Adsorption for wastewater treatment and water purification

Part 1:

Basic knowledge on adsorption process and types of adsorbents

Circular Economy for Water

kiertotalous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuriministeriö

Content and questions considered:


Illustration: Tatiana Samarina

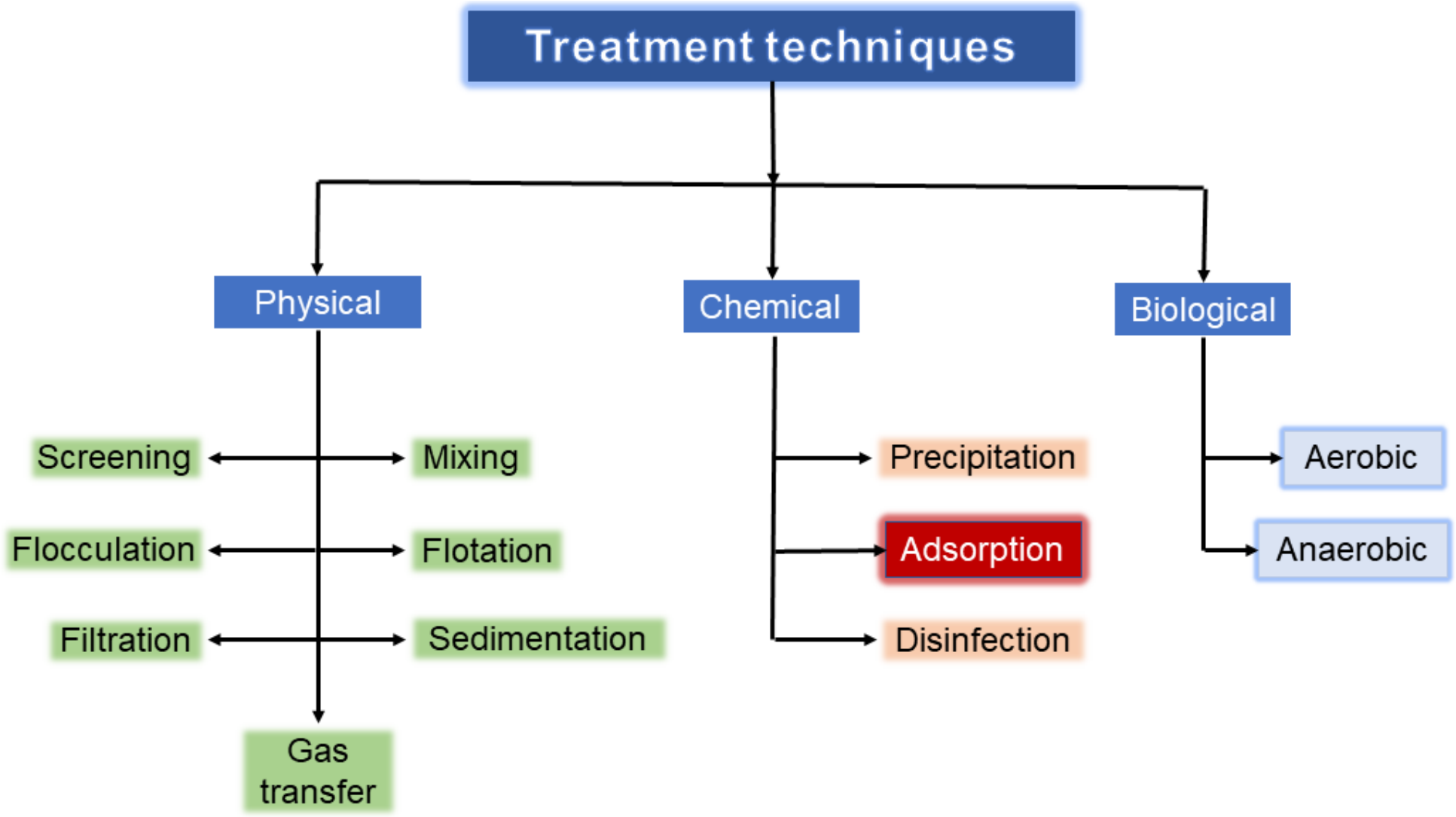
- ✓Definitions
- ✓Physical vs chemical
- ✓Factors affecting adsorption
- ✓Sorbent materials
- ✓Choice of Adsorbent


