DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18NTO301T - APPLICATIONS OF NANOTECHNOLOGY
Module-I, Lecture-2

Environmental pollutants in Water

SRM
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WATER

- 71% from earth surface.
  - 97% salt water (sea)
  - 3% fresh water
    - 87% ice and glaciers, underground, air.
    - 13% surface water (0.4% total water).
- Function
  - Domestic.
  - Industry.
  - Agriculture.
  - Recreation.
  - Safety and security.

WATER

- 70% total human body wt.
- 30 – 40% bone mass.
- Body functions:
  - Absorption of oxygen at alveoli.
  - Control of body temperature.
  - Blood component.
  - Digestion in kidneys and intestine.

WATER

- Ideal water supply
  - Quality.
  - Quantity.
- Water quality parameter
  - Physical.
    - Suspended solid (SS), color, taste, smell, temp.
  - Chemical.
    - Dissolved substances, alkalinity, hardness, fluoride, heavy metal, organic compound, nutrient (nitrogen & phosphorus), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD).
  - Biology.
    - Bacteria, virus, protozoa, etc.

WATER POLLUTION

- Uncontrolled land development since colonial era (end 19th century).
  - Agriculture (logging, estate, farms).
  - Mining (tin, gold, cuprum).
  - Industrialization.
  - Housing development.
  - Hydro dam.

Sources of Water Pollution

- Pollution of clean water resources
    - Erosion at water catchments areas.
    - Erosion of rivers.
    - Effluent from rubber and palm oil factories.
    - Effluent from mining site.
    - Effluent from industry area.
    - Effluent from farming area.
    - Effluent from domestic area.

TYPE OF POLLUTANTs

- pH.
- Organic content.
- Suspended solids.
- Ammonium-nitrogen.
- Microbes.
- Heavy metals
    - lead, cuprum, cadmium.
- Pesticides.

WATER POLLUTION

- Will cause
  - Soil contamination.
  - Air contamination.
  - Food chain contamination.
- Lack of clean water supply for
  - Domestic demand.
  - Industry use.
  - Agriculture use.

WATER POLLUTION

- Will also cause
  - Breeding of diseases vector.
  - Spreading of water borne diseases.
  - Food poisoning.
  - Skin problem.

WATER POLLUTION

- 80% of diseases in developing countries are due to water supply contamination.
- 4 – 5 million child died every year due to water supply contamination.
- More than 1 million died after severe diarrhea.

WATER the Elixir of Life

- Good water quality is where it free from disease organism, dangerous chemical substances, radioactive, accepted taste and smell.

Main Nanotechnological Processes for Wastewater Treatment

- Nanofiltration
- Nanomaterials for catalysis and photocatalysis
- Nanomaterials for water disinfection
- Nanomaterials for adsorption of pollutants
- Nanoscale zerovalent iron (nZVI)

Environmental and Human Health Effects of Nanomaterials used in Wastewater Treatment

- A very important factor that is highly significant for broader commercial use of these products in the future is their impact on human health and the ecosystem.
- Once nanoparticles come to nature, their interaction with chemical substances in the environment can often have negative consequences.

- It should be noted that the approach used for structuring nanomaterials plays a key role in determining their main properties, stability, morphological characteristics, adsorption ability, degree of catalysis, etc.

- As mentioned before, nano-sized materials have unique properties, completely different from the equivalent structures on the macro-level.

- The most important feature is the large surface to volume ratio, which is why they are suitable for different forms of water treatment (adsorption, photocatalysis, membrane processes, etc.).

- Other important properties are related to different behaviour and motion of electrons (quantum effects).

- Thus nanostructures have completely different optical, electrical and magnetic properties, greater reactivity with neighboring (polluting) atoms, faster chemical processes, etc.

