Plasma Nanocoating of Nonwovens

Industrial applications of low pressure plasma technology to boost functional performance of nonwovens

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FIGURE 1: **Europlasma roll-to-roll vacuum plasma coater CD1800/800 Nanofics.**

SUMMARY

Low pressure plasma polymerization is a unique technology to deposit ultrathin coatings on all exposed surfaces of a material or product. It is increasingly used in the manufacturing of nonwovens to achieve functionalities such as hydrophilic, hydrophobic, oleophobic or dielectric. Improvements in process and machine design allow to deposit the coatings in a very cost effective way, with a process that is completely dry and clean. The article will start with a short introduction of low pressure plasma polymerization technology. Then it will review industrial concepts for both batch and roll-to-roll treatment. An overview will be given of typical coating chemistries used for such coatings. Subsequently recent advances will be discussed using real industrial case studies. The article will conclude with an overview of the societal and environmental benefits of low pressure plasma technology.

Plasma Nanocoating

Plasma is considered as the fourth state of matter. By adding energy a solid can be transformed into a liquid, and a liquid into a gas. Adding energy to a gas will decompose the gas molecules into a reactive mixture of atoms, radicals and ions. In plasma technology electromagnetic energy is used to create a discharge in a gas at low or atmospheric pressure. In plasma nanocoating the discharge is used to make a monomer gas or vapor reactive, and polymerize these monomers to deposit an ultrathin film onto the substrate surface.

In low pressure plasma technology the discharge takes place in a vacuum. The monomer gas is everywhere in the vacuum chamber, which allows to coat all exposed surfaces of complex three dimensional structures, such as filtration membranes. In atmospheric plasma technology on the other hand, the discharge is taking place under atmosphere at the substrate surface, and has limited ability to penetrate into a three dimensional structure. For that reason atmospheric plasma nanocoating is typically used on film.

Industrial Technology

Europlasma is a pioneer and worldwide leader in low pressure plasma technology since 1993. It has a unique line of roll-to-roll coaters, such as the CD1800/800 Nanofics shown in **Fig. 1**, which is able to handle rolls with a diameter up to 800 mm and a width up to 1800 mm.

Europlasma built the first roll-to-roll coater for filter media in 1998, but it is only in the last 8 years that the technology is breaking through, with the customer base doubling to more than 20 industrial groups worldwide. A unique feature of low pressure plasma is that the coating also can be applied on finished filter elements. **Fig. 2** depicts for instance a chamber with a volume of 1836 liter which can hold vertical cartridge filters.

Some of the commercially available plasma nanocoating solutions for nonwovens are summarized in **Tab 1**. The industrial use for each of these coatings will be explained further in this paper.

Applications for Nonwovens

As mentioned above, there is a growing number of industrial groups that use plasma technology to gain competitive advantage from the functionalities that nanocoatings add to their products. They transform materials such as nonwovens, nanofiber membranes, ePTFE membranes, technical mesh, technical fabrics, laminates, porous plastics and/or finished products made from such

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materials, by functionalities added such as hydrophilic, oleophobic, dielectric and hydrophobic.

Hydrophilic

Europlasma has developed several hydrocarbon processes to deposit permanent hydrophilic effect. These coatings are marketed under the Nanofics 10 trade name, where 10 is referring to the water contact angle (WCA) of the coated material according to ASTM D5946.

These coatings are permanent in nature. **Fig. 3** shows for instance the WCA of coated versus uncoated polystyrene (PS) and glass. Both materials see a significant drop in WCA to below 10°, and after ageing in humid environment at elevated temperature the WCA remains intact.

Industrial applications are the coating of nonwovens for blood filter media, bioreactor media for cell cultivation, porous plastics for filtering of liquid nutrition or soap, Ni-MH battery separators, or evaporative pads for air conditioning systems.

Fig. 4 demonstrates the functional effect of Nanofics 10 coating on nonwoven polypropylene (PP) for Ni-MH battery separators. Strips of 200 mm × 25 mm are immersed 10mm deep during 1 min in a solution according to AATCC 197, after which the vertical wicking length is measured. The Nanofics 10 coated PP shows a much stronger wicking than the commercial reference material.

FIGURE 2: Europlasma batch coater CD1836 Nanofics.

Process	WCA (ASTM D5946)	Oil (ISO 14419)	Functionality
Nanofics 10	<= 10 °		Hydrophilic
Nanofics 110	>= 110 °	>= 5	Hydro/Oleophobic
Nanofics 120	>= 120 °	>= 7	Hydro/Oleophobic
Nanofics K			Dielectric
PlasmaGuard	>= 120 °		Halogen-free Hydrophobic

TABLE 1: Commercially available plasma nanocoating solutions.

