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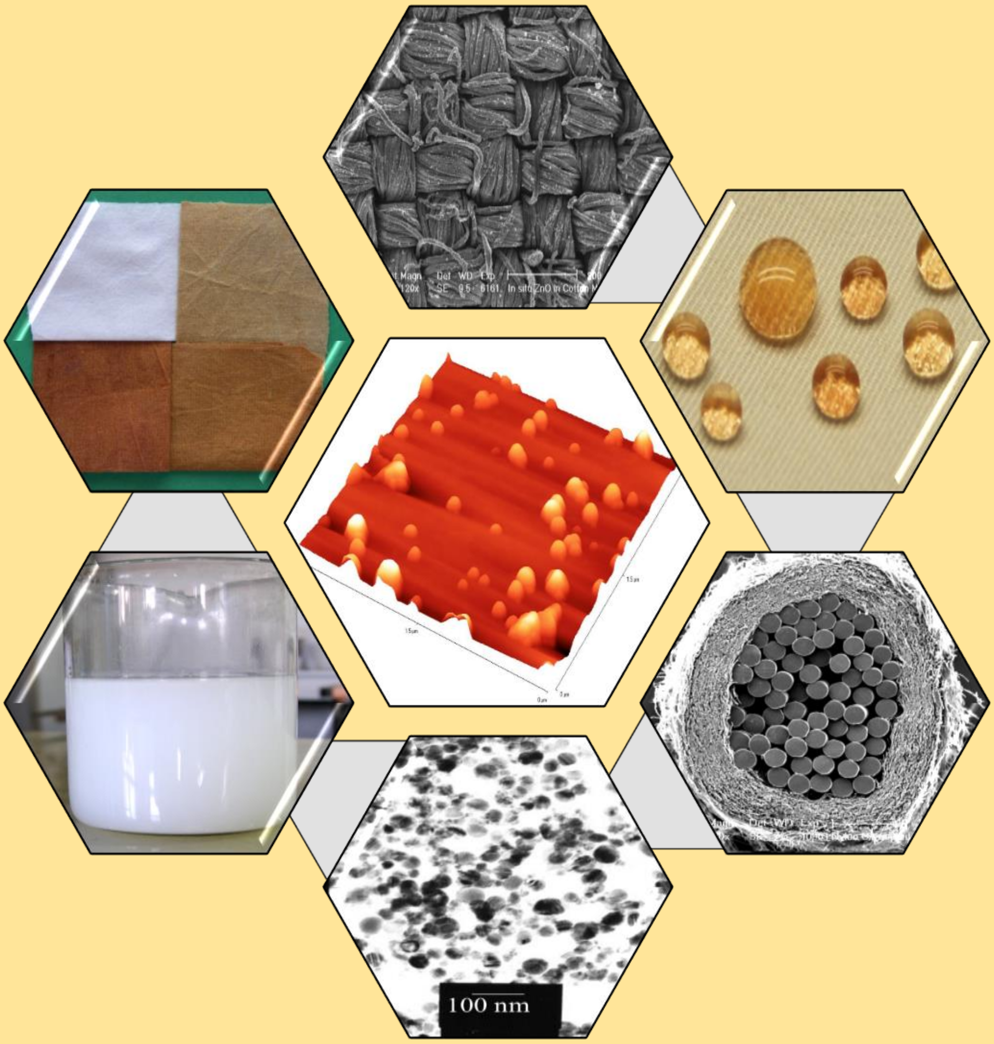
Frequently Asked Questions on Nanotechnology



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ICAR-CIRCOT Frequently Asked Questions on Nanotechnology 2021.

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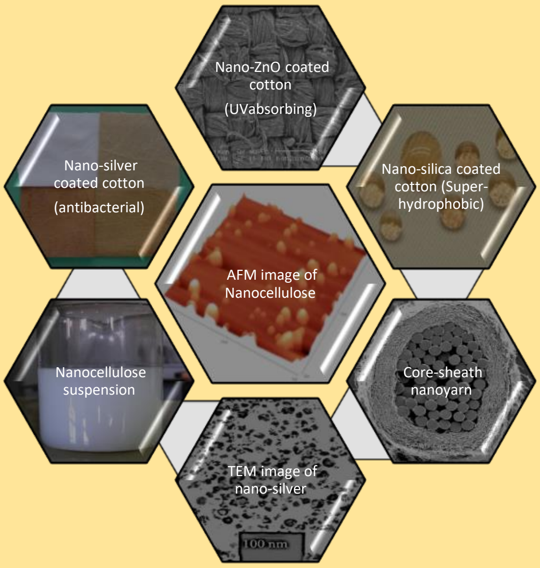

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Abbreviations

0D	Zero Dimension
1D	One Dimension
2D	Two Dimensions
AAS	Atomic Absorption Spectrometer
AFM	Atomic Force Microscope
Ag	Silver
atm	Atmosphere (unit of pressure)
BET	Brunauer–Emmett–Teller
CIRCOT	Central Institute for Research on Cotton Technology
CNT	Carbon Nano Tube
DBT	Department of Biotechnology
DLS	Dynamic Light Scattering
DST	Department of Science and Technology
EDAX	Energy Dispersive X-ray Spectrometer
FTIR	Fourier-Transform Infrared Spectrometer
ICAR	Indian Council of Agricultural Research
LASER	Light Amplification by Stimulated Emission of Radiation
m	Meter
MFM	Magnetic Force Microscope
MPa	Mega Pascal
nm	Nanometer
NP	Nano Particles
OECD	Organization for Economic Cooperation & Development
psi	Pounds per Square Inch
SAXS	Small Angle X-Ray Scattering
SEM	Scanning Electron Microscope
SPM	Scanning Probe Microscope
SQUID	Superconducting Quantum Interference Device
STM	Scanning Tunnelling Microscope
TC	Technical Committee
TiO_2	Titanium dioxide
TEM	Transmission Electron Microscope
XPS	X-Ray Photoelectron Spectroscope
XRD	X-Ray Diffractometer
XRFS	X-Ray Fluorescence Spectrometer
ZnO	Zinc Oxide

1. Basics of Nanotechnology, Characterization and Standards

a) What is nanotechnology?

Nanotechnology involves the production and manipulation of materials and structures in the nanometre scale (1 to 100 nm), that exhibit novel properties different from its bulk counterpart.

b) How old is nanotechnology?

