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Atmospheric Plasma Innovative Roll-to-Roll Machine for Continuous Materials

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***Abstract*—**Atmospheric plasma is emerging as a promising technology for many industrial sectors, because of its ecological and economic advantages respect to the traditional production processes. For textile industry, atmospheric plasma is becoming a valid alternative to the conventional wet processes, but the plasma machines realized so far do not allow the treatment of fibrous mechanically weak material.

Novel atmospheric plasma machine for industrial applications, developed by VenetoNanotech SCpA in collaboration with Italian producer of corona equipment ME.RO SpA is presented. The main feature of this pre-industrial scale machine is the possibility of the in-line plasma treatment of delicate fibrous substrates such as fibre sleeves, for example wool tops, cotton fibres, polymeric tows, mineral fibers and so on, avoiding burnings and disruption of the faint materials.

***Keywords*—**Atmospheric plasma, industrial machine, fibrous materials.

I. Introduction

COLD atmospheric plasma represents a promising technology for a wide range of industrial applications [1], and for this reason was object of intensive research in the last decades. One of the main advantage of cold atmospheric plasma is the possibility to treat the materials in ecologic way, without chemical reagents and without generation of hazard effluents. Thanks to these features, atmospheric plasma will become a valid and sustainable alternative to the conventional liquid chemistry treatments, contemporary satisfying the incoming severe environmental normative. Besides, this technology provides a more economical solution than liquid chemistry, or than low pressure plasma technology, because of the absence of vacuum equipment and large water amounts, that may be often heated up to the process temperature and disposed afterwards. Atmospheric plasma is a "dry" technology that allows treatments of materials in line, installed in existing production facility.

Novel atmospheric plasma machine for industrial applications – Nanofabia (Fig. 1), was developed by VenetoNanotech SCpA in collaboration with Italian producer of corona equipment ME.RO SpA. Machine is installed in Nanofab facility (Marghera, Venice) of Veneto Nanotech SCpA. The original construction of the machine permits the in-line treatment of delicate fibrous substrates such as fibre sleeves, for example wool tops, cotton fibres, polymeric tows, mineral fibers and so on, avoiding burnings and disruption of the faint materials, makes it substantially different from existing atmospheric plasma equipment. Veneto Nanotech machine can proceed in-line any kind of permeable web such as woven and non-woven fabrics or polymeric membranes, either in single or multiple layer configuration. Polymeric membranes made of nano-fibers could be treated as well.

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II. Technological Possibilities

Machine was originally conceived for the application in exiting textile production plants, either in the fibre preparation stage or in finishing department.

Atmospheric plasma can impart many features appreciated by the industry [1], introducing innovative properties to the finished garments (for example anti-shrinking of final wool garments, anti-pilling of woollen or blend fabrics, anti-static effect on materials, sterilization, anti-microbial properties and others) or optimising of the production processes (partial cleaning; improvement of hygroscopic, wetting and breathability properties of fabrics; optimization of fabrics desizing; enhancement of dyeing and impregnation processes as well as of printing, gluing and laminating).

III. Fundamental Effects

Nanofabia machine was already applied on different fibrous materials, and important features were experimentally proved: the increase of the tensile strength of the sleeves and of the breaking strength of finally produced yarns due to the higher cohesion between fibres, anti-static effect on wool fibres, optimization of hygroscopic properties and better affinity of fibres, yarn and garments to dyeing and others wet processes.

All listed effects could be produced by Nanofabia in a competitive way, using humidified air as process gas, without introduction of any special gases or precursors.

Fig. 1 Innovative Veneto Nanotech machine Nanofabia for in-line treatment of fibrous and web materials

For a deeper comprehension of nature and origin of the observed properties, fundamental studies of the interaction of cold atmospheric plasma with fibrous materials were performed at Veneto Nanotech on wool [2], cotton [3], polymeric, basalt and titania fibers. It was proved the formation of a nano-structure on each fibrous species. Authors suppose the preponderant role of the nano-scale roughness (in the range of tens of nm) generated on fibres by the atmospheric plasma for noted before properties of fibrous and textile materials. In any case, the observed variation of fibres morphology is always combined with chemical modifications the fibre surface, i.e. with generation of polar groups and radicals [4].

IV. Application Method and Machine Construction

Contrary to the existing atmospheric plasma machines, Nanofabia can treat mechanically delicate substrates (in particular continuous fibre sleeves, characterised by very low breaking force) at industrial speed, contemporary avoiding burnings on fibrous material (textiles, fibre sleeves).

