sofw journal
Home & Personal Care Ingredients & Formulations
powered by SOFW

Biologically Inspired: Fighting Germs Using HClO Hydrogels with Smectites

J. Gödeker, A. Drewer, T. Lamont

SOFW Journal 12/22 p. 2-7 | Volume 148 | Thannhausen, Germany, December 20, 2022

Biologically Inspired: Fighting Germs Using HClO Hydrogels with Smectites

J. Gödeker, A. Drewer, T. Lamont

abstract

Hypochlorous acid (HClO) is formed in the white blood cells of all mammals [1]. As part of a mechanism that developed several millions of years ago, it also helps the human body to protect against pathogens that enter it. This makes the weak acid a nature-based option for disinfection. Despite this, a disadvantage of water-thin solutions of hypochlorous acid is that they have significantly limited anti-microbial potential due to the reduced contact time. Hydrogels overcome this limitation and lead to improved and more sustainable use. Due to the high reactivity of hypochlorous acid, common additives such as polymer thickeners and natural clays are not suitable. Synthetic smectite clays – of which the presented PURABYK-R 5500 is one example – are very similar in structure to natural clays. However, due to their subsequent technical development, synthetic smectite clays exhibit better stability and are therefore very well suited to forming these hydrogels. They stabilize the hypochlorous acid in the required pH value range and are free from components that impair the activity of HClO. These unique additives are produced under controlled conditions from naturally occurring inorganic mineral sources. They offer the possibility of using structures from nature, paired with a very high purity and consistent quality. Their great potential is presented here using PURABYK-R 5500 as an example.

1. Introduction

The COVID-19 pandemic has changed many people's awareness of cleanliness almost overnight [2]. There is an increasing focus on the considerable importance of hygiene and preventing microbial contamination to our health, and the need for hygiene measures has grown significantly. This can also be seen in the markedly increased sales of hygiene products between 2019 and 2020 in particular [3].

Chemical substances, with which potentially harmful microorganisms such as bacteria, yeast, and fungi can be fought, and viruses can be rendered inactive, are grouped under the term anti-microbial substances. In household applications, this primarily concerns mitigating harmful microorganisms. To avert health risks, contamination of surfaces and the transfer of pathogens via pathogenic germs should be reduced. The search for products that are as sustainable and as safe as possible in order to guarantee the necessary hygiene for our health is more relevant than ever.

Hypochlorous acid – an effective nature-based weapon for combatting germs

The exceptional biomedical potential of hypochlorous acid has been known for a long time. In the first world war, HClO was used to disinfect wounds because of the lack of antibiotics [4]. Its very high efficacy as an anti-microbial substance is still used today in numerous cleaning applications, and for external applications and wound care. Because hypochlorous acid also plays an essential role in protecting the human body against a multitude of harmful pathogens [1], it is also seen as a safe, nature-based option for fighting germs. It is formed as an endogenous substance in all vertebrates as part of the immune response of white blood cells [1]. In humans, white blood cells primarily consist of neutrophil granulocytes (shortened to neutrophils). In these, the oxidant HClO is formed either extracellularly or intraphagosomally (within the cell). The heme enzyme myeloperoxidase (MPO) uses hydrogen peroxide and chloride to catalyze the production of HClO (see **Figure 1**) [5].

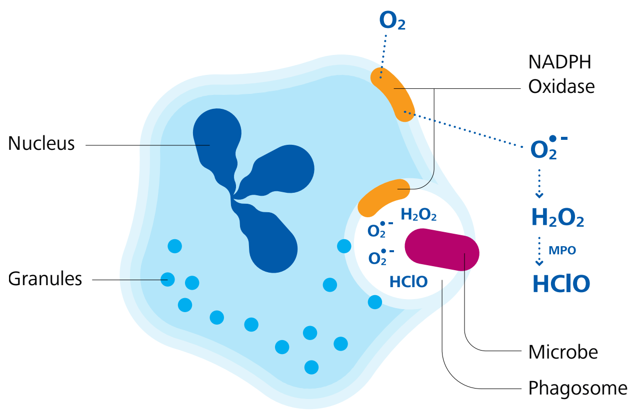

Fig. 1 Diagram of HClO generation as an immune response in white blood cells

Our white blood cells use this mechanism by absorbing harmful microorganisms and then rendering them harmless using hypochlorous acid as an oxidant. HClO very quickly penetrates the cell walls of single-cell microorganisms such as bacteria and viruses [6]. It oxidizes the proteins there, including the DNA (deoxyribonucleic acid) of the harmful germs. Chlorination of n-functionalities in the structures of microorganisms leads to chloramines forming, which are unstable in turn, and radically break down. This leads to the destruction of the DNA of viruses and therefore their inactivation [7].