- Nanoscale materials were used for centuries like, very small-sized gold and silver particles created colors in the stained glass windows of medieval churches built hundreds of years ago.
- A lecture entitled "*There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics*" in 1959 by the renowned physicist Richard Feynman is considered to be the beginning of modern scientific research in nanotechnology.
- The scientific research in this field gained momentum after the invention of tools like scanning tunneling microscope (STM) and atomic force microscope (AFM) in the early 1980s and the discovery of carbon nanotube (CNT) by Sumio Iijima in the year 1991.

c) Who is considered to be the Father of Nanotechnology?

- Physicist **Richard Feynman** is considered as the Father of Modern Nanotechnology. His famous lecture entitled "*There's Plenty of Room at the Bottom*" at an American Physical Society meeting at the California Institute of Technology (CalTech) on December 29, 1959 is considered to be the beginning of the era of Nanotechnology.
- **Norio Taniguchi**, a Japanese scientist was the first to define the term "nanotechnology" in 1974 as: "nanotechnology mainly consists of the processing of separation, consolidation, and deformation of materials by one atom or one molecule".
- The term nanotechnology caught enormous amount of public attention in 1986 when it was popularized through the book written by **Eric K Drexler** "*Engines of creation: the coming era of Nanotechnology*"
- In India, **Prof. C.N.R. Rao**, who has worked mainly in solid-state and structural chemistry is considered as the Father of Nanotechnology.

d) Who are all the Nobel Laureates in the field of Nanotechnology?

1) In 1925, Richard Adolf Zsigmondy received Nobel Prize in Chemistry for his demonstration of the heterogenous nature of colloid solutions and for the methods he used, which have since become fundamental in modern colloid chemistry.
2) In 1965, Richard P. Feynman received Nobel Prize in Physics for the fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles.
3) In 1986, the Nobel Prize in Physics was shared between Ernst Ruska for his fundamental work in electron optics & for the design of the first electron microscope, and Gerd Binnig & Heinrich Rohrer for their design of the scanning tunneling microscope.
4) In 1996, Robert F. Curl, Jr., Sir Harold W. Kroto, Richard E. Smalley received Nobel Prize in Chemistry for their discovery of fullerenes (new form of element Carbon).
5) In 2014, Eric Betzig, Stefan W. Hell and William E. Moerner received Nobel Prize in Chemistry for the development of super-resolved fluorescence microscopy.
6) In 2016, Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard L. Feringa received Nobel Prize in Chemistry for the design and synthesis of molecular machines.
7) In 2017, Jacques Dubochet, Joachim Frank and Richard Henderson received Nobel Prize in Chemistry for developing cryo-electron microscopy for the high-resolution structure determination of biomolecules in solution.

e) How big is nano?

Nanometer is one-billionth of a meter.

1 nm = 10^{-9} m

f) What is special about nanomaterials?

Conventional properties of materials are changed significantly in the nanometer scale. So, without changing material composition, novel properties could be obtained only by changing the size to nanometer region. More surface area, less crystal defects, enhanced surface-to-surface interactions result in exhibition of novel and newer properties by nanomaterials.

g) What are 0D, 1D and 2D nanomaterials?

0D = Zero dimension, meaning all 3 dimensions are in nanometer scale.

Examples: Nanoparticles, buckyballs, nanoemulsion.

1D = One dimension, meaning 2 dimensions are in nanometer scale.

Examples: Nanofibres, nanowires, CNTs, nanorods.

2D = Two dimension, meaning only one dimension is in nanometer scale.

Examples: Nanofilms, nanolayers, graphene.

h) What is graphene?

Graphene is a special type of nanomaterial consisting of single layer of carbon atoms arranged in a honeycomb like structure. Since the carbon in this structure has only 3 bonds, graphene becomes a highly electro-conductive material.

i) How are the nanomaterials produced?

There are mainly two approaches: (i) Top-down approach and, (ii) Bottom-up approach. In top-down approach, bulk (bigger) material is converted into nanomaterial by size reduction. In bottom-up approach, smaller material (atoms or ions or molecules) is converted to nanomaterial by controlled aggregation or agglomeration or precipitation.

j) What is DLS? How is it useful in nanotechnology?

DLS refers to Dynamic Light Scattering and, this principle is used in DLS particle size analyzer. This system analyses the suspended nanoparticles in the size range from 0.5 to 6,000 nm. Here, the assumption is that the nanoparticles are spherical in shape.

k) What is AFM? How is it useful in nanotechnology?

AFM refers to Atomic Force Microscope. This is a type of Scanning Probe Microscope (SPM) and uses the atomic forces of interaction between the sample and probe to obtain the image. The advantages of AFM include, it can obtain the 3-Dimensional image of sample, various surface properties of nanomaterials can be measured and micro-mechanical properties of samples can be analyzed.

l) What are the instruments used for nanomaterial characterization?

A) Particle size & its distribution – DLS size analyzer, TEM, SEM, AFM, SAXS.

B) Zeta potential – DLS analyzer, Potentiometric titration

C) Specific surface area and pore size – BET analyzer

D) Crystallinity – XRD.

E) Elemental composition – FTIR, TEM/EDAX, AAS, XRFS, XPS.

F) Fluorescence – Spectrofluorometer / Photoluminescence measurement

G) Magnetic properties – MFM, SQUID.

H) Viscosity – Rheometer

I) Mechanical properties – AFM

m) Give some examples of nanomaterials that are commercially available?

Nanomaterials of Silver, Gold, Copper, Alumina, Zinc Oxide, Iron oxide, Titania, Silica, Clay, Cabon nanotubes, Graphene, Cellulose, Chitosan, Silk fibroin are commercially available for diversified applications.

n) Which technical groups are working on making international standards in the field of nanotechnology?

