THE NATURAL PERFORMANCE ENHANCER

MICROFIBRILLATED CELLULOSE AT A GLANCE

CHARACTERISTICS AND POTENTIAL APPLICATIONS

Borregaard

CONTENTS

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WHAT IS MICROFIBRILLATED CELLULOSE (MFC)?

HISTORY OF MFC

Microfibrillated cellulose (MFC) was first studied in the late 1970s as a part of research at the ITT Rayonier labs in the US. Albin Turbak, who worked on MFC at the ITT Rayonier lab, pursued this new type of cellulose quality and discovered that by using a high-pressure homogenizer, cellulose fibers could be fibrillated into cellulose microfibrils.

This new material had interesting properties that were quite different from regular cellulose. ITT Rayonier did not develop full scale production, and in 1983, they gave a free license to all parties interested in investigating this new concept of MFC. From 1983 to 2005, little activity was seen in the industrial field of MFC, while the amount of patents after 2005 and until present (2015) has exponentially increased (see figure below, data up to 2012).

The interest in the concept of MFC has increased in the end-user markets since 2005, and more and more manufacturers of end-products are both patenting and testing out MFC.This interest can also be found in the search trends for the subject MFC, where a steady increase has been found during the same period (Figure 2)

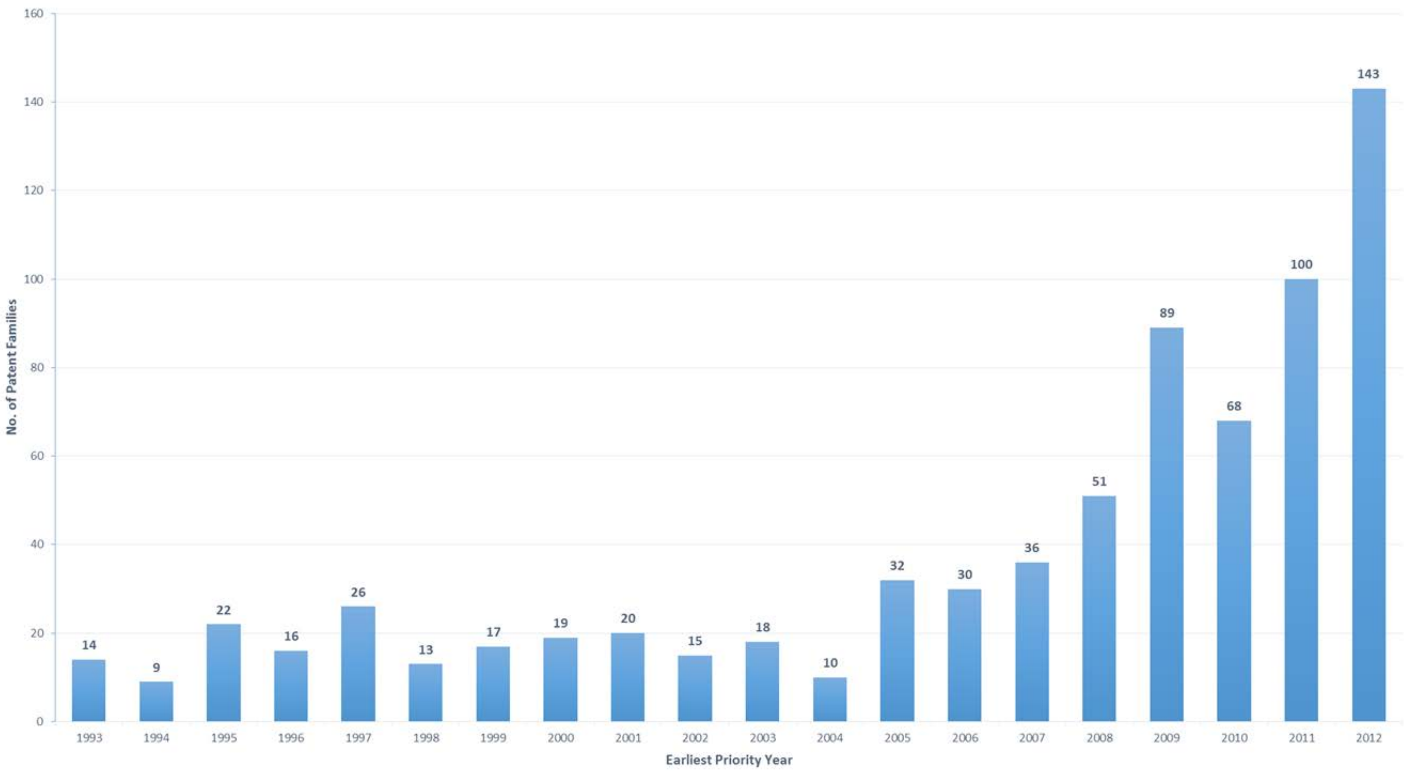


FIGURE 1
Patent families by year for microfibrillated cellulose and nanocellulose

Despite the large interest in MFC both in the academia and the industry, the commercial utilization of MFC has been limited. The main challenges in commercializing MFC has been to develop a process for the fibrillation of the cellulose that is suitable on a large commercial basis. The fibrillation of the cellulose, and the material handling during the process, can be a challenge and also drying the material without losing performance can be difficult.

As a result, focus on delivering MFC in a wet state, and the use of MFC in water based systems, has increased. The benefit of using MFC delivered in a wet state is that it is readily activated and less energy is needed to incorporate the MFC into formulations.

Borregaard is currently building the first large scale commercial plant for MFC production, with a capacity of 50 000 tons dispersion (1000 tons dry based).

