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FIG 4

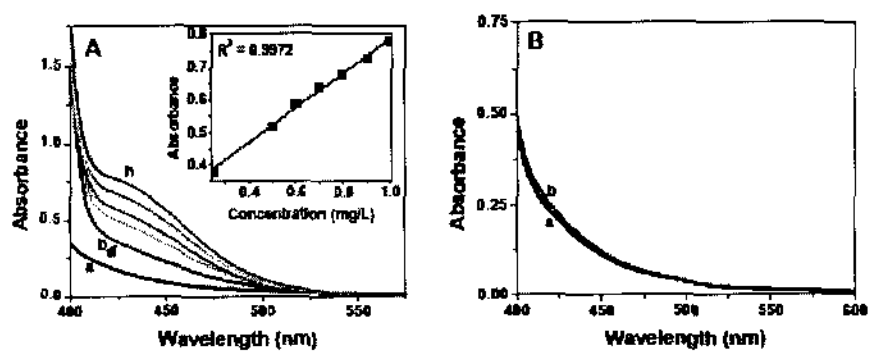


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FIG 5

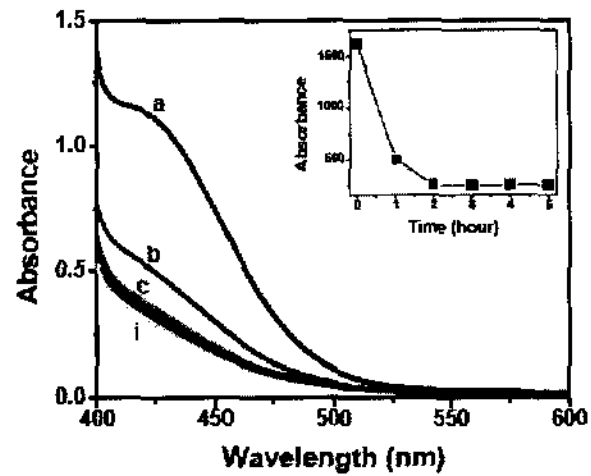


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**FIG 6**

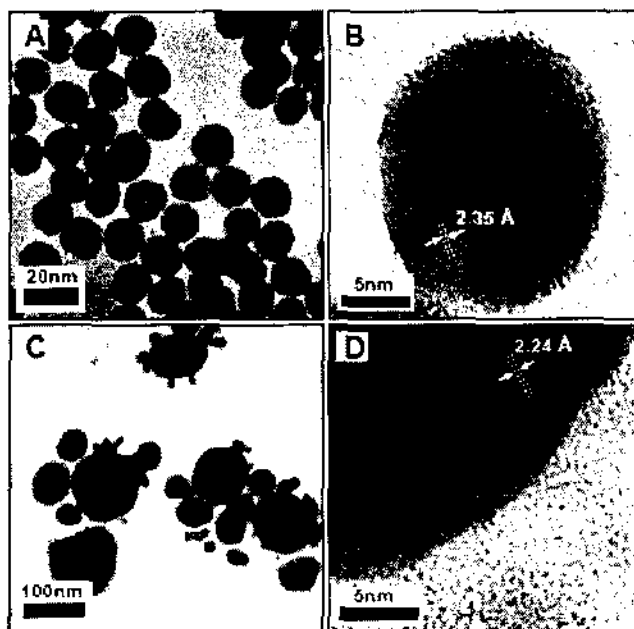


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**FIG 7**

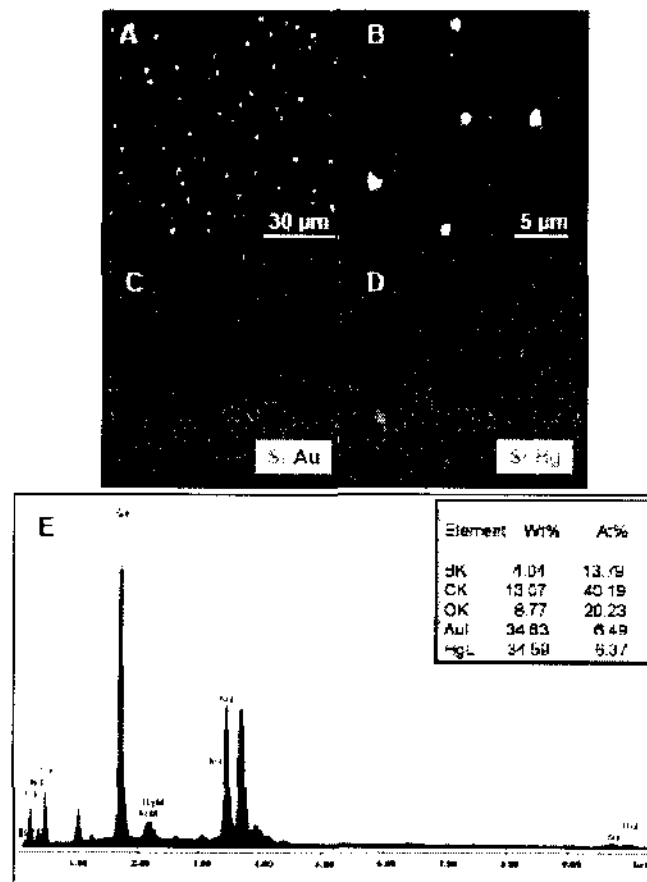


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**FIG 8**

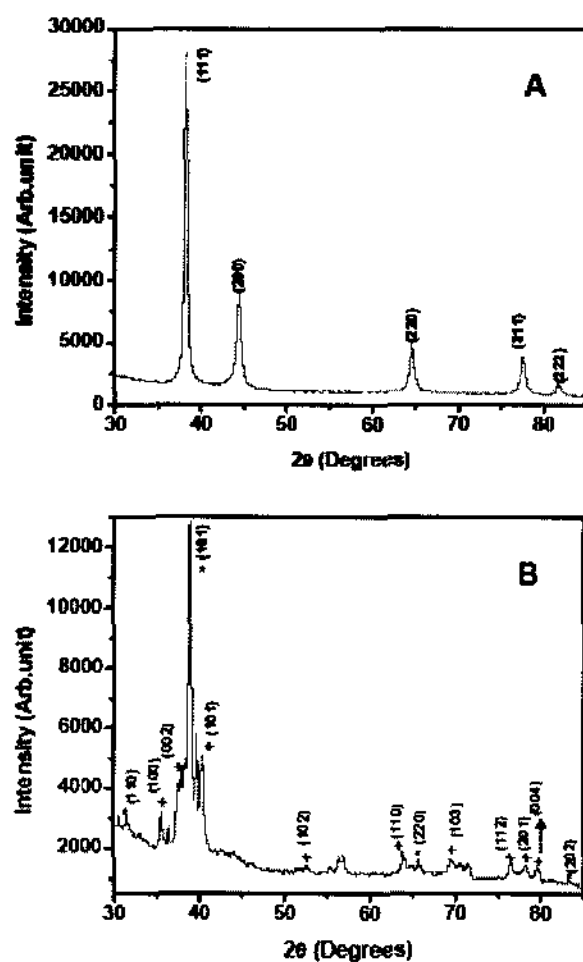


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FIG 9



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