D3.2

Report on Plasma Machine Modification

UltraFibre

SEVENTH FRAMEWORK PROGRAMME

Seventh Framework Programme

Capacities Programme

Proposal no: FP7 – 243456

Contents

1. Introduction

Fibre reinforced polymers find wide commercial application in the aerospace, leisure, automotive, construction and sporting industries. In recent years there has been much interest in developing natural fibre reinforced polymers for sustainable substitution of synthetic materials. However, natural fibres do not automatically have good interaction with polymers, which is required for optimal material performance. The UltraFibre project aims to apply plasma treatment processing for surface modification of natural fibres in order to obtain improved compatibility and adhesion to polymer matrices conferring a 25% increase in mechanical properties compared with the untreated fibre.

This Deliverable 3.2 reports on the development, design, and performance of an atmospheric plasma unit for treatment of natural fibres.

The **objectives** for WP3 as stated in the technical annex 1 are as follows:

- To produce a sustainable fibre treatment method based on AcXys Technology's atmospheric soft plasma process
- To prove the efficacy of the SoftPlasma process for natural fibre modification
- To benchmark against alternative fibre modification processes
- To modify the fibre-handling machine configuration to allow surface treatment of fibres using plasma treatment and suitable polymers and its integration into the UltraFibre process

The **work-plan** for WP3 during the first 18 months as stated in the Technical Annex 1 focuses on Tasks 3.1, 3.2 and 3.3.

Task 3.1 on Fibre modification survey was extensively addressed in Appendix A of Deliverable 3.1 (submitted in Month 11).

Task 3.2: Soft plasma pilot plant development
AcXys, in cooperation with DLO-FBR, will investigate modifications needed to adapt the existing equipment to make use of the SoftPlasma technique for fibre treatment. This will allow the fibres to be pre-treated to allow for their use in a wide variety of possible applications. A design of experiments will screen variables such as:

- Exposure time
- Feed gas composition
- Interaction between hydro-acoustic decortication variables and SoftPlasma conditions
- Stability of modification after processing
- Effect of secondary operations

Initial trials will be carried out with fibres produced by conventional mechanical processing and retting methods. In parallel, preparatory work will be performed on the small-scale decorticated fibres produced in work package 2. Through interaction with work package 5, characterization, the effects of the SoftPlasma and its interaction with the hydro-acoustic process will be understood.

Task 3.3: Surface treatment of natural fibres
Once the equipment has been modified, a variety of natural fibres will be surface treated to determine how well the soft plasma process performs with these fibres. Modifications to the equipment/processing conditions will be made, if necessary, through a series of iterative steps.

The **goal** of the development of an atmospheric plasma unit is to obtain improved compatibility and adhesion to polymer matrices conferring a **25% increase in mechanical properties** compared with the untreated fibre **at competitive price**.

In Chapter 2 the results are described related to the plasma treatment unit development (section 2.1), plasma unit design (2.2), its construction (2.3), initial experimentation using a belt system and a specially designed short fibre system (2.4 & 2.5) and issues encountered and solutions found or suggested (2.6).
Conclusions are presented in Chapter 3.
Future work in WP3 is addressed in Chapter 4.
Annex 1 provides details of dopant gasses used for the plasma trials.

1.1 Background for atmospheric plasma process

This section presents a general background to the atmospheric plasma process. The info is copied from the AcXys webpage.

1.1.1 What is Plasma?

The addition of energy into matter modifies electromagnetic forces binding atoms together. The state of matter evolves from solid to liquid, then from liquid to gas. Adding even more energy dissociates molecular bonds and may lead to ionization (Figure 1). Gas molecules are split into charged particles, ions and free electrons. Plasma is often called "the fourth state of matter".

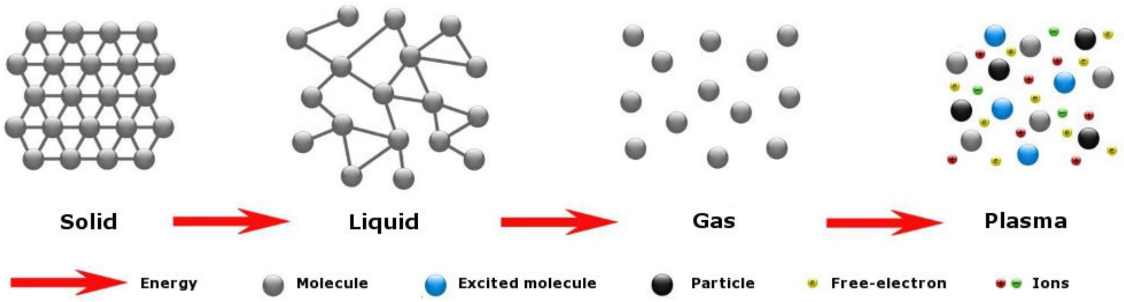


Figure 1: Positioning of plasma relative to gas.

1.1.2 Generating a Plasma

AcXys Technologies plasmas are produced by electrical discharge through a gas. Gas is first continuously injected in the plasma generator, then ionized and finally directed towards the surface to be treated (Figure 2). Controlling the electrical discharge leads to a low temperature plasma coming out of the source. At high processing speeds, treated materials do not have enough time to increase their surface temperature. For instance, heat-sensitive polymers are treated without damage. At www.acxys.com, sub Plasma Technology, nice illustrative films are presented.