In a similar way, the oxidative power of HClO causes the cell membranes and proteins of bacteria and viruses to become denatured. This leads to a very wide range of applications to combat all types of harmful microorganisms. Human cell structures are not impaired by this, since their structures are more highly organized and they have developed a protective mechanism, which prevents damage from hypochlorous acid [6]. One significant advantage compared to other active substances is also the fact that it is difficult for bacteria to develop resistance to HClO through mutation. Hypochlorous acid is also effective against the spores of bacteria and therefore stands out from widespread alcohol-based hygiene products (ethanol, isopropanol) [4]. Skin irritation, similar to that which can occur as a result of the frequent use of isopropanol and ethanol, can be avoided by using an aqueous formulation of the weak acid [4]. All these properties make hypochlorous acid a powerful resource to combat germs and this has led the World Health Organization (WHO) to recommend the use of HClO against the COVID-19 (SARS-CoV2) virus [8].

However, there are some challenges that need to be overcome in order to be able to use the acid outside the body as effectively as possible. Hypochlorous acid is only stable in aqueous solutions and is in a state of equilibrium with its conjugate base (ClO^-). This is much less reactive. At higher pH values, the balance tips toward hypochlorite and the oxidative effect decreases. If the compound is too acidic, free chlorine gas is produced (Cl_2).

To be able to use the full anti-microbial potential, the hypochlorous acid must be stabilized in a pH range of between 5 and 7. It should also be considered that due to the high reactivity, the presence of organic substances and transition metal ions needs to be excluded to the greatest possible extent. Otherwise, the hypochlorous acid can decompose and break down. Simple water-thin HClO solutions also have the major disadvantage of draining very quickly, which significantly limits the anti-microbial potential. The low viscosity of the solutions reduces the contact time with the surface to be cleaned, leading to a shorter working time. In particular, vertical application is only possible to a very limited extent. Hydrogels overcome this limitation and lead to improved and more sustainable use.

HClO-based hydrogels – a challenging system

The pronounced reactivity of HClO also makes it challenging to find a suitable rheology modifier for forming hypochlorous acid-based hydrogels. Organic chemicals weaken the active effect of HClO, so no organic polymer thickeners can be used. Furthermore, the presence of transition metal ions has a disruptive effect, which is why natural clays are not suitable. In addition to natural clays that are used in numerous applications due to their rheological properties, it is also possible to synthetically produce similar structures with improved stability and purity. Bentonites are natural clays whose rheological properties are determined by the presence of smectite structures [9]. These structures are also found in synthetic layered silicates (phyllosilicates, LAPONITEs). These nature-based substances are unique special additives that combine the desired properties (such as swelling capacity, thickening, thixotropy) with high purity and exceptional stability in relation to powerful oxidants such as hypochlorous acid. This makes them a perfectly suitable additive for forming HClO-based hydrogels. As shown in **Figure 2**, LAPONITEs are part of the phyllosilicate group of smectites and has a similar structure to the crystal structure of natural clays.

