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Biopolymer Based Paper Coatings Towards Sustainable Packaging

Abstract

Sustainability has become the main impetus for regulatory landscape which is poised to change the nature of industrial innovation. With sustainability being the key focus everywhere, the packaging industry will be forced to increase its reliance on renewable sources of packaging material. Biopolymer based coated paper and paperboards have the potential to replace synthetic polymer coated packaging material. A range of biopolymer based coated paperboards have been evaluated as an alternative to the prevailing synthetic polymer coated paperboard for packaging of short shelf life food products. Fitness to use is certainly the mainscope for any packaging solution; however manufacturability and scalability of paperboards coated with biopolymer holds the key for providing a competitive edge over the conventionally used synthetic polymer coated paperboard. This paper presentssome of the vital aspects of biopolymer usage in the papermaking process while offering a sustainable packaging solution for short shelf life food products.

Keywords: *Sustainability, Paperboard, Packaging, Biopolymer, Biodegradability, Repulpability*

Introduction

Over the next decade the lifestyle trends of convenience, health and environmental friendly packaging will grow in importance for the food packaging industry. Convenience and wellness will hold significant relevance due to changes in values and lifestyles influencing more people to prioritise convenience. These changes will result in significant increase in demand for convenient packaging, ready-to-serve and the on-the-go food as well as snack solutions of various kinds. A paradigm shift of focus from "how to get food" to "getting the right food" is on the anvil.With the young generation now quickly embracing new lifestyles major changes are occurring in the type of food products being consumed. Modern day convenient food products include Pizza, Burger, Finger Chips, and Pastries etc. which are predominantly high on fat and moisture content. Shelf lives of these food items are generally limited to few days owing to factors such as moisture loss, lipid oxidation and microbial growth. Synthetic low density polyethylene (LDPE) coated paperboards generally form a major share for packaging used for such food products because of their low cost, desirable barrier, ease of processing and conformance to end use requirements. LDPE is largely non-biodegradable and it isparticularly difficult to recycle or reuse due to mixed levels of contamination. Biopolymer based coated paperboards can offer significant environmental advantages of recyclability and reutilization compared to the conventional LDPE coated paperboards.

Biopolymers may also provide moisture barriers and complement other types of packaging by minimizing food quality deterioration and extending the shelf life of foods, Guilbert*et al* (1),Krochta and De Mulder-Johnston (2) andDebeaufort*et al*(3).Usage of biopolymers in paper coatings can also offer packaging functionalities such as grease barrier and improved surface for superior printability while maintaining environment-friendly characteristic of the material,Park*et al* (4),Mika *et al*(5) andAshori*et at*(6).Exploratory research literature reveals growing interest in sustainable packaging solution is going to open up possibilities for large scale usage of biopolymers in the paper industry, Innventia Global Packaging Outlook (7). However factors concerning large-scale usage of biopolymer based additives in an online coating system of paper machines are sparsely represented inthe literature which poses serious limitation to its scalability and hence its cost-performance is often challenged. In the current work four different biopolymer based paperboards have been studied for their fitness to use for packaging of short shelf life food products namely Burger, Pizza, Finger Chips and Pastries. This study has been expanded beyond packaging fitness to include the impact of these biopolymers upon effluent or back water system in a paper making process, broke repulpabaility and biodegradability.

Materials and Methods

Laboratory scale coating trials were performed with a range of different biopolymer based aqueous dispersions on a machine made 175 g/m^{2}uncoated virgin solid bleached sulphate pulp (SBS) paperboard. The uncoated board was internally sized with rosin and alum at the wet end and also surface sized with oxidized tapioca based starch solution. The biopolymer based coating solutions were applied on to the uncoated board using an automated rod coater with the objective to achieve a final coat weight of 10–12 g/m^2.Details of the different biopolymers based coating solutions and their rheological properties can be found from table 1 below.