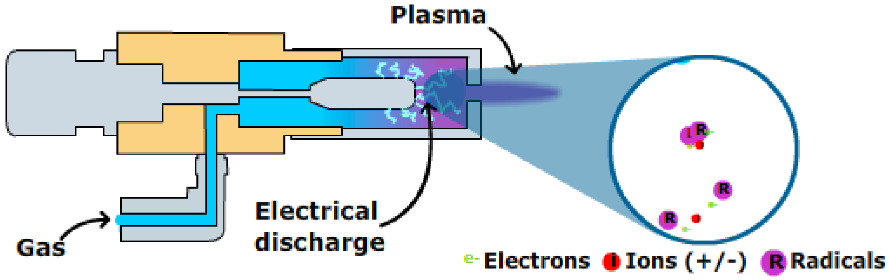


Figure 2: Schematic representation of plasma generating unit.

1.1.3 Effects on surfaces

Plasma is a continuous supply of highly reactive chemical species used for treating surfaces. Plasma cleans or activates surfaces. Activation is the modification of the composition of a surface, resulting in a change of its surface energy. Surface wettability is drastically increased by grafting polar functions. Consequently, it promotes a stronger adhesion for paint, ink, glue or varnish.

2. Results

2.1 Soft plasma unit development

The initial experimental aim was to investigate modifications needed to adapt the existing equipment to make use of the SoftPlasma technique for natural fibre treatment. However discussions with AcXys showed that fibre form was the main specification for machine modification. During the discussions Project partners Movevirgo and Smithers RAPRA indicated that the different target composites (see Deliverable 1.1) are based on different fibre forms (Figure 3):

- Extrusion: short fibre
- Injection moulding: short fibre
- Compression moulding: short fibre, long fibre, continuous roving, non-woven, fabric



Short fibre Roving Non-woven

Figure 3: Target composites are based on 3 different fibre forms.

More details regarding fibre specifications are provided in Deliverable 1.1 and in Appendix C of Deliverable 3.1.

In joint consultation, AcXys and DLO-FBR have listed advantages and limitations of the basic atmospheric plasma treatment technologies available at AcXys: ULS and ULD (details provided in Appendix C of D3.1). Also, several potential fibre transfer mechanisms have been considered (details provided in Appendix C of D3.1).

It was considered that adequate and effective analysis of the effect of plasma treatment on natural fibres and their adhesion to polymer matrices requires the plasma treatment unit and the analysis techniques to be close together. Therefore, it was decided to design and build a lab scale unit which fits within resources available in the project and which can be placed at DLO-FBR who has key expertise in fibre analysis and composite manufacturing and analysis.

Based on the above, AcXys has made a design for a plasma treatment unit.

Foreseen fibre treatment parameters include:

- Fibre form (short fibres, parallel, random web, thickness of fibre layer)
- Plasma treatment time
- Gas composition (dopants)
- Storage time and conditions prior to further processing into composites

Based on the data to be collected and reported (in Deliverable reports 3.3, 5.2 and 5.3) the feasibility of using plasma treatment to modify natural fibre surface for improved adhesion in polymer composites can be assessed. When required, AcXys is expected to translate the findings of the project into an industrial scale processing unit. This expectation is based on AcXys' following experiences:

- Many years of experience with building plasma treatment units for industry, for instance in, but not limited to, packaging industry where volumes are high.
- If necessary, treatment width may be adjusted by placing several units in line.
- Plasma treatment at industrial scale usually is a relatively cheap technology.
- Plasma treatment only uses electricity and gasses. There are no water emissions except for cooling water. The air emissions depend on the feed gasses. Nitrogen, like in 80% of regular air, is the basic gas used. Dopants are usually less than 1% of the N_2 consumption. Particular other gasses formed during plasma treatment of natural fibres would need to be identified. Plasma is generally considered a clean technology.

2.2 Plasma unit design

Based on discussions involving AcXys, DLO-FBR, Smithers RAPRA and Movevirgo, AcXys has made a design for a lab scale plasma treatment unit which can handle short fibres, fibre roving and non-wovens (Figure 4). Short natural fibres are mostly used in extrusion and injection moulded products. Natural fibre roving is of interest in sheet moulding compound (SMC) based products. Non-wovens are used in vacuum formed polyester products.

The unit comprises a 60 mm wide ULD plasma source, with a belt system for treatment of roving and non-wovens (Figure 5A), and a specially designed fibre feeding system for treatment of short fibres (Figure 5B).
The basic gas is nitrogen (N_2). For dopant gases, separate entrance tubes are included for H_2 on one hand and O_2, CO_2 or N_2O on the other hand, in order to avoid accidents with reducing and oxidizing gases coming together.
The plasma unit system is placed in a closed box with exhaust opening to extract resulting gases. A safety system is mounted in the exhaust tube to guarantee a minimum extraction flow.
The whole system is placed on wheels to allow simple moving of the system.

