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APTNESS OF PAPER /PAPERBOARD FOR REPLACING SUPs IN FOOD PACKAGING

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Abstract:

Single Use Plastics (SUPs) waste is a common issue concerning the whole world. Developing the alternates for SUPs is the need of the hour and the paper / paperboard is the suitable bio-based alternate for versatile and mass replacement of SUPs. Biodegradable and recyclable natures of paper/ paperboard are the apt solutions over SUPs but lack the vital barrier properties.

During manufacturing of paper/paperboard, many chemicals are being used to reach target properties and for trouble-free production. The chemicals being used in paper / paperboard production are tabulated as quick reference.

The paper/paperboard for food packaging should be suitable for the packaging utilization like primary, secondary or tertiary packaging and the chemicals in paper/ paperboard should not migrate into the food stuffs. In this paper, chemicals generally being used during the paper manufacturing, the practices being followed during food grade paper/paperboard production and the customer requirements to meet the food grade regulations are discussed.

The paper/paperboard can be substituted for SUPs by providing the necessary barrier properties as per the end-use requirement. To impart such barrier properties bio-based compostable solutions are commercially available. The barrier coating chemicals, its application methods, its functional properties and viability are briefed for understanding.

The suitability of the paper/paperboard for food packaging is elucidated and the evaluations of barrier coated boards with respect to functional aspects are clearly shared. Based on the field experiences, the measures to be followed during production of paper/paperboard with water barrier and oil and grease resistance are highlighted. However, the assessment of barrier coating chemicals with respect to time has to be ascertained to ensure it as a sustainable replacement for SUPs.

Keywords: Barrier coating, Compostability, PLA, Bio-plastics, Compliance

Introduction:

Paper/paperboard packaging has taken a different dimension given the gravity of situation, as Single Use Plastics (SUPs) are banned in India as well as in many other countries. This opened up a lot of space for sustainable packaging with more focus on cellulose-based packaging materials, as it is abundant, eco-friendly, biodegradable/ compostable, renewable and recyclable. However, their lack of barrier properties limits their applications in food packaging.

Paper/paperboard based materials for food packaging requires delicate balancing of additional barrier layers for resistance against water, oil and grease, moisture and oxygen etc. Conventional plastics such as low density polyethylene (LDPE) performed well in this domain with good heat seal-ability & water barrier. However, to replace the conventional plastics with new bio-based and biodegradable materials will be a

challenging task and requires more research. The new sustainable barrier materials should not only perform functionally equal to the LDPE and also should meet the food contact compliances such as US FDA, German BfR, BIS and other country-specific norms, besides easy availability. The urgent need to shift to alternate materials for conventional non-biodegradable/non-compostable plastics is a priority step for every nation. Cellulose-based packaging has become an attractive option for replacing single use plastic. This paper discusses on the potential of cellulose-based packaging, alternate barrier materials for conventional plastics and their functionality with respect to food packaging, requirements of food contact compliances.

Paper based materials as alternative to Single use Plastics

Among the alternative materials explored to replace SUPs, cellulose is the most abundant one in the nature and the paper/paperboard have the potential to replace almost all SUPs, provided suitable barrier material is incorporated in the design. Paper, being hydrophilic and porous substrate, requires suitable modification for it to be used in the food packaging applications. It should possess water barrier, Oils and grease resistance, oxygen barrier based on the end use requirement. Base paper/paperboard qualities-such as good formation, surface smoothness-are important for barrier material application in a better way and to have better coating coverage.

Paper/paperboard for food contact applications should preferably be virgin grade for aesthetics and purity; recycled paper is less preferred for food packaging due to purity requirements. The primarily source of virgin paper/paperboard is wood, which can be harvested responsibly and replanted. The pulping and bleaching process for manufacturing virgin grade varies based on input raw materials. The pulp can be bleached or unbleached based on the preference and the bleaching process adopted should be environment friendly; elemental chlorine free (ECF) bleaching is the predominant bleaching process which eliminates the formation of toxic compounds such as dioxin and furans in the process. The predominant chemicals used in ECF process are oxygen, chlorine dioxide, hydrogen peroxide. The paper/paperboard for food packaging should be manufactured by adopting good manufacturing practices. The process should use minimum amount of chemicals additives necessary for runnability, functionality and should be devoid of optical brightening agents (OBAs) and dyes. Commonly used chemical additives during pulping, paper or paperboard making is given in Table 1. However, it should be noted that for producing food contact paperboard, regulated substance needs to be used.