Table 1: Different types of biopolymer dispersions and coating properties

Sr	Biopolymer Primary Composition	Solids (%)	pH	Brookfield Viscosity – RV Spindle 2 @ 100 rpm / 25° C (cps)
1	Poly Vinyl Alcohol (PVOH)	20	8 – 9	300
2	Acrylic Copolymer (Acrylic)	20	8 – 9	350
3	Per Fluoro Poly Ether (PFPE)	25	7 – 8	200
4	Poly Lactic Acid (PLA)*	–	–	–

*It was not possible to apply Poly Lactic Acid(PLA) based coating using the conventional laboratory scalebar coaters since it is compatible only for extrusion coating application. The same set of uncoated paperboard samples has been used for extrusion coating of PLA on a commercial poly extrusion machine. Final coat weight of 25 g/m^2 of PLA were achieved through extrusion coating process.

A brief description about the various types of biopolymers used in this study is provided in the following section.

Poly Vinyl Alcohol (PVOH)

A fully hydrolysed polyvinyl alcohol (PVOH) designed to provide high film strength and binding power in relatively low-viscosity systems has been used. It permits higher solids solutions at a given viscosity and temperature, or lower solution viscosities at the same solids content and temperature. PVOH is particularly useful as a pigment binder for ceiling tile primers.

Acrylic Copolymer (Acrylic)

The acrylic copolymer used in this study is a dispersion of acrylic copolymers manufactured using the nano-technology.It offers faster drying, and the complete absence of wax and solvents ensures that it is easily recyclable and repulpable, reducing its environmental impact.

Per Flouro Poly Ether (PFPE)

PFPE products used in this work were manufactured using a photo-oxidation process involving low-temperature reaction of oxygen with tetrafluoroethylene (TFE) in the presence of UV light under controlled temperature, pressure and oxygen concentration. This is followed by a chemical reduction process that produces di-functional, fully fluorinated PFPE backbones with reactive end groups.

Poly Lactic Acid (PLA)

PLA is a hydrophobic polymer due to the presence of CH3 side groups. It is more resistant to hydrolysis than PGA because of the steric shielding effect of the methyl side groups. Regulation of the physical properties and biodegradability is achieved from the choice of hydroxy acids comonomer component during the manufacturing of PLA.

The paperboard coated with the various biopolymers dispersions discussed above,has been evaluated for their barrier properties, packaging functionality, biodegradability and finally typical attributes concerning online usage on paper machine. Table 2 below shows the categorization and sub-categorization of various parameters analysed for the different sets of biopolymer coated paperboards.

Table 2: The parameters evaluated for paperboards coated with different biopolymers

Sr	Barrier Properties	Packaging Functionality	Biodegradability	Repulpability and Effluent Impact
1	Grease Resistance (Kit Test)	Surface Tension	Compostability	Repulpability
2	Water Vapour Transmission Rate (WVTR)	Glueability	–	Back Water pH, Conductivity, Turbidity and Chemical Oxygen Demand
3	–	COBB	–	–

All the parameters shown above have been comparatively evaluated in conjunction to the conventionally used low density poly ethylene(LDPE) coated paperboard. An LDPE extrusion coating of 15 g/m^2 has been applied on the same set of paperboard samples using a commercial extrusion coater.

The following section provides a brief description of the methods adopted for testing of the properties shown in the table 1 above.

Barrier Properties

Oil and grease resistance is an important property of paper based packaging materials used for short shelf life food products namely Burger, Pizza, Finger Chips and Pastries owing to their high fat and oil content. The degree of grease repellence has been tested over the biopolymer and LDPE coated paperboards adopting TAPPI standard test method, T559 (8) which is also commonly known as KIT test.

Microbial growth is known to cause food spoilage and their deterioration. Presence of moisture further promotes microbial growth and therefore it is desired that the packaging material for food products should impart adequate moisture barrier for prolonging the shelf life of packaged food items. The rate of transfer of water vapour or moisture from a relatively humid atmosphere (Relative Humidity: 90%, 38 Degree C) through a barrier to a drier atmosphere is known as Water Vapour Transmission Rate (WVTR). It has been tested over the sample sets adopting TAPPI standard test method, T523(9) for evaluating their degree of moisture barrier.

