



## **Aquapak's Hydropol™ A Circular Economy Plastic**

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### **Introduction**

Aquapak has a range of formulated plastic materials in thermo-processible pellet form marketed under the trade names Hydropol™ and Cytopol™. The base polymer for these products is polyvinyl alcohol, and by careful combination of different hydrolysis levels in a patented process several products can be produced with specific functionality for end applications. However, the products are also formulated in such a way as to retain the inherent properties of the base polymer not only in functionality but also solubility and end of life.

Polyvinyl alcohol was first synthesised in the early 1920's but despite its promising properties was rapidly overtaken by what are now conventional polymers like PE, PP and PET because it is very difficult to process into a usable form for what became standard plastic processing, for example, blown film and extrusion. There are several global manufacturers of the polymer, but a high percentage of the material is used as an intermediate to produce other polymers, typically PVB.

The polymer has a structure which has the typical long carbon chain of most polymers but with OH (hydroxyl units) fixed to the carbon chain. The number determines the degree of hydrolysis and therefore the degree of solubility. Typically for the polymer to dissolve in cold water the hydroxyl level is around 88% or less. The higher the hydrolysis the greater the resistance to solubility in water at ambient temperature but the greater the application potential and functionality. The relatively low percentage of polyvinyl alcohol which is currently used directly is nearly all partially hydrolysed (cold water soluble) with some high hydrolysis material used in specialist applications like textile sizing.

The polymer is nearly always used by dissolving in water and then using the solution either directly or by producing a film via evaporation. The other complication in processing is that the higher the hydrolysis the less time stable is the solution as gelation occurs, so fully hydrolysed solutions are not only low in the percentage of the polymer but cannot be stored.

Aquapak's products are pelletised forms at all hydrolysis levels but predominantly high hydrolysis to maximise application potential. As they are available as standard plastic pellets stability and storage is not an issue.

The availability of a stable pellet form enables the excellent functionality of the base polymer to be exploited more widely:

- High tensile strength
- Excellent puncture resistance (films)
- Heat sealable
- Excellent barrier to Oxygen, Nitrogen and Carbon Dioxide
- Highly resistant to oils, fats, grease, solvents
- Good Clarity (films)
- Natural electrostatic dissipation
- Natural uv resistance



However, there is a further very pertinent set of properties which in the context of the drive to safer yet still highly functional plastics driven by the market desire to develop Circular economy materials can now be exploited in mainstream applications.

Aquapak's products have the capability to manufacture finished products which are recyclable, recoverable and biodegradable.

## Recyclability

A major concentration of Circular economy initiatives and pressure is to solve the problem generated in the packaging sector. Packaging, whilst vital for modern living, is highly visible and often misunderstood by the consumer. The packaging manufacturers, users and retailers are seeing an increasing number of both official (global policy) and NGO/consumer targeting, and particularly so at plastics.

Whilst there are a few examples of unnecessary packaging which are easy targets for criticism there is now a fundamental problem with this market sector. How do the manufacturers, brands and retailers continue to provide products which are convenient, safe and attractive but answer the question what happens to the package after its primary use? Undoubtedly this criticism will be aimed at other sectors, but packaging is at the forefront and therefore likely to set the benchmark.

Clearly the aim is to continue to provide/improve the functionality of the packaging but in addition have meaningful and economically feasible routes to dealing with it after its primary use. Recycling has been a theme and often a policy driver in many countries over the last 20 years and the obvious suspects, metal and glass, have largely been successfully dealt with, but plastics and plastic containing materials have proved to be a major issue. The very factor making plastics such a dominant material, their versatility, has made items made from them complex. This complexity of material combinations inevitably leads to confusion (consumer) and a cost of handling (waste industry).

The development of more sophisticated identification and sorting is a great step forward but unfortunately (unless the penalty becomes very severe) then adoption is at a relatively low level to maximise recovery of the complex materials. There is an increasing realisation that identification, sorting, and separation technology is not the entire answer and together with packaging design the introduction of new materials is key, that is, those which can offer multiple end of life options but retain/enhance functionality in primary use.