Table1: Commonly used Chemical additives during pulping, paper and paperboard manufacturing[1, 2.]

Area of utilisation	Name of the chemical	Primary component	Purpose
Kraft pulping	White liquor	Sodium hydroxide & sodium sulfide	For cooking of wood chips.
Pulp bleaching	Bleaching agents	Oxygen, ozone, chlorine di oxide, hydrogen peroxide,etc	For removing or discoloring the residual lignin inside the cellulose fibres
Paper/paperboard machine	Dye	Acid dyes, basic dyes, pigment dyes	For maintaining the shade.
	OBA	Derivatives of diaminostilbene	For increasing the brightness
	Sizing agents	ASA, AKD, rosin, SAE, SMA	Retarding the water absorbtion
	Starch: cationic starch, native starch, oxidised starch	Tapioca, maize, potato	For strength improvement, surface smoothening & replacing few proportion synthetic binders
	Retention and drainage aids	Poly DADMAC, PAC, polyamines, polyvinylamines, polyacrylamide, micro particles like bentonite, silica, etc…	Increasing the water drainage and retention of fines & fillers
	Strength resins	Starch, polyamide resins, glyoxylated poly acryl amide resin, PVAms, PAAE, DAS	Improving the strength
	Fillers	PCC, GCC, talc, TiO_2, aluminiumsilicate	Improving optical & surface properties and cost effectiveness

Areas of application:

There is a vast scope for paper based material to be used in food packaging applications. It is estimated that approx. 34% of paper based packaging is going for food packaging[3]. The areas of applications include but are not limited to: a) Liquid packaging/liquor Packaging; b) Food service applications including microwave oven ability; c) Ice cream boxes (deep freeze); d) cake boxes; e) food wrapping etc. Paper alone is not a good candidate for packaging of food materials, if barrier functionality is not incorporated on the paper substrate. The barrier layer can be single or multiple based on the end-use requirements. For example, liquid packaging requires multi-material structure arrangement incorporating LDPE and aluminium layer for moisture and oxygen barrier for prevention of food spoilage.

Conventional and emerging barrier coating materials for paper:

Predominant conventional barrier materials being used in paper and paperboard for food packaging are polyethylene (PE), polypropylene (PP) in addition to aluminium foil. Plastic material is applied onto the paper surface using extruders as single or multi-layer composites based on requirement of moisture vapour transmission rate (MVTR), water barrier, and oxygen permeability etc. Moisture and oxygen entering into the package will spoil the packed food materials. Polypropylene (PP) and polyethylene (PE) possess highest hydrophobicity among all the plastic materials (bio-based and fossil based plastics)[4]. Emerging environmental issues of these fossil based materials and public awareness are shifting towards eco-friendly & biodegradable barrier materials as they leave a huge ecological footprint; however, performance in terms of functionality and cost equivalent to the fossil based plastics are challenging.

Rapid advancements in material science & technology have resulted in new material developments which can impart barrier & functional properties with the material being compostable and recyclable. Polymer synthesis, polymer modifications

(coploymerization, polymer blending, nano composite technology, processing technology) is evolving to meet the challenges. Biobased compostable/biodegradable alternatives, new aqueous dispersible or water-based barrier coating chemicals and their blends are available for barrier applications on paper/paperboard. Table 2 depicts the list of polymers based on origin and biodegradability.

