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DEVELOPMENT OF SUSTAINABLE PAPER COATINGS USING NANOSCALE INDUSTRIAL SURFACE PROCESSING

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ABSTRACT: The term "sustainable production" comprises a weighting of economical, environmental and social considerations. The three categories are mutually dependent and therefore an assessment needs to take a systems analysis approach to make the right decisions by the various stakeholders ranging from developers, production industries, consumers and authorities. Part of the consideration is the public perception of the new product and the processes to manufacture it, which is an important aspect for products being developed using nanoscale surface processing. Such considerations are integrated in the PlasmaNice project, as environmental and social aspects are addressed using methods like life cycle check (LCC), life cycle assessment (LCA), and industrial risk assessment (RA) within the boundary of an economical production for different market segments. The results are intended to be used partly to inform the public about the processes and benefits of the prototype products, and partly to give feedback to the project partners on the environmental and safety aspects of the different material, processing, use and waste stages. By that being a link between the industrial project partners developing products, and the process and material developers providing new coatings with specific properties. The combination of RA and LCA/LCC within the early stages of product development provide a more holistic approach, It is commonly believed to be also economical beneficial as changes are easier to implement. The paper will provide some insights of this approach presenting some first results of the project describing the used processes and substances, safety and occupational health issues, consideration of nanomaterial safety, and the communication of safety issues to the public.

INTRODUCTION

In 2008 the EU project PlasmaNice (Atmospheric plasmas for nanoscale industrial surface processing) in the FP7-NMP-2007-large-1 was launched to develop new industrial coating materials and processes for more sustainable products made of e.g. paper and plastic film. The project is a cooperation of 14 research institutions, universities and industries from Belgium (2), Denmark, Finland (3), Germany (3), Hungary, Italy, The Netherlands (2), and Slovenia with Tampere University of Technology, Finland as coordinator. The partners are listed in Table 1.
One of the objectives for the PlasmaNice project is to develop prototype products with specific properties taking advantage of new processing steps as e.g. plasma treatment and deposition. The manufacture of the prototype products being used in different market segments are being assessed for their sustainability using the approach described in the following.
The term "sustainable production" comprises a weighting of economical, environmental and social considerations. The three categories are mutually dependent and depending on the weight of each category one may distinguish between different sustainable production strategies: In some countries the environmental aspect may be weighted more, while other countries have more focus on social or economic aspects, which may be dependent on a country's situation. Therefore, an assessment needs to take a systems analysis approach to make the right decisions by the various stakeholders ranging from developers, production industries, consumers and authorities. Part of the consideration is the public perception of the new product and the processes to manufacture it. This is e.g. an important aspect in case of products being developed using nanoscale surface processing. These considerations are integrated in the PlasmaNice project, as environmental and social aspects are addressed using methods of life cycle assessment (LCA & LCC) and industrial risk assessment (RA) within the boundary of an economical production for different market segments.

Table 1. Industries, SME's, research institutes and universities taking part in the developments of nano coated materials in the framework of the PlasmaNice project.

No.	Partner name	Short name	Country
1.	Tampere University of Technology (coordinator)	TUT	Finland
2.	Flemish Institute for Technological Research	VITO	Belgium
3.	Fraunhofer Institut Silicatforschung	Fh-ISC	Germany
4.	Technical Research Centre of Finland	VTT	Finland
5.	Eindhoven, University of Technology	TUE	The Netherlands
6	Jozef Stefan Institute	JSI	Slovenia
7.	Stora Enso Oyj	SE	Finland
8.	AFS (SME)	AFS	Germany
9.	Segers & Balcaen (SME)	SB	Belgium
11.	Print 2000 Nyomda Kft (SME)	PNK	Hungary
12.	SurA (SME)	SurA	Germany
13.	Sappi Ltd.	Sappi	The Netherlands
14.	Technical University of Denmark	DTU	Denmark
15.	2B Consulenza Ambientale de Leo Breedveld (SME)	2B	Italy

To avoid and minimise any risk that may be imposed to workers, consumers and the environment by new processes and substances, it is important to address the safety, environmental and economic aspects of new developing technologies. The goals within PlasmaNice are therefore to evaluate the environmental behaviour and sustainability of biopolymers used in the coatings and the safety aspects of the new process to be developed. Special focus will be given to analyse waste management scenarios, processing using nano-scaled materials and the plasma technology. The results are used partly to inform the public about the processes and benefits of the prototype products, but also to give feedback to the project partners on the environmental and safety aspects of the different material, processing, use and waste stages resulting and being a link between the industrial project partners developing products and the process and material developers providing new coatings with specific properties. The combination of RA, to address e.g. product safety and occupational health, and LCA/LCC, to address the overall environmental aspects, within the early stages of product development provide a more holistic approach. A number of possible aspects are indicated in form of a mindmap as shown in Figure 1. It is commonly believed that assessments starting already in the design phase of a product are beneficial as any changes at the early stages of the design are more easily and more economically implemented.