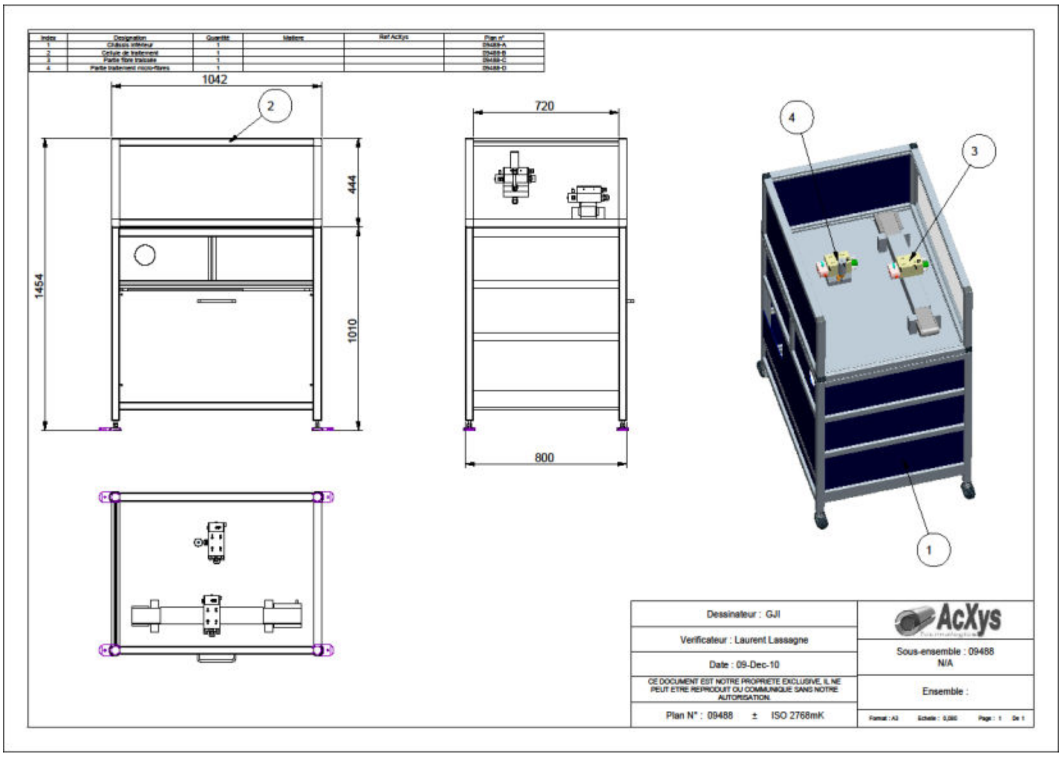
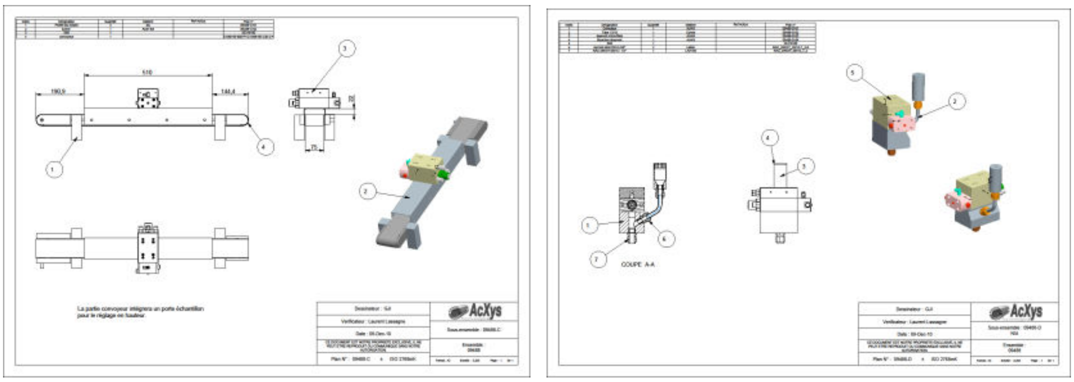


Figure 4: Design of lab scale plasma unit based on AcXys' ULD technology for treatment of natural fibres.



(A) (B)

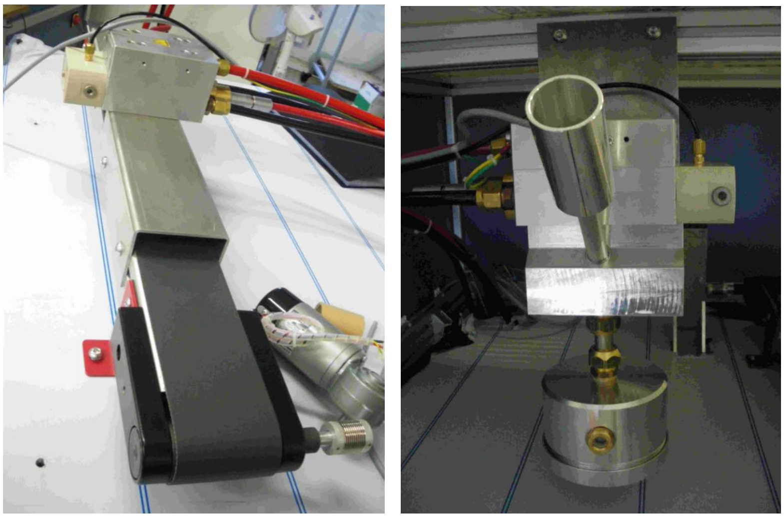
Figure 5: Design of belt system for treatment of natural fibre roving and non-wovens (A) and specially designed system for treatment of short fibres (B).

The plasma treatment unit aims at treatment of natural fibres like flax and hemp as addressed in Tasks 3.3 – 3.5 of the Technical Annex 1. The ultimate goal of the plasma treatment of natural fibres is to achieve a significantly better adhesion to polymer matrices compared to untreated fibres.