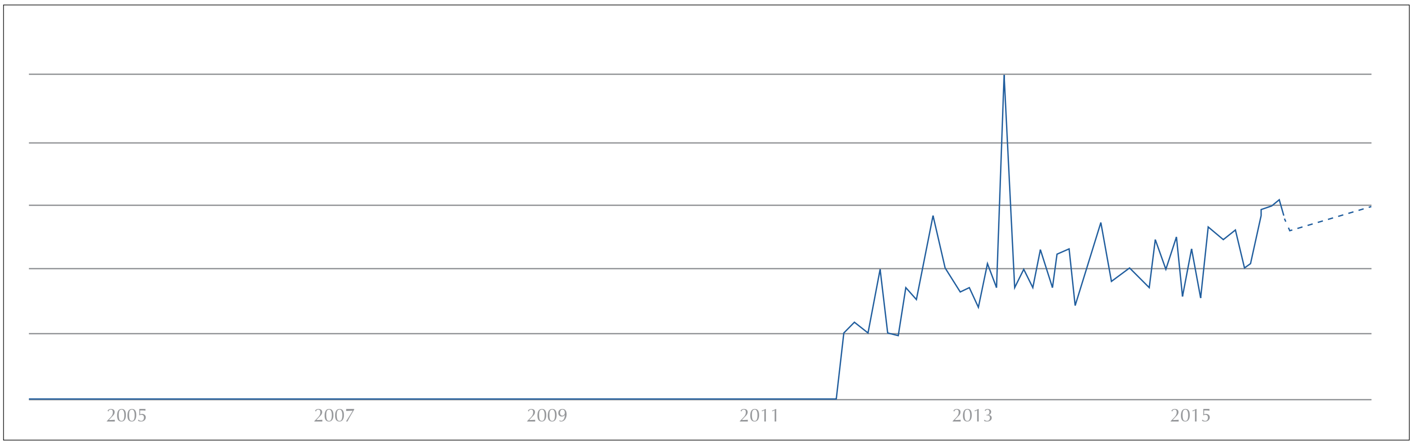


FIGURE 2
Microfibrillated cellulose and nanocellulose search trends.

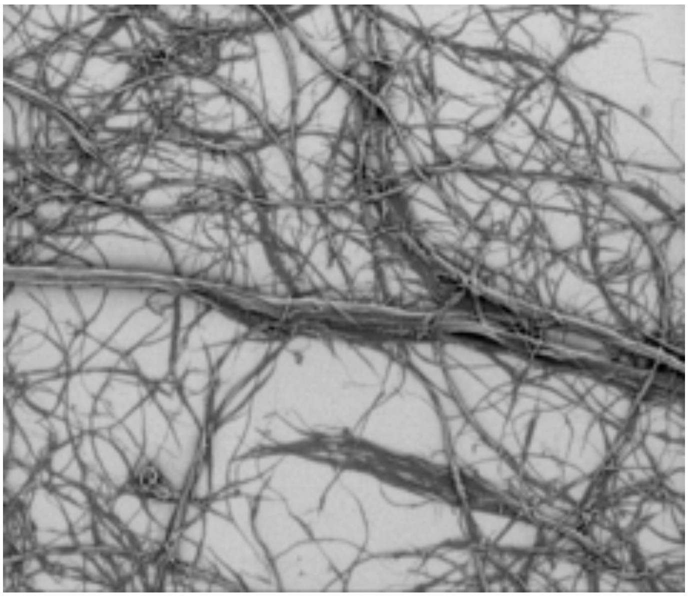


FIGURE 3
MFC (Exilva MFC from Borregaard) seen through scanning electron microscopy.

WHAT IS MFC?

The cellulose microfibrils are built up of cellulose polymers. The cellulose polymer is a linear polymer that consists of D-glucose units linked together (Figure 4).

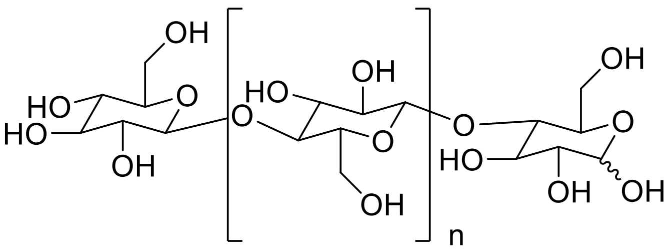


FIGURE 4
The cellulose polymer consists of D-glucose units

In nature, these cellulose polymers stack together and form cellulose microfibrils. When the cellulose polymers are perfectly stacked together, it creates highly crystalline regions. However, disorder in the stacking will also occur leaving more amorphous regions in the microfibril. The crystalline regions in the microfibrils, and the very high aspect ratio, gives the material high strength.

Microfibrillated cellulose has a much higher surface area than the cellulose raw material and therefore also a high number of accessible hydroxyl (OH) groups on the surface of the microfibrils. The exact surface area is hard to determine since many methods require drying of the material, but the fibrils aggregate strongly upon drying, which reduces the surface area. Spence et al. (2010) used a Congo red method for estimating the surface area of different MFCs and estimated it to be 100-200 m2/g. This method is performed in wet state, and therefore, it is likely to give rather accurate results.

VARIATIONS OF MFC

Various types of MFC have been developed; for example, MFC can be unmodified or chemically or physically modified with regards to the hydroxyl groups on the microfibril surface.

Unmodified MFC is produced by using mechanical treatment, possibly combined with enzymatic pretreatment and thereby leaving the hydroxyl groups on the microfibrils unchanged. The microfibrils in this type of MFC are often arranged in flexible aggregates and there are few individual microfibrils. In chemically modified MFC, the hydroxyl groups have been changed into, for example, carboxyl groups or carboxymethyl groups. Having a negative charge on the surface of the microfibrils, causes a repulsion between them and leads to easier separation. Often, this type of MFC has a high degree of individual microfibrils, and some of these types of MFCs are even transparent materials (contains only fibrils that are smaller than the wavelength of visible light). The surface of the MFC can also be modified with hydrophobic groups to increase the compatibility with hydrophobic systems.