- All these characteristics of nanomaterials make this technology attractive in terms of eliminating contaminants and enabling wastewater treatment

- Several different nanostructures have been defined with regard to treatment method

- In this respect, nanotechnological wastewater treatment processes can be divided into three main groups:

- Treatment and Remediation
- Sensing and Detection
- Pollution Prevention

- The greatest emphasis has currently been placed on the treatment and remediation of wastewater

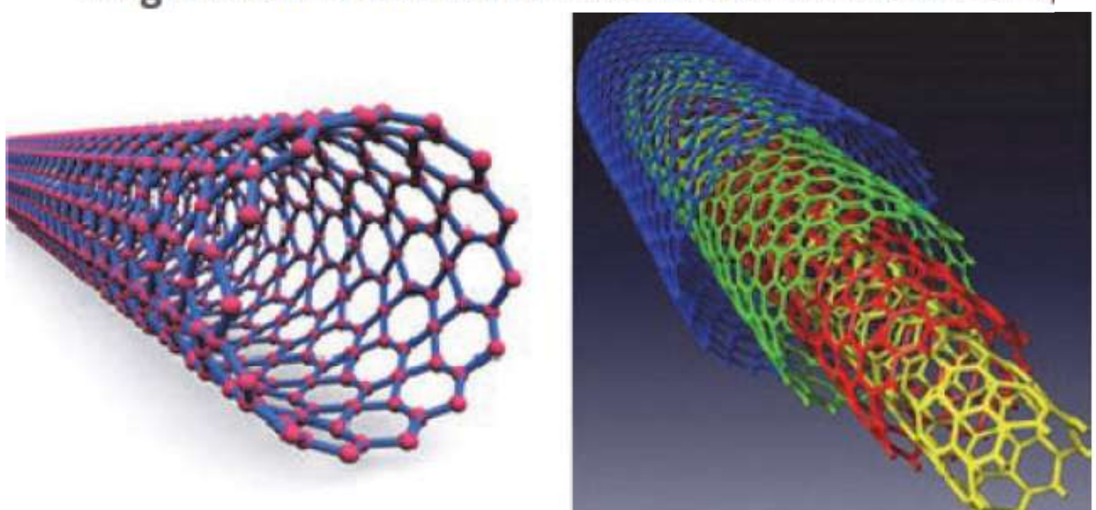
- Various nanomaterials are at different stages of research, and each one has its own unique functionality.

- Some nanoparticles destroy contaminants (oxidation in the presence of nanocatalysts), while other separate and isolate these contaminants (nanomembrane filtration).

- Carbon nanotubes have been recognized for their ability to adsorb dioxins.

- In this regard, they are much more efficient than the conventional activated carbon process

Single-walled and multi-walled carbon nanotubes



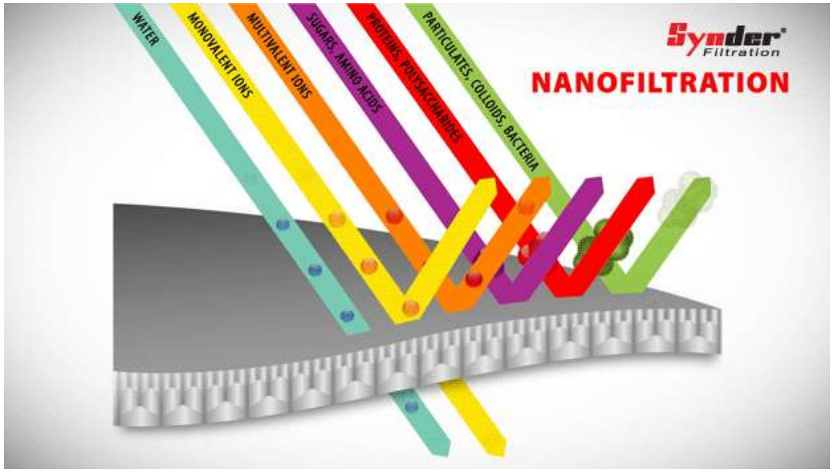
Important nanotechnological processes for wastewater treatment:

Nanofiltration:

- Membrane filtration plays an important role in removing various types of contamination and enables high level of water purification.