Following technical groups are working towards the development of standards in nanotechnology:

- ISO Technical Committee on Nanotechnologies (TC 229)
- ANSI-Nanotechnology Standards Panel (ANSI-NSP)
- ASTM Committee E56 on Nanotechnology
- BSI British Standards Committee for Nanotechnologies (NTI/1)
- European Committee for Standardization “Work program Nanotechnologies” (CEN/TC 352)
- IEC group for nanotechnology standardization for electrical and electronic products and systems (TC 113)
- IEEE Nanotechnology Standards Working Group
- Organization for Economic Cooperation & Development (OECD) Working party on Manufactured Nanomaterials (WPNM)

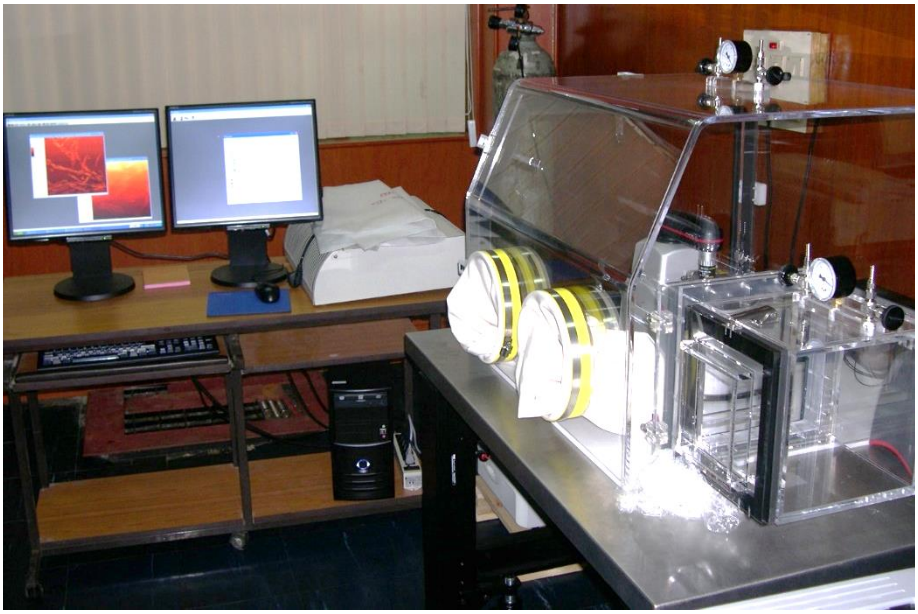
o) Which are the areas of Nanotechnology covered by the ISO/TC 229 standards?

Terminology and nomenclature; metrology and instrumentation, including specifications for reference materials; test methodologies; modelling and simulations; and science-based health, safety, and environmental practices.

p) What are the guidelines available in India for the production, handling and disposal of nanomaterials?

- DST: Guidelines and Best Practices for Safe Handling of Nanomaterials in Research Laboratories and Industries (https://dst.gov.in/sites/default/files/Draft-Guidelines%20.pdf)
- DBT: Guidelines for Evaluation of Nano Based Agri-input and Food Products in India 2020 (http://dbtindia.gov.in/sites/default/files/Guidlines%20Document.pdf).

ICAR-CIRCOT, Mumbai has been instrumental in formulation of these two nanotechnology guidelines as member of the steering committees of DST and DBT.



Atomic Force Microscope at ICAR-CIRCOT, Mumbai

2. Preparation of Nanomaterials

a) What are the different types of top-down approaches used for production of nanomaterials?

Top-down approach involves the breaking down of the bulk material into nanosized particles. Examples are mechanical milling / cryomilling, intensive refining, high pressure homogenization, high shear homogenization, lithography, gamma irradiation, thermal decomposition and laser ablation.

b) How are the nanomaterials produced by bottom-up approach?

Bottom-up approach involves the aggregation or agglomeration of atoms / ions / molecules into nanosized material. This can be achieved by various techniques like reduction, oxidation, Langmuir Blodgett technique, electrospinning and so on.

c) What are the different types of milling process?

Attrition ball mill, Planetary ball mill, Vibratory ball mill, Tumbling mill, High energy ball mill, Cryomilling.

d) What is planetary ball mill?

Planetary ball mill consists of several cylindrical grinding jars filled with loose grinding balls. Two superimposed rotational movements move the grinding jars, like in a planetary system the grinding jar rotates in an orbit around the centre. They are used for fine grinding of soft, hard to brittle or fibrous materials.

e) What is the normal ball to material mass ratio maintained in ball milling?

Normally 2:1 ratio is maintained but again it depends on the nature of the material.

f) What are the disadvantages of high energy milling process?

High energy consumption, greater time consumption, crystal defects, difficulty in controlling the uniformity of the products and formation of undesirable alloys are some of the disadvantages.

g) Which are the materials used for making the grinding balls of a ball mill?

Hardened steel, stainless steel, tungsten carbide, agate, sintered aluminium oxide, silicon nitride and zirconium oxide are used for making the grinding balls of a ball mill.

h) What is cryogrinding?

It is a low temperature (below −150°C) grinding with liquid nitrogen. This type of grinding is generally performed for organic materials and materials that are generally heat sensitive.

i) What is electrospinning?

Electrospinning is a nanofibre production method that uses high voltage to draw charged threads of polymer solutions or polymer melts, in the range of few hundred nanometer fibre diameter. Various parameters like voltage, polymer concentration, polymer viscosity and distance between tip and collector decides the quality of nanofibres.

j) What is electrospraying?

Electrospraying is an effective alternative for controlled application of finishing chemicals to only one surface of the textile fabric. The electric charge draws the liquid, which is coming out from the nozzle in the form of a fine jet that disperses further into droplets that are highly charged. The charge and size of the droplets are controlled by voltage and flow rate.

k) What is Langmuir-Blodgett film?

A Langmuir–Blodgett film is a nanofilm formed when Langmuir monolayers are transferred from the liquid-gas interface to solid supports by immersing the solid substrate into the liquid. A monolayer is adsorbed homogeneously with each immersion step, thus films with required thickness can be made.

l) How is the chemical reduction technique used for production of nanoparticles?

A chemical precursor reduced by a reducing agent in the presence of a stabilizer could lead to the production of nanoparticles. For example, silver nitrate can be reduced to silver nanoparticles by sodium borohydride in the presence of sodium citrate.

m) What are the pros and cons of bottom-up approach for nanomaterial synthesis?

The advantages include the production of nanoparticles with uniform particle size distribution and better control over the composition of the nanoparticles. The disadvantages include very low production rate and generation of effluent.

n) What are the pros and cons of top-down approach for nanomaterial synthesis?

The advantages include the higher production rate, ease of operation and minimal effluent generation. The disadvantages include the production of nanoparticles with wide size distribution and addition of impurities (elemental contamination).

o) What is Plasma Nanotechnology?

Plasma is the fourth state of matter in which an ionized gaseous substance becomes highly electrically conductive to the point that long-range electric and magnetic fields dominate the behaviour of the matter. Plasma Nanotechnology is the use of plasma in the growth and processing of nanomaterials.

High Pressure Homogenizer at ICAR-CIRCOT, Mumbai.

