An Exclusive Handbook of Flexible Packaging Materials: Equipped With Raw Materials, Manufacturing & Quality Machineries & Procedures, Case Studies and Troubleshooting's

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1. Title:

An exclusive Handbook of Flexible Packaging materials. Equipped with raw materials, manufacturing & quality machineries & procedures, case studies and troubleshooting's. This comprises equipment's, raw materials together with Polyethylene (PE) film manufacturing to packaging finished goods - wrapper / laminate in roll form and Pouch form. Each & every manufacturing stages have been focused including scopes, procedures, sample preparation, recipes, analytical tests, quality control following quality assurance and safety precautions. In addition, case studies, troubleshooting's, sustainability challenges, circular economy vs. flexibles, key information and latest innovations of adhesion have been featured.

2. Abstract/Concept:

Packaging is a scientific method of containing the (food) products against physical damage, chemical changes, further microbial contamination and display the product in a most attractive manner as per consumer preferences. Packaging provides a means to preserve, transport, store, distribute and merchandise of a product. Product packaging plays a vital role to reach the product to its consumer safely without compromising its quality. Packaging has a significant role in sustainability nowadays as it reduces food loss, keeps food quality better for a long period and reduces wasteful consumption and use of products. In developed and developing countries, concern about packaging design and wastes that are generating from it has arisen as poor packaging design and disposal of packaging wastes are creating frequent environmental problems. In the year 2012, 80 million tons of wastes were generated in Europe coming from packaging which is composed of 38 % paper, 21 % plastic, 20 % glass, 15 % wood, and 6 % metals. Packaging wastes are becoming a significant portion in the municipal solid wastes, too. So, packaging design, production, transportation, use and final disposal of packaging wastes need proper environmental consideration. A proper management system at the end of life of packaging can play an important role in reducing environmental burden. Life cycle assessment (LCA) is an environmental management tool that is used to identify the environmental impact of a product, process or service from "cradle to grave". It can be used in analyzing the overall environmental burden measuring the greenhouse gas emission, total energy consumption, raw material used, hazardous substances like CO2, SOx, NOx emissions throughout a product's life cycle.

3. Sustainable Background (The UN SDGs):

Our world and all the people living on it is being destroyed by plastic. Not only is plastic pollution choking the environment and destroying biodiversity but the very production itself is harming people's health, accelerating social injustice, and fueling the climate emergency. It's time to break our toxic relationship with plastic. Join the movement of Global Citizens, governments, activists, and organizations around the world demanding action by endorsing the call for a Global Plastics Treaty.

Flexible Packaging's can be used sustainably. Most importantly, 4 Goals (Out of United Nations announced 17 Sustainable Development Goals) are directly playing a crucial role as per below:

Goal serial	Goal Name	Goal description	Flexipack pertinent
Goal 9	Industry, Innovation and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	***Sustainable industrialization***
Goal 12	Responsible Consumption and Production	Ensure sustainable consumption and production pattern.	***Sustainable production***

Goal 13	Climate Action	Take urgent action to combat climate change and its impacts.	***Climate change sustainably***
Goal 15	Life on Land	Protect, restore and promote sustainable use of terrestrial ecosystems, manage forests, combat desertification and biodiversity loss and halt and reverse land degradation.	***Land degradation sustainably***

Table 1: SDG's (Sustainable Developmental Goals)

Figure 1: SDG's (Sustainable Developmental Goals)

Over the past 60 years, around eight billion tons of plastic has been produced, according to a recent study, 90.5 per cent of which has not been recycled. As a result, this year's Earth Day (**54th Earth day, 22nd April 2024**) theme "Planet vs. Plastic" demands a 60% reduction in the production of all plastics by 2040. Some perspectives are:

a. In 1950, the world produced just two million tons of plastic. We now produce over 450 million tons.
b. Half of all plastics ever manufactured have been made in the last 15 years.
c. Production is expected to double by 2050.
d. More than one million plastic water bottles are sold every minute.
e. Every year, about 11 million tons of plastic waste escapes into the ocean.
f. Only 9% of plastics ever produced has been recycled.
g. Plastics often contain additives that can extend the life of products, with some estimates ranging to at least 400 years to break down.

In a twisted type of irony, Microplastics are now in almost everything and everywhere. Even in in much of the food we eat and water we drink! Microplastics are tiny particles of plastic (from ½ inch to microscopic) is synthetic that never disappears. As Stephen Jamieson recently explained in a Future of Supply Chain podcast, "We're ingesting a credit card size worth of plastic every single week as humans, and the real health impacts of that, we don't truly know and don't truly understand." The goal is to develop an international legally binding instrument on plastic pollution, including in the marine environment, "by early next year, actually ratify a new treaty at the United Nations to eliminate plastic pollution by 2040". So, we have to think about optimizing our entire supply chain for sustainability, rather than just individual functions.

3.1. Perform Life-cycle assessments on our products:

A Life Cycle Assessment is a method for the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product throughout its life cycle (ISO standard 14040). In simple terms, it's a way by which you can understand the sustainability footprint of a product throughout its full lifecycle, from "cradle to grave." By enabling product footprints (SAP Sustainability Management) periodically across the entire product lifecycle, you can gain insights on the environmental impacts of your products across the entire lifecycle for disclosure and internal product and process optimization.

3.2. Design with end of life in mind:

"We need to invest in innovative technologies and materials to build a plastic-free world". And this starts with how we design products and packaging material in the goods we manufacture and deliver. The sooner we phase out all single use plastics, the better. We need responsible design and production solutions that facilitate a product and package redesign that enables companies to engage in the circular economy and reduces waste without sacrificing quality.