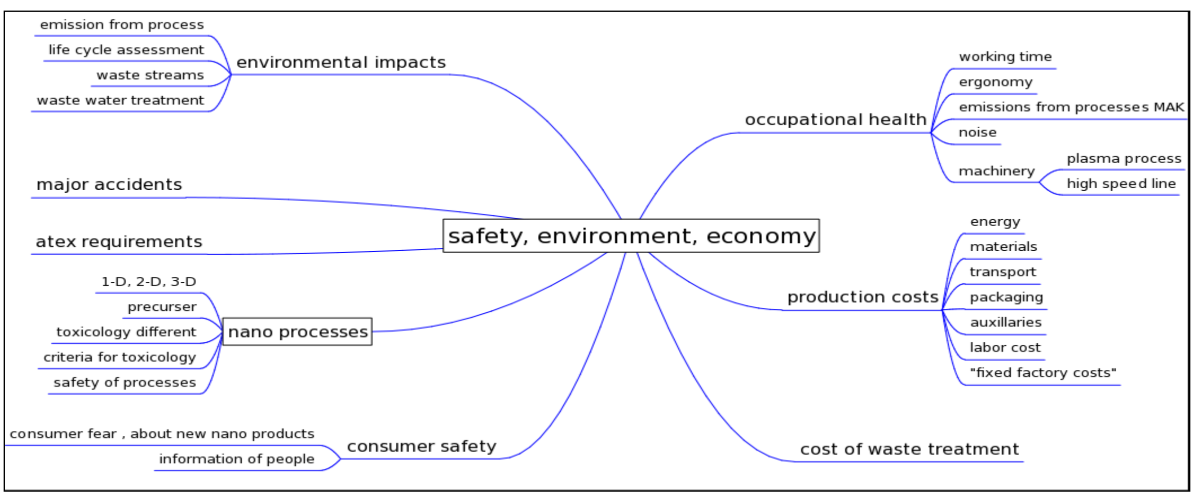

Figure 1. A mindmap on the safety, enivironmental and economical aspects to consider for support of a sustainable production of the new paper coating.

The strategy within PlasmaNice in the assessment of its technology is to use LCA and RA as design tools for safer and cleaner technologies, while improving their environmental performance by means of feedback to the developers. The paper will provide some first insights of this approach.

RISK ASSESSMENT OF NANOTECHNOLOGIES

Risks of nanotechnologies are currently high on the agenda, due to enormous investments in this sector in Europe, US and Japan. The identification of environmental impacts and risks from nanotechnologies is vital for their large-scale acceptance by society. This requires environmental risk assessment, risk management for workers and communication to the public.

In the literature various approaches on risk management of nanotechnologies have been published, often hampered by lack of knowledge on long-term effects of nanotechnologies and, due to the lack of substantiated data, struggling in between real risks and assumed risks. Examples of articles are Wardak (2008), Joshi (2008), Seager (2008) and Shatkin (2008a,b).

Wardak (2008) proposes a framework to identify risks from nano-products using a scenario analysis approach that allows expert judgement on a set of use and disposal scenarios, labeled with risk triggers to obtain semi-quantitative scores on their likelihood of occurrence and severity. Use and disposal scenarios describe product life-cycle stages that could result into risk attributed to the nano-product, whereas risk triggers are particular to nanoparticle properties. These are potential risks, as the risk assessment community is currently debating the specific risks attributed to nanotechnology. Through such a framework, Wardak aims at the identification of risks and opportunities in early stages of product development.

Joshi (2008) questioned if nanocomposites can improve the sustainability of biobased products. Recent developments in nanotechnology in the area of nanoclay composites are improving the technical performance of biobased polymers and enhancing their competitiveness in relation to traditional materials. Joshi (2008) assessed whether these developments also improve the environmental sustainability of biopolymers, by using a life cycle approach. It was estimated that nanoclay production results in lower energy use and greenhouse gas emissions in comparison to the production of common biopolymers and thus nanocomposites can improve the environmental performance of common biopolymers.