2.3 Plasma unit construction

The plasma unit was constructed and tested at AcXys facilities near Grenoble (Figure 6 & 7).

Figure 6: Plasma unit under construction at AcXys.



(A) (B)

Figure 7: Belt system for treatment of natural fibre roving and non-wovens (A) and specially designed system for treatment of short fibres (B).

The plasma unit comprising plasma source and fibre processing systems is placed in a closed box with fume exhaust (Figure 8). The outer dimensions of the whole unit are 165 cm high * 105 cm wide * 85 cm deep. The front end side of the housing is made transparent in order to allow monitoring of the trials. Also part of the housing of the tunnel around the belt is made transparent to monitor the plasma flame (Figure 9). The tunnel is made around the belt in order to keep the plasma intact for as long as possible.

Figure 8: Plasma source and fibre processing systems placed in closed box with fume exhaust.

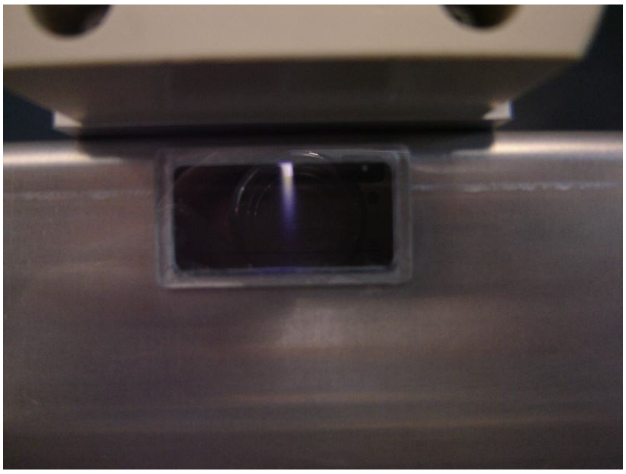


Figure 9: Plasma flame visible through transparent section in tunnel around belt.

Details of the plasma unit regarding dimensions, weight, and requirements related to power, gas and cooling water supply are provided in Table 1.

Table 1: Specifications of the lab scale plasma unit.

Size and Weight COMBOD60

Description	Depth	Width	Height	Weight
Vessel	800 mm	1044 mm	1500 mm	200 kg

Power supply COMBOD60

Tension	Frequency	Phases	Neutral	Ground	Power max.	Intensity
230 V	50/60 Hz	1	Yes	yes	1200 W	< 10 A

Gas supplies

Nitrogen COMBOD60

min flow rate	Pressure min.	Pressure max.	Tubes	Connections	Quality
60 l/mn	5.5 bars	6 bars	12 mm	Double collar	Industrial

> The supplied pressure of Nitrogen has to be higher than 5 bars when used with other doping gases (O_2, H_2). Nitrogen pressure is necessary for the security pneumatics valves to switch on.

Oxygen COMBOD60

max flow rate	Pressure min.	Pressure max.	Tubes	Connections	Quality
0,6 l/mn	5 bars	6 bars	6 mm	Double collar	Industrial

The following gases are similary used into Oxygen line:

- CO_2
- N_2O

However, it is to be noted that flow rate conversion would be required in those cases.

Hydrogen COMBOD60

Max flow rate	Pressure min.	Pressure max.	Tube diameter	Connection	Quality
1,8 l/mn	4 bars	6 bars	8 mm	Double collar	Industrial

Water supply COMBOD60

Max flow rate	Pressure min.	Pressure max.	Tube diameter	Connections	Quality
10 l/mn	1 bars	6 bars	12 mm	Single collar	Industrial

Details for the exhaust tube system are provided in Figure 10. A safety system is mounted in the exhaust tube to guarantee a minimum extraction flow in order to avoid accumulation of gaseous products from the plasma process in the box (Figure 11).

Exhaust COMBOD60

Nominal flow	Pressure min.	Pressure max.	Tube diameter	Connections	Quality
100m3/h			200 mm 80 mm		

Connections COMBOD60

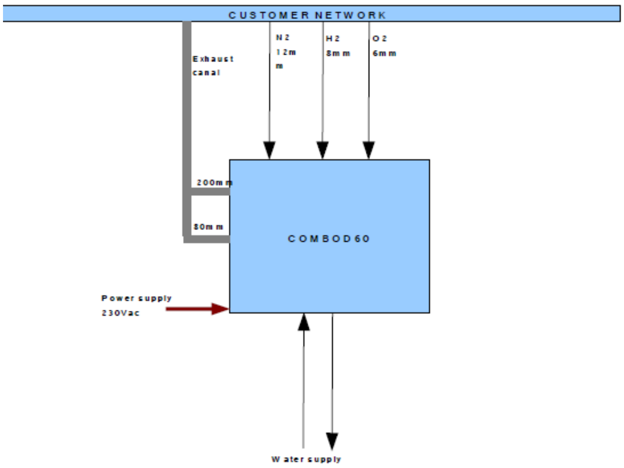


Figure 10: Exhaust specifications of the plasma unit.