Hydro/Oleophobic

Deposition of oleophobic nanocoatings is currently the most important area of industrial application for nonwovens. These coatings originate from halocarbon precursors. For maximum oil repellency Europlasma supplies the

ZUSAMMENFASSUNG

Plasma-Nanobeschichtung von Vliesstoffen – Industrielle Anwendungen der Niederdruck-Plasmatechnologie zur Verbesserung der Funktionalität von Vliesstoffen

Die Niederdruck-Plasmapolymerisation ist eine vielseitige Technologie zur Abscheidung ultradünner Schichten auf allen exponierten Oberflächen eines Materials oder Produkts. Sie wird zunehmend bei der Herstellung von Vliesstoffen eingesetzt, um Funktionalitäten wie hydrophile, hydrophobe, oleophobe oder dielektrische Eigenschaften zu erzielen. Verbesserungen in der Prozess- und Maschinenkonstruktion ermöglichen es, die Schichten auf sehr kosteneffiziente Weise abzuscheiden, mit einem vollständig trockenen und sauberen Prozess. Nach einer kurzen Einführung in die Niederdruck-Plasmapolymerisationstechnologie werden im Beitrag industrielle Konzepte für die Batch- und Rolle-zu-Rolle-Behandlung vorgestellt. Es wird ein Überblick über die für diese Anwendungen typischen Beschichtungschemien gegeben. Anschließend werden die jüngsten Fortschritte anhand realer industrieller Fallstudien erörtert. Der Artikel schließt mit einem Überblick über die gesellschaftlichen und ökologischen Vorteile der Niederdruck-Plasmatechnologie.

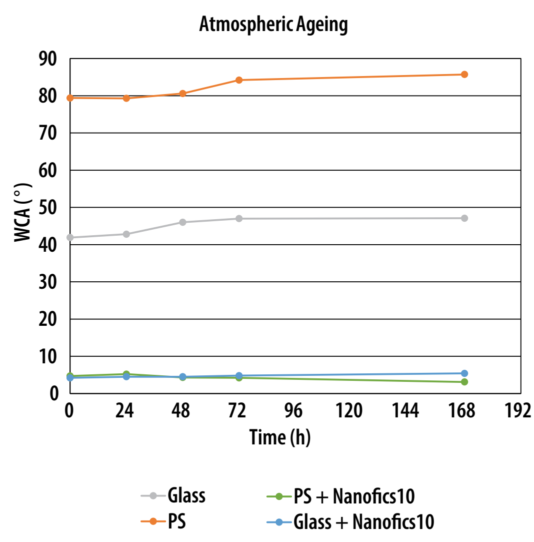

FIGURE 3: Atmospheric ageing of Nanofics 10 on PS and glass.

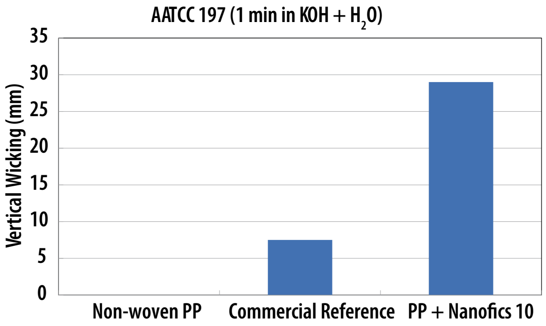

FIGURE 4: **Wicking of nonwoven PP coated with Nanofics 10.**

Non-woven PP	Coating	Charge	Resistance (mbar)	Filter efficiency (%)
Type 1 (35 g/m^2)	No coating	No charge	0.40	60
	Coated	No charge	0.40	92.33
	Coated	Charged	0.38	99.99
Type 2 (25 g/m^2)	No coating	No charge	0.24	40
	Coated	No charge	0.23	78
	Coated	Charged	0.25	99.87

TABLE 2: **Filter efficiency and resistance measured with Certitest 8130 apparatus, operating at 32 l/min and charged with NaCl-particles of 0,06-0,1 µm (materials and data supplied by Monadnock Non-Wovens LLC).**

Nanofics110 and Nanofics120 systems, with typical oil repellency levels of 5 and 7 according to ISO 14419.

Europlasma also offers a unique line of halogen-free solutions under the PlasmaGuard brand name. These coatings are highly water repellent, but not oil repellent, and were developed for durable water repellent (DWR) coating of sporting and outdoor textiles.

Dielectric

Media of special interest are the electrets (a dielectric material with quasi-permanent electric charge or dipole polarization), for which Europlasma has designed the Nanofics K system. These coatings are increasingly used on HEPA filters for cleanrooms, home air purification systems, gas turbines and respirator masks.

