Making Textiles from Waste

The technical textile solution to industrial waste

Sixteen partners from 10 different countries are uniting their forces to convert the feather waste stream from the poultry industry into useful raw materials for different technical applications, including flame retardant coatings for protective textiles, as well as fertilisers, packaging and composites. The main goal of KaRMA2020 is the industrial exploitation of this underutilised feather waste.

We're constantly being told that eating meat is bad for the planet, but before you go cold turkey on that bucket of wings, consider this: feather waste from the poultry industry could be the next secret weapon for the technical textiles industry.

The agriculture industry is under increasing scrutiny for its environmental impact. The number of vegetarians, vegans, flexitarians and pescatarians has never been higher, with an ever increasing number of consumers growing more aware of the ethics and impact of each forkful. Of the environmental impacts, those shouted loudest are the gases emitted and the water required throughout the animal's journey to the plate. With consumers becoming more conscious of the environmental and health implications of eating red meat, 2017 is set to see consumption of chicken increase. Of those adopting this dietary change, however, how many have considered the little publicised impact on the environment of feather waste?

To satisfy our appetite for food that's finger lickin' good, Europe alone is already producing 13.1 million tons of poultry. As a result, the poultry industry generates over three million tons of feather waste per year. Only a mere fraction of this enormous heap of waste is validated by being processed into low nutritional animal food. In some countries the majority of this vast amount of waste is simply being dumped as landfill. Because of health hazards and environmental impacts associated with landfill,

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this option is not appealing and even forbidden in European countries. Consequently, feather waste is predominantly incinerated. Since keratin contains a substantial amount of nitrogen, NOx greenhouse gases are emitted during combustion, which has to be controlled. And, regrettably, these waste removal methods cause an important source of keratin to be lost.

Meanwhile, material science is looking for new alternatives to decrease or even replace plastics made from non-renewable petroleum resources, to simultaneously benefit from renewable sources and decrease the amount of industrially generated waste. The validation of keratin extracted from feathers perfectly fits within this scope.

KaRMA2020

The KaRMA2020 project was launched on 1 January 2017 for a period of three years. Research partners involved in this project are IK4-Cidetec (Coordinator, Spain), Aimplas (Spain), VTT (Finland), Processum and RISE (Sweden), Centexbel (Belgium), Institute of Biopolymers and Chemical Fibres (Poland), University of Nice Sophia Antipolis (France), and FKuR Kunststoff GmbH (Germany). Companies involved include Avantium (Netherlands), Daren Laboratories and Scientific Consultants Ltd (Israel), Ciaotech srl (Italy), Vertech Group (France), Sioen Industries nv. (Belgium), and Grupo Sada and Fertiberia (Spain), which will bring the developed technologies from lab scale up to industrial level.

Pretreatment of feathers

The recycling story starts with the collection of feathers in slaughterhouses. These feathers are anything but clean and a breeding ground for many pathogens, moulds etc. Hence the feathers need to undergo a treatment to kill all pathogens in order to exclude every possible health risk during their subsequent manipulation phases.

The feathers will not be used as such in technical applications because they are too coarse and their structure is too heterogeneous. They can either be mechanically refined into nano- or microfibres or particles or treated by thermal, chemical or biotechnical conversion technologies to enhance their processability into final products. Steam, enzymes or novel solvents will be applied for this purpose. The keratin (fragments) can be submitted to chemical reactions to enhance their solubility by cutting the disulphide bridges that hold together the keratin strings. This will alter their 3-dimensional conformation (spatial shape), and by consequence their physical characteristics. Furthermore, it is possible to change their chemical structure to improve their compatibility in plastics and coatings.

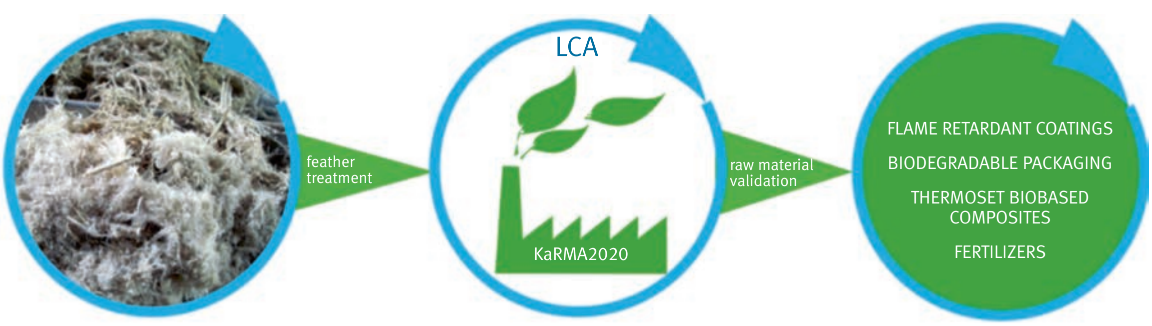
Applications

The aim of the project is to exploit and validate the use of feather waste in different cross-sectoral fields by creating valuable raw materials. Feathers consist of 90% keratin. The keratin's chemical nature, which is a protein made of amino acids, can result in beneficial properties in multiple technical applications. The project will focus on technical textile coatings and composites, fertilisers and food packaging.