3. Nanocellulose and Nanocomposites

a) What is nanocellulose?

Nanocellulose is a nanomaterial produced from cellulose. It can be produced from cotton, agro-biomass, wood, algae and tunicates. It can also be produced from bacterial cellulose.

b) How nanocellulose is produced?

Conventionally, nanocellulose is produced by acid hydrolysis process and high energy homogenization process. To reduce the effluent problem and to reduce the energy consumption, recently various pre-treatments are being used for energy efficient production of nanocellulose.

c) What is homogenization?

Homogenization is the process of emulsifying two immiscible liquids (i.e. liquids that are not soluble in one another) or uniformly dispersing solid particles throughout a liquid. The benefits include improved product stability, uniformity, consistency, viscosity, shelf life, improved flavor and color.

d) What is high pressure homogenization?

High pressure homogenization is a purely mechanical process, in which a fluidic product is forced through a narrow gap (homogenizing nozzle) at very high pressure (150-300 MPa or 20,000 to 40,000 psi). The liquid product is subjected to very high shear stress causing the formation of very fine emulsion droplets. Extreme shear and high energy input have to be applied to reduce droplets from the micro- to the nano-scale range.

e) What are the operating parameters which affect the efficiency of high-pressure homogenizer?

Pressure, temperature, number of passes, valve and impingement plate design and flow rate affect the efficiency.

f) What is the pressure range of working on ultra-high pressure homogenizer?

Pressure range from 300 to 400 MPa (40,000 to 60,000 psi).

g) Who are the major manufacturers of ultra-high pressure homogenizer in the world?

Microfluidics, DeBEE International, Silverson, Anton-paar, Goma and Stansted are the major manufacturers.

h) What are the common types of high pressure homogenizers?

Nozzle, Piston-gap and Interaction chambers (Y/Z type).

i) What are the advantages of high pressure homogenization process?

Low risk of product contamination, narrow size distribution of the nanoparticles produced are the advantages that allow aseptic production of nano-suspensions for medical use.

j) What is refining?

Refining is a mechanical treatment, which causes cutting and fibrillation of pulp fibres to improve their paper-forming properties. Fibrillation improves the fibre-fibre bonding during the paper sheet formation. This process is used as a pre-treatment step in nanocellulose production.

k) What are the different types of refiners?

Disc (single-disc, double-disc, and multi-disc) and Conical (Jordan-type, Claflin-type) refiners are generally available.

l) What is beating?

Beating is a batch process, where the pulp slurry circulates through an oval tank around a midsection and passes between a revolving roll with bars and a bedplate with bars resulting in cutting and fibrillation of pulp fibres. This process is used as a pre-treatment step in nanocellulose production.

m) What is cavitation and how it breaks the particle size?

It is the phenomenon of sequential formation, growth, and collapse of millions of microscopic vapour bubbles (voids) in the liquid. The collapse or implosion of these cavities creates high localized temperatures and pressure of about 1000–2000 atm and results into short-lived (microsecond duration), localized hot-spots in cold liquid. This process is used in ultra-high pressure homogenizer and ultrasonication.

n) What is LASER ablation technique?

Laser ablation is a method for fabricating various kinds of nanoparticles including semiconductor quantum dots, carbon nanotubes, nanowires, and core shell nanoparticles. In this method, nanoparticles are generated by sequential removal of layers from solid metals and industrial compounds.

o) What are nanocomposites?

Composites contain two or more different constituent materials (phases), each having its own significant characteristics, creates a new substance with superior properties than the original individual materials. In nanocomposites, at least one phase will have nanoscale morphology like nanoparticles, nanotubes or nanolayers.

p) What are the advantages of nanocomposites?

Nanocomposites exhibit improved strength to mass ratio, thermal stability and chemical resistance. Also, they exhibit novel optical and functional properties apart from their light weight nature.

q) What is a bionanocomposite?

Bionanocomposites include one or more biomaterials (like starch, cellulose, chitosan, biological hydroxyapatite) in their base structure. They are mostly used in biomedical and agricultural applications.

r) Are nanocomposites biodegradable?

The biodegradability of a material is mostly decided by its chemical composition. Hence, the nature of material(s) included in the production of nanocomposite materials decides its biodegradability.

4. Nano in Environment & Sustainability

a) What is the influence of Nanoparticles on sustainability?

Due to very high surface area to volume ratio, the requirement of chemicals in nano form is comparatively less as compared to that of its bulk counterpart. This will result in saving the material utilization. Also, corresponding level of lower effluent generation is beneficial in terms of cost and effectiveness.

b) Whether nanoparticles are harmful to the environment?

Nano form is an intermediate state of the matter, between atomic/ionic forms and bulk form. In the environment, due to the influence of various factors, the nanoparticles may get ionized or aggregated to bulk form. Hence, the chances are that the toxicity if any, may get reduced over a period of time. The scientific analyses of the environmental impact of nanoparticles are underway in various laboratories.

c) Whether nanoparticles can create environmental pollution?

In most cases, the pollution load of nanoparticles is the same as that of its bulk or atomic/ionic counterparts. It may cause pollution when it is released into the environment without any proper material handling system. In case of new engineered nanomaterials like graphene and CNTs, the environmental impact is yet to be ascertained.

d) What is the role of nanotechnology in water purification?

There are several nano-based techniques available in the market, using nano-silver, graphene, titania etc. that can purify the water. In addition, nanofilters are available for water purification by filtration technique.

e) Whether nanoparticles used for the water purification will spoil the health of the consumers?

The nanoparticles of silver, most commonly used for water purification, have been studied widely to ascertain its effect on the consumers. In most cases, the silver concentration in the potable water is well within the acceptable limits as prescribed by the international agencies. However, the actual impact depends on the nature of nanoparticles used and the amount of nanoparticles that get released into the water during use.

f) Which nanoparticles are used for effluent treatment?

For adsorption technique, CNTs/ polymer nanocomposites/ zeolites/ nanoscale metal oxide and nanofibres are used. For disinfection technique, nano silver/titanium dioxide (Ag/TiO_2) and CNTs are used. For filtration process, nano-Ag/TiO_2/zeolites/magnetite, graphene and CNTs are used. For photocatalysis, nano-TiO_2, nano ZnO and fullerene are used.

g) How nanomaterials can be used to prevent membrane fouling in the tertiary effluent treatment?