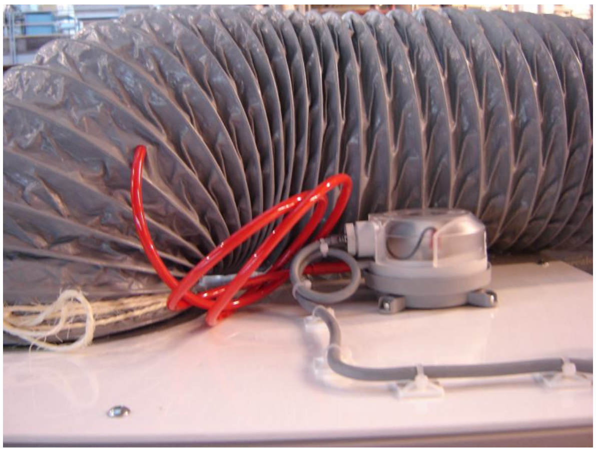


Figure 11: Safety module in the exhaust tube of the plasma unit.

Nitrogen gas flow can be adjusted up to 60 L/min. Maximum gas flow for hydrogen and oxygen is 1.8 and 0.6 L/min, respectively. Dopant gases CO_2 and N_2O are fed through the oxygen inlet and require a conversion factor: the 'oxygen flow' has to be set to 1.176 L/min to obtain a flow of CO_2 or N_2O of 1 L/min.

Required power can to be taken from the standard grid providing 230 V and up to 10 A.

Cooling of the plasma source is achieved by running water of maximum temperature of 18 °C at a flow of at least 10 L/min.

The belt speed can be varied in the range 2.9 to about 25 m/min.

The system for treatment of short fibres comprises a plastic gauze bag which is screwed onto the outlet to collect the fibres (Figure 12).

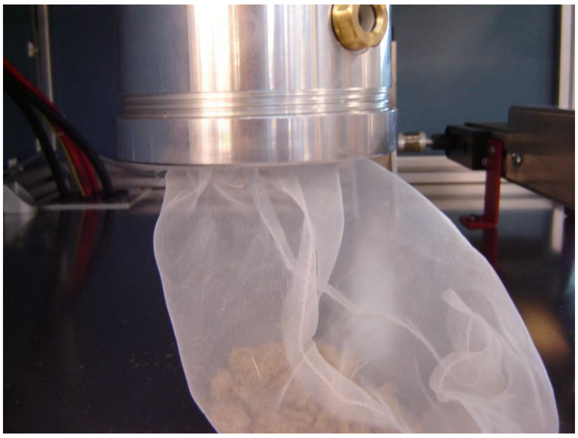


Figure 12: Gauze bag to collect fibres from the short fibre processing set up.

Access to the plasma system is facilitated by a door with a safety measure such that the plasma production is stopped when the door is opened.

The unit is built onto wheels to facilitate moving of the system (Figure 13).

Figure 13: The plasma unit is built on wheels.

2.4 Initial experimentation - Requirements to operate plasma unit and belt system

It was decided to place the plasma unit in DLO-FBRs technology hall, where a fixed supply system of high purity (5.0) N_2 gas is available (Figure 14). Source of this N_2 supply system is a 5000 L liquid N_2 tank. The minimum N_2 pressure under flowing conditions has to be about 2 bar to open a valve. All trials at DLO-FBR were performed at 6 bar N_2 pressure at flowing conditions. To set the pressure, a Praxair POR400-01BD reduction valve was used (Figure 14). To reach this pressure, the standard gas pressure on FBRs system was increased by about 2.5 bar.

Figure 14: Fixed N_2 gas supply system at DLO-FBR was used for plasma trials.

Dopant gasses of high purity are consumed from sourced 40 or 50 L bottles. Details of the gasses used are provided in Annex 1. Minimum pressure to open the valve is about 4 bar. In order to achieve good mixing with the nitrogen, the pressure of dopant gasses is set to 6.5 bar. Pressure reduction valves (Gloor, Switzerland) were required and sourced for each individual dopant gas (Figure 15).

Figure 15: Reduction valve between dopant gas bottle and plasma unit.

When mounting the plasma source on the belt system, care must be taken that the plasma flame can be transferred optimally into the tunnel. This is the case if the opening where the plasma leaves the source unit is positioned well above the slit in the tunnel. A perfectly vertical plasma flame is the proof that the source is positioned well.

Natural fibre roving and non-woven are not blown away from the belt when applying plasma based on a N_2 flow of 60 L/min. Even 5-10 mm short fibres, which show at least some kind of entanglements, stay in place on the belt without taping them.

The cooling water had a temperature of 16 °C and a flow of 12 L/min.

The present plasma unit allows batch processing only. The treatment cycle comprises: feeding fibres to the system, treating the fibres, collecting the treated fibre, feeding a new batch of fibres, etc. Feeding fibres requires opening of the door, which, in its original construction, causes stopping of the plasma production. Re-starting the plasma production takes about 2 minutes, whereas time required to collect a treated fibre sample and feed a next fibre sample takes about 10-15 seconds only. Plasma treatment of fibre quantities large enough for analysis in composites requires many batches and therefore it was decided to disconnect the safety device to allow continuous plasma production while opening the door. For example: for lab scale compounding of a 30 wt% natural fibre-PP or PLA composite, about 70 and 90 g of fibre are required, respectively, whereas the plasma unit can handle about 6 g of refined hemp and 2 g of refined flax per batch. Of course, the operator is aware of the issue of potential production of gasses like ozone, and care is taken to minimize exposure to and inhaling of gasses escaping from the box. Also see section 2.6.

