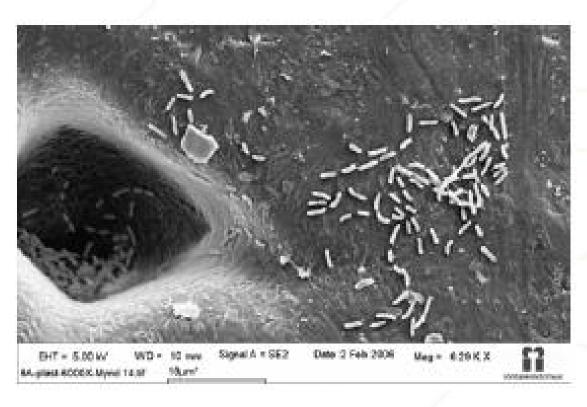# Surfaces and bacteria
PUFFIN workshop
Innovation Center Iceland
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Guðmundur Gunnarsson

Innovation Center Iceland

What influences bacterial adhesion

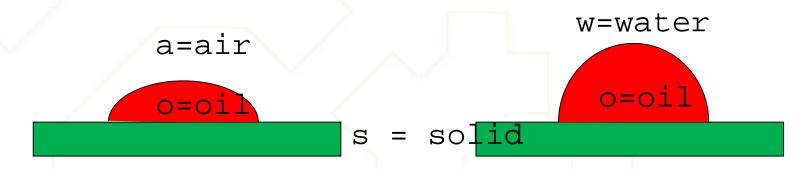

- Roughness
- The material
  - Hydrophilic
  - Hydrophobic
- Properties of the bacteria

Adhesion of materials to surfaces

- Adhesion of oil in air and under water

a=air

w=water

o=oil

o=oil

s = solid

$\Delta G = \gamma_{os} - \gamma_o - \gamma_s = -W_a$

adhesion if $\gamma_{os} < \gamma_o + \gamma_s$

$\Delta G = \gamma_{os} - \gamma_{ow} - \gamma_{sw} = -W_a$

adhesion if $\gamma_{os} < \gamma_{ow} + \gamma_{sw}$

Theory of surface tension

- **Surface tension between air and material**

- $\gamma = \gamma^p + \gamma^d$
  - γ^p polar componet of surface tension
  - γ^d dispersive component of surface tension

Surface tension of some liquids

Substance	γ (mN/m)	γ^p (mN/m)	γ^d (mN/m)
Water	72.8	51.0	21.8
Glycerol	64	30	34
Ethylene glycol	48	19	29
Dimethyl sulfoxide	44	8	36
Benzyl alcohol	39	11.4	28.6
Toluene	28.4	2.3	26.10
Hexane	18.4	-	18.4
Acetone	23.7	-	23.7
Chloroform	27.15	-	27.15
Diiodomethane	50.8	-	50.8

Surface tension between two phases

Interfacial tension between two phases (a and b) can be expressed in terms of the two components for each phase

$$\gamma_{ab} = \gamma_a + \gamma_b - 2\sqrt{(\gamma_a^p \gamma_b^p)} - 2\sqrt{(\gamma_a^d \gamma_b^d)}$$

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Adhesion of oil to surfaces

- Possible to calculate work of adhesion of oil to surfaces
  - Surface in air
  - Surface under water

Work of adhesion of a mineral oil to various solid surfaces in air and in water

	$W_{oas}/\text{mJ m}^{-2}$	$W_{ows}/\text{mJ m}^{-2}$
Quartz	72	9
Crown glass	65	20
Nylon 6,6	57	51
Polyester	53	54
PET	55	67
PVC	57	73
Skin – forehead (a)	64	64
Skin – forearm (a)	62	89
Tooth enamel (b)	63	84
Polyethylene	55	86
Polypropylene	52	99
Human hair (c)	49	74
Silicone DC200 film on glass	47	80
C18 amine monolayer on glass	47	102
PTFE	42	91
FC721 (3M coating) on glass	34	95

For mineral oil
$\gamma_o^d = 25$ mJ m^{-2} and $\gamma_o^p = 0$

W_{oas} = work of adhesion in air

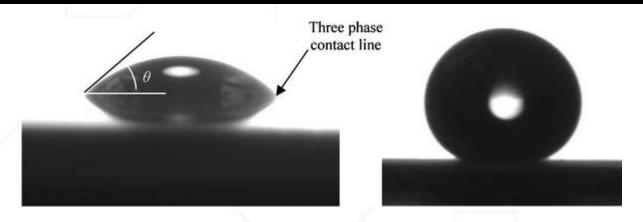W_{ows} = work of adhesion in water

Clint and Wicks 2001

- Oil adheres well to hydrophilic material in air
- Oil adheres badly to hydrophilic materials in water