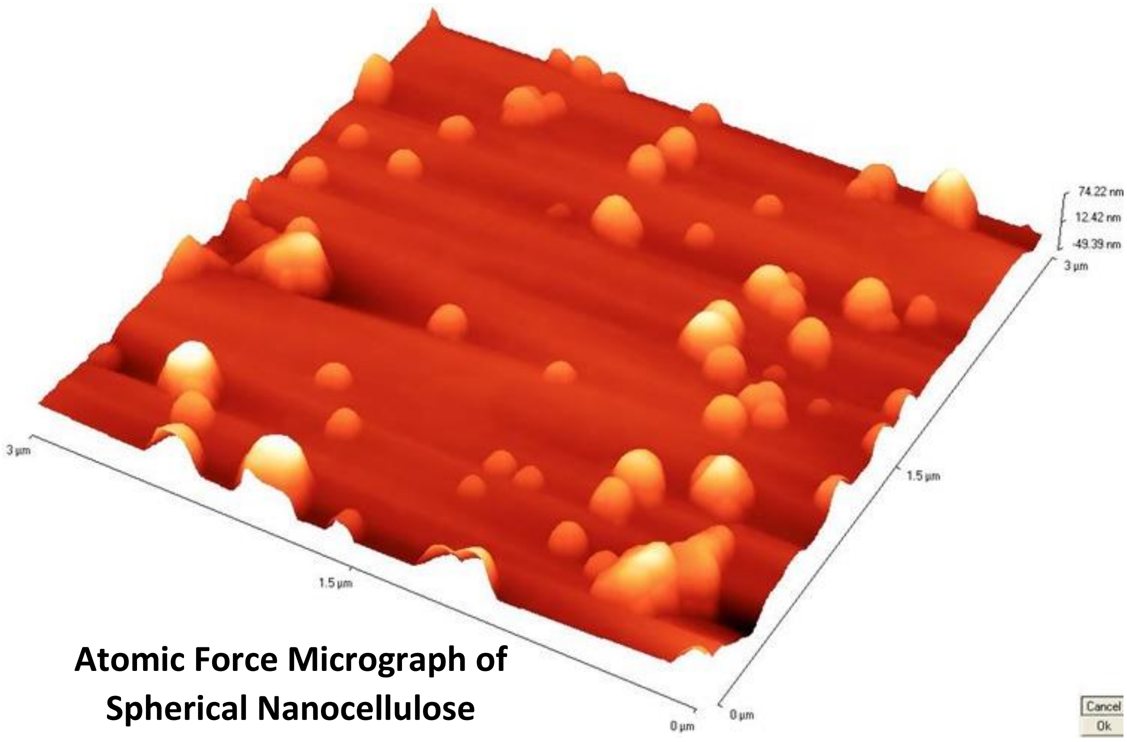
One of the problems associated with membrane processes during effluent treatment is the fouling of membranes. This problem is efficiently managed if the membrane is coated with nano particles like nano Ag or nano TiO_2.

h) What is the role of nanoparticles in filtration of air?

Nano composite based membranes are nowadays being used to filter the particulate matters present in the air. Also, nano-based coatings are being developed for use in face mask.

i) Whether the cost of nanoparticles is too high for adopting in effluent treatment process?

If overall process cost is taken into consideration including the environmental impact, the cost is competitive, since the quantum of nanoparticles required is very less.



Atomic Force Micrograph of Spherical Nanocellulose

5. Nano in Textiles

a) What kind of functionality in textiles can be improved using nanomaterials?

Nanomaterials are expected to either improve the existing properties or bring new functionalities to textiles such as super-hydrophobicity, antibacterial properties, antiviral properties, UV protection, self-cleaning property, conductive and antistatic properties.

b) How are the nanomaterials added to the textile materials?

Nanomaterials can be added to the textiles either during the fibre / yarn production or during the finishing. It can also be applied by the coating process.

c) What is the in situ method of production of nanomaterials?

In this method, nanoparticles are produced inside the textile fibres using precursors, catalyst and oxidation / reduction agents.

d) What are the benefits of using nanomaterials in textiles?

New and multi functionalities can be produced using nanomaterials. The amount of chemical requirement can be reduced significantly without affecting the required performance.

e) Is it also possible to produce nano-textiles without nanomaterials?

Yes, it is also possible to produce nano-textiles without nanomaterials. It can be done by creating nano-sized porosity or nano-structures or nano-thick polymer coating.

f) Is there any environmental benefit due to usage of nanomaterials in textiles?

Replacing conventional materials with nanomaterials will reduce the environmental burden. Less material is needed to achieve the same results and the higher textile performance helps to reduce the washing frequency so that less energy and water is being consumed.

g) Where can we see nanotechnology in consumer textile products right now?

Medical textiles, antibacterial bandages / gowns, antibacterial socks, superhydrophobic fabrics, stain-resistant fabrics, face masks are some of the products wherein nanomaterials are being tried extensively in the market.

h) Whether any safety measures need to be followed while applying nanomaterials to the textiles?

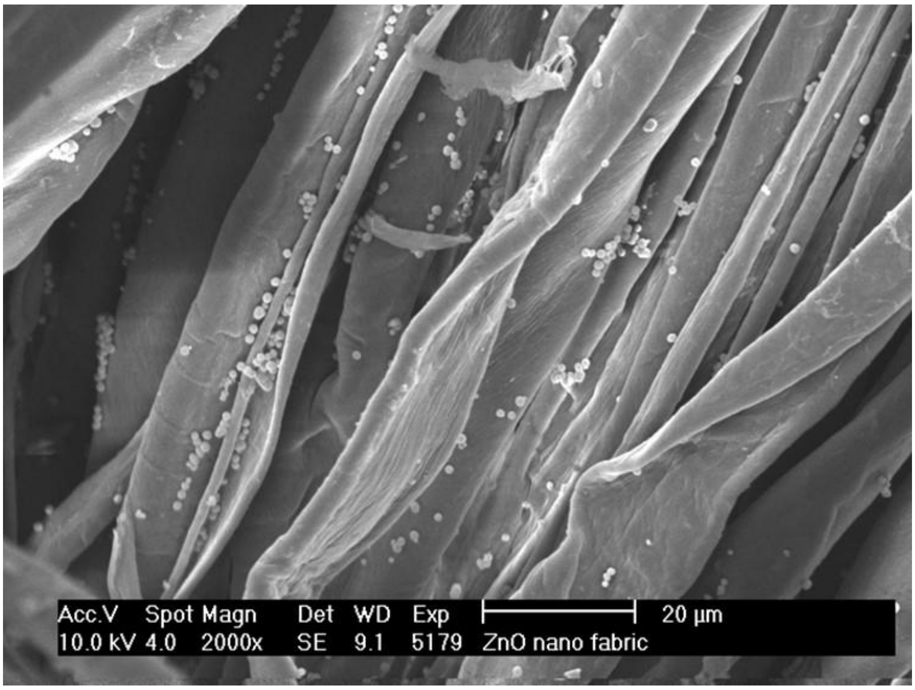
Yes. Protective gears are to be used while using nano formulations in powder form. For suspension form of nanomaterials, routine chemical safety gears need to be used.

i) What are nanofibres and how they are used?