Packaging Functionality

Surface tension is a measure of the wettability of any surface and it can be useful for characterizing packaging materials functional attributes such as printability and glueability. The surface tension of the biopolymer and LDPE coated paperboard surface is measured by adopting TAPPI standard test method, T552 (10) where a series of numbered solutions with gradually increasing surface tensions are applied to the paperboard surface until a solution is found that just wets the film surface.

Gluability of paperboards is one of the most vital aspects for package forming. It is determined for the biopolymer and LDPE coated paperboards employing bird glueability test, Ninness*et al*(11). Commercial aqueous polyvinyl acetate acrylic based liquid glue has been applied on the coated paperboard surface using a 0.38 mm bird bar, and the backside of the same paperboard sample is brought into contact with the glue layer. The time taken for achieving 100% fibre tear after the glue application, is considered to be the measure for gluability. The compatibility of biopolymer coated paperboards with water based glue can offer wide spread industrial application as opposed to the alternative hotmelt or heat sealing methods which can often limit the application window.

The water absorption characteristics of the biopolymer and LDPE coated paperboards has been evaluated by performing COBB test over a time span of 60 seconds in accordance to the test procedures laid down under TAPPI standard test method, T441 (12).

Biodegradability

Biodegradability of the paperboard samples were studied by vermicomposting those samples in a commercial compost bin, Basheer and Agarwal (13),Vikman*et al (*14) and Davie *et al(*15). The bed of the compost bin is cleaned and filled with a layer of black soil, on the top of which a layer of leaf litter is then applied.Subsequently the various biopolymer and LDPE coated samples of size 5 cm^2were placed above the leaf litter. Now a layer of cow dung is made above the samples and on top of which worms were placed so as to accelerate the composting process. Here after again a layer of black soil, leaf litter and cow dung is laid. And finally gunny bags wereplaced to cover the compost bin and water is sprinkled to make the compost moist. The compostibility of paperboard samples was evaluated by measuring their respective weight loss percentages after six weeks of composting.

Repulpability and Effluent Impact

Lack of adequate information about repulpability of biopolymer based paper coatings and its impact upon effluent is a limiting factor concerning its online usability in the paper making process.

The repulpability of the biopolymer and LDPE coated paperboards have been evaluated by first slushing them and then hand sheets forming out of the slushed pulp adopting TAPPI standard test method, T205, (16). The hand sheets were then visually inspected for the presence of transparent spots as it indicates the presence of synthetic material. Samples devoid of any such transparent spots are more adapt for online repulpability on paper machines.

Effluent impact is considered to be another vital dimension for online usability of such biopolymer based coating materials. The back water obtained from slushing the different biopolymer and LDPE coated paperboards have been respectively evaluated for pH, conductivity, turbidity and chemical oxygen demand (COD). The back water data of the biopolymer and LDPE coated paperboards have been compared to that of plain uncoated paperboards for evaluation of itssuitability for online coating application.

Results

Barrier Properties

The oil and grease resistance of the biopolymer and LDPE coated paperboards has been evaluated by KIT test. A higher value indicates high resistance to oil and grease resistance. Figure 1 below shows the KIT value for the different substrates used in this study.

The degree of moisture barrier offered by the biopolymer and LDPE coated paperboards has been estimated from water vapour transmission rate (WVTR) analysis. A lower WVTR value is desirable indicating superior barrier to moisture and vapour ingression through the barrier coating. The WVTR data is shown in figure 2 below with the units being $g/m^2/day$.

Barring the PVOH all the other biopolymer coated paperboard samples are exhibiting higher degree of oil and grease resistance and the results are comparable to that of LDPE coated samples. However the WVTR results indicate superiority of PLA coated samples over the rest of biopolymers, while the PVOH and Acrylic based biopolymers shows lowest barrier to moisture and vapour transfer.