Illustration: Tatiana Samarina

kiertotalous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuri-ministeriö

Adsorption in water treatment and purification



Definitions [IUPAC goldbook]

Sorption: the process by which a substance (sorbate) is sorbed (**ad**sorbed or **ab**sorbed) on or in another substance (sorbent). https://www.youtube.com/watch?v=XWaDXanE1WA

Absorption: the process of one material (***absorbate***) being **retained** by another (***absorbent***); this may be the physical solution of a gas, liquid, or solid in a liquid, attachment of molecules of a gas, vapour, liquid, or dissolved substance to a solid surface by physical forces, etc.

Adsorption: an increase in the concentration of a dissolved substance (***adsorbate***) **at the interface** of a condensed and a liquid phase (***adsorbent***) due to the operation of surface forces. Adsorption can also occur at the interface of a condensed and a gaseous phase.

- **Adsorbent:** a **material** at the surface of which adsorption may occur.
- **Adsorbate:** a molecular species **of gas, dissolved substance or liquid** which adheres to or is adsorbed in an extremely thin surface layer of a solid substance.

Desorption: the converse of adsorption, i.e. the decrease in the amount of adsorbed substance.

Q: Examples of adsorption and absorption in our daily life?

Chemical vs. Physical Adsorption

https://study.com/academy/lesson/chemical-vs-physical-adsorption.html
https://www.youtube.com/watch?v=RrJjmV2ml1s

Physisorption

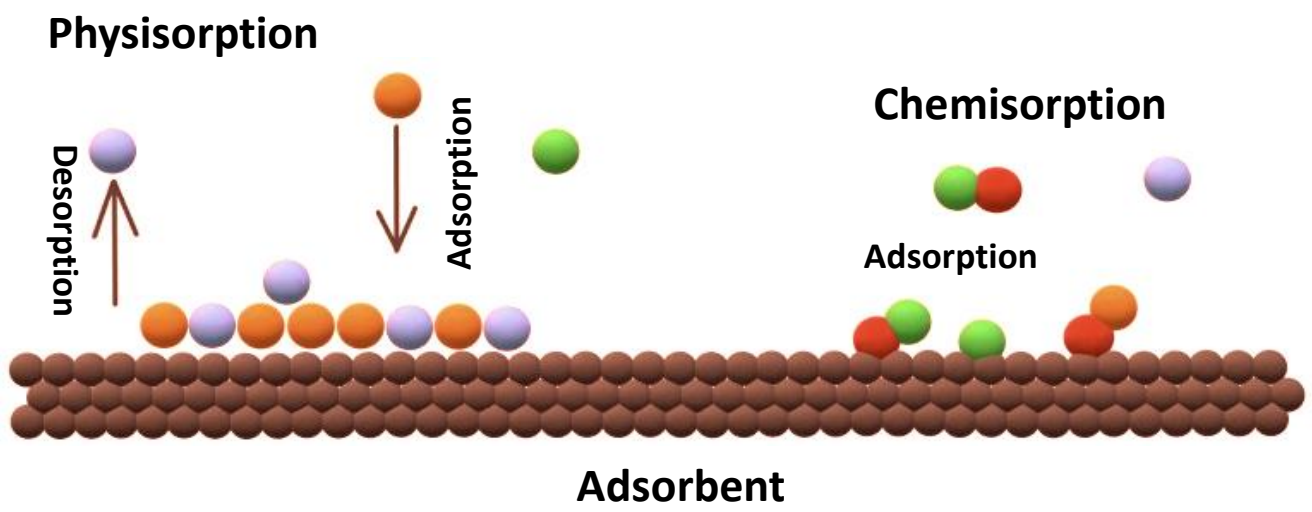
Adsorption in which the forces involved are ***intermolecular forces*** (van der Waals forces) of the same kind as those responsible for the imperfection of real gases and the condensation vapours, and which do not involve a significant change in the electronic orbital patterns of the species involved.

