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SUSTAINABLE ALTERNATIVE TO ACRYLIC EMULSIONS

Process innovation yields water-borne short oil alkyd resins for wood coatings. By Marcello Vitale, IVM Chemicals.

The development of water-borne wood coatings is still hindered by a limited set of resin technologies. A new production technology is being trialled with the aim of producing water-borne short oil alkyd (ALK) polyols to rival the best ones used in solvent-borne 2K paints and varnishes. The process also generates superior air-drying alkyds and new resins for WB UV formulations. Significantly increasing the biorenewable content contributes to the improved sustainability of wood coatings.

We all know that the current global economic model is not sustainable: we use up the annual resources of the world by July and we are on a path to increase average temperatures by over 3 °C, reduce habitable land by rising sea levels and increase the most intense weather phenomena, all due to our emissions of heat-trapping compounds in the atmosphere. [1] We are all called to act rapidly to change what we do and how we do it to try and mitigate the impact of the disasters that are now clearly in our sight. As individuals and as a society, we must become sustainable. Every industry and every company must look for ways to lower its environmental impact and ultimately to make its products sustainable and carbon neutral over their lifetime.

To assess the sustainability of any product, it is necessary to understand the materials and processes used in making it, how the product is used, and how it is finally disposed of (*Figure 1*). Life cycle assessment (LCA) analysis does just that, quantifying the various environmental inputs and outputs, including energy sources, the impact on human health and the ecosystems footprints.

VOC EMISSIONS PRESENT A CHALLENGE

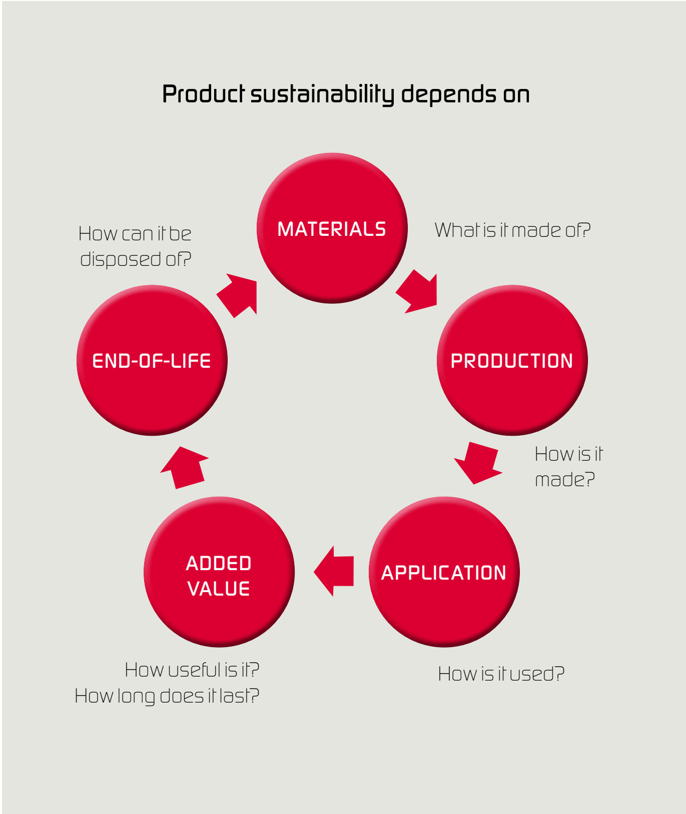
How do coatings, and in particular those for industrial wood, fit into this picture? They are made from mostly non-renewable resources, with processes that are relatively energy-intensive, contain several unhealthy compounds, and a good fraction of these (the volatile organic compounds, VOC, used as solvents, coalescents etc.) are released to the atmosphere either during paint production or application processes, providing no function in the final coating yet causing significant air pollution.

Of the 3,3 million tonnes of paints used for wood coatings (2019 [2]), for furniture, fixtures, floorings etc., over 60 % are solvent-borne, dissolved in 800 kilotonnes of flammable and often toxic aromatics, acetates or ketones. Such VOCs also impact air quality, for example by

RESULTS AT A GLANCE

- High molecular weight hydrophobic resins such as short oil alkyd polyols can be stably emulsified in water by screw extrusion
- The new water-borne resins obtained in this process can be used to formulate new water-borne coatings for wood.
- Replacing existing alternatives with these new paints and varnishes reduces carbon footprint, VOC emissions and the use of dangerous chemicals.
- Carbon footprint can be reduced from 2.4 kg CO_2/kg of paint (for current solvent-borne coatings) to less than 0.8 kg CO_2/kg of paint.