3.3. Enforce compliance at each step of the product cycle:

If we look at most companies' website for their mission statement or purpose, sustainability is front and center. And supply chain sits right in the middle, both as a major contributor to the problem, and a major opportunity to improve. This takes a stepwise approach to:

Record - The first step is to gather all necessary **ESG** (Environmental, Social and Governance) data along the entire value chain. This data cannot be found easily in one single system. Currently this is a highly manual and therefore time consuming effort compounded by data quality challenges. ESG is a management and analysis framework to understand and measure how sustainably an organization is operating.
Report - There are more than 600 **ESG** frameworks/standards out there and they are being constantly developed further (Take the evolving plastics taxes across Europe for example). The requirements for companies are constantly changing. A high effort is required to keep up with the current requirements to report along the respective regulatory & voluntary frameworks.
Act - In many companies sustainability action is already happening but in many cases this is still partly splits from the strategy or not yet covering all business processes.

Figure 2: Oil and gas companies have reset sustainable business plans to pragmatic net-zero goals that are grounded in secure, affordable, and resilient energy.

3.4. What can us, as individuals do about it?

The reality is that everybody has a role to play in the "Planet vs. Plastics battle, and the sustainability of the planet in general. Little things like using reusable bottles and straws and bringing reusable bags to the store are great first step.

4. **Graphical abstract/concept: PFD** (Process flow Diagram) **/ Flow chart**: First of all, Raw materials have been received at warehouse. Relevant raw material are now issued for PE (Polyethylene) manufacturing through multi-layer blown film machine. Printed Films like polyester, OPP, Nylon etc. are now being laminated. After inspection and slitting job, Finished Goods/Flexibles like laminate or wrapper or Pouches has been produced and delivered to customer after Lab/Quality clearance. In each stage wastage released and 1st stage, there required OPRP.

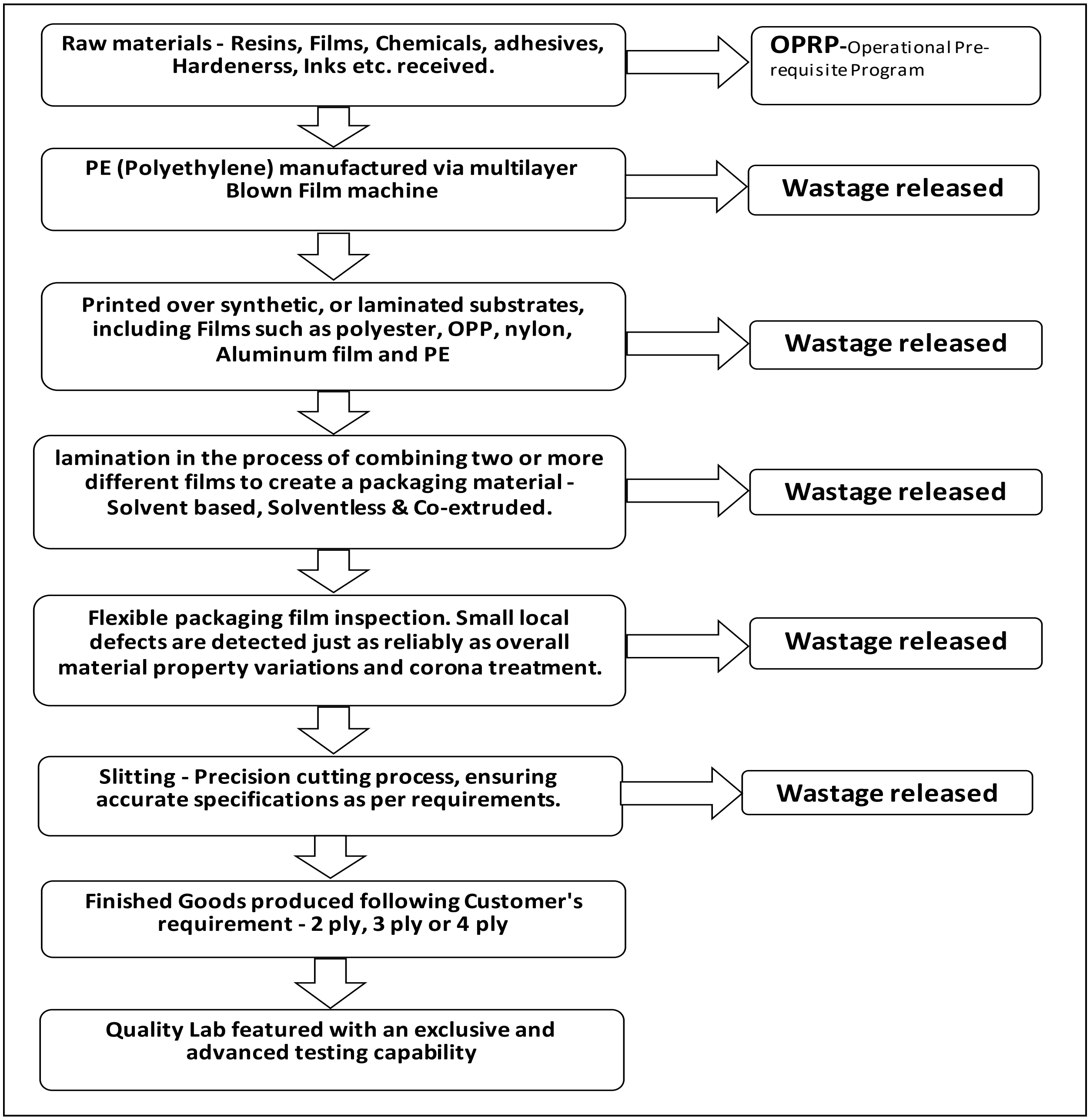

Figure 3: Graphical PFD (Process Flow Diagram)

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6. Preface:

The plastic industry continues to grow very rapidly and plays an important role in many fields such as engineering, medical, agriculture and domestic. It is now very difficult to find the point at which plastic cannot be considered as an essential component. The understanding of the nature of plastic films, their production techniques, applications and their characterization is essential for producing new types of flexible packaging. This handbook has been written to discuss the production and main uses of flexible packaging. A description of the properties of the most common films used in flexible packaging such as low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE), polypropylene (PP), PVC, polyamide (Nylon), and other plastics are also given in this handbook.