- weak bonding by van der Waals forces
- Reversible, fast
- Not specific (in most cases)

Chemisorption

Adsorption which results from ***chemical bond formation*** (strong interaction) between the adsorbent and the adsorbate in a monolayer on the surface.

- chemical bonding by reaction
- Irreversible (in most cases)
- Highly Specific
- Activated, may be slow



kiertotalous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuriministeriö

Why Adsorption?

- Simple principles
- Low CAPEX and OPEX
- Adsorbents are easily available
- Easy to maintain and operate

Q: what does it mean – CAPEX? OPEX**?**

Adsorbents might have unique physical or chemical properties, and remarkable selectivity to particular substance.

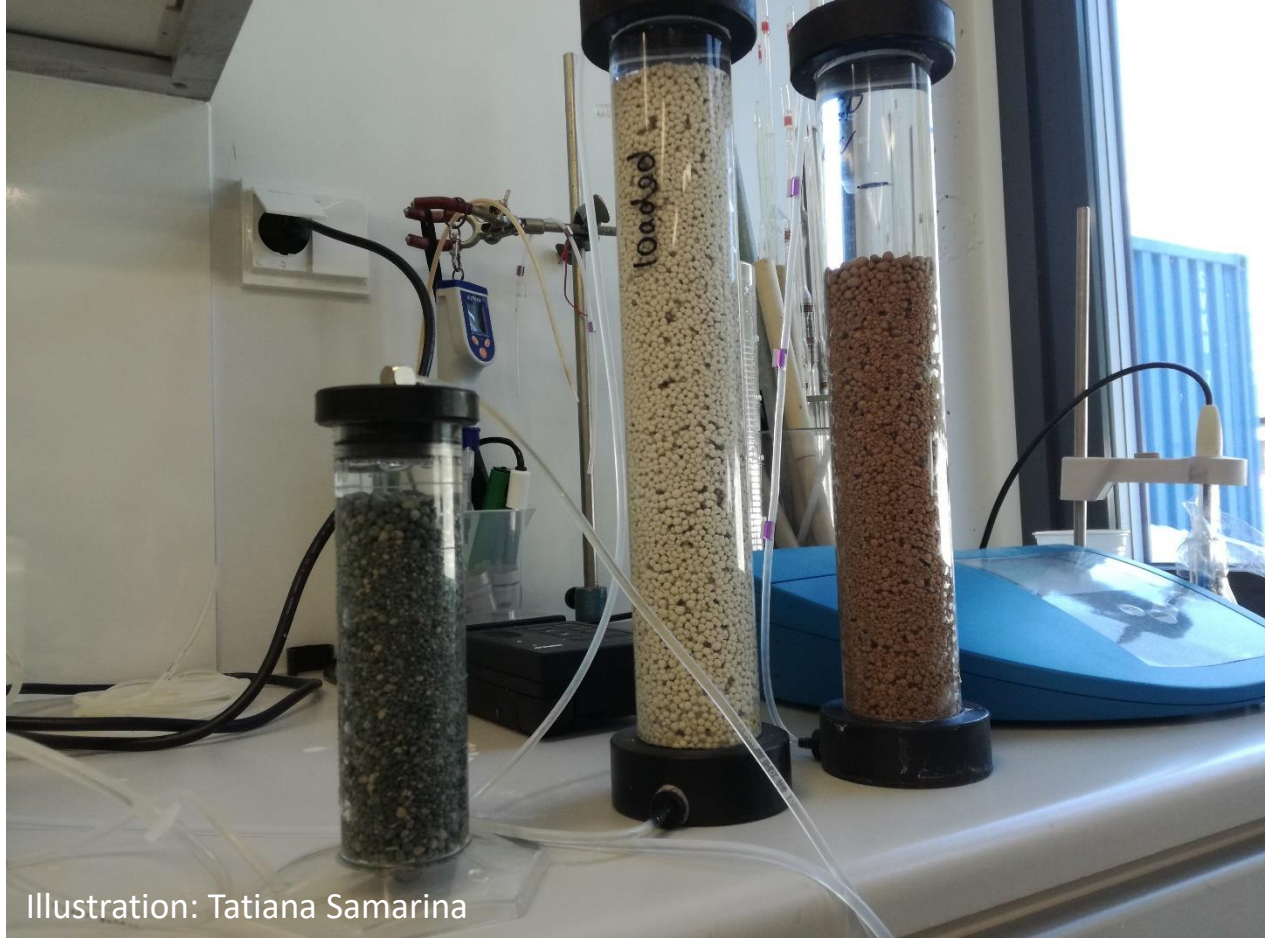


Illustration: Tatiana Samarina

Find out what these terms mean?

- chemical bond
- surface layer (interfacial layer)
- monolayer and multilayer adsorption
- van der Waals forces