Figure 1: Sustainability of a product.



triggering ozone formation at low elevations, and contribute to a large CO_2 footprint (CFP), estimated to be 2.4 kg CO_2/kg of paint (kC/kp) by LCA (preliminary internal results, cradle-to-gate value). In Europe, it is reported that up to 50 % of the total over 8 million tonnes of VOC emissions (2018) derive from the coating sector in both industrial and construction applications.[3] The industrial use of coatings is clearly the greatest source of non-methane volatile organic compound pollution in the 33 countries of the EEA + UK.
Eliminating or reducing the use of coatings would not be a viable solution either. Coatings have a positive effect on the durability of coated materials and items, and therefore an overall positive environmental impact. Accordingly, the use of coatings is expected to increase in the future.

INCREASED DEMAND FOR SUSTAINABLE WOOD COATINGS

This is particularly true of wood coatings: wood is an ideal sustainable material, biorenewable and biodegradable. Indeed, it is starting to replace plastics in single-use items, and steel and cement in construction. However, wood is also susceptible to damage from mechanical and chemical attacks; hence, it tends to benefit the most, among solid materials, from the protection provided by coatings.

THE NEED FOR MORE SUSTAINABLE WOOD COATINGS IS EVIDENT

At our company we're able to produce both coatings and binders, unsaturated polyesters (UPE) and ALK. This synergy was exploited previously in an EU-funded project to produce new UV-curable UPE with a high biorenewable content. These were used in high-quality UV-curable coatings with a low environmental impact.
The obvious next target are solvent-borne coatings. Switching from solvent to water as the resin carrier avoids the associated atmospheric VOC emissions and the impacts of producing and transporting the organic solvents.

SCREW EXTRUSION IMPROVES STABILITY OF WATER-BORNE ALTERNATIVE

Water-borne (WB) paints based on acrylic emulsions and PU dispersions are an alternative to solvent-borne coatings. However, they constitute no more than about 25 % of the market for industrial wood coatings because of outstanding quality issues with chemical and mechanical resistance, and the look and feel. Moreover, they still have a CO_2 footprint estimated at 1.4 kC/kp (preliminary internal results, cradle-to-gate value). This is mostly due to resins made from petrochemical sources including toxic materials such as acrylic acid and isocyanate monomers. Although biobased WB low-molecular weight (MW) long-oil ALK are also available, they are not suitable for most industrial applications because of the quality and drying speed.
Our hypothesis was that if new WB coatings contained the same binders as the gold standard SB 2K PU, they would yield the same high performance. Such solvent-borne 2K PU are based on high-quality high-MW short-oil hydroxy-functional ALK. An LCA that considers the WB version with standard biorenewable content yields a CO_2 footprint of only 0.8 kC/ kp (preliminary internal results, cradle-to-gate value; by comparison, the SB equivalent is 2.4 kC/kp). Biorenewable versions of such resins have now been developed, which are available as solvent-borne products. If they were turned into WB resins, the CO_2 footprint of the respective coatings would be even lower than the cited 0.8 kC/kp.
About a decade of research revealed that the novel application of screw extrusion, a mainstay of thermoplastic processing, affords a stable WB version of the target ALK and confirmed the possibility of employing such resins in high-quality wood coatings.

The LIFE programme is the main EU financing tool for environmental and climate progress and funded the LIFE-WB BioPaint project we present in the following. The project started in September 2020 and is scheduled to end in July 2024.