Aquapak is a global signatory to the **Ellen MacArthur Foundation** on plastic recycling targets.

Aquapak's products are being trialled in a number of applications which demonstrate this combination.

1. Replacing Barrier films and reducing layers in multi-laminates

Ability to replace barrier and tensile layers in multiple layer laminates thereby minimising layers without functional penalty. Additionally, printing without pre-treatment and removal of tie layers adds another simplified dimension. A simple hot water wash system can then remove the Aquapak layer enabling the other materials to be cleanly separated.



If sandwiched, then it allows the possibility of flaking the laminate and removing by hot wash.

Aquapak material has a unique IR signature allowing any more sophisticated plastic recovery process to identify and separate it. If hot wash is used, then the Aquapak solubilised polymer can be dealt with safely by 3 methods:

1. Biodegradation in standard waste water treatment;
2. Biodegradation in any available anaerobic digestion system;
3. If in enough concentration recovery of the virgin polymer from solution (Aquapak IP).

## 2. Replacing barrier layers in paper and board packaging systems.

Currently the plastics used to enhance the functionality of paper and paperboard are non-recoverable, non-recyclable. Whilst there are examples of brands putting in place collection of their specific product for material capture these are rare and often fraught with the problem of contamination.

Aquapak's materials give the necessary functionality to the product but offer two direct recovery options:

1. No requirement to separate from the paper/paperboard as the combination can be repulped in an industry standard paper recovery process. Aquapak product is entirely compatible and may also decrease the requirement for added paper strengthening chemicals in the process;
2. As in recycling the layer can be hot washed to remove it allowing clean paper/paperboard to be recycled

Aquapak is working in several projects with global brands, major converters and waste and recyclers to demonstrate the above recycling and recovery solutions at scale. Whilst many of these projects are commercially sensitive Aquapak will provide information and results where possible.

### **Repulpability**

Aquapak has successfully developed intermediate hydrolysis grades which demonstrate excellent adhesion to paper and paperboard with enhanced barrier properties. These Hydropol grades have been independently tested for repulpability (mimicking a standard paper recycling mill) and have all passed the testing protocols.

### **Biodegradation**

Aquapak's materials are inherently biodegradable, that is, given the right balance of environment and microbial presence it will biodegrade to carbon dioxide, water and mineralised natural biomass.

This is a complicated area and some caution is required to ensure the correct paths are chosen. For the purpose of this paper it will be divided into two parts, firstly captured and controlled biodegradation and secondly uncontrolled, environmental release.

#### (a) Composting.

Aquapak material in thin film form will compost. Tests have been undertaken with third party test houses on initial products and more work is to continue in this area following



internationally recognised protocols (EN13432, ASTM D6400, ASTM D6868 ISO 17088, ISO14885, ISO 18606, AS4736) to confirm the findings.

Compostability is only applicable to films and the results so far indicate that 15 microns is the upper limit (bear in mind that because of tensile strength that is the equivalent to a 35-micron PE film). The results of this testing will be included in an update of this paper and also included on Aquapak technical information.

#### (b) Anaerobic Digestion

Unusually, as most plastics are not, Aquapak product is compatible in AD systems. The mechanism looks like it is associated with the material dissolving or starting to dissolve allowing the residence activity of the microbes to have time to break the material down. A test was undertaken at a recognised UK waste facility which successfully processed 30-micron Aquapak film through its AD system and post analysis showed no fragments in the bi digestate or residue in the digester.

[Further work is ongoing to capture more data including working with third party accredited test laboratories test methods and Loughborough results

This method of biodegradation is common to waste water treatment processes and there is historical evidence of how polyvinyl alcohol behaves in these systems (see Appendix 1). There is clear evidence that polymer entering the waste water stream is successfully acclimated in the process yielding harmless by-products.