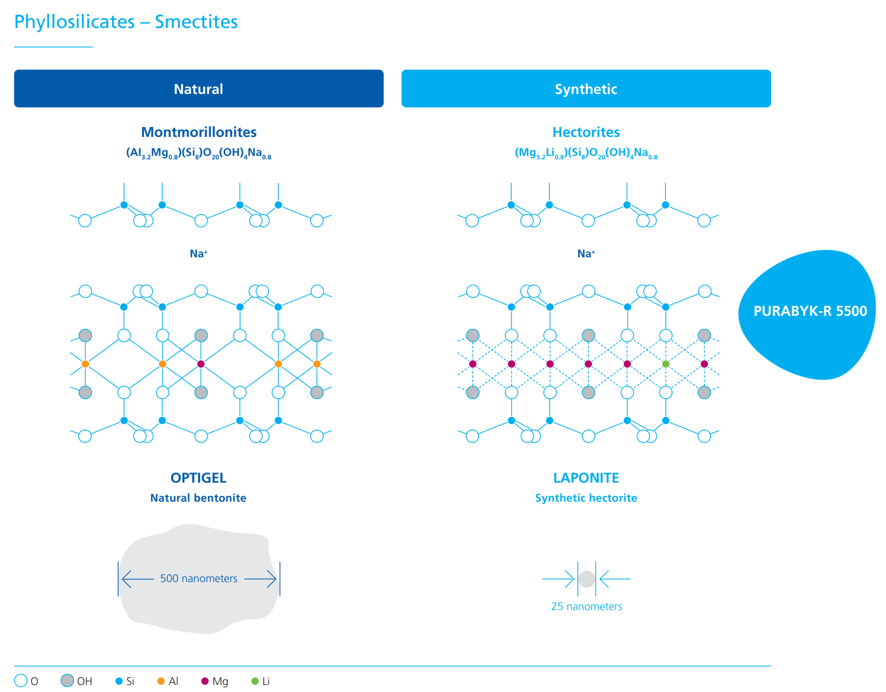

Fig. 2 Crystal structures in phyllosilicates: Natural and synthetic smectite compounds

PURABYK-R 5500 – a new, modified phyllosilicate with improved compatibility

PURABYK-R 5500, the newly developed additive presented in this article, belongs to the hectorite group, whose crystal structure is composed of two tetrahedral sheets sandwhiching an octahedral sheet.The octahedral sheet consists of magnesium ions, oxygen ions and hydroxyl groups.

Water molecules and other substances are easily deposited in the inter layer spacing of the clays which causes when the sheet distance to increase. This is also called "inter-crystalline swelling" [9]. The crystals of these compounds form stacks in the dry state. When they are dispersed in water, they form separate disk-shaped platelets. Through electrostatic interactions, these platelets form a 3-dimensional network (a "house-of-cards" structure), which leads to the desired rheological effect **(Figure 3)**.

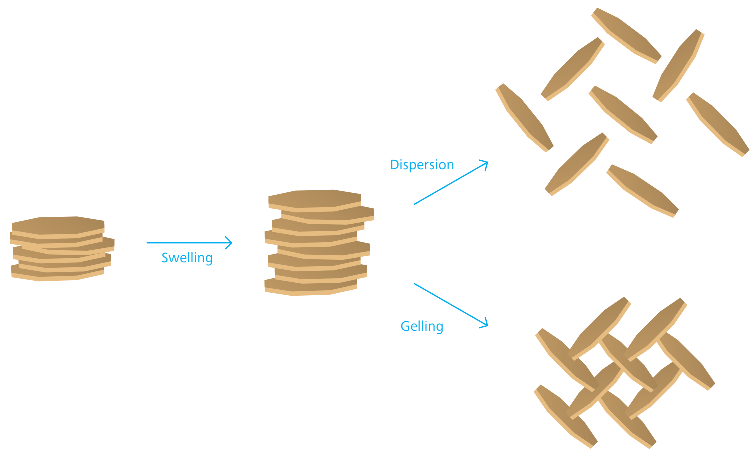

Fig. 3 Dispersion of smectite platelets in water: formation of gel structure

Another difference in relation to clay thickeners is the considerably reduced size of the individual platelets after dispersion. This leads to increased transparency in the formulations.

PURABYK-R 5500 has been specially developed to form stable HClO gels. Specific modification of this synthetic phyllosilicate increases its tolerance to electrolytes. This plays a major role when using hypochlorous acid in particular. In many cases, HClO is industrially produced by electrolyzing a highly concentrated sodium chloride solution. As a result, salt residue cannot be excluded. As a further development of the existing LAPONITE rheology additives, PURABYK-R 5500 tolerates a salt content of up to 4% and can be added directly without pre-dispersion **(Figure 4)**.