- Until recently, its biggest problem was a substantial investment cost (about 70 % of the total investment cost refers to membranes).

- As the price is lowering, the membrane wastewater treatment process becomes more and more popular in the market, mainly due to its high efficiency in the removal of solid waste materials, monovalent and divalent ions, various pathogens, etc.



https://synderfiltration.com/nanofiltration/membranes/

- Nanofiltration (with reverse osmosis, RO) is a high-pressure membrane treatment process.

- But unlike the RO, it requires a much lower drive pressure (7 to 14 bar), and so allows lower energy consumption.

- Centrifugal pumps are most often used for the pressure and circulation of wastewater within the nanomembrane.

- The plant consists of a large number of modules, with different membrane configurations within each module. In nanofiltration, the usual length of the module varies from 0.9 to 5.5 m, and the diameter ranges from 100 to 300 mm.

- The modules are installed on the stand and can be arranged either horizontally or vertically For vertical installation, a smaller number of connecting pipes and fittings are required, and the footprint is smaller.

- Nanofiltration produces water that meets highly stringent requirements in terms of water reuse. Since this process is highly efficient in the removal of organic and inorganic substances,
- bacteria and viruses, the need for subsequent disinfection of water is minimal.

Horizontal and vertical arrangement of modules

Table: Efficiency of nanofiltration in the removal of contaminants

Contaminant	Unit	Removal efficiency
Total dissolved solids	%	40 – 60
Total organic carbon	%	90 – 98
Colour	%	90 – 96
Hardness	%	80 – 85
NaCl	%	10 – 50
Sodium-sulphate	%	80 – 95
Calcium-chloride	%	10 – 50
Magnesium-sulphate	%	80 – 95
Nitrates	%	80 – 85
Fluorides	%	10 – 50
Arsenic	%	< 40
Atrazine	%	85 – 90
Proteins	log	3 – 5
Bacteria	log	3 – 6
Protozoa	log	> 6
Viruses	log	3 - 5

Nanotechnology offers a wide range of solutions for membrane materials, including:

-- Ceramic membranes for nanofiltration
--New polymeric membranes with anti-fouling coating (Organic brush-like coating, membrane impregnated with nanoparticles)
-- New composite membranes:
-- Thin film composite membranes
-- Metal/metal oxides + polymer
-- Carbon nanotube + polymer
-- Zeolites + polymer
-- Aquaporin + polymer

- According to Pendergast and Hoek (2011), all membrane types used in nanofiltration can be grouped in three categories:

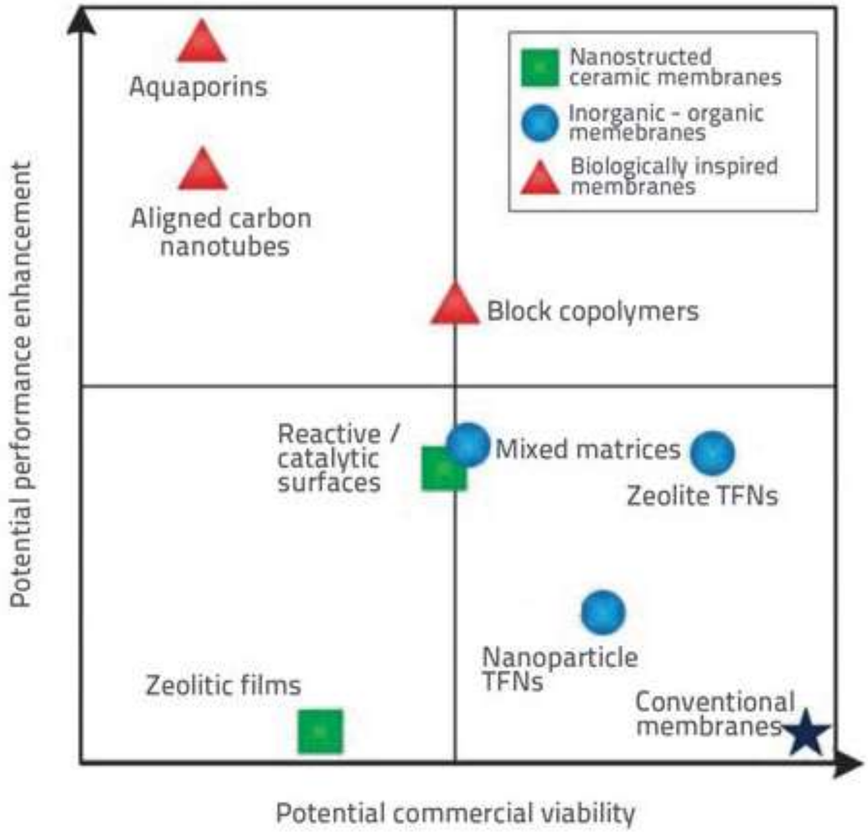
-- nanostructured ceramic
-- organic-inorganic membranes
-- biologically inspired membranes.