Table 2: List of polymers based on origin and biodegradability [5, 6]

Bio-based and non biodegradable	Bio based and biodegradable	Fossil fuel based and non biodegradable	Fossil fuel based and biodegradable
Bio PET	PLA	HDPE/LDPE	Polybutylene Adepate Terephthalate
Bio PE	PHA	PP	Polycapro Lactone
Bio Polyamide	Bio PBS	PVC	PBS
Bio PTT	Cellulose based biopolymers	PTT	PBAT
Bio PP	Starch based biopolymers	PS	PVOH
Bio PVC	Protein and lipid based biopolymers	PU	
	PHB	PA	

The difference between conventional plastics and bio-plastics are given in Table 3.

Table 3: Difference between Conventional and bio-plastics[5]

Conventional Plastics	Bio-plastics
Mostly made from fossil fuels and petrochemicals.	Produced from natural resources
Non-renewable and Non-biodegradable	Renewable & Biodegradable
Emits high amount of greenhouse gases	Emits fewer greenhouse gases. Considered carbon neutral.
Environmentally polluting	Environmentally friendly
Takes more time to disintegrate into smaller particles	Utmost biodegradation occurs in 6 months in controlled microb composting condition

It is seen from the above table that bio-based plastics have many advantages over the conventional ones. They are environmental friendly, derived from renewable resource, biodegradable and/or compostable, carbon neutral. These attributes makes a strong case for higher growth of these materials. The bio-based substitute for converntional plastics in food contact application are given in Table 4.

Table 4: Bio-based plastic substitutes for conventional plastics[7]

Conventional Plastics	Bio-plastics
Polyethylene (PE)	Cellulose based polymers Polyhydroxyalkanoates (PHA) polymers Polylactic Polymers (PLA)
Polystyrene (PS)	Starch based polymers Cellulose based polymers Polylactide Polymers (PLA)
Polypropylene (PP)	Cellulose based polymers Polyhydroxyalkanoates (PHA) polymers
Poly Ethylene Terephthalate (PET)	Polylactide Polymers (PLA) Bio-PET polymers

Among the fast growing bio-plastics, share of PLA is dominant (19.5%)[8], as it is bio-based and compostable. Also the share of biodegradable plastics is increasing as compared to non-biodegradable plastics and Asia is the biggest market for bio-plastic production by region[8]. The growth potential of Poly lactic acid (PLA) is high and the demand of PLA doubles every 3-4 years as per Jem's Law[5]. The growth is owing to new restrictions on usage of conventional plastics, SUPs in particular, in many of the countries as the plastic awareness has hit a high level across the globe.

Poly lactic acid based extrusion trial

Going by the trend and the growth rate, PLA, being renewable and compostable, looked upon as an attractive proposition for barrier coating of paper and paperboard. However, high purity of lactic acid or lactide is required for producing PLA with good quality. High and uniform molecular weight is desired for extrusion grade PLA. Optically impure PLA is not desirable for food contact applications as it may create metabolic issues[9]. TNPL initiated PLA based extrusion trials on paperboard for cup stock and on paper for pouches for sweets and savories

packaging. The temperature settings recommended by the extrusion die supplier for various polymeric materials is given in Table 5 for guidance purposes. However, based on the nature and purity of material, the temperature and other extruder settings need to be fine tuned for complete melting and uniform flow of film. Only conventional materials are listed and PLA is not listed in the Table 5. The temperature settings in the barrel and die zones were set as per the PLA supplier's recommendation and also from the TDS. The extruder was modified by installing a water circulation loop to control initial temperature in the barrel to suitably feed the PLA granules. The PLA extrusion trial was conducted with the cup stock reel with coat weight of around 20 gsm. Initially the grammage of PLA could not be controlled and also there was a neck in issue as well. Extrusion parameters such as die speed, zone temperature were carefully fine tuned to control grammage. The zone temperature setting during the PLA trial is given in Table 6. Pictures of PE and PLA granules are given in Fig 1 for visual comparison.