First of all, I tried my best to highlight the background of flexible packaging, influencing the SDGs, the environment and at large the whole universe because we're producing it at break-neck speed. According to the United Nations Development Program (UNDP), the world currently produces a staggering 430 million metric tons of new plastics every year and this is forecast to increase a whopping 70% by 2040.

In the first phase, at section 9 (9 – 9.3.8), I have discussed characterizations of Resins, films, chemicals, adhesives, hardeners, inks used for flexible packaging manufacturing. Also, structures and additives are defined, as well as other more specific properties. Finally some particularly important applications that require special structures or modifications have been discussed.

In the second phase, at section 10 (10 – 10.11.4.2), the main parameters impelling resin basic properties are described. The methods of processing of polyethylene films via Multi-layer blown machine has been discussed. Effects of extrusion variables on film characteristics and effect of blow ratio on film properties are considered. Overall, the whole manufacturing process from printing to lamination, inspection, slitting and finally Finished goods production including pouch making procedures have been discussed in this section. Apart from these, printing vs. inking technology, lamination vs. Adhesive-Hardener gluing technology, turning flexible films into packaging and pouching etc. have also been conferred.

In the third phase, at section 11 (11 – 11.2.17), Quality testing procedures vs. Lab equipment's along with Quality standards have been highlighted. Each & every Lab equipment's along with standard quality parameters have been discussed for easy understanding to everyone.

In the fourth phase, sections 12 to 14, Flexibles sustainability challenges encompassing wastage disposal keeping in mind that flexible packages containing plastics are sources of recoverable energy, Flexibles vs. circular economy and few key information has been conversed. I really trust in a solution that will eliminate plastic pollution from our planet by creating a socially inclusive, circular economy for plastics and that ensuring a low-carbon future.

In the fifth phase, at section 15, a good number of case studies like packaging discoloration, delamination, bad smell and microbial contamination etc., have been acquainted during my long term job span at Unilever Bangladesh, NRG printing & packaging and Consort flexipack limited, have been well deliberated. I strongly believe that these case studies will significantly help to us as well as all Flexible packaging manufacturer communities in resolving upcoming Market place complaints in future.

In the sixth phase, at section 16, I have emphasized specially lamination process and find out few troubleshooting's that we have been facing in our daily operation. These are voids, outgassing, bubbles, tunneling, hazing, ink bleeding or smearing etc. All these defects impact overall appearance of the package. In fact, laminating adhesives play an integral role in constructing multilayer flexible packaging by bonding layers. I have debated everything in detail along with root causes following remedial action to overcome in future. This will obviously play a positive impact in our day to day operation.

In the last phase, at section 17, I have focused on recent researches and innovations over the prime process, lamination of flexible packaging. As the needs of industry and the demands of consumers change, scientists are working to develop new adhesion technologies both within academia and business. The demand for more sustainable adhesive technologies is always increasing. I have presented new research in adhesion science - a reversible glue developed by researchers; customizable bio-adhesive patches and a review of the use of soybean protein adhesives in wood composites.

This handbook represents the efforts of many experts in different aspects of flexible packaging. Their efforts in preparing contributions to the volume are to be noted and I take the opportunity to express my heartfelt gratitude for their time and effort. My gratitude extends also too many colleagues for their kind comments in many aspects. A special thanks is extended to the Consort Flexipack Limited for the fine production of this Handbook **and Mr. Ariful Haque, DGM Marketing, Akij Foods & Beverages limited who commissioned the book and oversaw the whole project.**

(Azizul Haque)
April, 2024

7. List of declaration (s):

I declare that this paper was composed by me and that the work contained herein is my own except where obviously stated otherwise in the text and that this work has not been submitted for any other professional qualification except as specified. Every effort has been made to contact copyright holders of any material reproduced within the text and the authors and publishers apologize if any have been overlooked.

First and foremost, I would like to express my thanks to all of my colleagues who support me in writing this exclusive Book "An Exclusive Handbook of Flexible Packaging" which would obviously help in my future research work. Besides, I would like to convey my special thanks to my organization for giving an opportunity in writing this article. Moreover, I would like to thank and immense gratitude to all of my friends and family members for unconditional, unequivocal, and loving support without which I couldn't be able to complete this article. Last but not least, I would like to thank everyone who helped and motivated me in writing this article.

8. Introduction:

Flexibles are made up from one or more layers that give specific properties to the overall packaging material. The layers can be individual webs/sheets or coatings/treatments and are fixed firmly with each other. For example:

a. (Food) Contact layer: Needs to be able to heat seal, provides flexibility and strength
b. A layer for puncture and abrasion resistance.
c. Barrier layer: Protects from light, gas and odors, extends shelf life and
d. Print layer: Needs to be a printable surface, provides strength.