2. Material and methods

Formulation of the hydrogel with PURABYK-R 5500

The presented results were determined using a hypochlorous-acid-based hydrogel. To do this, thickening was achieved by directly adding PURABYK-R 5500 to an aqueous solution of hypochlorous acid. The viscosity of the compound increased significantly after the pH value was adjusted to 5.0–5.5 using orthophosphoric acid in particular. The pH value typically stabilized at 6.5. The formulation is displayed in **Table 1**.

A slightly turbid hydrogel was created that provides a dry, soft feel and non-sticky texture on the skin. A storage test showed that the viscosity remained stable after storage at 40°C for 12 weeks and that the gel structure was maintained.

The investigations discussed in the next section were carried out on the indicated formulation to further characterize the hydrogel produced.

INCI: Sodium magnesium fluorosilicate (nano) and tetrasodium pyrophospate

Method of addition	Less NaCl (< 2 %)	More NaCl (> 2 %)
Pre-dispersion	●	●
Direct addtion	●	–

Suitable for application in HClO solutions with NaCl content of up to 4 %.

- With an NaCl content of 2 % or less, the product can be added directly to the HClO solution.
- If the NaCl content is higher than 2 %, the product must be pre-dispersed in ultra-pure water before it is added to the HClO.

Fig. 4 PURABYK-R 5500 as a further development for simple use in HClO solutions

Item	Component	Function	Weight [g]
1	Ultrapure water	Solvent	16.0
2	Hypochlorous acid 500 ppm FAC	Active substance	80.0
3	**PURABYK-R 5500**	**Rheology additive**	**3.5**
4	Orthophosphoric acid (21% in water)	pH value adjustment	0.5.

Table 1 Formulation of the hydrogel

A more in-depth reflection – high-resolution procedure for forming the nanostructures

The size of the smectite platelets is in the nanoscale range. This means that the resolution of a simple microscope is not sufficient to show the morphology, since this is physically limited by the wavelength of light. To be able to represent these structures as a real image, extensive preparations and analysis methods are necessary. Transmission electron microscopy (TEM) is suitable as an imaging method. According to Louis de Broglie, electrons also have wave properties and it is possible to describe a wavelength of the particle [10,11]. Since the assumed wavelengths of the electrons are significantly smaller than the scale of the platelets, electron microscopy is well suited to showing nanostructures. For this, thin test sheets are exposed to a high-energy electron beam and the electrons are identified on a detector after the sample is subject to transmission [10,11]. The different scattering of electrons when the sample is exposed mean that conclusions can be drawn on the size and composition of the substance.

This high-resolution method can even be used to show the network structure of the platelets – the network structure which leads to the rheological effect ("house of cards" structure). In particular, cryo-TEM is a very good tool for "freezing" the interactions in a solution and realistically depicting them.The degree of exfoliation of the smectite platelets in dispersions can be determined using height determination based on atomic force microscopy (AFM). In this non-invasive method, a nanoscopically small needle is guided over the surface of the sample. The forces produced between the sample and the measuring needle (cantilever) are measured and evaluated for imaging [12].

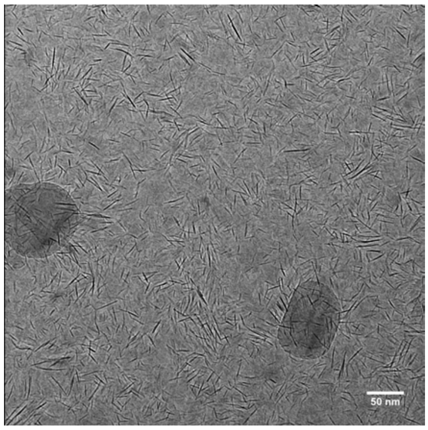

Fig. 5 Cryo-TEM images of a dispersed hectorite, sample was imaged on a JEOL 2200FS TEM with a Gatan K2 direct electron detector at the University of Warwick.