- They concluded that biologically inspired membranes possess the greatest potential for improvement but are far from commercial use.

- On the other hand, zeolite membranes have limited possibilities for further development but are closest to commercial use.

- Figure shows that no type of membrane exists in the optimal (upper right) quadrant, but this could change over time when the biologically inspired membranes technology reaches maturity

Comparison of potential performance and commercial viability of nanomembranes



Nanomaterials for catalysis and photocatalysis

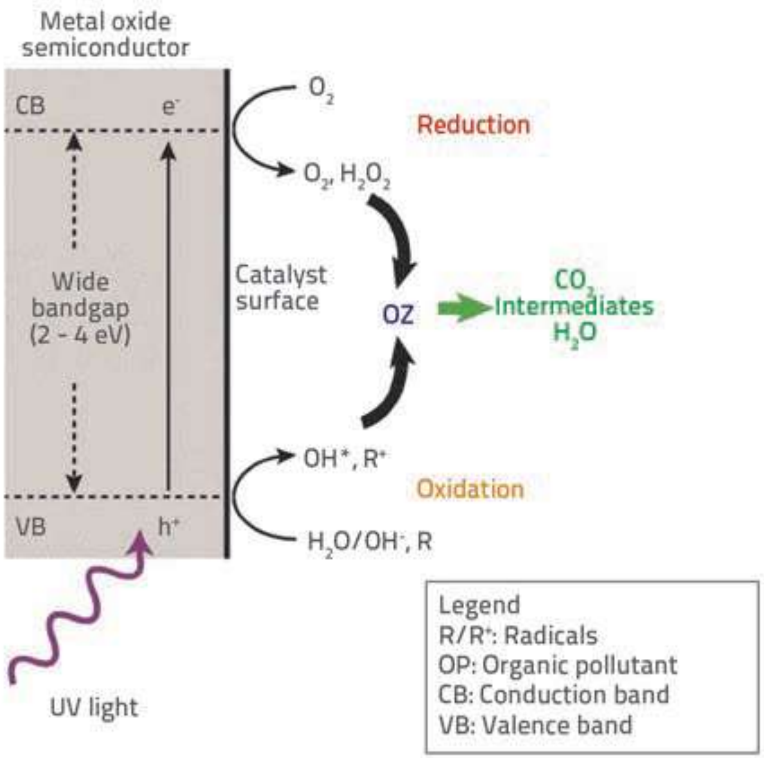
- Metal nanoparticles and metal oxides have proven to be very good catalysts in oxidation reactions.

- They exhibit a strong catalytic activity through which pollution molecules are oxidized forming less toxic substances, or converted into ecologically acceptable final products.