Another way to modify the surface of the microfibrils is to absorb surfactants or polymers onto the microfibril surface. This can alter the properties of the MFC and, amongst others, improve compatibility with hydrophobic systems and prevent loss of functionality upon drying of the material.

The various MFCs will give different functionalities in the end users products. This can relate to, for example, the amount of hydroxyl groups available, compatibility with various systems, rheological properties, stability (temperature, pH and salt) and transparency.

The properties of the MFC will also vary with the cellulose raw material used to produce the MFC. Different cellulosic raw materials vary in the composition and purity, degree of polymerization of the cellulose polymers, the fiber length and crystallinity, amongst others. All these parameters can have an effect on the MFC properties. A few examples of raw materials used to make MFC are cellulose from trees (hardwood and softwood), vegetables, sugar beet pulp and citrus pulp. Another type of MFC can be made from bacteria producing cellulose microfibers. Overall, it is important to have good control of the raw material to ensure high and consistent MFC quality.

2

WHAT CAN YOU EXPECT WHEN USING MICROFIBRILLATED CELLULOSE?

THICK AND EASY FLOWING FORMULATION

MFC water suspensions have high viscosity already at low concentration, and it is extremely shear thinning material (Pääkkö et al. 2007, Iotti et al. 2011). Viscosity is a measure of how much the material resists flow.

As mentioned earlier, MFC consists of a three dimensional network of long and thin fibrils. This network is very strong and it resists the flow efficiently, thus providing the high viscosity. However, when you start mixing the suspension, in rheological terms apply force on the suspension, the network eventually breaks and the fibers start to flow in small aggregates. The aggregates can flow easier than the network, thus leading to a lower viscosity upon flow. When the mixing speed or shear rate is increased, these aggregates resize and orientate along the flow. This leads to a decreasing viscosity with increasing shear rate and it is called shear-thinning behaviour. MFC is extremely shear thinning, as illustrated in Figure 5.

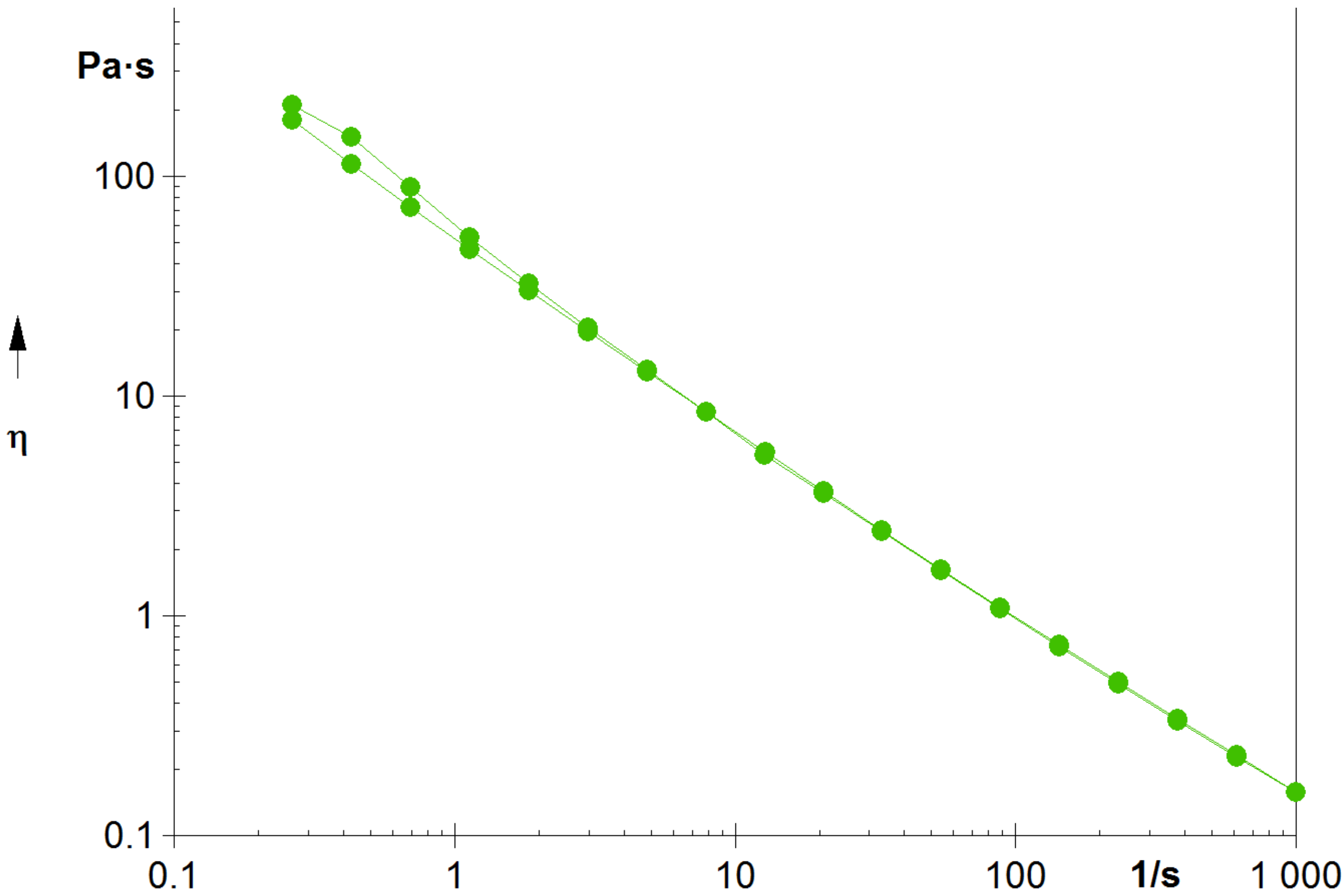


FIGURE 5
Viscosity as a function of shear rate for 2% MFC suspension in water. Viscosity drops drastically over the shear rate range 0.2...1000...0.2 s-1 (point time 1 s).