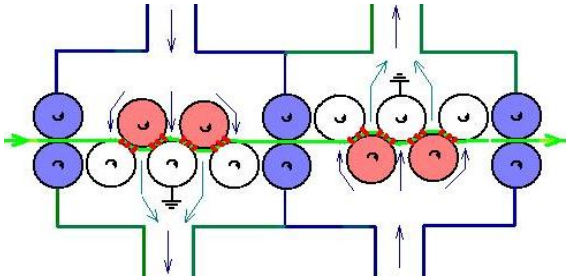

Fig. 2 Principal scheme of the Machine. Material proceeds between two series of reels (some are grounded and the others are connected to generator), with the upper train shifted respect to the lower one. The discharge occurs between reels of different trains. In this configuration the working gas is forced to flows in the discharge gaps between reels (electrodes) and passes through the porous material. Different sections of machine are separated by pairs of inlet and outlet grounded reels

These innovative features, making the Veneto Nanotech machine suitable for a wide range of industrial applications, become possible due to the particular construction geometry. It is based on conventional Dielectric Barrier Discharge (DBD), generated between the transportation reels of machine that in the same time makes role of discharge electrodes.

The principle of machine construction is schematically presented on Fig. 2.

Configuration of machine provides that:

- the working gas flows through the material, enhancing the gas exchange in the substrate;
- the working gas flow is concentrated in plasma zones (gaps) between reels (electrodes), thus homogenizing the plasma and preventing the burnings of fibres;
- the material is mechanically fixed between reels in the same zone where flux and plasma are concentrated (discharge zones);
- the material is kept fixed in a soft way between reels when it proceeds along the machine. Due to the reels position, only small force is applied to the material for its transportation along the machine.

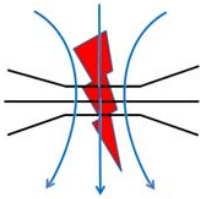

Fig. 3 Schematic presentation of discharge zone. Working gas flow (vertical lines) is concentrated in the discharge gap, where the moving material (horizontal lines) is kept fixed by reels (electrodes)

Described principle [5, 6] permits to treat rather delicate, from mechanical point of view, materials that otherwise could be subjected by burnings, such as low weight fibre sleeves (wool, cotton, polymeric or any other) or extremely low weight membranes made of nano-fibres.

V. Pre-industrial Machine Features

Machine of pre-industrial scale installed in Veneto Nanotech lab permits to treat sleeves or continuous webs at the velocity up to 15 m/min. Total length of plasma zones (in machine direction) is about 17 cm. Atmospheric plasma is generated by DBD discharge between isolated reels (electrodes) at 40 kHz frequency. The width of plasma zones is 60 cm. The total discharge power can be adjusted up to the level of 6 kW. The gap between reels (electrodes) can be regulated in the range 0,5 ÷ 3,0 mm. Air flux through the machine is in the range 0 ÷ 1500 m^3/h.

Installed pre-industrial machine presents the module that can be scaled for concrete industrial application by adjusting of principal parameters such as the width of plasma zones (i.e. reels size), the transportation speed, the air flux and the total power applied to the discharge.

Installed machine is connected to an air treatment system that allows to control air humidity of the flux in the range RH

20 ÷ 80%, that permits the investigation of treatment efficiency on the basis of humidity variation. It was found that the results on fibrous materials depend, at different extent, on the relative humidity of process gas (air). For the concrete applications the humidity was optimised to match conventional industrial value (typically RH 55 ÷ 65%) by adjustment of other process parameters. In this way the process costs are subsequently reduced by exclusion of air conditioning.

The machine can be upgraded to perform the in-line deposition on textile materials, assisted by atmospheric plasma. The deposition option enlarges significantly the application field of the machine. The deposition process studies and upgrading works are in the progress at Veneto Nanotech SCpA.

VI. Conclusion

Novel machine based on “green” atmospheric plasma technology for in-line treatment of continuous materials was created in Veneto Nanotech SCpA in collaboration with ME.RO SpA. Machine can treat permeable web materials (woven and non-woven fabrics) and polymeric membranes. The unique possibility of the machine is in-line treatment of the fibre sleeves of different nature. Recent try-outs on textile substrates demonstrate the competitive performance of the machine for treatment of fabrics and fibres sleeves of wool, cotton and polymeric fibres. The performance of the machine was demonstrated by use of ambient air as working gas, without introduction of any special gases or precursors. Industrial researches for technologic transfer in different local and international industrial groups are in progress.

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