- The main reasons for these properties of nanoparticles are:

-- very small particle size, i.e. a large surface to volume ratio

-- high reactivity directly related to nanoparticle size.



- There are several technical challenges that have to be met to enable broader practical application of this process, including

- -- optimization of catalysts in the exploitation of available light energy
- -- more efficient separation of nanocatalysts after treatment and re-application
- -- improvement of selective properties during chemical reactions.

- The biggest drawback of this technology is the high operating cost of providing the required light energy (UV radiation), which is why this technology is still not considered to be economically viable.

- The research has therefore concentrated on the exploitation of (natural) solar energy for photocatalytic processes.

Nanomaterials for water disinfection

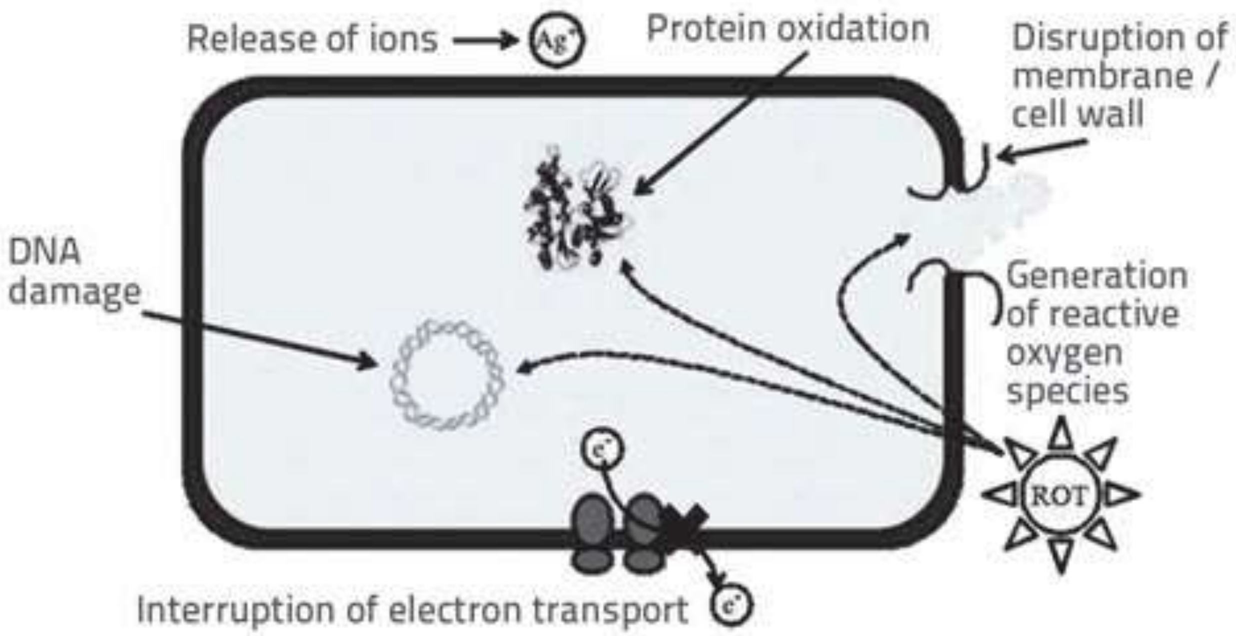
- Few nanomaterials have proven to have great antimicrobial activity as well. Such materials include chitosan, silver nanoparticles, titanium dioxide, fullerene nanoparticles, carbon nanotubes, etc.

- All these nanomaterials are mild oxidants and are relatively inert in water, and are
- therefore note expected to create harmful by-products.