There appears to be a link to acclimated microbes and the historical use of polyvinyl alcohol, particularly in textile operations and subsequently in detergent tablets, which has “taught” the microbes in waste water treatment to process it efficiently. Further work will be undertaken to confirm that viable product types using Aquapak material are fully processed, which includes continuing work with UK water companies to both demonstrate and model the material flows. A project is currently being scoped to work with the Water Research Council (UK) to confirm the safe disposal and provide extra data for the behaviour of Hydropol in waste water systems.

## 2. Uncontrolled:

#### (a) Marine/Ocean

A major concern given the amount of toxic plastic waste in the oceanic environment. Clearly no one wants to deliberately release plastics into the environment but unfortunately it is present and a major global concern. The main issues are the accretion of toxins into the plastics causing long term effects on marine flora and fauna which can then enter the foodchain, and the longevity of the material causing direct macro pollution as seen in the many cases of marine mammals entanglement and digestive blockages.

All our commonly used plastics are hydrophobic (water hating) which necessarily means they resist the water they are in and attract other hydrophobic materials to them such as pesticides and other toxins. This allows for these plastics to concentrate toxins in combination with longevity – a perfect storm.



Aquapak's material is hydrophilic (water liking) and has no propensity to attract toxins or form micro plastics and is itself non-toxic to marine fauna as defined by tests conducted by the Open University. This toxicity screening has been tested by OWS (Belgium) using the Daphnia test protocol for ASTM D6691 and OK Marine. The first Hydropol product 30110 which represents a family of grades 30122,30123 and 30124 has successfully proven non-toxicity under the test protocol. Ocean conditions vary, and it is too early to say how quickly Aquapak material will break down but the fact it is non-toxic and safely digestible reduces the problem hugely.

Aquapak is undertaking further work with Prof. Richard Thompson (University of Plymouth) to model oceanic behaviour as well as Prof. Theodore Henry of Heriot-Watt University to look at macro effects and eco-toxicity modelling. Testing of several film constructions based on Hydropol, as well as Hydropol pellets and coated paper.

(b) Fresh water

There are current test methods and Standards for the biodegradation of polymers in freshwater systems (ISO 14851). A series of third-party accredited tests is planned initially looking at the most likely material to enter this environment – film.

(c) Soil

There are two aspects to soil biodegradation.

1. The usage of plastic films in agricultural and land management
2. Littering of plastics.

(d) Landfill

Tests will be undertaken (ASTM D-5511) which determine biodegradation in high solids anaerobic conditions like that found in wet managed landfill.

In (1) there are existing test methods (ISO 17556) to determine the breakdown and biodegradation in these applications and Aquapak will follow these protocols where the material is used in these products, typically monolayer and multilayer films, but also (in land management) the use of plastic anchors and ties.

Clearly littering is a much more difficult issue and any material deliberately littered has a disproportionate impact mainly because of visibility. It is likely given the nature of Aquapak materials that they will not dwell in the environment like standard plastics and do not have the toxic hydrophobic microplastic formation. Aquapak will continue to work with regulators and NGOs in this area.

## Appendix 1

### References on behaviour of PVOH in the environment particularly in waste water

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## Appendix 2

### Open University Report.



# Ecotoxicological Effects and Biodegradability of Aquapak's PVOH in the Managed and Natural Environment

Final Report– Draft Version 3, 22/11/17

## 1 Executive Summary

This project addressed the Department for Environment, Food and Rural Affairs (DEFRA) desire for a biodegradable single-use carrier bag that breaks down into harmless by-products in a variety of different organic waste treatment processes (composting and anaerobic digestion) and in various natural environments (marine and terrestrial). In response to this, this project investigated whether a polyvinyl alcohol (PVOH) based carrier bag would satisfy these criteria. Moreover, because unfortunately not all plastic based products are captured at the end of their life by recycling and/or waste treatment processes, this project examined any risk that a hydrophilic polymer based product may pose to marine life and the aquatic food web. At the request of the DEFRA, the project was not

designed to be an in-depth study of one environmental compartment, rather a broad indication of biodegradation and ecotoxicity in many different environments.