Nanofibres are produced either by mechanical / chemical processes or by electrospinning technology. They can have multifaceted properties such as excellent filtration, high surface area and high permeability. These materials can filter toxic gasses, pathogens (bacteria, viruses), and harmful substances present in the air.

j) How plasma is applied in textiles?

Plasma technology is a water free technology and can be exploited as an environment-friendly and versatile way of treating textile materials to improve variety of properties such as wettability, liquid repellency, dyeability and coating adhesion.



Scanning Electron Micrograph of Nano-Zinc Oxide Coated Cotton Textiles

6. Nano in Agriculture

a) What are the applications of nanomaterials/nanotechnology in agriculture?

- Slow release smart agrochemicals and delivery systems for crop improvement.
- The antimicrobial properties of nanoparticles enable them to protect crops against microbial attack.
- Genetic modifications and gene or drug delivery in plants and animals are carried out using nano-carriers or nano-bullets.
- The nanomaterials carrying herbicides, insecticides, fertilizers, pesticides and genes are referred to as magic bullets.
- Nanomaterial based sensors are used to detect plant diseases and assess the soil/water quality.
- Nanotechnology also finds applications in post-harvest management like food packaging, barcodes / smart labels, processing and testing.
- Nanomaterials have potential applications in remediation of contaminated soils as they adsorb the toxins and pollutants on their surface owing to their large surface area and thus help in the catalytic removal of pollutants from the soil.

b) What are nanofertilizers?

Nanofertilizers are the crop nutrients made into nano-form or embedded into nano-carriers for improved utilization efficiency. These can be of two forms: (i) Nanomaterials carrying fertilizers like nano-encapsulation, nano-delivery system and (ii) Fertilizers in the nano-form like Nano-Zinc, Nano-Iron, Nano-Sulfur and so on.

c) Why nanofertilizers are better than the conventional fertilizers?

- Nanofertilizers improve the availability of nutrients by increasing their stability as encapsulation protects them from the harsh field conditions.
- Targeted and controlled delivery by nanofertilizers prevents unwanted nutrient loss and leads to better utilization of nutrients.
- Nanofertilizers also enable slow and sustained release of nutrients thus making them available to the crops for a longer duration.

d) What are nanopesticides and why they are preferred to conventional pesticides?

- Nanopesticides are the formulations of pesticides in the form of either nanocapsules or nanoemulsions, which provide protection to crops in an effective manner with minimum negative impact on the environment due to reduction in the quantity of pesticide required for controlling the pests/insects.
- Formulations of nanoemulsions improve the bioavailability of pesticides by increasing the solubility of their active molecules which are poorly soluble in water and nanoencapsulation of pesticides enables their slow and sustained release with minimum effect on the non-target organisms.

e) How nanotechnology reduces the adverse effects of pesticides and fertilizers?

- The indiscriminate use of large doses of agrochemicals (fertilizers, pesticides, herbicides) is posing a great risk to the environment and non-target organisms.
- Nanotechnology enables the efficient use of agrochemicals by targeted delivery and controlled release resulting in reduction of their active doses with minimum toxic effect on the non-target organisms and environment.
- Moreover, nanoformulations of agrochemicals do not need frequent applications on the crops as they are more stable than the conventional ones against harsh field conditions and thus provide nutrients and protection to the crop for a longer duration by producing the maximum effect using minimum dose.

f) Do nanoparticles have antimicrobial properties?

Nanoparticles like silver, copper, zinc oxide have good antibacterial and antifungal properties and hence, they can be used for the protection of crops against microbial attack.

g) Do nanomaterials cause toxicity in plants?

Different researchers have found different toxicity behaviour of nanoparticles. In some cases nanoparticles have promoted the growth of plants and in other cases they have reduced the germination percentage and growth of plant which suggests that the toxicity of nanoparticles may be influenced by several factors like the type of nanomaterials, concentration, nature of the plant and other environmental factors.

h) What factors influence the toxicity of nanoparticles?

The toxicity of nanoparticles is influenced by several factors such as their physicochemical properties (material property, size, shape, specific surface area, solubility, type of material and stability), exposure time and dosage concentration. Moreover, the plant species, their stage of development, soil type and other environmental factors like pH, ionic strength, organic matter and soil microbes also influence the toxic effect of nanoparticles.

i) Do all the nanoparticles show toxicity? What are the major phytotoxic effects of nanoparticles?

Some nanoparticles do not show toxicity even at high concentrations however others show toxic effect even at low concentrations suggesting that toxicity of nanoparticles depends on their physicochemical properties. The toxicity level of bionanomaterials are relatively less when compared to that of inorganic nanomaterials.

j) How nanoparticles are translocated to different parts of the plant?

Due to their small size, nanoparticles may enter the plants by uptake through the soil or foliar sprays. Endocytic pathway is another way by which plants take up nanoparticles from their surroundings. Once entered, they are translocated to different parts of the plant by either symplastic or apoplastic pathways. In case of uptake through the soil, NPs adhere to the root surface, penetrate the cell membrane, enter the vascular bundles and are then tarnslocated to aerial parts of the plant through transpiration via xylem. Whereas in case of uptake through the foliar spray, nanoparticles enter the plant leaves either by penetrating through the stomatal openings or by entrapment in the cuticle which are then translocated to the stem and the root cells via phloem.

k) Do nanoparticles accumulate in the edible parts of the plants?

The translocation and accumulation of nanoparticles in the edible parts of the plants also depends on various factors like physicochemical characteristics of nanoparticles and plant species, developmental stage of the plant, type of nanomaterial, dosage concentration and exposure time. Although accumulation of nanoparticles in the edible parts of the plants has not been observed in several studies, some reports have revealed their accumulation.

l) Do nanomaterials are transferred to humans and other animals through food chain or other routes?