NEW PROCESS TO REDUCE VOC AND CARBON FOOTPRINT

The overall objective of LIFE WB BioPaint is to pilot an innovative process to produce novel WB resins and the paints using them. They will be nearly VOC-free, non-hazardous, have better mechanical properties than benchmarks, and be of comparable cost.
Specifically, within this project we are building a prototype pilot line able to disperse in water:

- the high-quality high-MW hydroxy-functional ALK now used as binders in the best SB 2K PU paints and
- UV-curable UPE, particularly the biobased ones developed within the previous project

The paints using such WB resins would be able to fill niche applications that currently use

- traditional SB 2K PU paints and would reduce VOC emissions, CFP and the use of dangerous chemicals
- UV or oxidatively-cured SB paints applied by spray or curtain coating, reducing VOC emissions, CFP and the use of dangerous chemicals
- WB paints now made from petrochemical materials, reducing CFP
- WB paints made from hazardous components such as acrylic acid, reducing health and environmental risks.

Based on long-term research work, we designed and installed a novel screw-extrusion prototype pilot and ancillary systems especially developed to emulsify in water high-MW hydrophobic polymers. These emulsions are used to formulate advanced paints that will be tested in a wide variety of final coating applications for maximum environmental improvement. In the general analysis of a product sustainability for a coating (*Figure 2*), we can see that the application stage is much improved by greater use of WB coatings, since this mostly avoids VOC

Figure 2: Novel paint contributions to sustainability as highlighted.

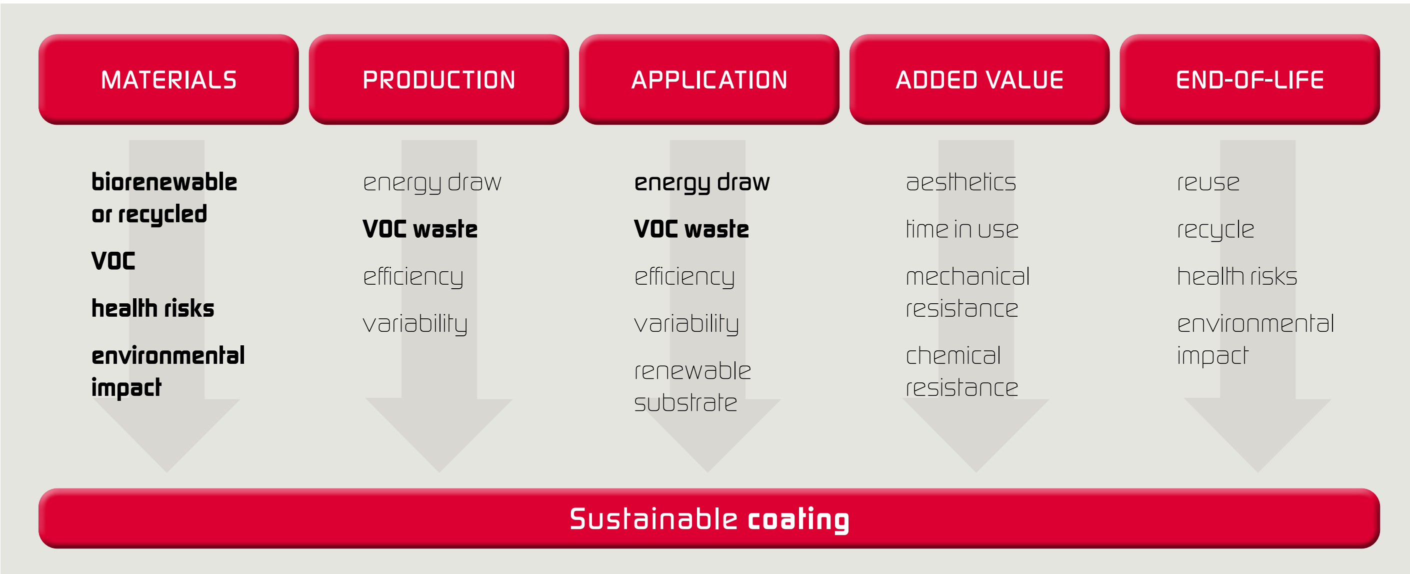


Table 1: Proof-of-concept formulations with short oil alkyd emulsions compared to conventional WB reference coatings.