Packaging Functionality

Wettability is evaluated by measuring the surface tension with the aid of dyne solutions. The data is presented in figure 3 below and the units of measurement being dynes/cm. A higher dyne value indicates higher surface tension which can offer superior wettability for the printing inks and glue.
The biopolymer and LDPE coated paperboards have been subjected to bird glueability test and the results are presented below in figure 3 superimposed to the wettability results. The lower the time taken in seconds for achieving 100% fibre tear after glue application on the substrate it is considered to be faster the glue setting speed.
The water absorption characteristics of the biopolymer and LDPE coated paperboards has been interpreted by performing COBB test (60 seconds). The desirability is to achieve lower water absorption rate and the data is presented in g/m^2 in the figure 4

Figure 1: KIT value of barrier coated paperboards

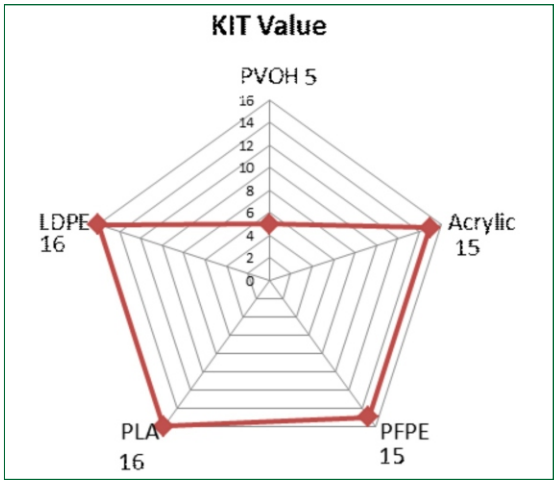


Figure 2: WVTR of barrier coated paperboards

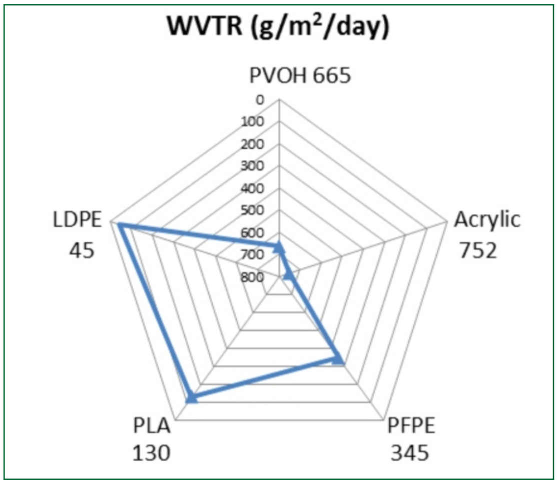


Figure 3: Surface Tension and Glueability paperboards

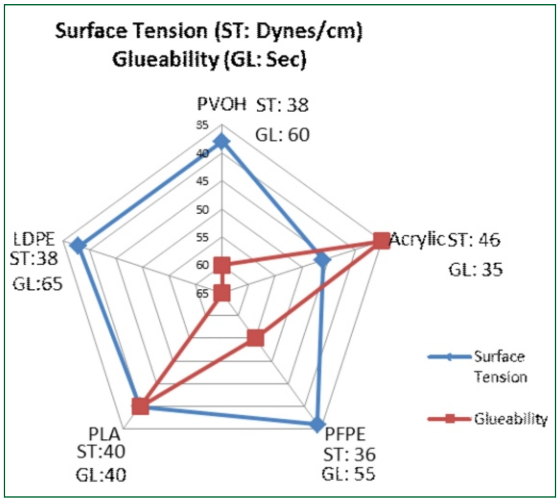


Figure 4: COBB of different paperboards

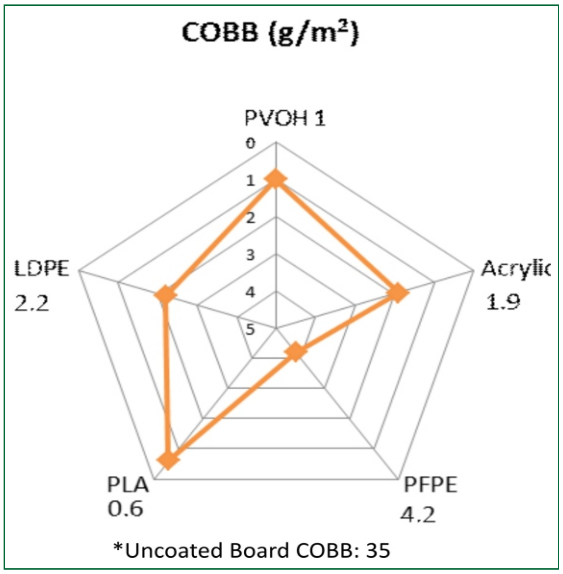
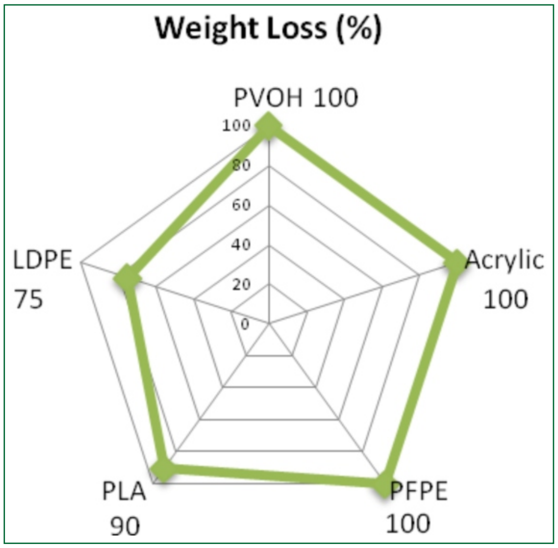


Figure 5: Weight Loss after six weeks of vermicomposting of barrier coated paperboards



on next page.