Technical textile coatings

Many technical textiles are coated with a full layer of polymers such as polyurethanes, acrylates and silicones to create a barrier on top of the textile. This technique allows coated textiles to meet requirements including water- and airtightness. However, most currently used polymeric systems are not biobased. By replacing part of the coating material with keratin, the coating becomes partially biobased. The environment will benefit from an increased substitution of fossil based for biobased materials derived from waste streams.

Certain coated textiles require waterproofness combined with water vapour permeability to enhance ▸



Feather waste management strategy | Raw material manufacturing | Market analysis the wearer's comfort. Because of the hydrophilic nature of processed keratin, adding keratin to the existing coating systems might be beneficial to their breathability, allowing water vapour transport throughout the coating.

In some applications it is mandatory to use a flame retardant coated textile. Because of the growing amount of flammable materials in buildings, the escape time after ignition of a fire has been reduced over the last few decades from 17 minutes to less than three minutes. It is of vital importance, therefore, to create flame retardant (interior) textiles. This is surely the case when the textile product is destined to be used in the contract market and in (public) transportation. Flame retardant textiles are of course also intensely used in the production of protective clothing, such as firefighter suits or in protective clothing for workers in blast furnaces, astronauts, police and military, industrial workers – in short all professionals exposed to fire.

In most cases, inherently flame retardant fibres such as aramid (AR), polyamide-imide (PAI), modacrylic (MAC) and polybenzimidazole (PBI) are used to manufacture the outer layers of the garment. Well-known brand names are Kevlar (p-AR), Nomex (m-AR) and Kermel (PAI). Thanks to their excellent flame retardant behaviour (limited oxygen values around 30%) it is not necessary to submit them to an additional flame retardant treatment. However, if less stringent demands are in place, one can think of using flame retardant coated polyester or polyamide, for example.

Until a few years ago, decabromodiphenyl ether (deca-BDE) was the most commonly used flame retardant in the textile sector, because of its good all-round flame retardant properties. However, in 2012, this deca-BDE was registered as a SVHC component (substance of very high concern) as it was classified as persistent and bio accumulative toxic (PBT). From March 2019 onwards, deca-BDE will be officially restricted, necessitating the urgent switch to alternative and harmless flame retardants.

Moreover, in many cases the end user demands the use of non-halogenated flame retardants. Influenced by, for example, non-governmental organisations, people tend to generalise and to shed a negative light on all halogenated products. The truth is not as simple as that, for it has to be mentioned that several non-halogenated flame retardants (e.g. trixylyl phosphate, tris(aziridinyl)phosphinoxide) are toxic and therefore forbidden to be used in textiles (REACH regulation), whereas polymeric halogenated flame retardants are even included in the 'white list' of OEKO-TEX®, a label guaranteeing the absence of harmful products in textiles. So every compound, halogenated or not, must be assessed on their potential hazards.