FIGURE 6
MFC is an ideal thickener for cosmetic spray products. This picture shows how 0.3% MFC (Exilva MFC from Borregaard) makes an oil in water sunscreen formulation with inorganic pigments (titanium dioxide) thicker and prevents dripping totally (on the right hand side) compared to reference without MFC (on the left hand side). Sun screen containing 0.3% MFC is a liquid product whereas adding 1% MFC makes a thick cream which also can be sprayed without dripping.

When the shear is stopped and the MFC suspension is standing still, the network of fibrils builds up again and the suspension regains its viscosity. This occurs fast, and the viscosity goes back to the original value or close to that. Figure 5 illustrates this by showing a flow curve measured from low shear rate to high shear rate and back. The upwards and downwards curves are on top of each other, meaning that the suspension does not show any time dependent behaviour and viscosity recovers immediately to the original values when shearing is decreased. Sometimes extensive shearing (mixing) can cause permanent aggregation of the fibers and lower viscosity of the suspension. However, this rarely occurs in a formulation where there are other substances between the fibrils which prevent them from aggregating.

High viscosity at low shear rates and shear thinning behaviour makes MFC a good thickener. For example, MFC can be used as a thickener in sprayable sun creams. It allows the spraying of very thick suspension since the viscosity decreases during the spraying. However, when the cream is on the skin and no forces are applied to the cream, the viscosity retains quickly and the product stays where it was applied and does not drip. Another good example is paints. When they are applied, for instance by brushing, the viscosity must be low enough, so that the paint is easy to apply and does not leave brush marks. Immediately after application, the viscosity increases. This prevents dripping and sagging.

HIGH YIELD STRESS AND IMPROVED STABILITY

A certain amount of force is needed before a MFC suspension starts to flow. This means that it has a yield stress.

Stress is measured by applying force on a certain area of the material, and this force divided by the area is stress. The stress value where the material starts to flow is called yield stress. Figure 7 shows a stress ramp measured for 1.4% MFC suspension. The test starts with insufficient stress to make the suspension flow, and therefore the viscosity is extremely high. At a certain point (yield point), the stress exceeds the yield stress, the material starts to flow and the viscosity drops. The yield stress of the suspension in Figure 7 is above 41 Pa.

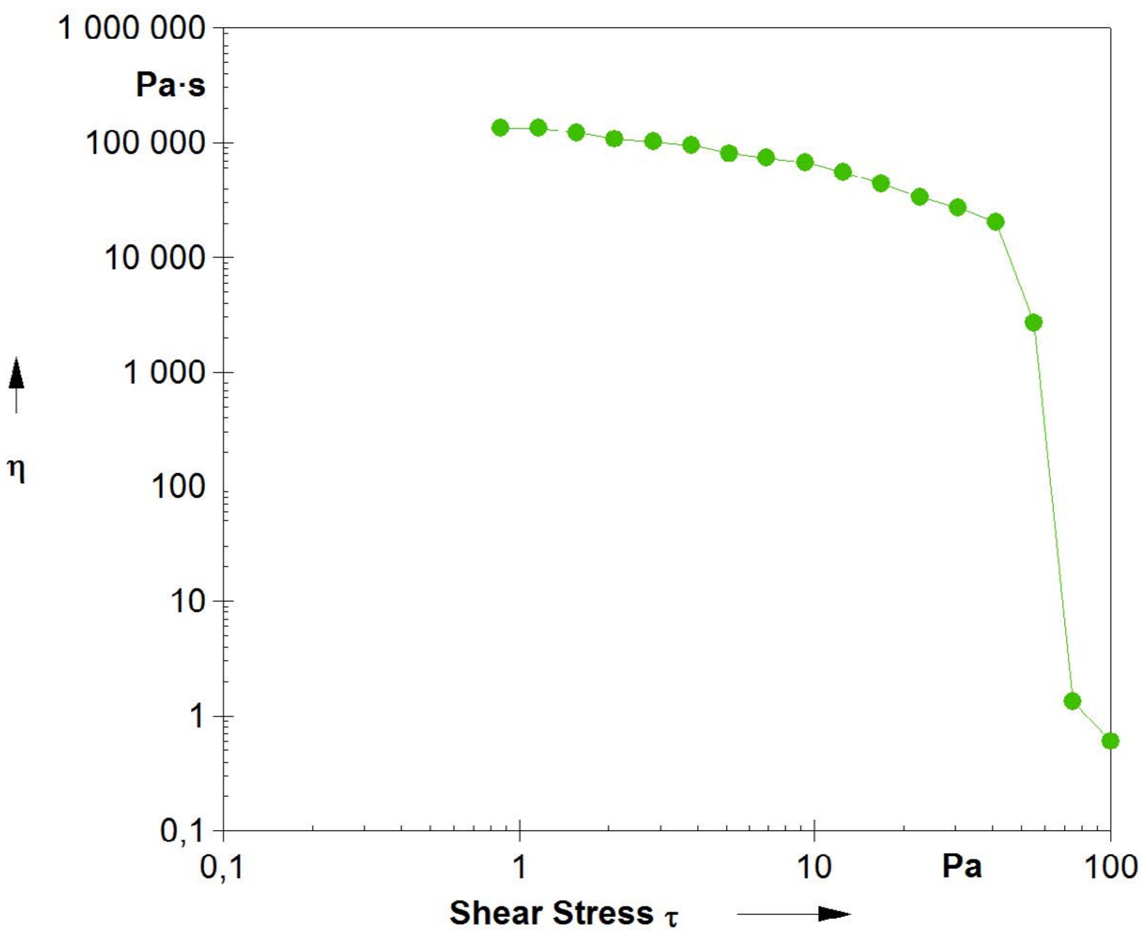


FIGURE 7
Stress ramp measurement showing the yield point for 1.4% MFC suspension (Exilva, Borregaard).