- There are several ways of applying the nanomaterials in water disinfection processes:

-- direct action on (bacterial) cells in the sense of preventing electron passage through the membrane
-- break through the cell membrane
-- oxidation of some cellular components
-- Hydroxyl radicals (within the action of nanoparticles as photocatalysts)
-- the formation of dissolved metal ions that can cause damage to cellular components

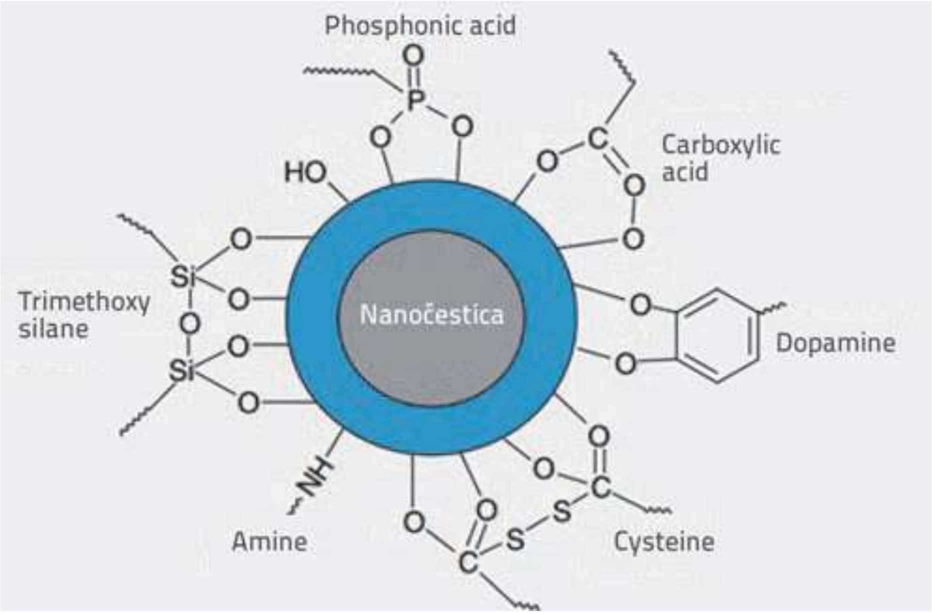
Various mechanisms of antimicrobial activities exerted by nanomaterials



Nanomaterials for adsorption of pollutants

Nanoparticles possess two important characteristics that make them very good adsorbents. These are the large specific surface of nanomaterials and surface multifunctionality or the ability to easily chemically react and bind to different adjacent atoms and molecules.

These characteristics make nanoparticles not only effective adsorbents for various contaminants in wastewater but also allow for long-term stability, as this also results in adsorbent degradation (with the addition of catalytic properties of nanoparticles) and improves the adsorption efficiency.