To achieve these aims the project was split into four work packages:

- Biodegradation under simulated waste treatment environments
- Microbial optimisation and acclimation of simulated waste treatment processes
- Biodegradation in the natural environment
- Aquatic food web impact

The following outlines the methods and research findings in each of these work packages:

#### *Biodegradation under simulated waste treatment environments*

This package investigated the biodegradability of PVOH filmic material under simulated industrial composting and anaerobic digestion conditions. To determine the aerobic (with oxygen) compostability of a PVOH filmic material the follow assessments were undertaken: product environmental impact (characterisation of heavy metal component), biodegradability, disintegration & compost quality. In summary, the PVOH material provided by Aquapak Polymers Limited contained only trace levels of metals that were well within environmental acceptable limits. The material was not biodegradable under simulated idealised composting conditions (BS EN ISO 14855-1:2012 methodology; analysis by evolved CO<sub>2</sub>) using a stabilised (composted) green waste or within fresh food waste. Biodegradability in these experiments required 90 % of the total carbon within the test material to be transformed into biomass, water and gas. The PVOH material achieved 7 %, a figure that is likely to correlate with the glycerol content of the film. The PVOH film did pass acceptable levels of disintegration over a 12-week simulated test; likely due to the hydrophilic (water absorbing) properties and mechanical sheering forces induced when turning the experimental vessels. Based on these results, PVOH when composted may reduce in physical size but will not biodegrade.

Anaerobic biodegradability experiments were undertaken following BS ISO 14853 methodology, at 35 °C and 60 °C in anaerobic sewage sludge and food waste. In both food inoculum (substance used to inoculate, in this case, the microbiology associated with industrial anaerobic digestion) and sewage sludge, total anaerobic degradation was highest in the 35 °C conditions. In all conditions, PVOH showed both the highest biogas generation and percentage degradation when compared to other test plastics (low density polyethylene and a certified compostable biobased plastic (poly lactic acid)). At best, PVOH showed a 20 % degradation in the 35 °C food waste inoculum, this however falls below the >70 % required for a biodegradable label/certification in this type of environment. These results show that whilst PVOH may not fully degrade in anaerobic digestion environments, it might be deemed 'biocompatible' as it contributes to biogas production above and beyond other types of plastic.

#### *Microbial optimisation and acclimation of simulated waste treatment processes*

This work package investigated two hypotheses:

- Optimising. Introducing 'environmental' microbes collected from industrial effluents containing PVOH may enhance degradation rates when introduced into simulated waste treatment experiments.
- Acclimation. Simulated waste treatment experiments exposed to PVOH would over time become more microbiologically acclimated to the polymer and therefore be more suited to its biological breakdown.

These hypotheses were investigated in both aerobic and anaerobic environments using BS EN ISO 14855-1:2012 and BS ISO 14853 methodology respectively.

'Optimisation' experiments used silt collected from the effluent outfall of a factory known to use PVOH (paper mill). These samples were then 'fed' PVOH as the sole carbon source so that only bacteria able to utilise PVOH would develop. These microbes were then added to experiments to

assess whether this would improve ultimate percentage degradation (work package 1 results). In the aerobic compost environment degradation was increased from 7 to 10 %, whereas it had no effect in the anaerobic (c. 4 % - same as the baseline assessment in 35 °C sewage sludge).

An acclimated seed derived from inoculum previously exposed to plastic (work package 1 material) was added to new stabilised inoculum to increase the rate of plastic degradation under aerobic and anaerobic simulated industrial conditions. There was no measurable effect for PVOH, however the time taken to reach 90 % degradation for both cellulose and the compostable biobased material were significantly reduced. The anaerobic experiments showed the best results here, ultimate biodegradation was significantly increased from 4 to 22 %, alongside increases in LDPE, compostable and cellulose.