The acrylic copolymer coated paperboard samples demonstrates its superiority over theLDPE and all the other biopolymer coatings with respect to both wettability and glueability. The PLA coated samples shows just an adequate surface tension and glue setting speed.

The COBB values indicate significant drop in the water absorption rate for all the biopolymer coated samples while compared to that of the uncoated paperboard samples. However, it does not effectively distinguish theirperformance with respect to glue setting speed.

Biodegradability

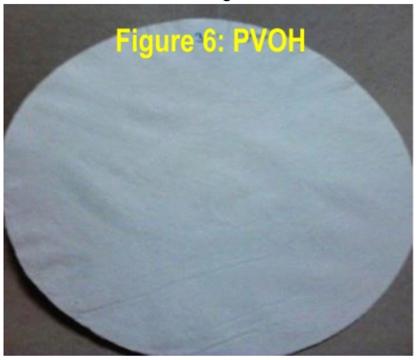
The compostability of various biopolymer coated paperboard samples have been evaluated in conjunction to the conventionally used LDPE coated paperboard by subjecting them to a controlled vermicomposting environment. The drop in sampleweight after six weeks of composting has been measured and the percentage weight loss is reported considered to be the measure for biodegradability. It is implied that biodegradable substances should demonstrate complete weight loss after composting. Figure 5 below shows the weight loss data.

The composting data reveals excellent biodegradability of most of the biopolymer coatings chosen as a barrier option in this study, with the exception being PLA coated board which exhibits90% weight loss after six weeks of controlled composting. The weight loss data for the LDPE coated boards reaffirms its poor biodegradability quotient and it was observed that the LPDE layer did not degrade at all while the paperboard layer got completely degraded.