Some reports have shown that nanoparticles are absorbed from the surrounding environment by some water fleas, earthworms and fishes during food intake and were observed to be accumulated at low levels in several organs. Although there are very less reports on the transmission of accumulated nanoparticles to the next trophic levels, some studies have shown the transmission of nanoparticles from algae and tobacco to the next trophic level.

m) What is the fate of nanoparticles inside the plants? Do they persist in the plant after uptake?

Only the nanoparticles with size less than 25 nm enter inside the cell and are translocated to different parts of the plants. Some nanomaterials also undergo biotransformation which may either lead to their detoxification or conversion into more toxic forms. Biotransformation is mediated by soil microbes, root exudates of the plants, and other factors to which nanoparticles are exposed during uptake and translocation. However, there is very little information about the site of storage of nanoparticles in the plant.

n) How nanotechnology can be used to add value to agro-biomass?

Nanocellulose can be produced from any agro-biomass that is rich in cellulose; like, cotton linters, sugarcane bagasse and banana pseudostem fibres. Nano-lignocellulose produced from lignocellulosic agro-biomass can be used as fillers in biocomposites. Nanocoating and nanofinishing can add value to biomass based products like fibre mats, panels and so on.

o) What is the role of nanotechnology in post-harvest management?

To avoid post-harvest losses, nanomaterials can be used for food storage and transportation. Fruits and vegetables can be handled with nanocoatings and nanopackings to keep them fresh for longer.

p) What is the role of nanotechnology in maintaining the soil and crop health?

Nanotechnology enabled precision farming allows real-time monitoring of field conditions like soil conditions, soil fertility, moisture level, temperature, crop growth, status of crop nutrient, insect attacks, different plant diseases, weeds etc. The obtained data helps in the optimization of plantation time and harvesting, water and time management, fertilizer dosage along with other agro-chemical applications.

q) How nanotechnology helps in the quality maintenance of agricultural products?

Identity Preservation (IP), tracking of agricultural products and barcode technology via nanodevices helps in the quality maintenance of agro-products and proper monitoring of production system. Nanobarcodes consist of particles having easy machine readable and encodable properties. Gold, silver nanoparticles are being used for the manufacturing of these types of barcodes.

**DLS Nanoparticle Sizer Analyzer
at ICAR-CIRCOT, Mumbai.**

7. Nanotechnology Research at ICAR-CIRCOT, Mumbai

The ICAR-Central Institute for Research on Cotton Technology (ICAR-CIRCOT), one of the premier constituent institutes of the Indian Council of Agricultural Research (ICAR), was established in the year 1924. The Institute is conducting research and development on all aspects of postharvest processing of cotton and value addition to cotton by-produce. The research on nanotechnology was initiated in the year 2004 with the microbial production of nano-silver for application in cotton textiles. Later, the scope is widened to include nano-Zinc Oxide, Nano-titania, Nano-Chitosan, Nanocellulose and Nano-Sulphur for diversified applications in cotton textiles, paper and pulp, packaging films, paints, coating of fruits & vegetables, filters, face mask and nanocomposites. A brief account is given below:

Nanomaterials under Research & Development	• Nano-Silver, Nano-Zinc Oxide, Nano-Sulphur, Nanocellulose, Nano-titania, Nano-Chitosan.
Bulk scale production of nanomaterials	• Nanocellulose: 10 kg per shift of 8 hours • Nano-Zinc Oxide: 1 kg per shift of 8 hours
Facilities available	• Nanocellulose Pilot Plant with beater, refiner, reactor, high pressure homogenizer and freeze drier • Electrospinning facility for production of nanofibres. • AFM, DLS size analyzer (0.6 nm to 6000 nm), XRD and SEM. • In addition, various instruments are available in chemistry, microbiology and physics laboratories.
Technologies available for commercial use	• Nanocellulose, Nano Zinc Oxide and Nano Silver production. • Nanomaterials application in textiles and composites. • Nanofibres production by Electrospinning.
Support provided to various stakeholders	• Training programmes are organized for various stakeholders in the field of Nanotechnology. Around 15 training programmes organized during the period, 2010 to 2020. • Incubation facility available for budding entrepreneurs who would like to develop nano-based products. • Commercial testing facility provided for nanomaterials and nano-based products.

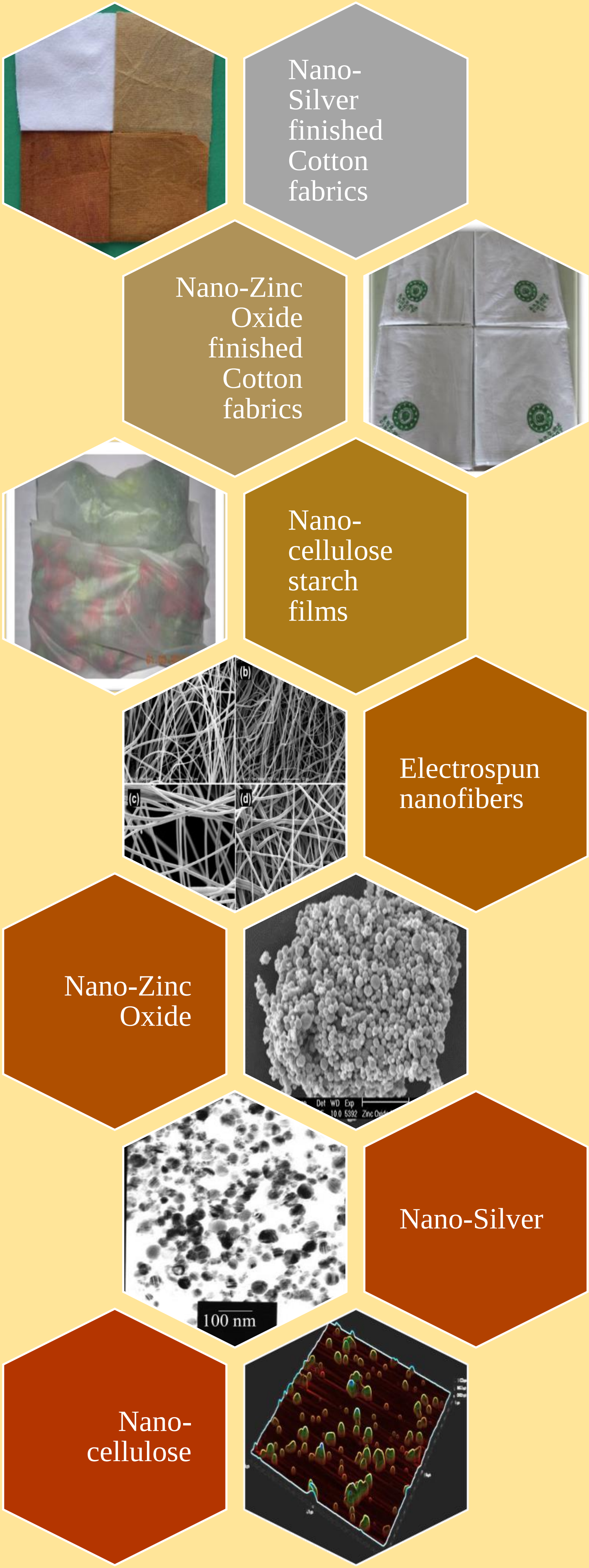
Major Nanotechnology Research Projects at ICAR-CIRCOT, Mumbai