Multifunctionalities of metal oxide nanoparticle surface

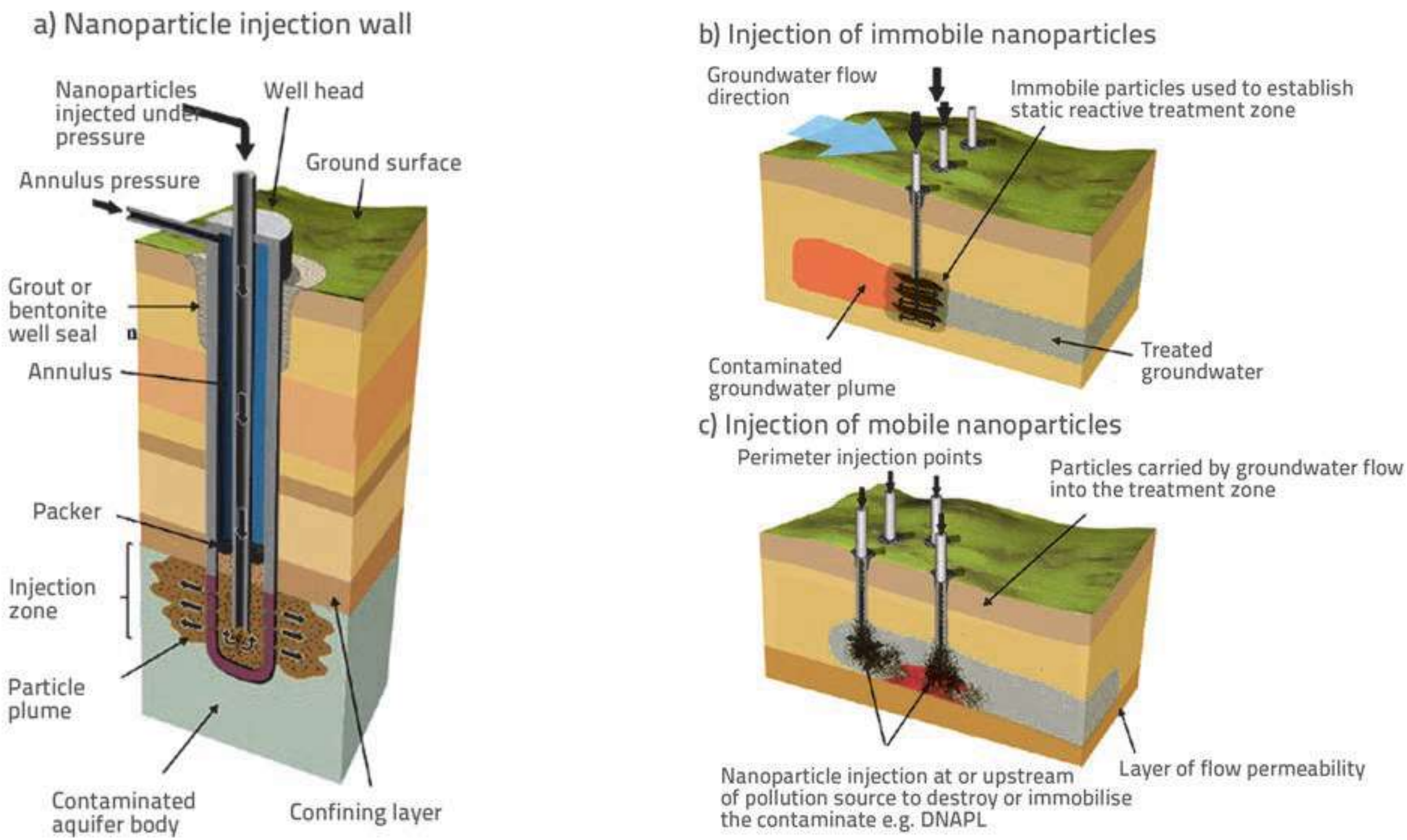
Nanoscale zerovalent iron (nZVI)

- The zerovalent iron (nZVI) is considered to be the most interesting nanomaterial due to its low production costs, positive environmental effects, and high reactivity with contaminants.

- This nanotechnology has found extensive application in contaminated groundwater
- treatment, and has already reached the commercial level of application in the world.

- In addition, it has already proven to be a highly efficient technology for the removal of variousorganic and inorganic pollutants, including chlorinated solvents, pesticides, nitroamines and nitroaromatics, organophosphates, inorganic anions, arsenic, uranium, numerous metals, etc.

Key characteristics that nanoparticles must have in terms of remediation of contaminated groundwater are:
-- high reactivity with contaminants
-- high mobility within porous medium
-- appropriate life span
-- negligible harmful effects.



a) Nanoparticle injection wall
Nanoparticles injected under pressure
Well head
Ground surface
Annulus pressure
Grout or bentonite well seal
Annulus
Packer
Injection zone
Particle plume
Contaminated aquifer body
Confining layer
b) Injection of immobile nanoparticles
Groundwater flow direction
Immobile particles used to establish static reactive treatment zone
Contaminated groundwater plume
Treated groundwater
c) Injection of mobile nanoparticles
Perimeter injection points
Particles carried by groundwater flow into the treatment zone
Nanoparticle injection at or upstream of pollution source to destroy or immobilise the contaminate e.g. DNAPL
Layer of flow permeability