		% Alk				
	% Solids	Emulsion on formula	Solids on binder	Drying speed	Resistance to liquids	Notes
2K clear topcoat for industry	37.03 36.39	0 50	0 69	= (in oven)	= or >	glossier
2K white topcoat for industry	46.59 46.43	0 9	0 20	= (in oven)	=	glossier and whiter
2K clear self-sealer	26.96 27.13	0 62	0 100	= (at RT)	=	glossier
2K clear topcoat max resistance	28.52 28.29	0 40	0 71	= (at RT)	<	similar hardness
1K clear topcoat	31.99 31.24	0 38	0 55	= (at RT)	<	emulsifier needs to be optimised
2K white topcoat, minimal cost	46.59 46.94	0 45	0 100	= (at RT)	=	whiter

emissions at the application sites. As these sites are globally distributed, the related improvement in air quality would also be widespread. In addition, the reduction in organic solvent use will yield emission improvements both at the resins and paint production site as well as upstream where component materials are produced. Further environmental advantages at this stage will derive from the increased use of more sustainable starting materials and the reduction in noxious components. Overall, the resulting impacts can be quantified as in *Figure 3*.
Energy consumption at the application sites is, unfortunately, going to increase on average, since water evaporation requires more heat over a longer time than the equivalent evaporation of organic solvents. The environmental impact, in particular the carbon footprint, will depend on the energy source, whether it is renewable or fossil.

PROCESS INNOVATION TO AVOID THERMAL SHOCK

The proof-of-concept work was carried out on high-quality high-MW short-oil hydroxy-functional ALK. It was not possible to emulsify some of them using conventional processes. For example, one branched resin characterised by an acid number of 13, an OH number of 110 and 32 % oil length reaches an excessive viscosity during the emulsification inversion process. As a result, the final particle size distribution is very wide and the emulsion coagulates and separates.
However, the process conditions within a screw extruder overcome this problem. Enormous shear forces are applied to very small volumes where the ratio of components can be precisely controlled. Moreover, it is possible to control temperature changes almost analogically while diluting gradually, rapidly moving from the relatively high temperature (above 100 °C) required to pump high MW ALK to a temperature where the material can be safely handled (below 40 °C) without any thermal shock. The high-pressure system avoids water boiling even at temperatures above 100 °C for initial contact with the hot resin.
The pH parameter, which is crucial for dispersibility and stability, can be also adjusted separately at different stages within the process.

EMULSIFIED ALK IMPROVED COALESCENCE

During the preparatory explorations, we identified a suitable emulsifier for the initial experiments and production runs. As a more hydrophilic component, it impacts water and hydrophilic stain resistance in topcoats. Optimisation of an emulsion, in terms of its character and quantity, is one of the first results sought in the pilot operation.
We therefore approached an extruder manufacturer to validate this hypothesis and were able to successfully emulsify the “impossible” resin (*Figure 4*). The first sample of the resulting emulsion has now been stable for several years in a sealed tube kept for observation.
This resin was then employed in formulations made for various applications: WB wood coating products can be 1K or 2K, pigmented or clear, for industrial applications (with oven/forced air drying) or for use by craftsmen (with ambient drying), used as sealers or topcoats. The novel emulsions yield sealers with good pigment dispersion and greater filling power than acrylic resins. *Table 1* shows the results when used in several different topcoats, where a number of different performance vectors are vital.
In general, we noted that the emulsified ALK tend to improve the coalescence of the accompanying acrylic emulsions or PUD, thereby reducing the need for organic coalescents. Gloss is generally higher, whites are more brilliant, and pigment dispersion and covering power tend to be better.

Figure 3: Expected environmentally significant impacts at 5 years from project end.

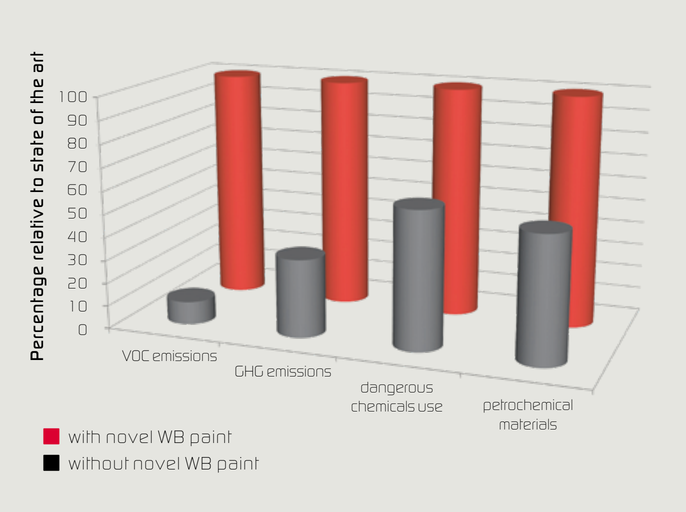


Figure 4: Proof-of-concept screw-extrusion emulsification of short oil alkyd.