SNo	Title of the Project	Sponsored by
1	Synthesis and Characterization of Nano-Cellulose and its Application in Biodegradable Polymer Composites to Enhance Their Performance	World Bank funded NAIP project of ICAR, New Delhi
2	Electrospinning Geometry Optimization for Preparation of Core-sheath Nanofibres and Conversion of Nanofibres into Yarns	DST, New Delhi
3	Biodegradable Electrospun Fibre Mat for Use in Packaging of Fresh Perishable Agricultural Material	NFBSFARA of ICAR, New Delhi
4	Zonal Technology Management and BPD Unit at CIRCOT, Mumbai (National Agricultural Innovation Project, Component 1)	World Bank funded NAIP project of ICAR, New Delhi
5	Cellulose based nanocomposite film for application in food packaging	CRP-Nanotechnology of ICAR, New Delhi
6	Application of Nanoparticles in paper coating	ICAR-CIRCOT, Mumbai Code No.: CH-70
7	Application of zinc oxide nanoparticles for imparting different functional finishes to cotton textiles	ICAR-CIRCOT, Mumbai Code No.: CH-71
8	Application of silver nanoparticles for antimicrobial finishing of cotton textiles	ICAR-CIRCOT, Mumbai Code No.: CH-72
9	Design and Development of Electrospraying setup for production of high performance cotton textiles	ICAR-CIRCOT, Mumbai MP-75
10	Surface modification of cotton textiles using nano technology to impart super hydrophobicity	ICAR-CIRCOT, Mumbai Code No.: CH-82
11	Nano-finishing of cotton textile to impart flame retardence and U.V. protective functionalities	ICAR-CIRCOT, Mumbai Code No.: CH-83
12	Improving the interfacial interaction of nanocellulose with commodity polymers toenhance their performance	ICAR-CIRCOT, Mumbai Code No.: CH 86
13	Toxicological and environmental impact of ICAR-CIRCOT's nanomaterials (Nanocellulose, Nanosilver and Nano-ZnO)	ICAR-CIRCOT, Mumbai Code No.: CH 98

High Impact Nanotechnology Publications from ICAR-CIRCOT, Mumbai

- A novel one-pot 'green'synthesis of stable silver nanoparticles using soluble starch, ***Carbohydrate research***, 341(12), 2012-2018, 2006.
- Functional finishing of cotton fabrics using zinc oxide–soluble starch nanocomposites, ***Nanotechnology***, 17(20), 5087-5095, 2006.
- Functional finishing in cotton fabrics using zinc oxide nanoparticles, ***Bulletin of materials Science***, 29(6), 641-645, 2006.
- Biological synthesis of silver nanoparticles using the fungus *Aspergillus flavus*, ***Materials letters***, 61(6), 1413-1418, 2007.
- Functional finishing of cotton fabrics using silver nanoparticles, ***Journal of nanoscience and nanotechnology***, 7(6), 1893-1897, 2007.
- Biomimetics of silver nanoparticles by white rot fungus, *Phaenerochaete chrysosporium*, ***Colloids and Surfaces B: Biointerfaces***, 53(1), 55-59, 2006.
- Spectroscopic characterization of zinc oxide nanorods synthesized by solid-state reaction, ***SpectrochimicaActa Part A:Molecular and Biomolecular Spectroscopy***,65(1),173-178,2006.
- Silver− protein (core− shell) nanoparticle production using spent mushroom substrate, ***Langmuir***, 23(13), 7113-7117, 2007.
- Functional behaviour of polypropylene/ZnO–soluble starch nanocomposites, ***Nanotechnology***, 18(38), 385702, 2007.
- Preparation and characterization of cellulose nanowhiskers from cotton fibres by controlled microbial hydrolysis, ***Carbohydrate Polymers***, 83(1), 122-129, 2011.
- Functional behaviour of paper coated with zinc oxide–soluble starch nanocomposites, ***Journal of Materials Processing Technology***, 210(14), 1962-1967, 2010.
- Nanofibrillation of cotton fibers by disc refiner and its characterization, ***Fibers and Polymers***, 12(3), 399-404, 2011.
- Effect of Fenton's pretreatment on cotton cellulosic substrates to enhance its enzymatic hydrolysis response, ***Bioresource technology***, 103(1), 219-226, 2012.
- Preparation of nano cellulose fibers and its application in kappa-carrageenan based film, ***International journal of biological macromolecules***, 51(5), 1008-1013, 2012.
- A novel process for synthesis of spherical nanocellulose by controlled hydrolysis of microcrystalline cellulose using anaerobic microbial consortium, ***Enzyme and microbial technology***, 52(1), 20-25, 2013.
- Energy Efficient Manufacturing of Nanocellulose by Chemo- and Bio-Mechanical Processes: A Review, ***World Journal of Nano Science and Engineering***, 5(4), 204-212, 2015.
- Nanocellulose-Polymer Composites for Applications in Food Packaging: Current Status, Future Prospects and Challenges, **Polymer-Plastics Technology and Engineering**, 56(8), 805-823, 2017.

ICAR-CIRCOT Regional Stations


Nano-Silver finished Cotton fabrics
Nano-Zinc Oxide finished Cotton fabrics
Nano-cellulose starch films
Electrospun nanofibers
Nano-Zinc Oxide
Nano-Silver
100 nm
Nano-cellulose

ICAR-CIRCOT

Mumbai.

Nanocellulose Pilot Plant

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