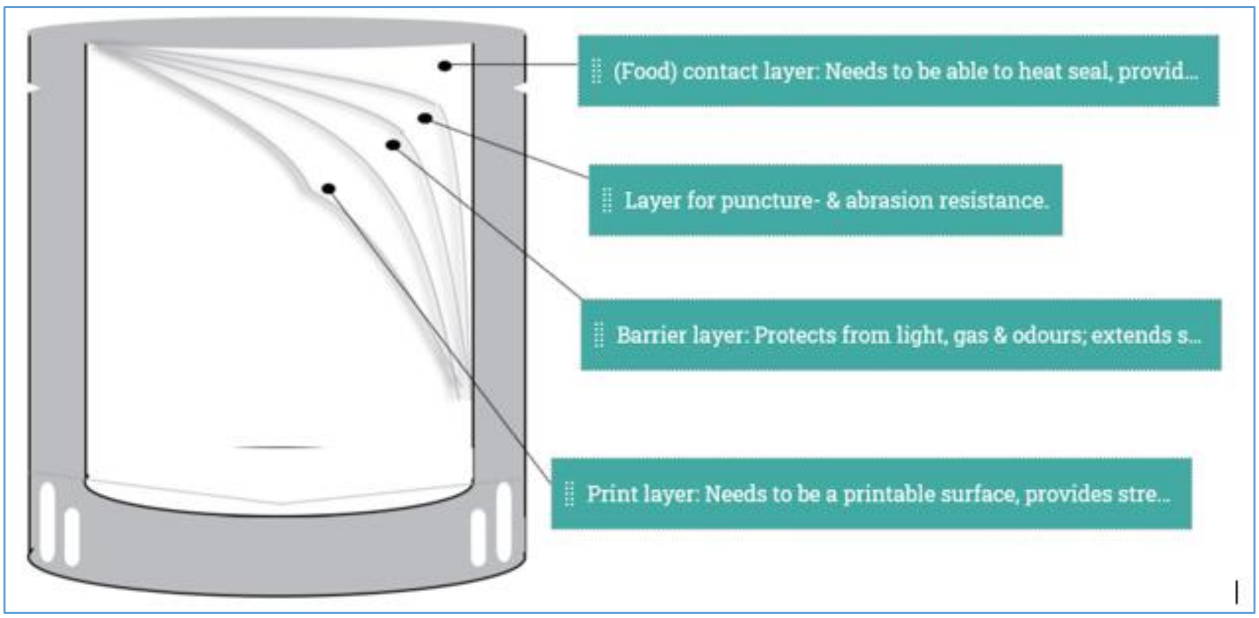
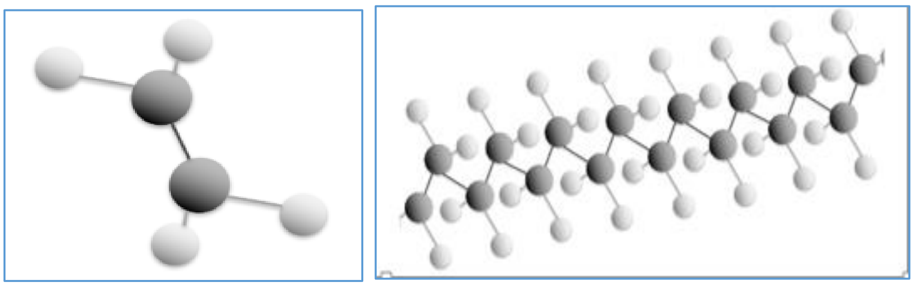


Figure 4: Flexible structure breakdown.

The magic ingredient for flexibility is polymer. Flexibles are able to bend and flex to meet the changing needs and demands of converters, suppliers, packagers, retailers and consumers. This is the flexible, light material that can be formed, sealed together and used in thin layering. The key material group are "Polymers". Polymers are macromolecules that are formed by linking many monomers together through chemical bonds. A monomer consists of 4 – 100 atoms and a polymer consists of over 100 atoms. The monomer compound is the "resin".

9. Materials:

9.1: Resins: Resin is a unique chemical mixture that has been a part of nature for a very long time. For instance, **Elite from Dow, Exceed from ExxonMobil, 222 WJ from Sabic are most commonly used.**
MFI is a simple measurement of the quantity of polymer pushed through a die of specified dimensions at a set temperature within 10 min. It is frequently used to compare grades of the same polymer, as it gives an indication of the molecular weight present in that batch or grade. Melt flow rate values are calculated in g/10 min. Melt flow rate = g/10 min.
LDPE has an MFI of 0.3 ± 0.05 g/10 min.
Melt flow rate is an essential property of thermoplastics that will help you to determine the rate at which polymer will flow at a melting point under the applicable standard weight.



This pictures show for example, the polymer, Polyethylene: H_2C-C_2H and (H_2C-C_2H) n respectively.

Figure 5: PE (Polyethylene) Structure

Polyethylene (PE) is a lightweight, durable thermoplastic with variable crystalline structure. PE is one of the most widely produced plastics in the world (tens of millions of tons are produced worldwide each year). It is used in applications ranging for films, tubes, plastic parts, laminates, etc. in several markets (packaging, automotive, electrical, etc.). Polyethylene is made from the polymerization of ethylene (or ethene) monomer. Polyethylene chemical formula is $(C_2H_4)_n$.

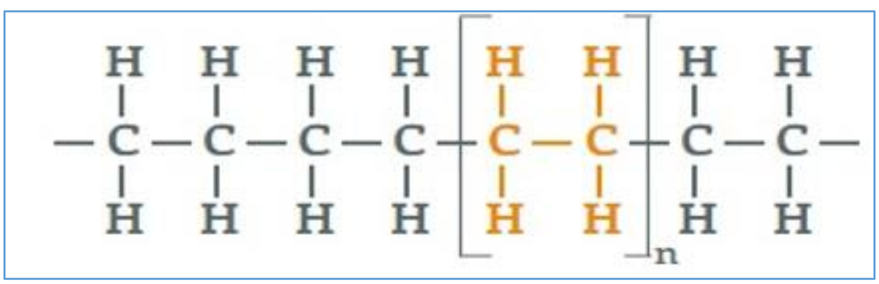
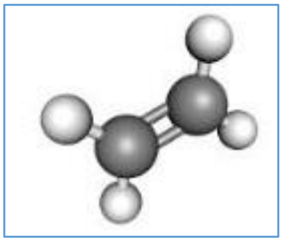