kierto-talous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuri-ministeriö

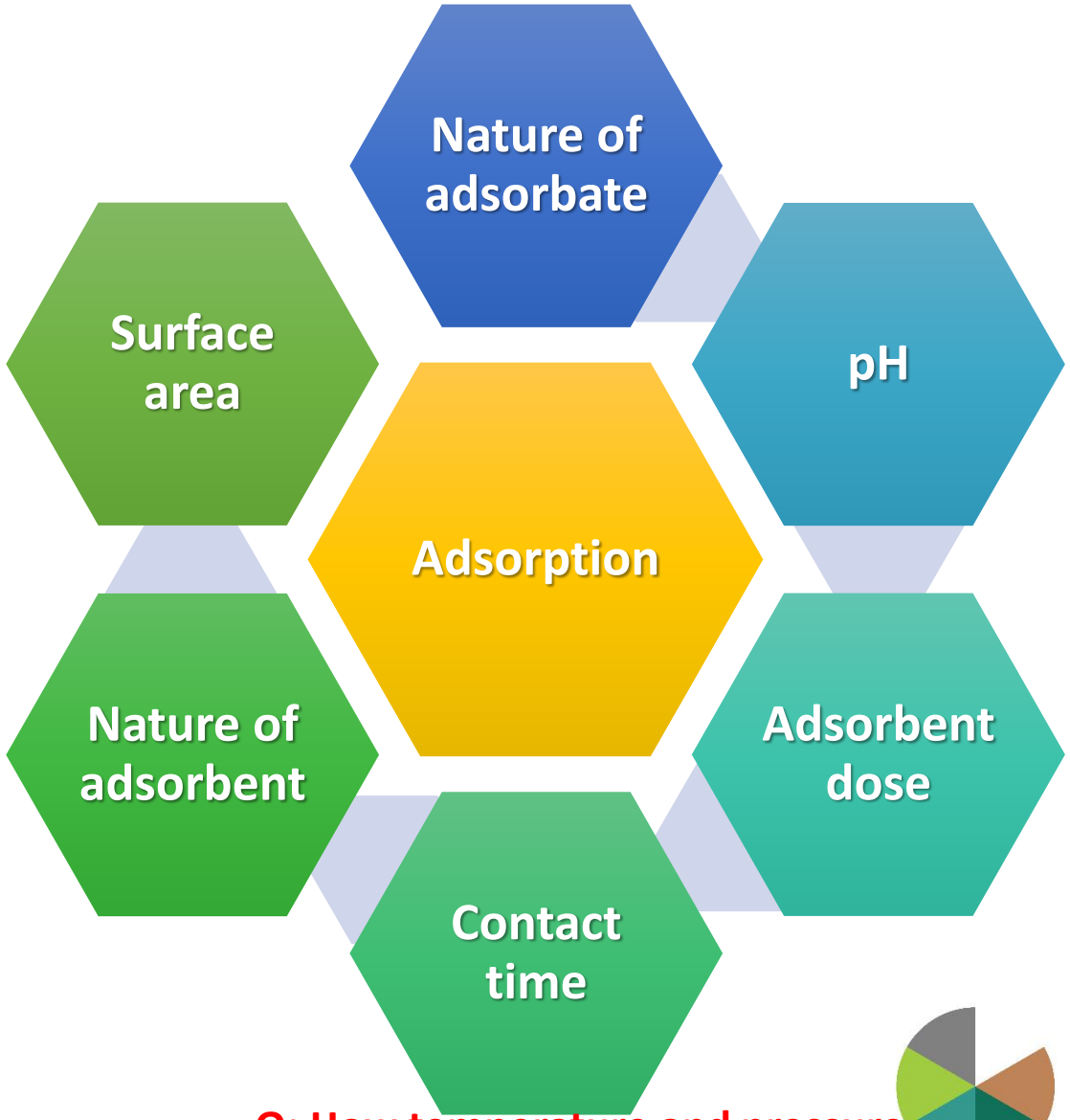
FACTORS AFFECTING ADSORPTION

Specific surface area is a property of solids defined as the total surface area of a material per unit of mass (with units of m^2/kg or m^2/g) or solid or bulk volume (units of m^2/m^3 or m^{-1}). It is a physical value that can be used to determine the type and properties of a material.

The extent of adsorption is proportional to the specific surface area of the adsorbent. Adsorption capacity of adsorbent increases with increase in its surface area.

Nature of adsorbent and adsorbate. The physiochemical nature of material and substance, e.g. surface functional groups, carbon backbone, possibility of chemical reactions.

The greater the solubility of adsorbate, the smaller is the extent of adsorption. The higher affinity of adsorbent and adsorbate, the greater is the extent of adsorption.



Q: How temperature and pressure will influence on adsorption? What else?