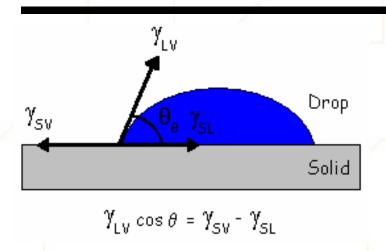 – Order in water reverse to that in air

Water drop on a surface

Three phase contact line

§ Drop spreads
  § hydrophilic, low contact angle
  § High surface energy

§ Drop does not spread
  § hydrophobic, high contact angle
  § Low surface energy

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Contact angle

$\gamma_{LV} \cos \theta = \gamma_{SV} - \gamma_{SL}$
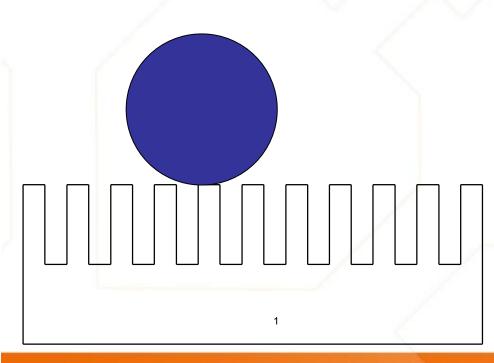
Θ = contact angle
γ = surface tension or surface energy (unit: mN/m or mJ/m^2)

- Surface energy of a surface can be determined by mesuring contact angle of different liquids with the surface
- Contact angle of water
  - Hydrophobic surface, Θ > ca. 70 – 80 °C
  - Hydrophilic surface, Θ < ca. 50 - 60 °C

Roughness and contact angle

- Contact angle of a water drop on a rough hydrophobic surface is higher than on a smooth surface of the same material

$\cos\theta = f_1 \cos\theta_0 - f_2$ Cassies equation

f_1 = proportional surface area of material 1)

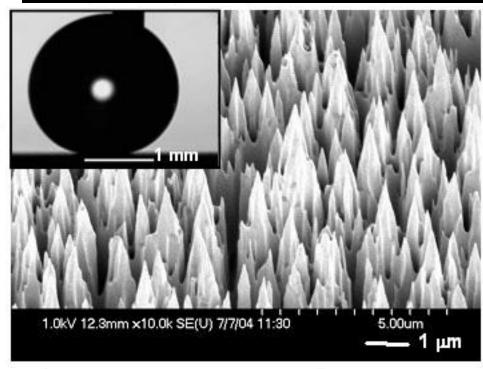f_2 = proportional surface area of pores or air

$\theta_0 = 90°$, $f_1 = f_2 = 0{,}5 \rightarrow \theta = 120°$

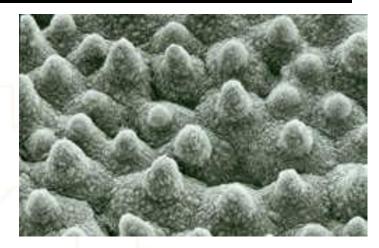$\theta_0 = 110°$, $f_1 = 0{,}2 \quad \rightarrow \theta = 154°$

"SUPERHYDROPHOBIC"

Superhydrophobic surface

http://www.aip.org/png/2006/247.htm

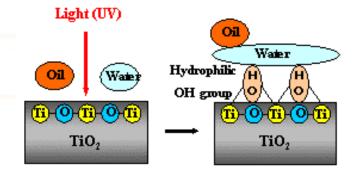http://www.nees.uni-bonn.de/lotus/en/lotus_effect_html.html

Self cleaning
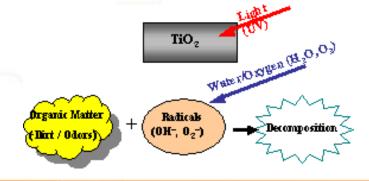
Superhydrophilic surface

- A drop of water on a superhydrophlic surface spreads, disapears and form a film

- Dew can not form on a superhydrophilic surface

- Raindrops impinging on a superhydrophilic surface form a film that drains of the surface

- Water can penetrate between dirt and surface contributing to self cleaning effect

- A superhydrophilic surface dries fast

Photocatalytic self cleaning surfaces

- Surface is coated wth titania nanoparticles

- Ilumination with UV light results in a superhydrophilic surface

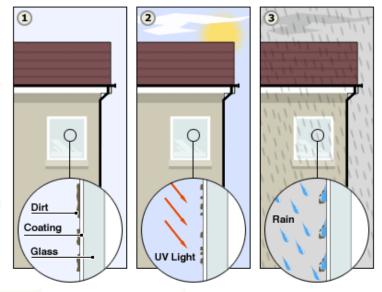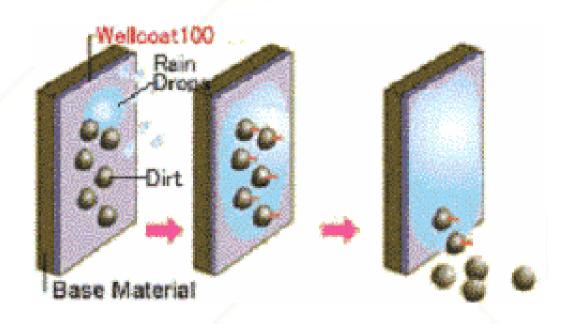- Free radicals (hydroxyl, oxygen) form and break down organic matter on the surface

http://www.newkast.or.jp/english/museum/index.html

Applications of photocatalytic surfaces

- **Self cleaning windows**
  - On the market in many countries
- **Self cleaning ceramic tiles**
  - UV light needed
  - Self clening with indoor light beeing developed
- **Sprays with photocatalysts**
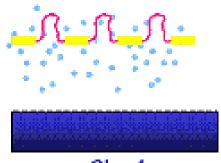 - Curtains etc.