Using the feeding technique as indicated above, plasma treatment production rates of about 200 g/h of hemp and 70 g/h of flax could be achieved when applying 6 passages at 2 sides and starting from previously prepared fibre non-woven samples. The application of 6 passages at 2 sides was selected in first instance in order to obtain thorough treatment of fibres to evaluate the effect of dopant gasses. Fibre mat samples were prepared manually and appeared time consuming as well, yet more quick for the more coarse hemp fibres than for the finer flax fibres. Hemp tow was obtained from Smithers RAPRA, and originally sourced from Hemp Technology, flax sliver was sourced from Ekotex. Both fibre grades were refined using the Shirley Trash Separator before plasma treatment.

Power consumption was in the range of 1000 – 1100 W when applying 60 L/min of N_2 plasma and any of the dopant gasses (O_2, CO_2, H_2) and using the belt system.

Variables such as exposure time, feed gas composition, interaction between hydro-acoustic decortication variables, SoftPlasma conditions as well as the stability of modification after processing are currently being evaluated or will be evaluated in the next period.
Details regarding the effect of plasma treatment on fibre and fibre-matrix adhesion characteristics will be described in Deliverable 3.3.

2.5 Initial experimentation - Requirements to operate short fibre system

Feeding of short fibres using the specially designed short fibre treatment system was difficult because of the small entrance opening. Processing rate is maximum 50 g/h while applying only 1 passage. This system seems rather suitable for extremely short fibres and powders which are blown from the belt system.

Feeding of fibres using the short fibre treatment system also requires opening of the door and involves similar safety approach as addressed for the belt system (section 2.4).

2.6 Issues & solutions

Access to the fibre processing area is achieved by opening the door which covers one full side of the box. Plasma treatment of fibre quantities large enough for analysis in composites requires many times opening the door while the plasma is switched on. To protect the operator, and to optimize the confinement around the plasma flame, a smaller door would be helpful. For a future lab scale unit, in the large door a smaller door may be constructed which is just large enough to feed fibres.
A fully automated design for industrial scale processing will automatically go around this problem.

The entrance of the tunnel to make a confined environment for the plasma has sharp edges. The relatively low resistance between the 60 mm wide fibre mat and the belt occasionally causes the mat to block at the entrance of the tunnel when too much fibres are sticking outside the 60 mm width of the tunnel.
This problem may be solved by making the entrance walls slightly tapered.

The plasma source can be mounted either on the tunnel of the belt system or on the system suitable for treatment of short fibres. The plasma source is not automatically mounted in the optimal position on the tunnel. If the plasma source is not positioned well above the slit in the tunnel, the plasma will hit the side 'walls' of the tunnel, and will lose energy. The construction of a so called recess system may help to facilitate optimal positioning of the plasma source on the tunnel.

After about 10 hours (effective time) of N_2 based plasma treatment of flax and hemp fibres and 2.5 h of N_2 + O_2 based plasma treatment of hemp fibres, suddenly no plasma was observed anymore. After extensive evaluation by AcXys from a distance asking a range of (experimental) questions, it appeared necessary that a service engineer of AcXys visited DLO-FBR. It was found that an insulation part of the plasma source had been broken. Possible reason is that the part was damaged during transportation of the equipment, and that at some moment an electrical short cut took place, resulting in a fatal destructive damage of the plasma source.

2.7 Economic calculations

Considering the preliminary state of the development, commercial viability can be quantified in ranges. Based on the following assumptions:

- Expected cost of 100 cm ULD system: € 100,000.
- 5 years depreciation time, no interest calculated.
- 40 working hours per week, 40 weeks per year.
- Gas consumption as used for current lab trials and prices as paid by DLO-FBR for liquid N_2 in tank and dopant gasses in bottles:
    - N_2: 10 L_{gas}/min.cm at 646 L_{gas}/L_{liquid} at 0.156 €/L_{liquid}
    - O_2: 0.05 L_{gas}/min.cm at 798 L_{gas}/L_{liquid} at 1.95 €/L_{liquid}
    - CO_2: 0.05 L_{gas}/min.cm at 513 L_{gas}/L_{liquid} at 1.18 €/L_{liquid}
    - N_2O: 0.05 L_{gas}/min.cm at 664 L_{gas}/L_{liquid} at 2.68 €/L_{liquid}
    - H_2: 0.1 L_{gas}/min.cm at 788 L_{gas}/L_{liquid} at 0.94 €/L_{liquid}
- Non-woven weight of 300 g/m^2 as for current lab trials or 1000 g/m^2 as an estimated upper limit. Plasma treatment at both sides.
- Processing speed of 2.9 m/min as for current lab trials, or 10 m/min as an estimated upper limit. 6 Passages as currently performed at lab trials in order to make sure that certainly an effective treatment is obtained or just 1 passage.
- 0.2 fte operator at 15 €/h to operate the machine (Machine should require human assistance mainly when starting a new batch, which can be a roll of non-woven).
- Power consumption of 178 W/cm ULD width at 0.22 €/kWh.

Plasma treatment costs can be calculated, and it depends very much on production rate:

- 0.12 €/kg of fibre for a non-woven of 1 kg/m^2 at a processing speed of 10 m/min

- 8.75 €/kg of fibre at conditions for thorough processing as we are currently performing at DLO-FBR: 0.3 kg/m^2, processing speed of 2.9 m/min, 6 passages.

Economic benefits may be calculated as follows. As a first indication it can be stated that, saving potential is about 1.5% of 3% MAPP for a 30% flax-PP composite. This is about 50 g of MAPP per kg of fibre. Assuming that 50 g of MAPP costs about € 0.20, plasma processing should cost less than 0.20 €/kg of fibre to be considered economically feasible.