FIGURE 8

MFC (Exilva MFC from Borregaard) tested as stabilizer for acrylic based exterior flat paint (45% polyvinylchloride, PVC, solids volume 37%). Reference paint on the left hand side contains 0.31% HEC and paint on the right hand side contains 0.38% MFC. The stability was tested over 2 weeks at 49 °C. Reference paint showed moderate syneresis whereas syneresis in the paint with MFC was very low. No settling was observed in either of the formulations.

MFC suspensions have high yield stress which makes them good stabilizers for dispersions or emulsions. Since the fibers are much stronger than the interactions between them, the yield stress is dependent on the amount of contacts between the fibers and forces (interactions) at these contact points. The highest yield stress is achieved when the fibers are well dispersed, but still have strong adhesion at the contact points. The higher the yield stress, the heavier particles the material can stabilize. Back to the examples of sun cream and paints; both are suspensions with pigment particles that need to be dispersed evenly in the formulation. The MFC network can “trap” the particles between the fibers and stabilize the suspension effectively. Figure 8 shows an example from paints where MFC can stabilize the acrylic paint better, compared to hydroxyl ethyl cellulose (HEC).

FIGURE 9
MFC can hold a lot of water compared to its mass. This picture shows 2% MFC suspension in water, which is creamy or gel-like even if it contains 98% water.

IMPROVED WATER HOLDING CAPACITY

As described earlier, microfibrillated cellulose has a huge surface area with many OH groups. These OH groups form strong hydrogen bonds with water molecules and keep them bound on the fiber surface.

As a consequence, MFC can hold water many times its own weight, resulting in the gel-like appearance. Good water holding ability means that MFC can stabilize water based formulations and keep substrates wetted longer. Good examples are paints and other types of coatings where MFC can prolong the open and wet edge time. This means that when the coating dries more slowly, the time window for applying a new layer, or correcting defects in the coating layer without brush marks, is longer. This makes the application process more flexible.

STRENGTH AND REINFORCEMENT

Microfibrillated Cellulose has a very high aspect ratio with fibril diameters in the nanometer range and fibril length in the micrometer range. This high aspect ratio, together with the high crystallinity of MFC, makes MFC a potential reinforcement of composites, films and coatings, amongst others.

The strength of crystalline cellulose has been compared to the strength of Kevlar and various composites containing MFC has been described as having tensile strengths greater than cast iron (Moon, 2011 and Miao, 2013)

MFC is biodegradable and thus a good candidate for reinforcing agent in biodegradable plastics and packaging materials. For instance, MFC can be combined with polylactic acid and be used in nanocomposites. Polylactic acid is a versatile polymer derived from renewable sources like sugar beets and sugar canes. However, a problem with the polylactic acid is that it is brittle. It has been tested to use MFC to reinforce the polylactic acid composites and increase the strength. The incorporation of MFC resulted in improved mechanical properties, especially the toughness of the composite was improved. (Nakagaito, 2009).

MFC makes flexible composites needed in many novel applications, like reinforcement of Li-ion batteries. It has been demonstrated that MFC can be used to reinforce methacrylic-based composite polymer electrolyte membranes. The MFC reinforced membranes had excellent mechanical properties, high conductivity and good overall mechanical performance. Especially the flexibility of the membranes was very good, and this is interesting for, amongst others, the use in flexible and extra thin batteries for flexible electronics (Chiappone, 2011).

Cellulose in general is biocompatible (Lin and Dufresne 2014) which means it can be used in composite materials used in the human body. For example, an MFC/polyvinyl-alcohol composite coating can be used to reinforce Bioglass-based porous scaffolds. Bioactive glasses are a group of surface reactive glass-ceramic biomaterials. The biocompatibility and bioactivity of these glasses has led them to be investigated extensively for use as implant materials in the human body, to repair and replace diseased or damaged bone. However, a problem with this material is its brittleness, which causes challenges in load bearing applications. It has been tested to dip Bioglass samples into an aqueous solution of MFC and polyvinyl alcohol. The addition of the MFC/polyvinyl alcohol coating led to a 10-fold increase in tensile strength of the material (Bertolla, 2014).

For further reading on the use of MFC in reinforcement of composites, Miao and Moons ((Moon, 2011 and Miao, 2013) reviews on cellulose reinforced polymer composites and cellulose nanomaterials are recommended.

BARRIER PROPERTIES

MFC has good film forming properties, and the dried MFC films have been reported to have very interesting barrier properties. Two parameter that has been studied is the water vapor permeability and oxygen barrier properties of MFC films (Lavoine, 2012).

The oxygen barrier properties of MFC films are excellent and have been reported to be comparable to many well-known synthetic polymer films. The good oxygen barrier properties are believed to be related to the crystalline structure of MFC and the ability of the microfibrils to form a dense network with inter and intra fibrillary hydrogen bonds.

The water vapor permeability of MFC films are also good but not as good as for other polymer films. This is due to MFC's high affinity for water, but this can be improved by modifying the hydroxyl groups on the surface of the microfibrils, either chemically or by absorption of polymers.

An interesting approach, also subject to studies, is to coat MFC films on polymer films that typically have good water vapor permeability. As a result a good oxygen barrier and a good water barrier can be obtained. This is a new way of producing barrier materials and could offer the advantages of both the polymers and the MFC.

The novel barrier properties renders MFC an appealing new biomaterial for, amongst others, food packaging, paper coating and printing applications. For further reading on MFC and its barrier properties, a review article from Lavoine and co-workers is recommended (Lavoine, 2014).