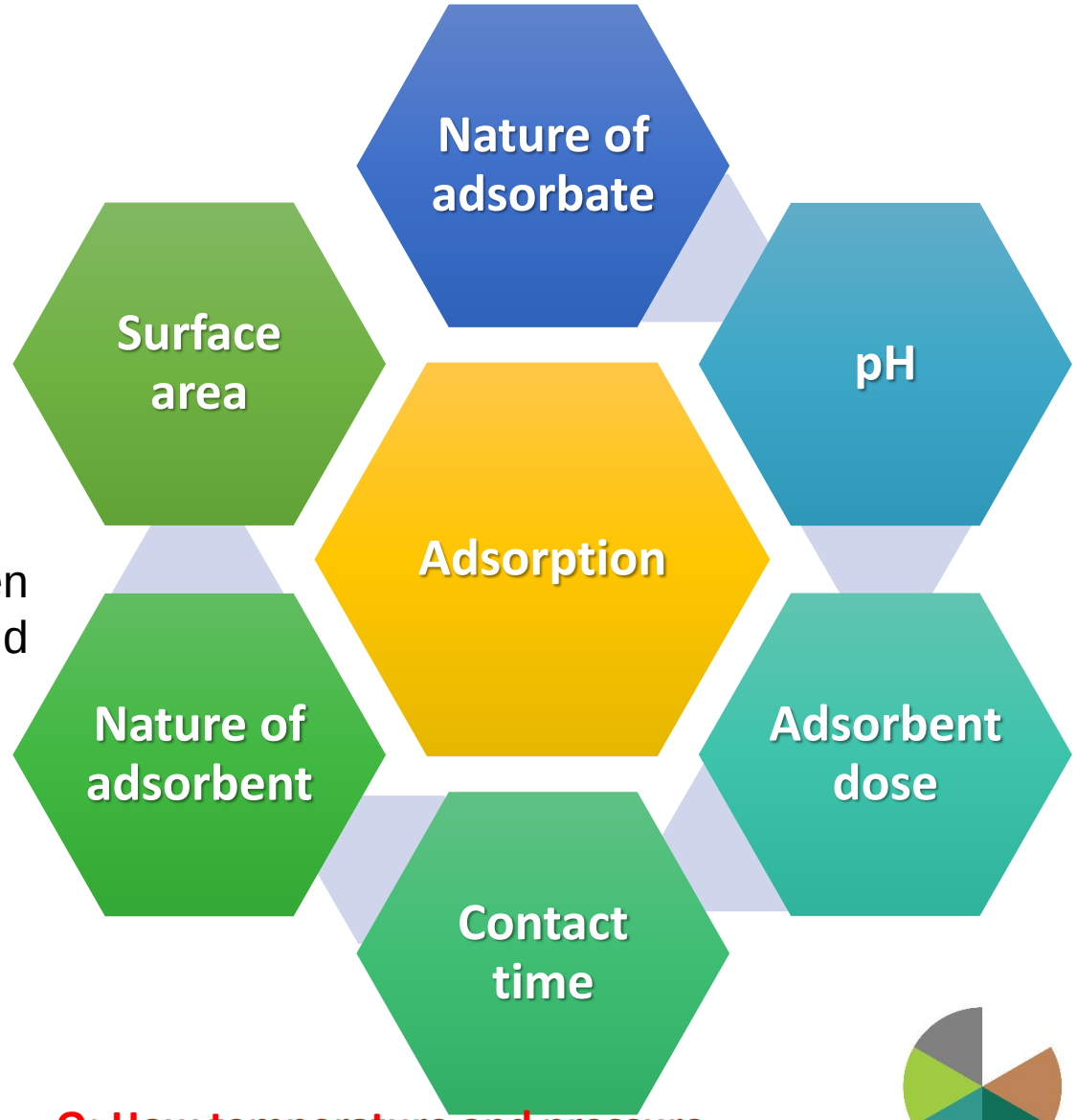
FACTORS AFFECTING ADSORPTION

Selectivity and adsorption capacity. The absorbing substances may enhance adsorption (synergistic effect) or may interfere with each another, decreasing an adsorption capacity of adsorbent.

Chemisorption is often selective yet irreversible, while physisorption is less selective. However, adsorbent could be easily restored and reused for several cycles