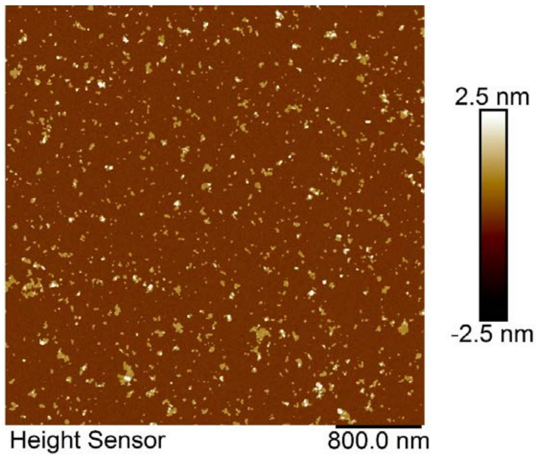

Fig. 6 AFM image of hectorite in solution, Bruker Icon-PT instrument

3. Results and discussion

Micro- and macro-morphology using TEM and AFM

In **Figure 5**, two cryo-TEM images of a hectorite in an aqueous dispersion can be seen. The network structure ("house-of-cards" structure) can clearly be seen here, which the exfoliated platelets form through electrostatic interaction. This leads to the desired rheological effect, namely, in this case the formation of a thixotropic hydrogel. It is also possible for different particles (opacifiers, fragrance capsules, etc.) to stabilize by being deposited into this network of platelets and this is certainly conceivable with the image. The dimensions of the individual smectite platelets moving in a range of 25 nm along the two axes shown at this level can also be seen. The concentration of the hectorite material determines the density of this 'house of cards' network.

The extent of exfoliation of the platelets in an aqueous dispersion can be determined by a topographical analysis using the AFM method. **Figure 6** shows the corresponding AFM image of the hectorite presented here. It can clearly be seen that the smectite platelets are homogeneously distributed.

The height distribution can be used to obtain information about which proportion of smectite lamellae are present in single, double, triple, etc. stacks. Evaluation of the measured data reveals that the majority (cumulatively 73.6%) are in the height range below 1.75 nm and can therefore be considered to be completely exfoliated. There are no platelets that are in stacks of more than three (cumulatively 100.0% in the range from 2.75 nm to 3.25 nm) which represents good delamination.

Viscosity behavior of the hydrogel – thixotropy and yield point

The aqueous formulation based on hypochlorous acid with 3.5% PURABYK-R 5500 forms a hydrogel which shows a thixotropic behavior. **Figure 7** shows that HClO hydrogel has a high low-shear viscosity and a low high-shear viscosity (see blue curve). This demonstrates the highly sheer thinning properties of the hydrogel. The viscosity develops again after the force is removed, but this is somewhat delayed, thus exhibiting thixotropic behaviour (dark blue curve). However, the original viscosity of the hydrogel is quickly reached again.

In a comparison of two samples (one was measured directly after incorporation of the PURABYK-R 5500; the other was left for 12 h), it is evident that the gel structure forms quickly after incorporation of the rheology additive, but that it can take some hours before the final viscosity has completely formed.
With further measurements, it was determined that the hydrogel based on PURABYK-R 5500 forms a clear yield point above which the sample no longer shows an elastic behavior (gel structure), and instead starts to flow. This supports the good sprayability and pumpability of the hydrogel, which significantly improves handling, depending on the application.