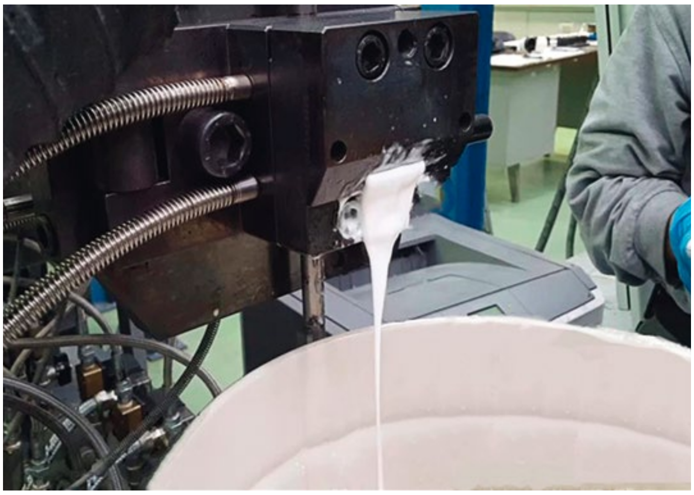
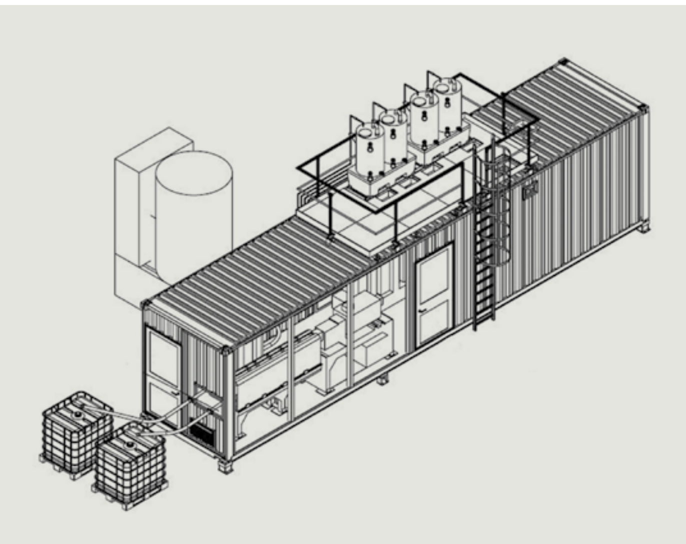


Figure 5: Emulsification line-in-a-box.



FLEXIBLE ATEX-COMPLIANT EMULSIFICATION

In order to run the pilot line within our resin production department, we needed to overcome one big engineering problem. A solvent-borne resin production site is, of course, subject to ATEX restriction, since there is always a possibility of an accident that leads to the formation of an explosive atmosphere. However, extruders that comply with such restrictions are less flexible than we desired and extremely expensive.

Using a model from an engineering company designed for the installation of small chemical production units or labs in extreme conditions, the whole line, including the extruder itself, the dosing units, the temperature regulation system and all the control electronics, is arranged within a 12 m container that is kept in overpressure. All wall sections can be removed for ease of maintenance, but the day-to-day work will take place without the operators having to physically access the line. The input and output of materials and products will take place right outside, and controls will be remote with cameras to permit monitoring of the systems inside the container. This is what we call an "emulsification line-in-a-box" (see *Figure 5*).

As an added bonus, the line could be transported essentially as a plug-and-play unit, minimising the time needed for its construction on site and therefore the interference with ongoing production.

REFERENCES

[1] Synthesis Report of the Sixth Assessment Report, A Report of the Intergovernmental Panel on Climate Change, available at www.ipcc.ch/ar6-syr/
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[3] EU Emission Inventory Report, EEA 05/2020

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