3. Conclusions

- A lab scale atmospheric plasma treatment unit has been developed and constructed by AcXys for operation at DLO-FBR facilities, In this way, plasma treatment and analysis of natural fibres can be performed in short term iterations, thus allowing most efficient analysis and development of the plasma treatment process.
    - The design is based on discussions involving AcXys, DLO-FBR, Smithers RAPRA and Movevirgo.
- The plasma equipment comprises a 60 mm wide ULD plasma source mounted on a belt system for treatment of fibre roving and non-wovens. A tunnel has been made around the belt in order to keep the plasma conditions intact for as long a time as possible. The belt speed can be varied in the range 2.9 to about 25 m/min.
    - Fibre roving is expected to be of interest in sheet moulding compounds (SMC).
    - Non-wovens are used in vacuum formed polyester products.
- A special system is designed and constructed for treatment of short fibres.
    - Short fibres are mostly used in extrusion and injection moulded products.
- The basic gas for the atmospheric plasma treatment unit is nitrogen (N_2). N_2 gas of high purity (5.0) is provided by the fixed supply system available at DLO-FBR which is fed from a liquid N_2 tank. Maximum gas flow in the equipment is 60 L/min.
- For adding dopant gasses, separate entrance tubes are included for reducing gases (H_2) on one hand and oxidizing gases (O_2, CO_2 or N_2O) on the other hand, in order to avoid accidents with reducing and oxidizing gases coming together. Dopant gasses were sourced as 40 or 50 L bottles. Typical dopant gas concentration in N_2 is 0.5-1%. Pressure reduction valves were required and sourced for each individual gas.
- Natural fibre roving and non-woven are stable (not blowing away) on the belt when applying plasma based on a N_2 flow of 60 L/min. It appears that even 5-10 mm short fibres, which show at least some kind of entanglements, stay in place on the belt without taping them.
- Plasma treatment production rates of about 200 g/h of hemp and 70 g/h of flax were achieved when applying thorough treatment (6 passages at 2 sides) and starting from previously prepared fibre non-woven samples.

4. Future Work (Months 20 to 30)

- During coming months, plasma treatment process will be evaluated for adhesion between natural fibres and polymers. Variables such as: exposure time, feed gas composition, interaction between hydro-acoustic decortication variables and SoftPlasma conditions, stability of modification after processing will be evaluated. The results will be described in Deliverable 3.3 report, which is due in Month 22.
- In a next step, in consultation with project partners, fibre samples will be plasma treated for scaled up trials in WPs 4, 6 and 7.
- LCA data will be collected and provided to RAPRA as input to WP9.

4.1 Recommendations

- In a future design, the walls at the entrance of the tunnel around the belt system may be tapered in order to facilitate feeding of the fibre non-woven into the tunnel.
- In a future design of a similar flexible plasma source unit, the construction of a so called recess system may help to facilitate optimal positioning of the plasma source on the tunnel and short fibre system.

Annex 1 Details of dopant gases

THE LINDE GROUP Linde

Waterstof 5.0 Detector

Chemische naam: Waterstof
Formule: H_2

Specificatie/kwaliteit

Zuiverheid		≥	99,999	vol %
Verontreiniging	N_2	≤	5	vpm
	H_2O	≤	5	vpm
	O_2	≤	2	vpm
	C_xH_y	≤	0,5	vpm

Verpakkingsvormen

	V_{cil} (l)	V_{gas} (m^3)	P_{vul} (bar)	Artikelcode
Cilinders	1	0,2	200	3200101
	5	0,9	200	3200105
	10	1,8	200	3200110
	50	9,0	200	3200150
Pakket (16 cil.)	800	144	200	3200580
	m^3 bij 15 °C en 1 bar			

Cilinderkenmerken

Kleur volgens norm	**NEN-EN 1089-3**	
Schouder	Vuurrood	RAL 3000
Cilindrisch deel	Vuurrood	RAL 3000
Aansluiting volgens NEN 3268	LU 1	

Fysische eigenschappen

Moleculair gewicht (kg/kmol)	2,02		
Dichtheid gas (kg/m^3 bij 1,013 bar en 0 °C)	0,090		
Relatieve dichtheid (lucht = 1)	0,070		
Kookpunt (°C) (K)	-252,8	respectievelijk	20,4
Kritische temperatuur (°C) (K)	-239,9	respectievelijk	33,3
Explosiegrenzen (vol % in lucht)	4 – 75,6		

Overige informatie

Veiligheidsinformatieblad	Waterstof, samengeperst (VIB nr. 8360)
Productbeschrijving	Kleurloos en reukloos samengeperst gas; zeer brandgevaarlijk; explosief

Toepassingen

Als draaggas in de gaschromatografie	Solderen van edelmetalen en non-ferro legeringen
Als reductiemiddel	Brandgas bij kwartsbewerkingen
Gasdetectie apparatuur	

Linde Gas Benelux B.V.
Havenstraat 1, Postbus 78, 3100 AB Schiedam
www.lindegasbenelux.com
BESTELLEN:
www.lindegasonline.nl / E-mail: mailorder.lg.nl@linde.com
Tel.: +31 88 262 62 62 / Fax: +31 10 246 15 06

Linde Gas Belgium N.V.
Westvaartdijk 85, B-1850 Grimbergen
www.lindegasbenelux.com
BESTELLEN:
E-mail: order.lg.be@linde.com
Tel.: +32 2 257 88 49 / Fax: +32 2 257 88 76

NL-PB-0033/05

Details of Hydrogen used in UltraFibre.