HClO hydrogel with PURABYK-R 5500

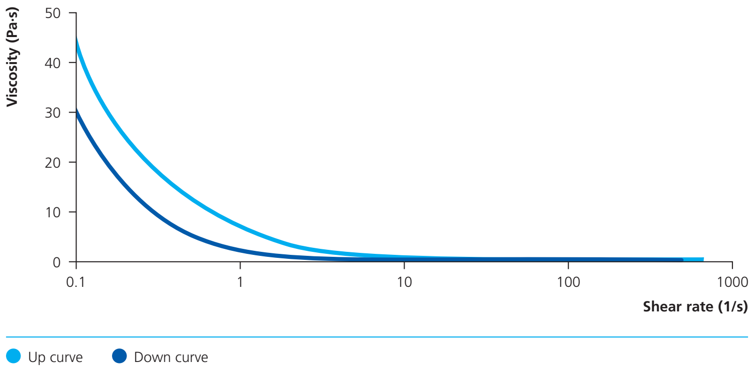

Fig. 7 Viscosity curve, 12 h after incorporation of PURABYK-R 5500

Biocide effectiveness – influence of PURABYK-R 5500

Tests on the influence of PURABYK-R 5500 on the biocide effectiveness of the HClO hydrogel were conducted at the accredited test laboratory HygCen Germany GmbH. To do this, phase 2 level 1 quantitative suspension tests were held with different standard bacteria and virus strains. Tests were conducted according to the EN 13727 (bactericidal activity) or EN 14476 (virucidal activity) test methods with a low load (0.3 g/l bovine serum albumin). It was shown that the biocidal effectiveness against bacteria and viruses was maintained in full with an addition of 3.5% PURABYK-R 5500. The criteria indicated according to EN 13727 and EN 14476 are also met by the phyllosilicate formed in the hydrogel.
Depending on the practical use and the specific process, phase 2 level 2 tests must be added if applicable. However, based on decades of successful use of this synthetic hectorite compound in these applications, it can be assumed that using rheology additives does not lead to impairment of the biocidal effectiveness of the active substance, and therefore the product. The suspension tests performed on the hydrogel mentioned here supported this experience.

4. Conclusion

Synthetic phyllosilicates such as the PURABYK-R 5500 presented here are very versatile additives. They can be appropriately produced using technical modifications for various, and very demanding, applications. Their structure resembles that of natural clays (smectites), but they can be produced to a much higher purity and are easy to modify. This makes them very safe and robust compounds, which significantly expands the area of application of these smectites.

In this article, the interesting structures that form these compounds are considered in more detail and evaluated in a scientifically sound way. This enables better understanding of the properties such as rheology and interactions with other components of different systems, and therefore applications. These findings are extremely important, because they form the basis to optimally use this high-performance additive and therefore exploit its full potential. The example of hypochlorous acid has shown that the limits of the application of rheology additives can be expanded with these compounds. Very demanding systems can be thickened with it too, offering improved and more sustainable application for the systems.

References:

[1] *Michael S. Block and Brain G. Rowan*, Hypochlorous Acid: A Review, J Oral Maxillofac Surg, 2020; 78; 1461-1466.

[2] https://klinegroup.com/six-cleaning-trends-turbocharged-by-the-pandemic/, veröffentlicht am 02.11.2021. Retrieved on 14.09.2022.

[3] Data query from https://my.klinegroup.com/, Umsatz der Produktgruppe Desinfektion und Sanitizers zwischen den Jahren 2017 und 2021. Retrieved on 31.08.2022.

[4] *Margie Recalde*, Hypochlorous acid: harnessing nature´s germ killer, Optometry Times; December 2019.

[5] *A.J. Kettle, C.C. Winterbourn*, Myeloperoxidase: a key regulator of neutrophil oxidant production, Redox Report, 1997; 3(1); 3-15.

[6] https://mediset.de/hypochlorige-saeure/, retrieved on 14.09.2022.

[7] *Clare L. Hawkins, Michael J. Davies*, Hypochlorite-induced damage to DNA, RNA, and polynucleotides: formation of chloramines and nitrogen-centered radicals, Chem Res Toxicol., 2002; 15(1); 83-92.

[8] WHO Interim guidance, Cleaning and disinfection of environmental surfaces in the context of COVID-19, 2020; 1-8.

[9] *G. Lagaly*, Anorganische System- Tonmineraldispersionen, Fließverhalten von Stoffen und Stoffgemischen, 1986, Hüthig & Wepf Verlag, 147-167.

[10] https://www.mri.psu.edu/materials-characterization-lab/characterization-techniques/transmission-electron-microscopy-tem, retrieved on 14.09.2022.

[11] https://www.leifiphysik.de/quantenphysik/quantenobjekt-elektron/ausblick/transmissions-elektronen-mikroskop-tem, retrieved on 14.09.2022.

[12] *G. Binnig, C.F. Quate*, Atomic Force Microscope, Physical Review Letters, 1986; 56(9); 930-934.

authors

Dr. Jessica Gödeker | Jessica.Goedeker@altana.com
Head of Technical Service Homecare & Industrial Solutions, **BYK**

Anne Drewer | Anne.Drewer@altana.com
Global Head of Enduse Care and Industrial Solutions, **BYK**

Tom Lamont | Tom.Lamont@altana.com
LAPONITE Applications chemist, **BYK**