INNOVATION OPPORTUNITIES

Microfibrillated Cellulose inhabits many different interesting properties related to rheology (flow and stability), reinforcement and barrier.

Due to the rather large range of different properties expected when using MFC, the material is often described as having the potential of being a multifunctional additive bringing more than one property into the application or formulation. This is an opportunity to perhaps simplify the formulations while at the same time obtain new properties and improved formulations.

It can be said that MFC inhabits properties of both soluble polymers and insoluble additives and in an interesting way combines the properties of these two worlds. MFC is not soluble in water, but in many cases, it behaves like a water-soluble polymer and is able to improve flow properties and stability of the formulations in the same manner as the water soluble polymers. However, the non-soluble nature of MFC and the high crystallinity renders the material more stable towards high temperatures, high shear and changes in pH than most water soluble polymers. An internal study of Borregaard's Exilva MFC has shown that the material is stable in the pH range of pH 1-13 over several months. So, for producers or scientists looking for additives or ingredients that are effective and stable over a vide pH range, it might be a good idea to have a closer look at MFC as an alternative. Also, MFC in general does not need swelling time or pre-hydration and is not dependent on a certain pH level to be activated. This can contribute to shorter production times and a more efficient production processes.

Increased focus on greener and more environmentally friendly materials made from renewable sources is emerging. MFC also improves the environmental profile and CO2 footprint of the formulations and materials.

The rheological properties of the MFC, in combination with the reinforcement and barrier properties, form a part of an additive that can both stabilize the formulation and give the desired flow properties, as well as give strength and barrier properties in the end-product. The high water holding capacity of MFC can also contribute to control drying time and keep surfaces wetted longer.

Examples of possible application areas for MFC, and how the different properties of MFC can contribute to an improvement in these applications, are described in more detail in chapter 4.

3

CRITICAL SUCCESS FACTORS WHEN APPLYING MFC

When introducing MFC into a formulation one of the most critical success factors is to make sure that the MFC is dispersed correctly. To make use of the large available surface area of the MFC, it is important that the product is incorporated properly in the matrix surrounding it.

The microfibrils in the MFC has high affinity for each other and high shear is needed to obtain good dispersion. Lower shear equipment can also be used, but then longer time is required. If optimal dispersion of the microfibrils is not achieved, the functionality and the transfer of the characteristics from the MFC may be lower or less efficient, decreasing the potential performance in the finished product.

When MFC is added into a formulation there are a few things that are important to consider. The MFC should be added to the most polar phase of the formulation, preferably in the water phase. For example, in an emulsion, the MFC should be added to the water phase before mixing with the oil phase. MFC is a robust material and can be added in a homogenizing or milling step that will help the dispersion of the MFC. As an example, MFC can be added in a grind phase with pigments and fillers, and this will aid the dispersion.

Various types of equipment can be used to disperse MFC. In the lab, the use of high shear equipment, like an Ultra Turrax homogenizer or a Dispermat disperser, will generally give a good dispersion. However, lower shear equipment, like a propeller mixer, can also be used, but longer time is required. It is important to ensure that the whole dispersion volume is homogenously mixed and that there is an efficient transfer of the energy from the stirrer to the full volume of the dispersion.

The dry content of the MFC also has big impact on the dispersion. In general, the higher the dry content of the MFC, the more energy and higher shear will be required in order to disperse the MFC properly. If the MFC is diluted to a low concentration in a low viscosity medium, higher shear and longer dispersion times might be needed. In this case, it might be a good idea to do a step-wise dilution by first making a more concentrated dispersion of the MFC, and then dilute it further afterwards.

4

POTENTIAL APPLICATIONS

The previous chapter showed how versatile material MFC is. This chapter will show examples where these properties can be utilized, based on Borregaard's own experience and the literature.

COATINGS – IMPROVING RHEOLOGY CONTROL AND COATING QUALITY IN WATER-BASED PRODUCTS

A high variety of rheology performers have been used in coatings for decades, since good control over the rheology is crucial for the application and quality of the product. We have listed some examples:

- Improving stability: MFC has high yield stress and high viscosity at rest, which is important for the product´s performance as an anti-settling aid and as anti-syneresis aid.
- Very high pH stability: MFC has shown extremely high stability towards pH. The product can withstand differences in pH from pH 1 to pH 13, giving flexibility in processing the product as MFC typically can tolerate any part of the production process when it comes to pH.
- Matting effect: Opaque appearance of MFC gives a matting effect to the final paint or coating products. This typically eliminates coatings and paints where high gloss is wanted.
- Good spray properties and anti-sag agent: MFC has very high shear thinning capabilities and rapid viscosity recovery. This behavior makes it suitable for products where rapid response to shear forces is wanted. Typical example is application by spraying.
- Longer open time and wet edge time: MFC is good at holding water, so it can keep the coating wet longer. This prolongs the time when corrections or second layer can be applied without brush marks or other defects.
- Good film and barrier properties: MFC improves the mud-crack and scrub resistance of paints. This comes probably from the strong and flexible network of the microfibrils, which can resist defects coming from the drying or external stress (see also Borregaard's technical bulletin on this topic). These properties enable thicker layers to be applied, which reduces the number of film layers needed.
- No VOC: MFC will not add any VOC substances to the coating

FIGURE 10

The anti mud-crack effect of adding Exilva to a 45% PVC exterior acrylic paint was compared to the same formulation based on a standard HEC. A film was prepared at multiple thicknesses, ranging from 14 through 60 Mils. Exilva provides increased crack resistance during curing from 2°C to 24°C (35°F to 75°F) when added 0.38% to the paint. With Exilva, no cracking was observed even at 60 Mils thickness (i.52 mm) (lower picture), whereas the HEC paint displayed cracking for all thicknesses above 14 Mils (0.36 mm) (upper picture). See more in Borregaard's technical bulletin.