Table 5 : Temperature range recommended for various polymers by Extrusion Die manufacturer[10]

No.	Raw Materials	Temperature setting ranges (^{0}C)
1	PE MFI=0.3-1	190-230
2	PE MFI=.05-0.3	210-240
3	EPE (foam product)	170-200
4	CPE	220-250
5	HDPE	200-240
6	LLDPE	180-230
7	PS	170-200
8	EPS (foam product)	170-200
9	HIPS	200-250
10	PP	200-240
11	CPP	220-240
12	PVC (film)	160-180
13	PVC (hard product)	170-180
14	PVB	140-170
15	EVA	140-170
16	ABS	190-240
17	SAN	200-230
18	POM	170-200
19	PMMA	200-240
20	PC	230-260
21	PA	230-250
22	PUR	170-210
23	PSO	300-340
24	PET	230-250

Table 6 : Zone Temperature setting during PLA Trial

S. No.	Zone	Temperature setting during PLA Trial
1	Barrel Area1	135
2	Barrel Area 2	145
3	Barrel Area 3	150
4	Barrel Area4	155
5	Barrel Area5	160
6	Barrel Area6	165
7	Barrel Area7	170
8	Filter Heating	175
9	Flange Heating	175
10	Connecter Heating	175
11	Mould Neck Heating	175
12	Mould Area1	185
13	Mould Area2	180
14	Mould Area3	180
15	Mould Area4	180
16	Mould Area5	180
17	Mould Area6	180
18	Mould Area7	185

Fig 1: PE and PLA granules

Fig 2: Blanks and cups made with PLA coated board

Fig 3: Pouches made of PLA coated paper

The PLA coated material was converted into 80 ml cup blanks and conducted cup making trial at various cup making machines (Fig 2). Heat Sealing and cup forming were satisfactory. Water barrier property was also satisfactory.

PLA based coating was also tried with TNPL Radiant Print Platinum 70 gsm paper for sweets and savories pouch. Pouches were made from the PLA coated paper in the laboratory, in comparable to the commercial pouches available in the market meant for packing sweets and savories (Fig 3).

Note it is important to have consistent quality of PLA from supply to supply to have better control of film application and to avoid wastages during processing. Also the temperature settings need to be carefully optimized to control degradation of PLA. The PLA coated paperboard is compostable as certified by CIPET.

Water-based barrier coating

There are many commercially available water-based barrier coating materials available in the market and predominant among them being the acrylic-based polymers. The coating can be applied either in online mode (during paper/board manufacturing) or in offline mode. A trial with water based barrier material was conducted in cup stock variety to assess the performance requirements both online

and offline mode with bar/blade metering. Preferable metering techniques for water based coating application are in the order: Curtain > air knife > bar > blade for better coverage of barrier film.

A number of practical issues were faced during the online trial. Poor performance of barrier layer, due to penetration of the same in the base board, warranted a primer coat. Pinholes observed on the surface (Fig 4) which impaired the barrier performance. Generation of foam was controlled by suitable measurers to avoid pinholes. Blocking was observed during the trial; however, it was subsequently controlled by employing various steps: a) chemical modification by the supplier; b) installation of air curtains to bring the final web temperature; c) removing the jumbo rolls in small quantities/diameters; d) rewinding the jumbo rolls immediately after production etc. Blocking is a major issue in the online mode and it leads to production losses. Cleaning of excess dried barrier material carried forward to the rollers, screen and dryers is a difficult exercise, which leads to production losses and wastages. Besides the above steps, it demands a chiller roll arrangement in the machine to further reduce web temperature. The above issues led to shifting the barrier application to offline.

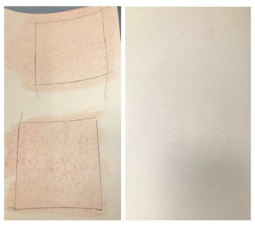

Fig 4: Pinholes in barrier layer

Trials conducted with water based barrier coating in offline mode is free from the many of the issues of online mode and hence it is preferred over online mode. The barrier coated material is not alike the conventional LDPE material with respect to conversion process. The production of cup blanks by automatic die-punching process with barrier coated material is not on a par with LDPE coated material due to frequent jamming which also affects the life of the die. The blanks also got stuck in the cone forming section of cup making machine which demands the pressure and temperature optimization.