Activation of adsorbent surface is applied when adsorption capacity or selectivity of raw material should be improved.

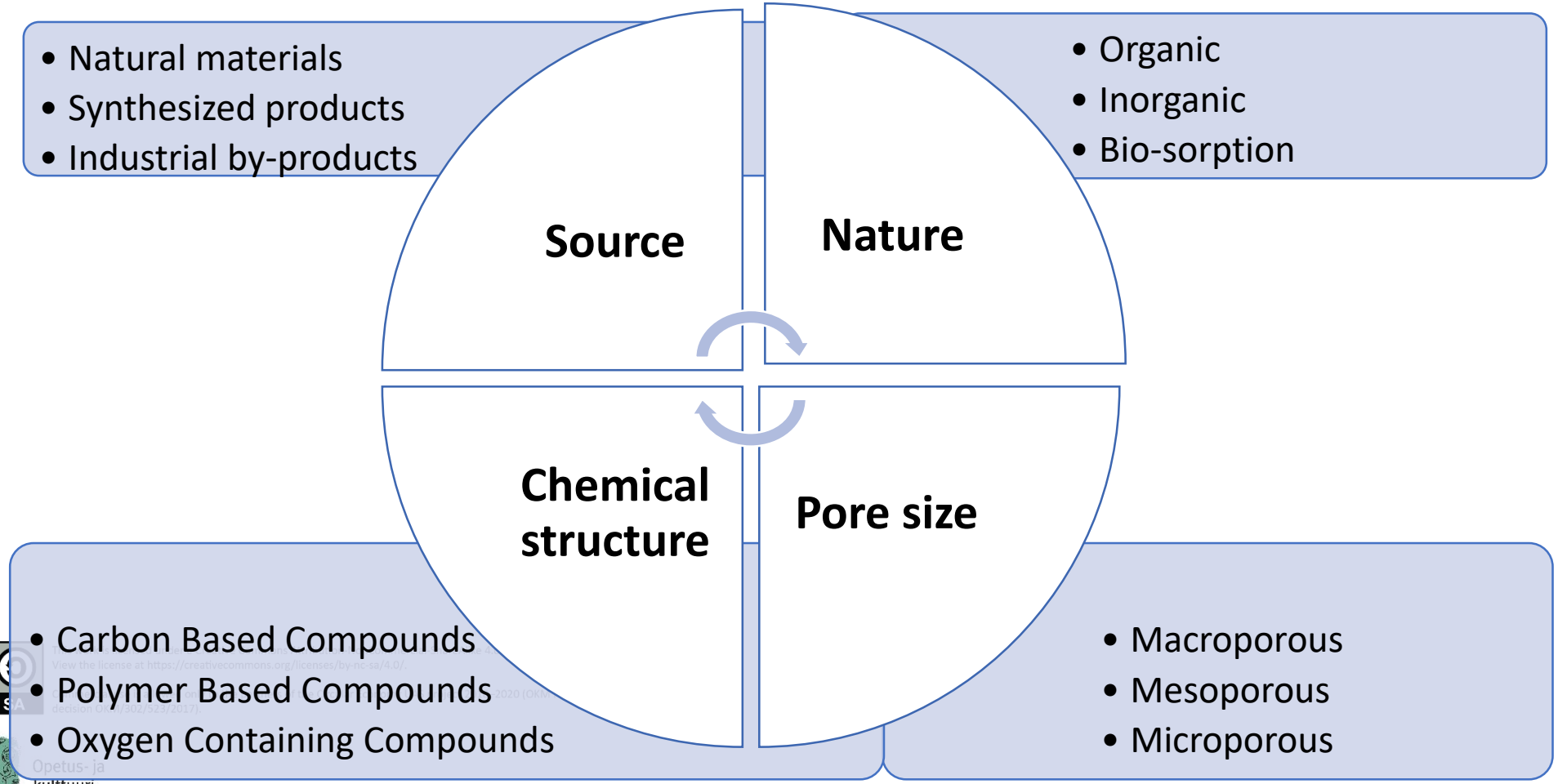
Activation gives more vacant sites on surface. This can be done by crashing bulk solid in small pieces, breaking lump of solid into powders, or leaching the adsorbent with chemicals