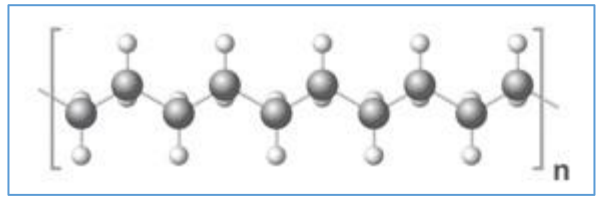
Figure 6: Molecular Structure of Polyethylene

Polyethylene Preparation: Polyethylene is made by addition or radical polymerization of ethylene (olefin) monomers. (Chemical formula of Ethene - C_2H_4). Ziegler-Natta and Metallocene catalysts are used to carry out polymerization of polyethylene.



Structure of PE Monomer C_2H_4

Ziegler-Natta Polymerization Or Metallocene Catalysis



Structure of Polyethylene $(C_2H_4)n$

9.1.1. Low-Density Polyethylene (LDPE) is a semi-rigid and translucent polymer. Compared to HDPE, it has a higher degree of short and long side-chain branching. It is produced at high pressure (1000-3000 bar; 80-300°C) via free radical polymerization process. The LDPE is composed of 4,000-40,000 carbon atoms, with many short branches. Two basic processes used for the production of low-density polyethylene: stirred autoclave or tubular routes. The tubular reactor has been gaining preference over the autoclave route due to its higher ethylene conversion rates. **Feels soft, slightly blurry appearance, stretches in all directions.** LDPE structure:

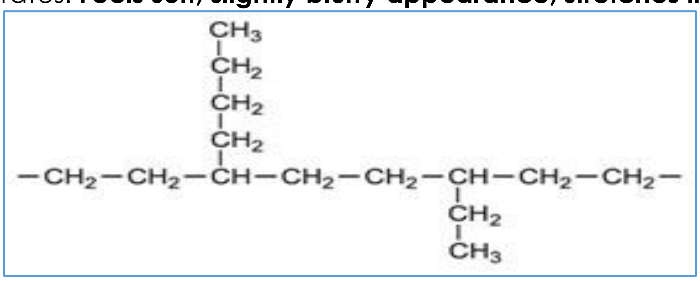


Figure 7: LDPE Structure

9.1.2. Linear low-density polyethylene (LLDPE) is produced by polymerization of ethylene (or ethane monomer) with 1-butene and smaller amounts of 1-hexene and 1-octene, using Ziegler-Natta or metallocene catalysts. It is structurally similar to LDPE. The structure of LLDPE has a linear backbone with short, uniform branches (unlike longer branches of LDPE). These short branches are able slide against each other upon elongation without becoming entangled like LPDE. In the present-day scenario, linear low-density polyethylene (LLDPE) has been quite successful in replacing Low Density Polyethylene.

9.1.3. High Density Polyethylene (HDPE) is a cost-effective thermoplastic with linear structure and no or low degree of branching. It is manufactured at low temperature (70-300°C) and pressure (10-80 bar) & derived from either modifying natural gas (a methane, ethane, propane mix) or the catalytic cracking of crude oil into gasoline. HDPE is produced majorly using two techniques: Slurry Polymerization or Gas Phase Polymerization. **High Density Polyethylene Molecular Structure:**

$$-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-$$

High density polyethylene is flexible, translucent/waxy, weather resistant, and displays toughness at very low temperatures. **Feels soft, milky appearance, stretches in all directions.** In summary,

9.1.4. Common properties of LDPE, LLDPE & HDPE:

	LDPE	LLDPE	HDPE

Polymer Full Name	Low Density Polyethylene	Linear Low-Density Polyethylene	High Density Polyethylene
Structure	High Degree of short chain branching + long chain branching	High Degree of short chain branching	Linear (or Low degree of short chain branching)
Catalyst and process	Using radical polymerization using tubular method or auto clave method	Using Ziegler-Natta catalyst or metallocene catalyst	Ziegler-Natta catalyst in: - Single-stage polymerization - multi-stage polymerization or a Cr or Phillips-type catalyst
Density	0.910-0.925 g/cm^3	0.91-0.94 g/cm^3	0.941-0.965 g/cm^3
Crystallinity	Low crystalline and high amorphous (less than 50-60% crystalline)	Semi-crystalline, level between 35 to 60%	High crystalline and low amorphous (>90% crystalline)
Characteristics	Flexible and good transparency, good moisture barrier properties High impact strength at low temperature Excellent resistance to acids, bases and vegetable oils	As compared to LDPE, it has: Higher tensile strength Higher impact and puncture resistance	Excellent Chemical Resistance High tensile strength Excellent moisture barrier properties Hard to semi-flexible
Recycling Code	4	4	2
General Applications	Shrink wrap, films, squeezable bottles garbage bags, extrusion moldings, and laminates	High performance bags, cushioning films, tire separator films, industrial liners, elastic films, ice bags, bags for supplemental packaging and garbage bags	Molecular weight distribution is relatively narrow, has applications in injection moldings or flat yarns, and the latter type Molecular weight distribution is wide, is used to make film products, hollow plastic products and pipes