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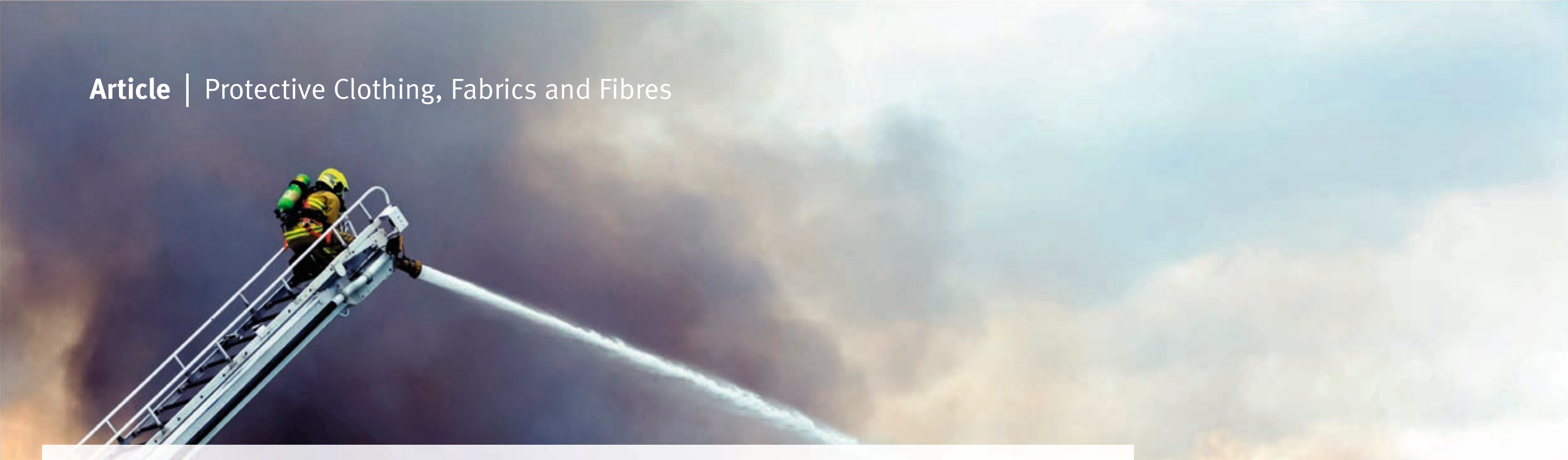
The most widespread alternatives to halogenated flame retardants are nitrogen and/or phosphorous compounds, minerals like alumina trihydrate, borates, ceramics, graphite, and others. Research performed at Centexbel (FR4tex trajectory) showed that is not easy to replace deca-BDE with non-halogenated flame retardants: for coatings it was impossible to identify any drop-in replacement. Non-halogenated flame retardants may have good flame retardant properties, but they are very application-specific. For example, coloured products such as red phosphor or graphite cannot always be used and attention must be paid to hydrolysis of the components (e.g. organophosphates) if washability is desired. Minerals need very high loadings to be efficient, which will result in a lesser coating quality. The polymeric halogenated flame retardants were also evaluated and showed satisfactory results in many coating systems, without showing migration.

Increasing environmental awareness triggers the demand for flame retardants from natural resources. Research has been performed on the use of DNA, casein, chitosan, lignin, etc. as alternative bio-flame retardants, but has not resulted in commercial products up till now. Because keratin consists of amino acids, the structure contains a large percentage of nitrogen, and therefore it has the potential to be processed into a bio-flame retardant. One of the key elements of certain non-halogenated flame retardants is nitrogen. Nitrogen contributes to the formation of a protective cross-linked layer on the surface during fire, protecting the underlying material. It can also dilute the flammable gases/oxygen mix by releasing nitrogen gas. Both actions will reduce flammability. It has to be examined whether keratin on its own contains enough nitrogen to have a positive effect on the burning behaviour of a coating.

In order to increase the flame retardant effect, phosphorus components will be linked to the keratin. Phosphorus-containing flame retardants can act in the solid and gas phases. When heated, phosphorus compounds release a polymeric form of phosphoric acid which causes the material to char, thus inhibiting the pyrolysis process which supplies fuel to the flame. The char acts as a two-way barrier, both hindering the passage of the combustible gases towards the flame and shielding the polymer from the energy (heat) supply. ▸



> "novel flame retardants, based on nitrogen and phosphor, will be synthesised and evaluated in textile coatings"

Nitrogen is known for its significant synergy with specific phosphorus compounds by mutually reinforcing their functions. Therefore, novel flame retardants, based on nitrogen and phosphor, will be synthesised and evaluated in textile coatings.

Next to water vapour permeability and flame retardancy, the effect of adding keratin on other textile properties will be examined (e.g. washability, abrasion resistance, waterproofness, etc.). It is also possible that the refined keratin, which is hydrophobic by origin, needs to undergo chemical treatments to enhance the compatibility with the polymeric binder system.

Biobased composites

Composites are lightweight materials made from two (or more) constituent materials. These materials remain separate and distinct in the final product. The total composite structure will benefit from the properties of both components. At this very moment, classical materials such as steel and wood are increasingly being replaced by composites, predominantly in applications were strength and weight are important assets.

The KaRMA2020 project will examine composites built of a (biobased) reinforcement textile and a biobased thermoset resin. These fibre-reinforced composite materials are very popular in high-performance products that need to be lightweight and yet strong enough to withstand harsh loading conditions.

At first, composite resins were often made from non-biobased polymers. Currently there is a tendency to switch to biobased ones. As sustainability is a key driver for innovation, the aim of the project is to produce biobased composites based on feathers.

New types of resins will be developed by making copolymers from keratin and humins, a lignin-like waste polymer. These resins will be applied as composite matrix. Humins are known for their intrinsic flameproof character, which paves the way for many applications. Feather fibres will also serve as structural elements to reinforce the polymeric matrix. Furthermore, poultry feathers will be incorporated into a polymeric matrix during a spun bond process. The produced nonwovens will be used as reinforcement material in composites.