ADHESIVES – GOOD STABILITY AT HIGH AND LOW PH

Adhesives are in many instances manufactured through processes including a wide range of pH. Thus, pH stability of the additives used in these processes is key to obtain and maintain functionality of the resin or the finished adhesive.

Typically, stabilizing additives, and additives designed for efficient rheology performance, have limitations to their functionality at extreme pH ranges. The non-soluble nature of the cellulose microfibrils provides an increasingly robust and stable product system towards high variety in pH during production.

Since MFC is a water-based suspension, it is suitable for waterborne systems, like:

- Waterborne polyurethane formulations
- Waterborne epoxy formulations
- Waterborne acrylic formulations
- Urea formaldehyde systems

Examples of functionalities MFC can add to the adhesives:

- Very high pH stability
- Extremely shear thinning and quick recovery of viscosity, good spray properties
- Longer open time due to high water retention
- MFC does not add VOC substances to the adhesive

PERSONAL CARE – NATURAL THICKENER WITH MANY FUNCTIONS

MFC can be used in personal care products like face creams, sun sprays and shampoos as a stabilizer and viscosifier which also gives good skin feel.

FIGURE 11
MFC is good stabilizer and thickener for face creams and gives nice skin feel.

This is clear advantage compared to certain synthetic viscosifiers which tend to make the product sticky. Recently, studies performed with Borregaard's Exilva MFC, has pointed out some areas where it may generate improvements:

- Ability to spray thick formulations: extreme shear thinning and fast viscosity recovery of MFC makes it a potential thickener for products which are applied by spraying, like sun care products (more information on Borregaard's technical bulletin)
- Soft focus: MFC has a mattifying effect on skin which is described to increase the visual attractiveness.
- Immediate anti-wrinkle effect: MFC can reduce the roughness of the skin immediately after applying the anti-wrinkle cream. This is probably related to its ability to fill roughness, its soft focus effect, moisturizing and film forming properties (check also Borregaard's technical bulletin).
- Hair conditioning effect: MFC has shown to reduce the wet combing force of hair meshes both on grey and bleached hair (more results shown on Borregaard's technical bulletins on gray hair and bleached hair)
- MFC fits well to the current trend of using natural materials in cosmetics.

HOME CARE – STABILITY EVEN AT LOW PH

MFC can be used as a stabilizer and thickener in home care products like liquid hand dishwashing detergent or liquid laundry detergent (Barnabas et al. 2010, Boutique and Vandenberghe 2009).

MFC makes the formulation thicker and can increase the product sensation. Since MFC is opaque or transparent it does not change the optical properties. It can suspend solid particles in the formulation or stabilize emulsions, but at the same time the product is easy to pour out of the bottle or other package. It can be used with surfactants and at low pH where many of the traditional viscosifiers do not work. In addition, MFC is able to encapsulate fragrances and keep them active longer.

CONSTRUCTION - RHEOLOGY CONTROL AND INCREASED STABILITY

MFC can be used in cementitious systems, like concrete and mortar, to maintain a homogeneous material mix and prevent segregation. MFC is particularly suitable for a non-sticky cementitious system. Even a small amount of MFC gives high viscosity at rest, stability and rapid viscosity build-up. At the same time, MFC offers a high shear thinning effect making the application of cement easy.

Advantages:

- Rheology control – enhances yield stress, giving strong thickening and shear thinning
- Creates a non-sticky and non-plastic concrete
- Increases stability of end products

AGRICULTURAL CHEMICALS – ENHANCED UPTAKE OF HERBICIDES

One of the less obvious application areas for MFC is agricultural chemicals. Borregaard has shown that MFC enhances the uptake of herbicides (see patent application by Øvrebø (2015) and Borregaard's technical bulletin) when added to the spray solution (see Figure 10). After the herbicide has been sprayed on the leaves, it needs to permeate through the leaf cuticle into the plant. In case of glyphosate (commonly used herbicide), this only occurs if it is dissolved in water. Because of the high water holding capacity of MFC, it is reasonable to assume that MFC keeps the water on the leaf longer and, in that way, prolongs the time the glyphosate is able to penetrate the leaf cuticle. However, the mode of action is not totally understood.

In addition to herbicides, other type of pesticides and fertilizers can be applied by spraying on the fields. MFC has the potential to improve the uptake of such compounds as well. As for the other application areas, MFC can also stabilize suspensions and emulsions, for example nutrient formulations.

FIGURE 12

Fresh weight of black nightshade plants 2 weeks after treating them with a herbicide solution (glyphosate) (grey column) and glyphosate and different amounts of MFC (Exilva). Fresh weight is given as a percentage of the untreated plants. The picture shows the same plants treated with 0.6 mM glyphosate (A) and with 0.6 mM glyphosate + 0.01% MFC (B) 2 weeks after the treatment. MFC improved the effect of herbicide (lower fresh weight of the plants meaning that herbicide has effectively prevented the growth) and quite low concentrations were sufficient (0.0025-0.02% of the spray solution). (ref to bulletin)

OILFIELD – EXCELLENT FLOW PROPERTIES

Flow properties, together with good temperature- and pH stability, makes MFC a good candidate for oil drilling and other oil production applications.

Drilling fluids are used to carry out the cuttings from the wellbore to the surface, cool drill pipes and bits, reduce friction between the formation and drill equipment, stabilize wellbore and avoid formation collapse. Drilling fluids should tolerate high temperatures and salt concentrations, be environmentally friendly and safe and be low reactive. MFC fulfills these requirements and it could be used in drilling fluids alone or in combination with other polymers (modified polysaccharides, guar gum, xanthan gum) (Turbak et al. 1982; Weibel 1983; Laglois et al. 1997; Laukkanen et al. 2011; Li et al. 2015).