THE LINDE GROUP Linde

Oxygen 5.0 Instrument

Chemical name: Oxygen
Formula: O_2

Specification / grade

Purity		≥	99.999	vol %
Impurity	N_2	≤	5	ppm
	Ar	≤	3	ppm
	H_2O	≤	3	ppm
	C_nH_m	≤	0.2	ppm

Cylinder / content specification

	V_{cil} (l)	V_{gas} (m^3)	P_{vul} (bar)	Product code
Cylinders	10	2.2	200	2110110
	50	10.8	200	2110150
	m^3 at 15 °C and 1 bar			

Cylinder characteristics

Colour according to standard	**NEN-EN 1089-3**	
Shoulder	Pure white	RAL 9010
Cylindrical part	Basalt grey	RAL 7012
Connection according to NEN 3268	RI 2 (G 5/8")	

Physical properties

Molecular weight (kg/kmol)	31.99		
Density gas (kg/m^3 at 1.013 bar and 0 °C)	1.429		
Relative density (air = 1)	1.105		
Boiling point (°C) (K)	-183.0	respective	90.2
Critical temperature (°C) (K)	-118.4	respective	154.8

Additional information

Material Safety Data Sheet	Oxygen, compressed (VIB nr. 8340)
Product description	Colourless and odourless compressed gas; oxidizing agent

Applications

Laser cutting	Petrochemical industry
Coulometry	Laboratory applications
As component in calibration gases	

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Details of Oxygen used in UltraFibre.

THE LINDE GROUP

Linde

Kooldioxide 4.0

Chemische naam: Kooldioxide
Formule: CO_2

Specificatie/kwaliteit

Zuiverheid		≥	99,99	vol %
Verontreiniging	N_2	<	60	vpm
	H_2O	<	25	vpm
	O_2	<	15	vpm

Verpakkingsvormen

	V_{cil} (l)	m_{gas} (kg)	Artikelcode
Cilinders	5	3,7	2330105
	10	7,5	2330110
	13,4	10,0	2330113
	27	20,0	2330127
	40	30,0	2330140
Pakket (12 cil.)	600	450	2330560

Cilinderkenmerken

Kleur volgens norm	NEN-EN 1089-3	
Schouder	Stofgrijs	RAL 7037
Cilindrisch deel	Stofgrijs	RAL 7037
Aansluiting volgens NEN 3268	RU 1	

Fysische eigenschappen

Moleculair gewicht (kg/kmol)	44,01		
Dichtheid gas (kg/m³ bij 1,013 bar en 0 °C)	1,977		
Relatieve dichtheid (lucht = 1)	1,529		
Kookpunt (°C) (K)	-78,5	respectievelijk	194,7
Kritische temperatuur (°C) (K)	31,1	respectievelijk	304,2
Dampdruk (bar bij 20 °C)	57		

Overige informatie

Veiligheidsinformatieblad	Kooldioxide (VIB nr. 8377)
Productbeschrijving	Kleurloos en reukloos onder druk tot vloeistof verdicht gas
Aanduiding volgens NEN-EN-ISO 14175	C1

Toepassingen

Brandblusmiddel	Zuurgraadcorrectie van afvalwater
Sodabereiding	Inertiseren
Drijfgas voor spuitbussen en koelvloeistof	Als component in lachgasmengsels
Bemesting van glas- en tuinbouw	Opschuimen van kunststoffen
Productie van ureum	Superkritische extractie

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NL-PB-0138/06

Details of Carbondioxide used in UltraFibre.

THE LINDE GROUP Linde

Lachgas 2.0 AAS

Chemische naam: Distikstofmonoxide
Formule: N_2O

Specificatie/kwaliteit

Zuiverheid		≥	99,0	vol %
Verontreiniging	$N_2 + O_2$	≤	0,9	vol %

Verpakkingsvormen

	V_{cil} (l)	m_{kin} (kg)	Artikelcode
Cilinders	5	3,5	24760105
	10	7,5	24760110
	40	30,0	24760140
	50	37,5	24760150

Cilinderkenmerken

Kleur volgens norm	**NEN-EN 1089-3**	
Schouder	Gentiaanblauw	RAL 5010
Cilindrisch deel	Gentiaanblauw	RAL 5010
Aansluiting volgens NEN 3268	RU 1 (W21,8 x 1/14")	

Fysische eigenschappen

Moleculair gewicht (kg/kmol)	44,01		
Dichtheid gas (kg/m³ bij 1,013 bar en 0 °C)	1,980		
Relatieve dichtheid (lucht = 1)	1,531		
Kookpunt (°C) (K)	-88,5	respectievelijk	184,7
Kritische temperatuur (°C) (K)	36,4	respectievelijk	309,6
Dampdruk (bar bij 20 °C)	51		

Overige informatie

Veiligheidsinformatieblad	Distikstofmonoxide (lachgas) (VIB nr. 8330)
Productbeschrijving	Kleurloos onder druk tot vloeistof verdicht gas met typerende geur; narcotiserend; explosief boven de 200 °C; brandbevorderend

Toepassingen

Atomaire absorptie spectrometrie	Extractiemiddel en oxidatiemiddel

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NL-PIB-0027/06

Details of Laughing gas used in UltraFibre.