Seager (2008) proposes coupling of multicriteria analysis (MCA) and life cycle assessment (LCA) for further research on the risks of nanotechnologies. Based on the US-EPA nanomaterials research strategy, Seager states that the product life cycle is the proper thinking about materials, including nanomaterials. The major advantage of LCA is that it quantifies environmental impacts at different product life cycle stages and avoids shifting potential environmental problems from one stage to another. However, nanomaterials present at least three significant challenges to existing LCA techniques: material variability, uncertainty in toxicity and risk, and uncertainty of the performance of nanomaterials. In order to deal with the uncertainty due to the application of LCA for nanomaterials, Seager proposes to use MCA in combination with LCA, since MCA alone might be too subjective. Although uncertainties do exist, LCA will become increasingly useful to support decision-making and policy making on nanomaterials (Seager, 2008).

Also Shatkin (2008) advocates the use of scientific tools (LCA and RA) to support decision-making on nano-technologies. Combining LCA and RA into a prospective and semi-quantitative analysis offers an analytical approach for early identification and evaluation of potential impacts. The challenge of assessing nanomaterials is the limited information currently available. To overcome this problem, Shatkin suggests expert workshops and multicriteria decision analysis (MCDA). Qualitative and semi-quantitative approaches can allow transparent evaluations to identify potential impacts of nanomaterials in early stages of product development (Shatkin, 2008).

The relevance of the abovementioned articles is that they will function as a trigger to handle certain problems related to the lack of knowledge on the long-term risks of nanotechnologies. It provides a framework to identify risks from nano-products using a scenario analysis approach that allows expert judgement. It stresses the importance of the use of adequate tools like LCA, RA and MCA. Finally, the combination of these tools into a prospective and semi-quantitative analysis offers an analytical approach for early identification and evaluation of potential impacts, allowing the identification of risks and opportunities in early stages of product development.

THE PROCESS EQUIPMENT

The new developed nano-coated paperboard will as a start use the pilot extrusion coating line established at Tampere University of Technology as shown in Figure 2. Here also devices for in-line plasma treatment and nano-coating will be installed. Three different plasma technologies for activation and material deposition will be evaluated:

- Plasmatrix: using air plasma for surface cleaning and activation
- PlasmaLine: using indirect atmospheric plasma treatment for activation or coating
- PlasmaZone: using direct atmospheric plasma treatment for activation or coating

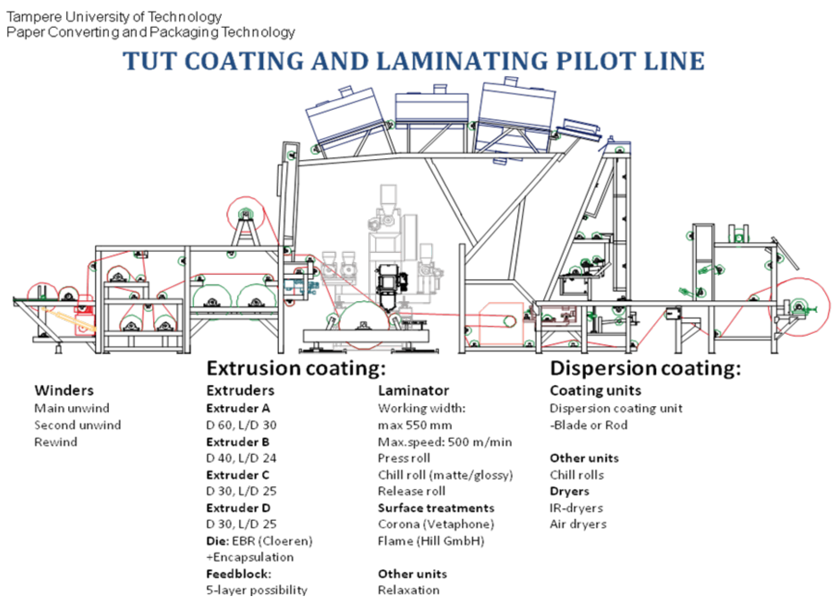

Figure 2. The pilot coating and laminating facility at TUT/PCT that is being equipped with different plasma assisted coating devices. The drawing shows the basic parameters.