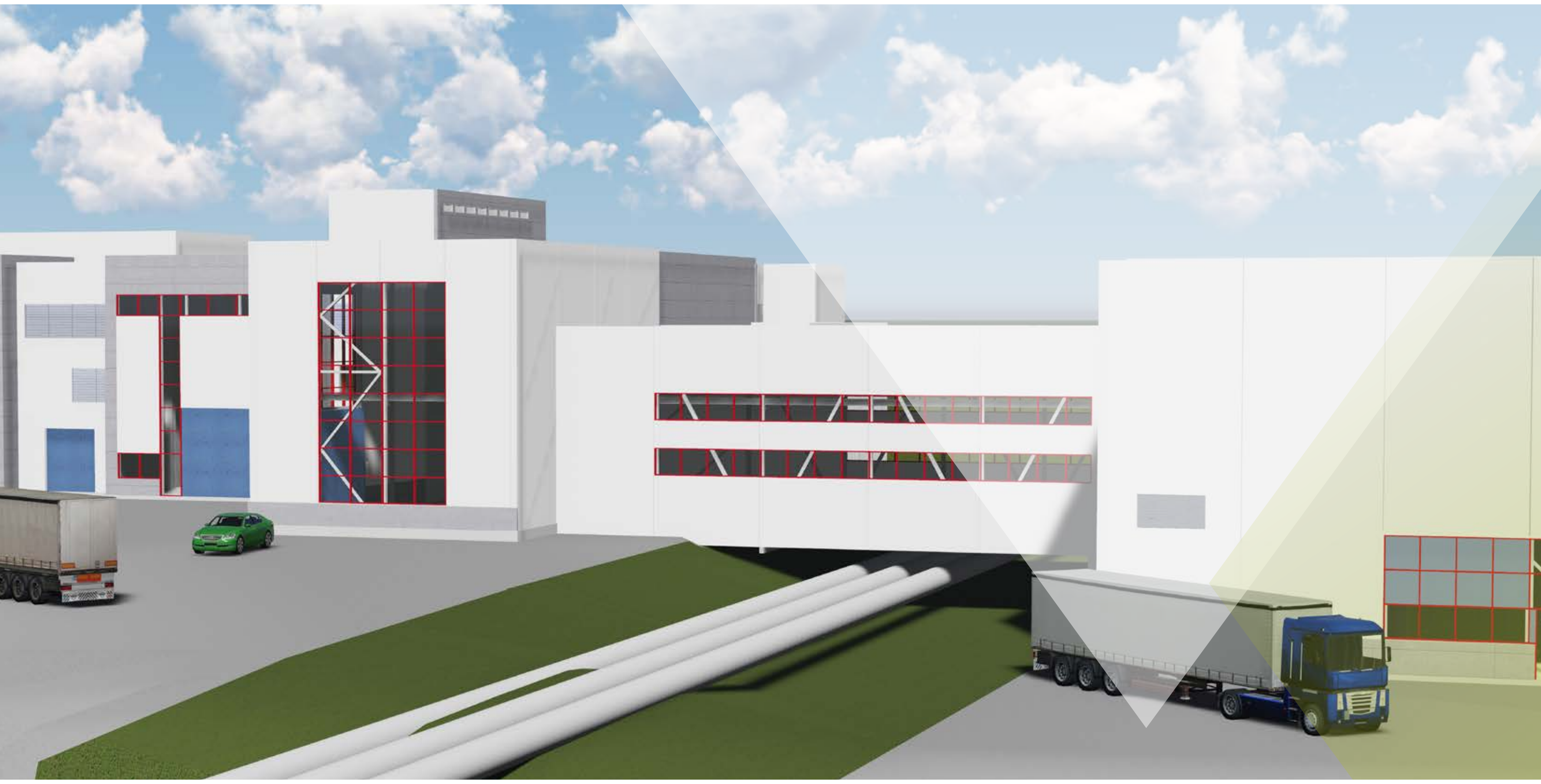
MFC can also be used in well treatment fluids to help obtain the oil and gas collected from the well (Lafitte et al. 2015). For example, fracturing fluids are used to break down the geological formation around the well bore and create fracture by pumping the fluid at high pressure. This enhances the production rates.

PAPER AND PACKAGING – WET STRENGTH AND BARRIER PROPERTIES

MFC can improve wet and dry strength in paper and multilayer packaging (Taipale et al. 2010; Kajanto and Kosonen 2012).

It can also be used to increase the amount of fillers in paper, which improves the optical properties and reduces the cost by lowering the grammage (Hentze 2010). On the other hand, it can make the dewatering more difficult and reduce opacity. MFC can improve the barrier properties of packages (oxygen and grease barrier) and improve the printability.

MFC can be used for paper coating, since it is shear thinning, easy to apply, and the coating layer becomes even and thin. This improves the printing properties. However, MFC might reduce the gloss of paper and possibly suits better for matte paper. MFC coating also improves the oxygen and grease barrier properties.
It is very hygroscopic, which can reduce the water barrier properties, but this can be improved by adding some hydrophobic elements to the coating.



5

WHAT IS EXILVA AND BORREGAARD?

Borregaard produces environmentally friendly biochemicals and biomaterials to replace oil-based products based on natural and sustainable raw materials.

One of Borregaard's new products is the microfibrillated cellulose product called Exilva. Borregaard is currently building a commercial plant for producing Exilva at Borregaard's main factory site in Sarpsborg, Norway. The plant will be operational from Q3 2016 and the capacity will be 50 000 metric tons of Exilva dispersion (1000 metric tons dry active material) per year. For more information about Exilva, have a look at our web page www.exilva.com.

FIGURE 13
Borregaard's first of a kind commercial plant for production of microfibrillated cellulose is being built in Sarpsborg, Norway.

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