Finally, composites will be produced via 'Resin Transfer Moulding' or 'Prepreg' technology in which feather-based nonwovens will be combined with the feather-modified matrix. The novel fireproof composites will have an intended use in structural applications, in which flame retardancy is a very important parameter.

Fertilisers

As stated previously, keratin contains nitrogen in its structure, one of the main components of fertilisers. The keratin will be fragmented into smaller parts to be absorbed more easily by plants. The partially fragmented keratin, however, will still contain nitrogen in the solid matrix and be released slowly. Hence, contrary to many liquid nitrogen fertilisers, the nutrients from feather-based fertilisers do not leach from the soil by rain.

Alternatively, keratin will be used to coat the semi-permeable membrane that surrounds the nutrient granules containing nitrogen, potassium and phosphorus. Such a fertiliser granulate is called a 'controlled release fertiliser'. In this type of fertiliser, water penetrates the coating and dissolves the nutrients. The nutrient solution migrates out of the granule, providing a uniform release of nutrients in time. The nutrients are thereby released over a longer period of time, which ▸

extends their availability to the plant. The use of keratin as a coating will enable the development of a fully biodegradable fertiliser.

Biobased and biodegradable food packaging

In supermarkets poultry is mostly offered in plastic trays made from a combination of different plastics such as polyester and polyethylene. The major drawback is that these materials are fossil based and cannot be composted later on. In theory, these materials could be recycled, but the collection of waste after domestic use, and the subsequent sorting of all different types of plastics is not in place yet due to technical constraints. All this plastic packaging waste is either dumped as landfill or incinerated (in which the plastics act as a source for energy production).

Ideally, materials from waste streams can be recuperated as raw materials for the production of materials that will not end up as waste. This approach leads to a double benefit.

In KaRMA2020 keratin particles will be added to biobased plastics to produce fully compostable and recyclable packaging. The industrial process starts by an industrial compounding process in which the refined keratin is added to the thermoplastic polymer matrix. In a further step the keratin-containing pellets will be the starting material for the production of plastic sheets. Subsequently, the sheets will receive their final shape, e.g. a tray to pack poultry meat or eggs, via a thermoforming process. Research is needed to understand the optimal keratin particle size, content and properties, extrusion parameters, etc. to create plastics which fulfil the requirements.

The aim is to produce a compostable tray with the same properties as the current PET or PP trays, but resulting in a 50% reduced CO_2 emission during production. In other words, it will be possible to pack a chicken 'in its own feathers' – this in respect of the environment.

Sustainability assessment and waste management

The KaRMA2020 project strongly emphases the use of biobased materials, sometimes even combined with biodegradability. Next to their technical performances, the sustainability of these materials must be compared with currently used conventional materials, mostly based on fossil fuel. The most widespread technique to compare different processes and end products in an objective manner is a Life Cycle Assessment (LCA). This study looks at the extraction and processing of raw materials, manufacturing, distribution, use, reuse, maintenance, recycling and final disposal. Energy and water use, emissions, etc. associated with all stages of the life cycle of a product are evaluated.

Social Life Cycle Assessment (SLCA) takes it even a step further, as social and socio-economic aspects are also taken into account.

LCA and SLCA of the developed manufacturing processes at an industrial level will be carried out to optimise and ultimately illustrate the environmental efficiency of the proposed technologies.

Waste management strategies will be defined, aiming not only to study singular waste sources and to treat them as potentially valuable materials, but also to cover all encountered waste in an integrated fashion. A conceptual starting point is 'waste denial', which can be summarised as a positive evaluation of all waste streams, aiming at their valorisation. Hence, every residual waste stream from a downstream process will be considered as a feedstock for another process. This 'waste denial' concept is a fundamental point of the circular economy principles. ■

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Author

After her studies as industrial chemical engineer, Ine De Vilder obtained her PhD in applied sciences, chemistry in 2011. Since then she has worked as a Research Scientist at Centexbel. Centexbel is the Belgian scientific and technical centre for the textile and plastics industry. The centre, a non-profit organisation with 160 employees, has strong links with textile producing and plastic converting companies in Belgium. As a collective research centre, Centexbel helps the companies to reinforce their market position by promoting and supporting innovation. To fulfil its mission, Centexbel offers an extensive range of activities and services to the textile and plastics industry, including testing (chemical/physical/microbiological/burning behaviour), certification, consultancy, training and research and development.

Ine De Vilder is active in the research group dealing with Textile Functionalisation and Surface Modification, covering new and/or environmental friendly finishing and coating formulations, energy saving processes, and new applications including smart textiles and thermoset composites. She has several years of experience in flame retardant coatings and was already involved in multiple European projects.

In the KaRMA2020 project Centexbel will be involved in the mechanical grinding of the feathers, as well as in the incorporation of the keratin particles into textile coatings and the characterisation of the latter.

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