Repulpability

The presence or absence of transparent spots in the hand sheets formed by slushing the respective biopolymer coated, LDPE coated and the uncoated plain paperboard samples, is considered to be the measure for repulpability. The transparent spots are thought to be originating from synthetic material which cannot be repulped in a general purpose broke handling system on paper machines.The respective hand sheets imagesis shown below in the

Figure 6: PVOH



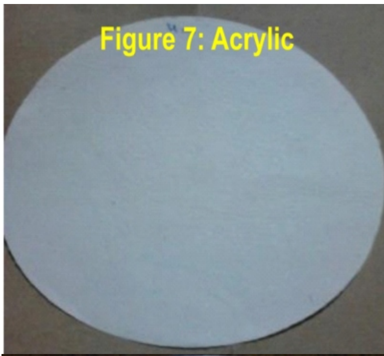


Figure 7: Acrylic

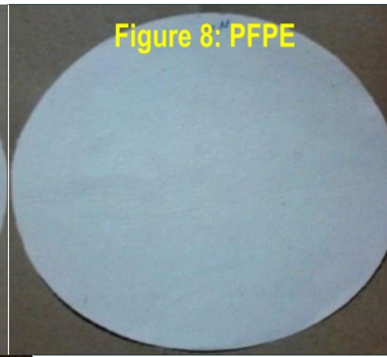


Figure 8: PFPE

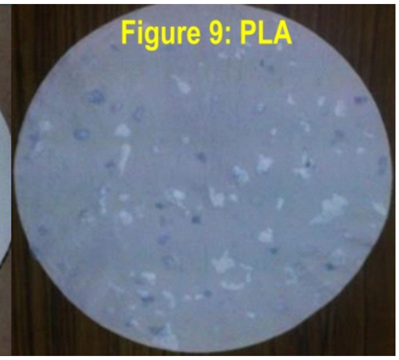


Figure 9: PLA

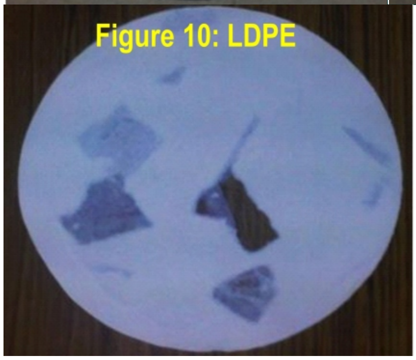


Figure 10: LDPE

figures 6, 7, 8, 9 and 10.

The images reveal presence of large number of transparent spots with the PLA and LDPE coated samples whereas the rest of the biopolymer coated samples are devoid of any such spots. This indicates a conventional slushing methodis not adequate enough for disintegration of paperboards containing PLA and LDPE substances and thereby can pose serious limitations to its online usage in paper machines equipped with conventional broke handling systems.

Effluent Impact

Table-3 below shows the pH, conductivity, turbidity and chemical oxygen demand (COD) data for the respective back water recovered while slushing the different biopolymer and LDPE coated paperboards samples.

The back water data again reaffirms limited compatibility of PLA and LDPE based coatings for online usage in paper machines owing to significant rise in chemical oxygen demand and turbidity levels. The alternative biopolymer based coatings, viz., PVOH, Acrylic and PFPE shows limited effluent impact and can be considered for inline usage on paper machines.

Conclusion

Paperboards coated with biopolymers such as Acrylic copolymer and PFPE based coatings can offer sustainable packaging solutions for the future improvement of food packaging industry. They have significant environmental advantages over the conventional LDPE paper coatings. Inline usage of such biopolymer based coating solutions in a conventional paper making process can open up potential economic benefits across the entire value chain while making positive contributions to the ecosystem of short shelf life food packaging.Further research is however needed to gain more knowledge regarding the interactions between the coating matrix, active biopolymer compounds, and target micro organisms to evaluate the materials performance for a wide range of food products.

Table 3: Parameters of back water recovered during slushing of biopolymer and LDPE coated paperboards.

Back Water Property	Uncoated Board	PVOH	Acrylie	PFPE	PLA	LDPE
pH	7.32	7.62	7.42	7.62	7.72	7.87
Conductivity (µS)	620	695	654	685	627	680
Trubidity (NTU)	4.7	5.5	4.5	4.7	10.5	107.2
Chemical Oxygen Demand (ppm)	540	603	568	568	798	806

Acknowledgement

The support provided by ITC Limited, Paperboards and Specialty Papers Division, for carrying out this study is gratefully acknowledged by the authors.

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