The key advantage of dielectric nanocoatings is that they increase the air filter efficiency without affecting the pressure drop. The pressure drop is not affected because the coatings applied are typically thinner than 50 nm, and add less than 0.5 % weight gain to the media.

For electrets, the plasma coating allows to charge the media to much higher filter efficiency, and the efficiency is better maintained during the lifetime of the media. The test data in **Tab. 2** for instance allow to compare the performance of plasma coated and not coated nonwoven PP media for mouth masks, before and after charging. The data were obtained with a Certitest 8130 apparatus (TSI Incorporated, Minnesota, USA), operating at 32 l/min and loaded with NaCl-particles of 0.06-0.1 µm (materials and data supplied by Monadnock Non-Wovens LLC).

In type 1 media of 35 g/m^2 nonwoven PP for instance, the filter efficiency of the material without coating and charging is only 60 %. When the material is coated the filter efficiency increases to 92.33 %. If the coated material is subsequently charged, the filter efficiency is boosted to 99.99 %. Similar improvements are achieved in the type 2 media of 25 g/m^2 nonwoven PP. For both media the resistance measured in mbar is quite similar for coated and uncoated materials, confirming that plasma nanocoating does not affect the pressure drop.

The results of a recent study with Filter & Aerosol Technologie GmbH (Fiatec) are summarized in **Tab. 3**. Filtration testing was performed according to ISO 16890-2 using KCL aerosols of 0.3-10 µm on 25 g/m^2 nonwoven PP (commercial grade purchased from IREMA-Filter GmbH). For each sample the filter efficiency for particle size range up to 1 µm (ePM1) was determined. Also the pressure drop (Pa) was measured at a flow of 5.33 cm/s.

The positive impact of coating and charging on the filtration efficiency are

Coating (Y/N)	Charged (Y/N)	Pressure drop (Pa)	ePM_1 (%)
No coating	No charge	34	50
No coating	Charged	32	85
Coated	No charge	28	55
Coated	Charged	29	95

TABLE 3: **Filter efficiency and pressure drop according to ISO 16890-2 using KCL aerosols of 0.3-10 µm at a flow of 5.33 cm/s (performed by Fiatec) on 25 g/m^2 nonwoven PP (commercial grade purchased from IREMA-Filter GmbH).**

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holds a MSc in Materials Engineering and MBA of the KU Leuven in Belgium.
He managed Europlasma as CEO from 2008 to 2018, during which period he transformed Europlasma from high tech machine builder to licensing company of nanocoating solutions.
After the company was acquired by Andlinger & Company in August 2018, Filip joined the board of Europlasma as an executive director responsible for the development of next generation technology.

Sam Loulidi, MSc

Sam Loulidi holds a MSc in Industrial Sciences: Chemistry of the Universiteit Antwerpen and obtained his PhD in Engineering in 2022 at the Vrije Universiteit Brussel in Belgium. He started his professional career at Europlasma in 2014 as a R&D Engineer and rose to the function of R&D Manager in 2018. Over the course of his professional carrier at Europlasma he developed multiple plasma deposited coatings (patented) and innovative industrial medium vacuum CCP reactor designs.

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confirmed. In this study the pressure drop of the plasma coated materials is even lower than on the uncoated samples. This effect is most probably related to slight etching of the material and enlargement of the pores as a result during plasma processing (at suboptimal parameters).

Societal and Environmental Benefits

Plasma technology has been at the forefront of the fight against COVID-19. Plasma coated media show much higher filtration efficiency, hence offer better protection to people against the coronavirus and potentially other viruses and bacteria. These media are essential in products such as face masks and both domestic and industrial air purification systems. Moreover, nanocoatings are so thin that they have no impact on the pressure drop, greatly contributing to the comfort of the wearer of the face mask. In air purification systems it also means that less energy is needed to circulate the air through the filters. The energy consumption and environmental footprint using nanocoated products will therefore be significantly lower.

Another study performed with Europlasma customers comparing low pressure plasma with wet chemical processing for durable water repellent (DWR) coating confirmed that plasma nanocoating has significant environmental benefits:

- reduction of 80 % in consumption of coating chemicals, because the coating applied to reach functionality is much thinner;
- 100 % reduction in water consumption because the plasma process is completely dry;
- 50 % reduction in energy consumption because no curing steps are required to dry out the process water.

For these environmental breakthroughs Europlasma received multiple awards: from ITMA 2015 for Best Innovation in Sportswear and Outdoor Apparel, ISPO 2016 for Best Performance Footwear Component, CES 2017 Innovation Awards Honoree for Tech For A Better World, and Filtrex 2017 Innovation Award Nominee.