Superhydrophilic silica based coatings

Water can penetrate between dirt and surface
Help in washing away impurities with rain

Easy to clean coatings

- Low surface energy coating that give a high water contact angle, 110°

- Low adhesion forces between surface and dirt - dirt can easily by wiped away.

- Previous results have shown that bacteria in water suspensions adhere better to stainless steel with easy to clean coating than to stainless steel itself.

Modification of surfaces with surface active polymers

- **Mirapol Surf-S polymers adsorb on hard surfaces from diluted water-based formulations**
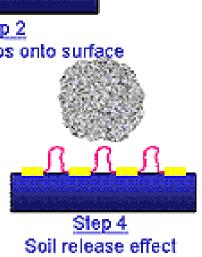
Step 1
polymer in solution approaches surface

Step 2
polymer adsorbs onto surface

Step 3
water sheeting effect

The polymer modifies the surface's energy, making it more hydrophilic

Step 4
Soil release effect

Rhodia.com
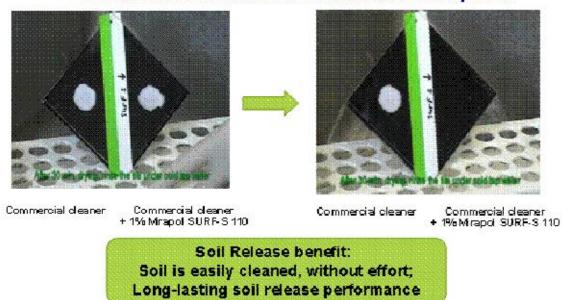
Added to cleaning formulation

Polymer not easily washed away

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Easy to clean

Why measure surface energy?

- Adhesion of bacteria to a surface is influenced by the surface energy of the surface and the surface energy of the bacteria

- Bacteria can be hydrophilic or hydrophobic

- Hydrophobic bacteria adhere better to all surfacs than hydrophilic bacteria

- All bacteria adhere better to hydophobic than hydrophilic surfaces

Surface energy of bacteria can be measured

Material	Surface energy (mN/m)
Psuedomnas putida*	35.3
Listeria monocytogenes*	49.1
Glycerol	64
Hexane	18.4
Glass	64.4
Stainless steel	45.9
Polyethylene	31
Teflon	17.6
Water	72.8

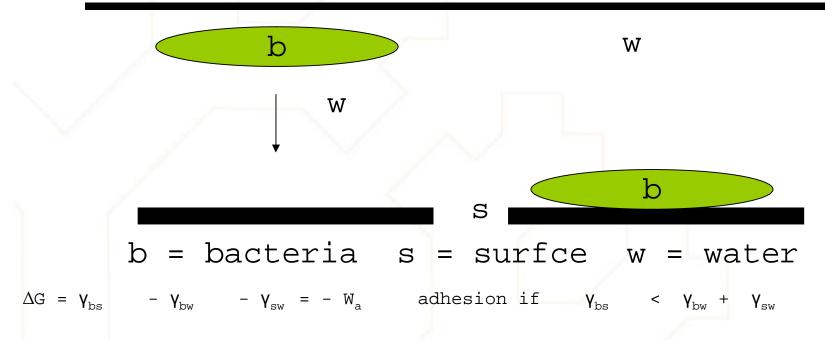**Hydrophilic materials**
   - high surface energy

Hydrophobic materials
   - low surface energy

*Bacteria isolated from Icelandic fishing Industry

Free energy of adhesion of bacteria to a surface

b

w

w

b

s

b = bacteria   s = surfce   w = water

$$\Delta G = \gamma_{bs} - \gamma_{bw} - \gamma_{sw} = -W_a \quad \text{adhesion if} \quad \gamma_{bs} < \gamma_{bw} + \gamma_{sw}$$

γ_{bw} = surface energy between bacteria and water

γ_{sw} = surface energy between surface and water

γ_{bs} = surface energy between surface and bacteria

Adhesion can occur if free energy of adhesion negative

Surface	Free energy of adhesion of bacteria to surface (mJ/m^2)	
	Pseudomonas putida	Listeria monocytogenes
Polyethylene	-55	-8
Stainless steel	-16	24

- **Pseudomonas has a tendency to adhere to most surfaces**
- **Psuedomonas is very common in the fish industry**
        - can be explained by above results