Understanding Nanotechnology in Nature

“The Lotus Effect”
Lotus effect

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Water on the surface of a lotus leaf.

Computer graphic of lotus leaf surface.
Water droplets on taro leaf with lotus effect (upper), and taro leaf surface magnified (0-1 mm is one millimetre span) showing a number of small protrusions (lower).

The **Lotus effect** refers to the very high water repellency (**superhydrophobicity**) exhibited by the leaves of the lotus flower (**Nelumbo**).[1] Dirt particles are picked up by water droplets due to a complex micro- and nanoscopic architecture of the surface which enables minimization of adhesion.

This effect can easily be demonstrated in many other plants as for example tropaeolum, cane, or columbine, and in certain animals (as for many insect wings).

The phenomenon was first studied by Dettre and Johnson in 1964 using rough hydrophobic surfaces. Their work developed a theoretical model based on experiments with glass beads coated with paraffin or PTFE telomer. The self-cleaning property of superhydrophobic micro-nanostructured surfaces was discovered in the 1970s[2] and has been applied since the 1990s[3] in biomimetic technical products.[4][5][6][7][8][9]

Perfluoroalkyl superhydrophobic materials were developed in the mid 1990's for use with chemical and biological fluids.

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### Functional principle

Due to their high surface tension water droplets tend to minimize their surface trying to achieve a spherical shape. On contact with a surface, adhesion forces result in wetting of the surface: either complete or incomplete wetting may occur depending on the structure of the surface and the fluid tension of the droplet.[10] The cause of self-cleaning properties is the hydrophobic water-repellent double structure of the surface.[11] This enables the contact area and the adhesion force between surface and droplet to be significantly reduced resulting in a self-cleaning process.[12][13][14] This hierarchical double structure is formed out of a characteristic epidermis (its outermost layer called the cuticle) and the covering waxes. The epidermis of the lotus plant possesses papillae with 10 to 20µm in height and 10 to 15µm in width on which the so-called epicuticular waxes are imposed.
These superimposed waxes are hydrophobic and form the second layer of the double structure.

The hydrophobicity of a surface is determined by the contact angle. The higher the contact angle the higher the hydrophobicity of a surface. Surfaces with a contact angle < 90° are referred to as hydrophilic and those with an angle >90° as hydrophobic. Some plants show contact angles up to 160° and are called super-hydrophobic meaning that only 2-3% of a drop's surface is in contact. Plants with a double structured surface like the lotus can reach a contact angle of 170° whereas a droplet’s actual contact area is only 0.6%. All this leads to a self-cleaning effect.

Dirt particles with an extremely reduced contact area are picked up by water droplets and are thus easily cleaned off the surface. If a water droplet rolls across such a contaminated surface the adhesion between the dirt particle, irrespective its chemistry, and the droplet is higher than between the particle and the surface. As this self-cleaning effect is based on the high surface tension of water it does not work with organic solvents. Therefore, the lotus-effect is no protection against graffiti.

This effect is of a great importance for plants, not for keeping them clean but as a protection against pathogens like fungi or algae growth. This also applies to animals like butterflies, dragonflies and other insects not able to cleanse all their body parts. Another positive effect of self-cleaning is the prevention of contamination of the area of a plant surface exposed to light resulting in a reduced photosynthesis.

[edit] Technical application

Some nanotechnologists have developed treatments, coatings, paints, roof tiles, fabrics and other surfaces that can stay dry and clean themselves in the same way as the lotus leaf. This can usually be achieved using special fluorochemical or silicone treatments on structured surfaces or with compositions containing micro-scale particulates. Super-hydrophobic coatings comprising Teflon microparticles have been used on medical diagnostic slides for over 30 years. It is possible to achieve such effects by using combinations of polyethylene glycol with glucose and sucrose (or any insoluble particulate) in conjunction with a hydrophobic substance.

As self cleaning of superhydrophobic microscopic to nanoscopic surfaces is based on a purely physio-chemical effect it can be transferred onto technical surfaces on a biomimetic basis.[15][16][17] The first and most successful product with superhydrophobic self-cleaning properties was the facade paint Lotusan launched in 1999, and it has been applied on more than 500,000 buildings worldwide so far.[18]

Further applications have been marketed, such as self-cleaning glasses installed in the sensors of traffic control units on German autobahns developed by a cooperation partner (Ferro GmbH). Evonik AG has developed a spray for generating self-cleaning films on various substrata. Lotus effect superhydrophobic coatings applied to microwave antennas can significantly reduce rain fade and the buildup of ice and snow. “Easy to clean”
products in ads are often mistaken in the name of the self-cleaning process of the lotus-effect. Patterned superhydrophobic surfaces also have the promises for the lab-on-a-chip, microfluidic devices and can drastically improve the surface based bioanalysis.[19]

[edit] Research history

Although the self-cleaning phenomenon of the Lotus was known in Asia for more than 2000 years, only in the beginning of the 1970s with introduction of the scanning electron microscope was botanist Wilhelm Barthlott able to resolve the mechanism behind it (Barthlott & Ehler, 1977, Barthlott & Wollenweber, 1982, Barthlott 1992, Forbes 2008). First experiments were done with Tropaeolum whereas first in-depth studies were conducted on Lotus leaves (Barthlott & Neinhuis, 1997) and in the mid 1990s both authors succeeded to develop their technical applications in successful and sustainable industrial products. Barthlott coined the trademark Lotus-Effect and since the late 1990s physicians and material scientists have thoroughly examined the phenomenon and in the meantime extensive literature and numerous dependent patents exist. Wilhelm Barthlott has been awarded with numerous prizes for the discovery of the functional principle of self-cleaning surfaces and its technical application (1997 Karl-Heinz Beckurts Preis, 1998 Nomination Deutscher Zukunftspreis des Bundespräsidenten, 1999 Philip Morris Forschungspreis, 1999 Deutscher Umweltpreis, 2005 Innovationspreis Bundesministerium für Bildung und Forschung and several others).

[edit] See also

- Biomimicry

[edit] References

   http://pubs.acs.org/subscribe/journals/jacsat/suppinfo/ja0547836/ja0547836si20050928_020859.pdf.
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[edit] External links

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- International Space University page
- Perfluoroalkyl Superhydrophobic Materials
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