#### *Biodegradation in the natural environment.*

The biodegradability of PVOH in the marine and terrestrial environment was assessed in this work package. The ASTM method D6691-09 was used as the basis for the marine simulation experiment, where a natural sea water was used as the inoculum and respiration (evolution of CO<sub>2</sub>) was used as the measure of degradation. Experiments were undertaken at 15 and 30 °C.

The terrestrial experiments buried PVOH in five different soils types over the course of one year, with samples analysed at time zero, six and 12 months for changes in in polymer structure using Fourier transformed infra-red spectrometry (FT-IR). In all soil types, changes in ratio of focal peaks were apparent after two months exposure, indicating differing breakdown rates in the selected bonds. Comparison of the initial and final spectra of PVOH indicated the largest reduction in relative absorbance of the peak at 1088.59 cm<sup>-1</sup>; however, when examined as a percentage decrease, 1418.93 cm<sup>-1</sup> showed the greatest reduction. This absorbance is likely identifying alcohol related bonds in the plastic and therefore suggestion that the early onset of microbial degradation is focused on alcohol groups.

#### *Aquatic food web impact*

It is well documented that plastic materials inadvertently enter the marine environment and the food chain/web. The aims and objective of this work package was to assess any environmental and/or ecological impact of PVOH filmic material in aquatic environments. Baseline assessments were made of the underlying chemical and microbial community alternations due the presence of PVOH in freshwater and marine waters. In closed experiments it was shown that the addition of PVOH added a selection pressure that changed the diversity of the microbial community, as well as the amount of organic and inorganic carbon, which were expected results.

The ecotoxicology experiments examined the effects of PVOH on different species along the food web. The presence of PVOH film dissolved in freshwater **at realistic contamination concentrations** had no deleterious effect on growth rate of the algal species **Selenastrum capricornutum**.

**Moreover**, at concentrations lower than 50 g L<sup>-1</sup> the presence of the polymer enhanced growth of the algae. Equally, there were no deleterious effect from dissolved PVOH on water fleas at 0.001, 0.01, 0.1, 1 & 10 g L<sup>-1</sup> of PVOH in terms of loss of swimming and death rate. The ecotoxicological effects of PVOH on *Homarus gammarus* (European lobster) were examined by exposing them to pelleted food combined with ground microplastic films (<180 µm) for 6 hours per day over 30 days. To determine the effect of microplastic on growth, nutritional state, the carapace length, hepatosomatic index and hepatopancreas water content were determined. There were no significant differences between PVOH treatment and control after 30 days in all but one of the measures. Post hoc tests indicated that there was reduced growth in the PVOH condition. This investigation used a small number of replicates; therefore the outcome should be cautiously interpreted.

To summarise, based on the results of these experiments, it can be concluded that PVOH is not biodegradable under simulated compost and anaerobic environments over a time of <1 year. PVOH however may be viewed as compatible with both processes in terms of physical disintegration and contribution it would make to biogas yield. There was evidence to suggest that anaerobic digestion process would in fact become more accustomed to the presence of PVOH over time from a



microbiology point of view, therefore contributing to more biogas from the same weight of material over time. PVOH was not biodegradable in sea water (as measured by CO<sub>2</sub> release) but showed some chemical changes in terrestrial soil environments after one year of exposure. The presence of PVOH in aquatic environments had no adverse impacts on key indicator species of algae and water flea.



## **Appendix 3**

### **Summary of tests related to Hydropol materials**

- 1. Composting: ISO 14855; EN13432: ISO 17088; ISO 18606; ASTM D6400; ASTM D 6868; AS 4736**
- 2. Anaerobic Digestion: ISO 15985; ASTM D5511**
- 3. Fresh Water: ISO 14851**
- 4. Soil: ISO 17556**
- 5. Marine: ASTM D6691; OK Biodegradable Marine**

## Appendix 4

### Marine Test Toxicity ASTM-D-6691 OK Marine



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## Appendix 5

### Repulpability Report



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