Table 2: Common properties of LDPE, LLDPE & HDPE

9.1.5. Some other typical properties of LDPE, LLDPE & HDPE:

Property	Polymer		
	LDPE	LLDPE	HDPE
Glass transition temperature (Tg; °C)	–120	–120	–120
Melting temperature (Tm; °C) 105-115 122-124 128-138	105-115	122-124	128-138
Heat distortion temperature, at 455 kPa (°C)	40-44	-	62-91
Density (g/cm^3)	0.915-0.940	0.915-0.935	0.94-0.97
Tensile modulus (GPa)	0.2-0.5	-	0.6-1.1
Tensile strength (MPa)	08-31	20-45	17-45
Elongation (%)	100-965	350-850	10-1200
WVTR* at 37.8 °C and 90% RH (g μm/m^2 d)	375-500	-	125
O^2 permeability, at 25 °C (10^3 cm^3 μm/m^2 d atm)	160-210	-	40-73
*WVTR: Water vapour transmission rate (d = day, 24 h), RH: relative humidity			

Table 3: Some other typical properties of LDPE, LLDPE & HDPE

Polyethylene resins are generally characterized by three parameters:

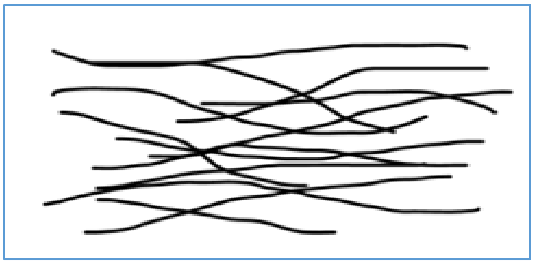
a. Molecular weight distribution (measure of processing ease and product properties),
b. Melt index (measure of molecular weight) and
c. Density (measure of branching or rigidity).

These three parameters are considered to be intrinsic properties of polyethylene.

9.1.6. Polypropylene, PP: This material feels soft and may have a slightly blurry appearance. Pull it in two directions. In one it stretches a lot, in the other less. Density: Will float in water, 0.895-0.920 g/cm^3. Polypropylene (PP) is usually considered safe for humans. It is considered the safest of all plastics; it is a robust heat-resistant plastic. Because of its high heat tolerance, it is unlikely to leach even when exposed to warm or hot water. It is approved for use with food and beverage storage. **Feels soft, slightly blurry appearance, stretches more in one direction compared to the other.** Recycling code **# 5.**

9.1.7. Polyamide, PA: This material is soft like PE and PP but transparent and glossy like PET (Polyethylene Terephthalate). Density: Will sink in water, 1.14 g/cm^3. **Almost glass-like transparency, but is very soft.** Recycling code **# 7 (All other plastic materials)**

9.1.8. Classification of polymers: Polymers can be classified into thermoplastics, thermosets or elastomers. For packaging purposes, thermoplastics are most relevant. These are linear polymers – no bonding, the polymers are intertwined and become fluid on the application of heat. These can be softened, solidified and re-softened a number of times, allowing process waste and recycling of spent material. Another one is Branched polymers.



LINEAR: Monomer units simply join onto each other to form long chains.

Linear polymers have no bonding, the polymers are intertwined giving them strength and stiffness

BRANCHED: Monomer units cross link between chains in three dimensional pattern

They have a lower strength and stiffness than linear polymers but a better process ability for film making purposes.

Figure 8: Linear and Branched Monomers

So linear structures can be considered as Necklaces whilst the branched structure is more like a web with more spaces in between. This explains how the branching structure has a direct effect on some of the functionalities as per below:

Property	Less branching ↓	More branching ↑
Density	Higher ↑	Lower ↓
Crystallinity	Higher ↑	Lower ↓
Clarity	Lower ↓	Higher ↑
Softening point	Higher ↑	Lower ↓
Tensile strength	Higher ↑	Lower ↓
Elongation	Lower ↓	Higher ↑
Gas barrier	Higher ↑	Lower ↓
Grease resistance	Higher ↑	Lower ↓

Figure 9: Properties of Linear and Branched Monomers

Now, the properties of a variety of flexible materials like polymers, paper and Aluminum are as follows:

Material	Description	Characteristics
Paper		Print carrier, stiff
PET	PolyEthylene Terephthalate	Print carrier, high gloss, barrier
PP	PolyPropylene	Print carrier, puncture resistance, fat barrier
Pa6	PolyAmide (nylon)	Mechanical strength, stiffness, puncture resistant
HDPE	High Density PolyEthylene	Added stiffness
LDPE LLDPE Metallocene	Low density PolyEthylene Linear Low Density PE New generation PE	Sealant Strength, sealant Manifold properties
Surlyn	Ionomer resin	Low temperature sealant
PS	PolyStyrene	Deep drawn webs
Al	Aluminium foil	Barrier, print carrier

Figure 10: Properties of Flexible Raw Materials

9.4. Packaging Films:

Flexi laminates moved to BOPP + MBOPP +PET + MPET. BOPP is environment friendly.
BOPP made with polypropylene; BOPP bags are recyclable **(although not biodegradable)**. Polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), and polystyrene (PS) are **not biodegradable**. Polyethylene or polythene film **biodegrades naturally**, although over a long period of time ... Biodegradable films need to be kept away from the usual recycling stream to prevent contaminating the polymers to be recycled. If disposed of in a sanitary landfill, most traditional plastics do not readily decompose. ***Biodegradable*** plastics are plastics that can be decomposed by the action of living organisms, usually microbes, into water, carbon dioxide, and biomass. **Biodegradable** refers to **the ability of things to get disintegrated (decomposed) by the action of micro-organisms** such as bacteria or fungi biological (with or without oxygen) while getting assimilated into the natural environment.

9.2.1. BOPP stands for bi-axially-oriented polypropylene. It's a variant of polypropylene (PP). Polypropylene a thermoplastic polymer, alternately known as polypropene. It's an ideal printing surface and can be made into labels and stickers, as well as textiles and a host of different plastic parts and materials. BOPP film can be white, metal-colored, or clear. The ability to make clear BOPP film allows the creation of transparent labels to show off the contents of clear containers. With the appropriate inks and adhesives, BOPP labels can also be waterproof. BOPP labels immersed in ice-water or subjected to high-humidity without deteriorating. Labels made from BOPP are extremely tough. The material offers exceptional resistance to fatigue compared to other common label materials and has an unusual resistance to common solvents, bases, and acids.