To produce the nano sized coating a nozzle is producing nano particles from the coating material precursors during the coating process. Therefore, the precursor is not produced, transported, stored or handled in the "nano" state. The overall process flow is shown in Figure 3.

RESULTS

The first steps of the RA and LCA assessment involved extended data gathering. For this purpose a questionnaire was developed, sent to the PlasmaNice partners and after return analysed to elicit safety issues concerning the equipment and materials. This was assisted by collecting literature data on the environmental and safety issues. Further the relevant legislation and standards are compiled. As seen in Figure 3 a process flow diagram for the paperboard coating process using siloxanes is drawn. These steps are useful for both the Hazard Identification for the RA and the Inventory of the LCA. They also give some first insight where to allocate e.g. a risk caused by nano particles as indicated by the coloured boxes in Figure 3. The main potential risk to be exposed to nano particles is found to be close to the atomizer equipment during processing and therefore is to be categorised as a potential occupational health problem. The nano coating on the final coated product is only nano sized in its thickness and bound onto the paperboard or film. In the latter case, the potential exposure to people is assumed to be negligible.

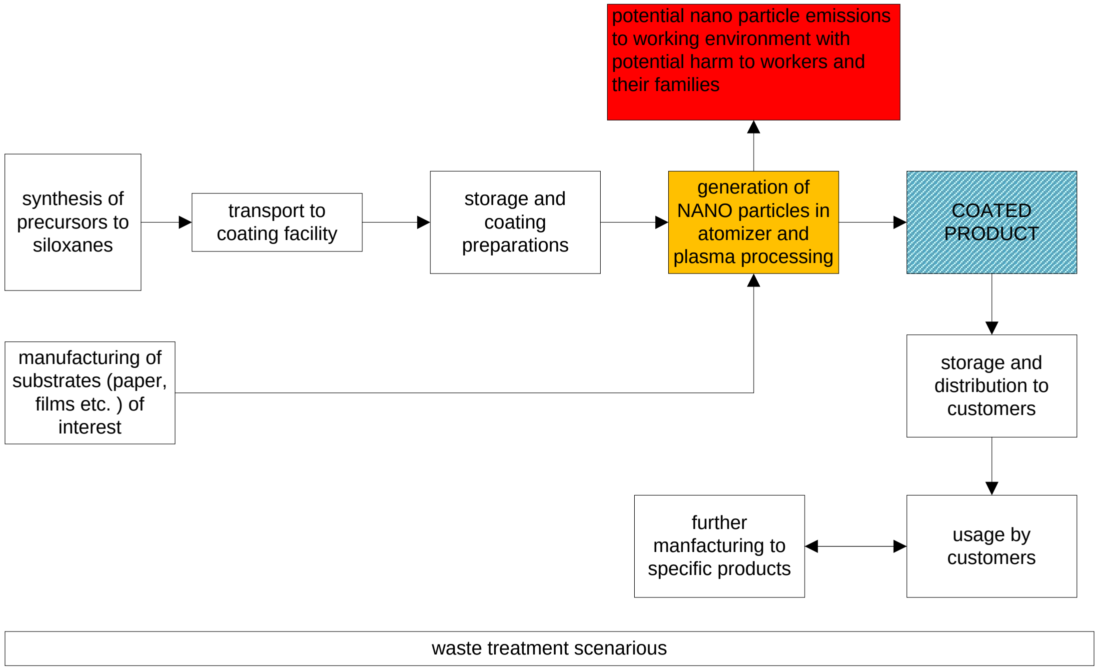

Figure 3. Process flow diagram of the paper and film coating using siloxane precursors and nanoparticle generation in an atomizer prior to product coating.

CONCLUSIONS

The goal and scope of the RA and LCA and relevant background information have been gathered. These will be used to assess the sustainability of the products using various combinations of materials and processes. A preliminary assessment of the paper and film coating process using plasma technology revealed that nano particles are only produced during the coating process and the main potential emission source is expected to be close to the atomizer. After curing the coating material is polymerized giving a nano sized coating being bound to the paperboard or film which is assumed a negligible emission source. Thus a potential exposure with nanoparticles seems restricted to the workspace and it seems to be a potential occupational health problem that may need attention, but which is expected to be fully controllable if appropriate measures are in place such as good ventilation.

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