Q: How temperature and pressure will influence on adsorption from gas and liquid phase?

CLASSIFICATION OF ADSORBENTS

There are several classification based on properties and nature of adsorbents



Adsorbent selection criteria

Adsorbents	Surface area (m^2/m^3)	Price, EUR/ton
Commercial activated carbon	500 - 2000	1200-2500
Polymer/Resin	60-100	1500-3000
Alumina	200 - 300	110
Bauxite	25 - 250	90
Natural Zeolites	50 - 250	300-1000
Synthetic Zeolites	300 - 750	1500-3000
Bentonite clay	47 - 73	150
Kaolinite clay	20.6 - 23.5	40
Wood	3.8 - 6.4	10

- Capacity
- Chemical and thermal stability
- Selectivity
- Regeneration ability
- Price

Q: Which parameter could help you to choose the adsorbent?

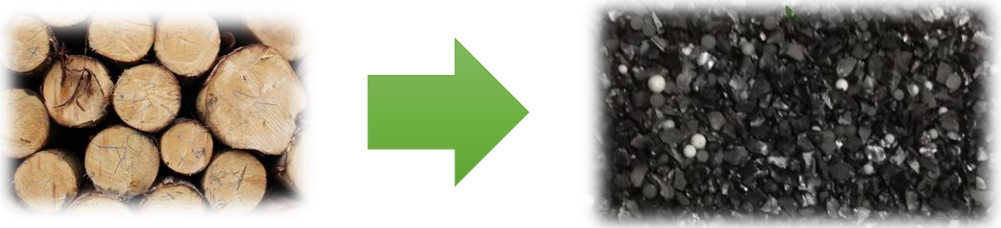
1) Crystalline/amorphous
2) Hydrophobic/Hydrophilic
3) Surface area
4) Pore size and shape

kiertotalous AMK CIRKULÄR EKONOMI YH CIRCULAR ECONOMY UAS
Opetus- ja kulttuuri-ministeriö

COMMERCIALLY AVALIABLE ADSORBENTS

Activated carbon (AC)