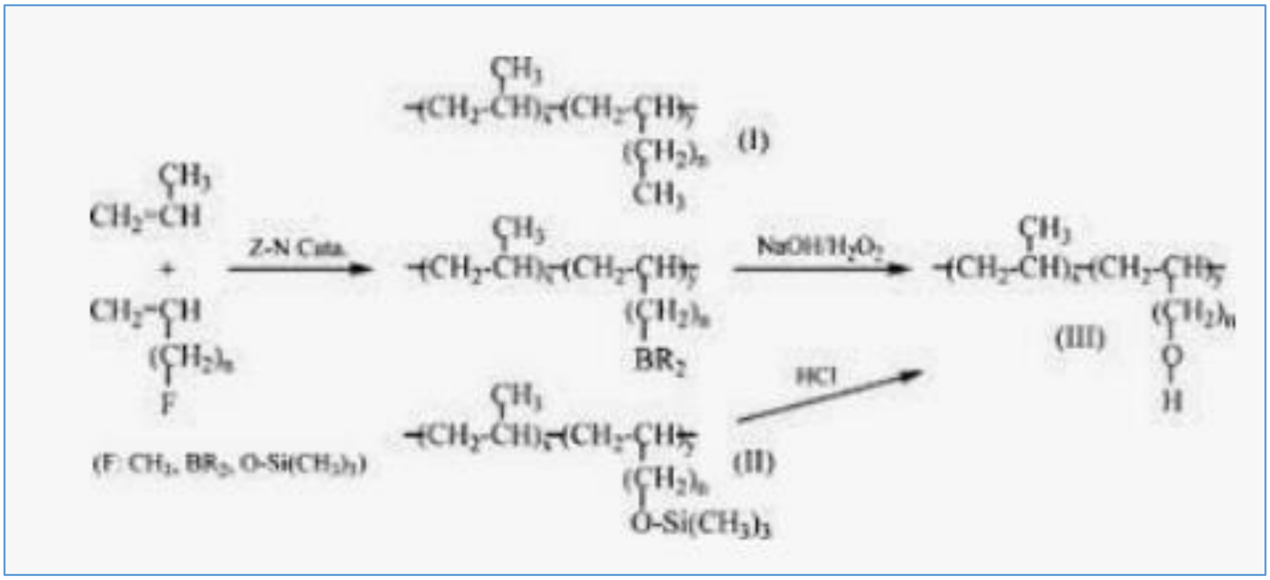


Figure 11: BOPP Structure

9.2.2. PET, Polyethylene terephthalate, better known as PET Plastic (also sometimes as PETE), is the most used thermoplastics globally with various textile, films, electronics, packaging, automobiles, etc. The biggest utilizer of PET is the textile industry, in which thermoplastic is mostly known by the name Polyester. It has a fantastic set of different properties, making it very attractive for manufacturers like chemical, mechanical, thermal resistance, and dimensional stability. It is semi-crystalline in nature and colorless. Some of the important properties include water resistance and toughness (the strength to weight ratio is impressive). The material is virtually shatterproof, which improves its applicability by many nautches. PET plastic is also highly recyclable and has the number "1" as its recycling symbol. Density 1.38 g/cm^3. **Almost glass like transparency, feels brittle, makes a crackling noise when scrunched.**

According to many worldwide reports, PET, with an annual production of 56 metric tons, is the most used thermoplastic in the world. The textile industry consumes approximately 60% of that, and other major consumers include the packaging and bottling industry with 30%.

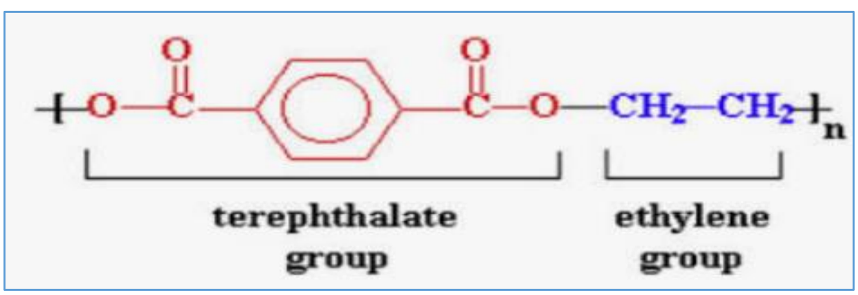


Figure 12: PET Structure

PET Copolymers:

Figure 13: PET Copolymers

PET or PETE is originally a homo-polymer but can be modified to produce copolymers (polyethylene terephthalate glycol-modified) depending on the application.
9.2.3. MPET, Metalized PET is a smart solution to enhance your packaging solution. Metalized films (or metalized films) are polymer films coated with a thin layer of metal, usually aluminium. They offer the glossy metallic appearance of an aluminium foil at a reduced weight and cost. Metalized films are widely used for decorative purposes and food packaging, and also for specialty applications including insulation and electronics. Metalized films are used as a susceptor for cooking in microwave ovens. An example is a microwave popcorn bag.

9.2.4. MCPP, Metalized cast Polypropylene is a film coated with a metal layer (usually aluminum, nickel or chromium …). The thickness of this metal layer depends on the required properties of the packaging such as moisture-proof, gas-proof, water-proof, etc. MCPP film is widely used in the production of packaging for the food industry, pharmaceuticals, vacuum bags, etc.