Water based barrier coated paperboard underwent extensive field trials. Though the heat sealing of the cup in cone formation and the bottom curling were satisfactory, leakage of water noticed in cup bottom joint (Fig. 5) during hot water test which was addressed in subsequent trials.

From the various trials performed, it was observed that the barrier chemical formulation and application uniformity are very critical for smooth runnability and the performance of barrier layer.

Food contact regulation/compliance

The biodegradable and bio-based barrier coating material and their blends should meet the country specific food contact compliances. Paper and Paperboard meant for food contact applications should not pose any health risks to consumers, should not alter composition and organoleptic properties of food, and finally it should be manufactured by following the Good Manufacturing Practices (GMPs). GMP ensures that the food contact materials are produced in such a way that the contamination in each stage of production cycle and transportation is prevented by having proper SOPs with sufficient risk assessment, strict quality control measures in place. It should be done in each and every stage right from raw material selection, storage, manufacturing, conversion, packing, storage of finished goods and transport.

US, EU and China have implemented mandatory and binding regulatory requirements (Table 7) that GMP should be in place during manufacturing of food contact paper/paperboards.

Table 7: Regulations of US, EU and China [11, 12, 13]

S. No.	Country	Regulation
1	USA	FDA Title 21 CFR 174.5 –General provisions applicable to indirect food additives.
2.	EU	European Commission Regulation (EC) No. 2023/2006 – Good manufacturing practice for materials and articles intended to come into contact with food.
3.	China	National Standard for Food Safety GB 31603-2015 –General hygienic specifications for production of food contact materials and articles.

Food contact material should meet the compliance requirements of US FDA, German BfR, EU, BIS etc. The compliances applicable for paperboard meant for food contact applications is given in Table 8.

Table 8: Compliances applicable for paperboard meant for food contact applications [14, 15, 16,17,18,19]

S. No.	Country	Compliance
1	USA	US FDA 21 CFR 176.170& US FDA 21 CFR 176.180 Part 176: Indirect food additives: paper and paperboard components. Sec. 176.170: Components of paper and paperboard in contact with aqueous and fatty foods Sec. 176.180:Components of paper and paperboard in contact with dry food
2.	Germany	German BfR XXXVI
3.	EU	EU (EC) 1935/2004
4.	India	BIS:6615
5.	China	GB4806.8 and GB 9685

Challenges

1. PLA

- Availability & high cost of bio-based barrier coated material are the hurdles to scale up at large scale
- Sound knowledge of extrusion process and application of PLA is desired in comparison to LDPE extrusion process. It possesses a very narrow processing window and temperature of extrusion process needs to be carefully controlled to avoid thermal degradation.
- High purity of lactic acid or lactide is required for producing PLA with good quality, high molecular weight and high yield. High molecular weight PLA is desirable for food packaging applications, as it is resistant to support fungal and bacterial growth[20]. Optically impure PLA is not desirable for food contact applications as it may create metabolic issues [9,21,22].
- Chance of mixing of PLA coated material with conventional plastic coated material will ruin the very purpose of composting when proper segregation and collection system is not in place.

2. Water based barrier coatings

- Blocking issues need to be addressed with suitable modification in the polymer and application.
- Pin holes generation must be arrested to have uniform layer by carefully controlling the foam.
- Primer coating is required to improve surface of base board before barrier film application.
- Chemical odor issues during hot liquid filling also needs attention and must be addressed.
- Permanence of heat sealing with time has to be ascertained.
- Leakage at bottom of joint in the cups.
- The barrier coated material caused frequent jamming in blank-punching machine and also in cone forming section of cup making machine. Needs suitable modification in the die punching process/polymer.

Way Forward

The transition towards biodegradable/ compostable plastics is the need of the hour. As of now PLA is the dominant compostable plastic which is used in the paper/paperboard coating for replacing SUPs. The available water-based barrier chemicals such as acrylic based polymers are re-pulpable and recyclable which will not leave any filmy residues during recycling. The collective effort of manufacturers of paper/paperboard, barrier coating chemicals and guidance by regulatory authorities will facilitate further developments for mass replacement of SUPs.

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