Carbonization → **Activation**



Illustrations: Tatiana Samarina

Powder form (PAC)

Granular form (GAC)

Extruded Activated Carbon (EAC)
Pellet or cylindrical shaped

Excellence:

- heterogeneous pore structure
- high surface area and high efficiency
- fast kinetics
- various oxygen-containing groups on surface
- enable to adsorb both:

non-polar and polar substances

Properties of Activated Carbon

Pore Volume	0.56-1.20 cm^3/g
Surface Area	600-1600 m^2/g
Average Pore Diameter	15-25 Å
Regeneration/Conditions	Yes/100-140^oC

Applications:

- *Removal organic chemicals and chemical disinfectants, heavy metals*
- *Enhancing the taste*
- *Removal of odours and color, some microorganisms*

kiertotalous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuri-ministeriö

COMMERCIALLY AVALIABLE ADSORBENTS

Activated alumina


Illustration: Tatiana Samarina

Powder form

Granular form

Properties of Activated Alumina

Pore Volume	0.29-0.37 cm^3/g
Surface Area	210-360 m^2/g
Average Pore Diameter	18-48 Å
Regeneration/Conditions	200-250 ^oC

Excellence:

- ✓ Relatively well-known and commercially available
- ✓ Highly porous materials with a high surface area and an interesting distribution of both macro- and micropores
- ✓ The presence of impurities do not affect the performance

Applications:

•Drying of gases, organic solvents, oils

•Removal of HCl from Hydrogen

Water purification:

- *Removal of fluoride*
- *Removal of arsenic, selenium, lead, and sulfur*
- *Removal of organic pollutants and dyes*

kierto-talous AMK CIRKULÄR EKONOMI YH CIRCULAR ECONOMY UAS

Opetus- ja kulttuuri-ministeriö

COMMERCIALLY AVALIABLE ADSORBENTS

Natural and Synthetic Zeolites

Natural

Synthetic

Molecular sieves are synthetic Zeolites with uniform pores to selectively separate compounds by size & shape

Excellence:

- 40 natural and over 100 synthetic materials
- abundant and frequently studied mineral
- high porosity
- different cavity structures
- unique surface chemistry
- high capacity and selectivity

Applications:

Separation and drying of gases (molecular sieves)

Water purification:

- *Removal of heavy metals, ammonium, and Hg*
- *Reduction of hardness*
- *Recovery of fructose in food industry*

kiertotalous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuriministeriö

Properties of Molecular Sieves

Type	4A	5A	13X
Effective diameter of pores (Å)	4	5	13
Regeneration Temperature (°C)	200-300	200-300	200-300

COMMERCIALLY AVALIABLE ADSORBENTS

POLYMERS & RESINS

Excellence:

- unique chemical properties
- could be modified for specific case
- regeneration is possible
- high capacity

Applications:

Separation and analytical chemistry
Recovery & purification of steroids, amino acids, proteins & enzymes

Water purification:

- *Reduction of hardness and TDS*
- *Separation of fatty acids from water*
- *Removal of impurities from contour waters*
- *Recovery of chemicals/metals from industrial effluents*

kiertotalous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuriministeriö

Content bullets and conclusions:

- Adsorption is powerful tool for water purification and waste management;
- There is a need to develop more efficient selective, inexpensive and eco-friendly low cost adsorbents;
- Low cost adsorbents can be used for wastewater management in small communities and remote areas;
- Continuous mode can be used for adsorption process as well;
- Regeneration of adsorbents could decrease the overall expenditures of technology.

kierto-talous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuri-ministeriö

Kiertotalouden uudet tuulet

1 op:n Adsorption for wastewater treatment and water purification.

Part 1: Basic knowledge on adsorption process and types of adsorbents

Tatiana Samarina & Outi Laatikainen,

KAMK: Kajaanin ammattikorkeakoulu

KiertotalousAMK

https://kiertotalousamk.turkuamk.fi/opintojaksot/

kierto-talous AMK
CIRKULÄR EKONOMI YH
CIRCULAR ECONOMY UAS

Opetus- ja kulttuuri-ministeriö