9.5. Packaging Chemicals:

9.3.1. Methyl isobutyl ketone (MIBK) is a colorless liquid with an odor similar to mothballs. MIBK is also known as 4- methyl-2-pentanone, hexone and isopropyl acetone. While it is usually in liquid form, MIBK can change into a gas. MIBK will dissolve in water, alcohols, benzenes and ethers. This is **an organic compound** that has a low odor and is referred to as an oxygenated solvent. Methyl isobutyl ketone (MIBK) is used **as a solvent for vinyl, epoxy, acrylic, natural resins, nitrocellulose, paints, varnishes, lacquers, protective coatings, rare metal extraction, and dyes**. In addition, it is used as a denaturant for rubbing alcohol, as a synthetic flavoring adjuvant, and as a fruit flavoring agent. MIBK structure:

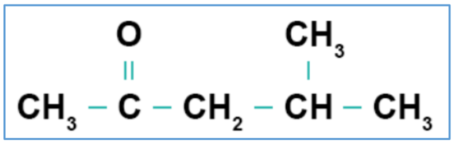


Figure 14: MIBK Structure

9.3.2. Ethyl Acetate is used primarily as a solvent and diluent, being favored because of its low cost, low toxicity, and agreeable odor. Ethyl acetate is the acetate ester formed between **acetic acid and ethanol**, Chemical structure is CH3COOC2H5 or C4H8O2.

9.3.3. Toluene is a clear, colorless liquid with a benzene-like odor. The chemical formula of toluene can be written as **$C_6H_5CH_3$**. Toluene is a naturally occurring compound derived primarily from petroleum or petrochemical processes. Pure toluene (melting point, -95° C [-139° F]; boiling point, 110.6° C [231.1° F]) is a flammable, toxic liquid, insoluble in water but soluble in all common organic solvents.

9.3.4. Methyl Ethyl Ketone (MEK) is primarily used as a solvent and in manufacturing plastics, synthetic rubber, paraffin wax, paints, inks, glues, and other chemical products. MEK's properties allows it to have a higher boiling temperature and a slower evaporation rate making it have a longer lasting effect than many other solvents. MEK structure:

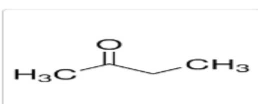
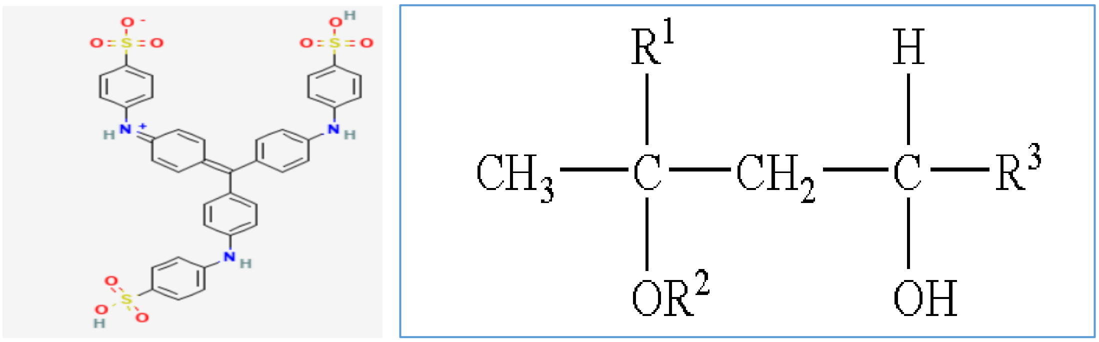


Figure 15: MEK Structure

9.3.5. Slip Agent is not only **reduces the coefficient of friction (COF) but also used to reduce adhesion between the mold and injection molded polymer**. The slip agents have exactly the same effect on metallization and reduce adhesion. It is worth noting that there is no control over which surface the slip agents appear on. **Slip** properties enable two surfaces to slide more smoothly over each other, e.g. for easier opening of screw tops. In contrast, **anti-block** properties reduce the adhesion of two surfaces. Anti-block agents **act to reduce the COF between film layers** and are therefore essential additives in the production of plastic films.

9.3.6. Inks are used with many different packaging materials for printing. As such, plastics, paper, board and cork may be directly printed on. Adhesion is one of the essential properties in printing Ink and coatings industry that ensures the coating (or ink film) remains adhered to the surface for long especially under aggressive conditions. **Inks** are formulated using four main components: pigments, binders, solvents and additives. **Pigments (Dye)** are used to create color impressions and optical effects. (Solute)
Binders keep the pigments evenly dispersed and bind them to the surface of the substrate.
Solvent creates a chemical bond between the ink and the material that it's being printed on.
Additives in the form of surfactants are used frequently to improve ink printability **Ultra-gloss ARSR** Inks are highly efficient inks used for both polyester and BOPP film, featured with high print density, excellent print finish and excellent adhesion properties. Most color printers follow the CMYK (**cyan, magenta, yellow, black**) model. Ink isn't a chemical compound but a solution or a heterogeneous mixture of many components like dye...chemical solvent etc... So it can't have a chemical formula just like Coca-Cola and orange juice.
For instance, Chemical Formula: C14H26N2O4S - Chemical Formula of ink (Blue)



General Chemical Formula of Ink

Figure16: Chemical Formula of Ink

Ink is made with a combination of ingredients including varnish, resin, solvents, pigments, and additives including waxes and lubricants. Black ink is made using carbon black pigments, and white pigments like titanium dioxide can be used to lighten other ink colours. Ink can be a complex mixture, containing a variety of substances such as solvents, resins, alcohol, lubricants, carbon, pigments, dyes, aniline, dextrin, glycerin, fluorescents and other materials. A wide range of raw materials are used in ink formulations including resins, polymers, plasticizers, dyes, conductive salts and pre-micronized pigments. These are supplied in powdered form, liquid form (i.e. pre-dispersed in aqueous or organic solvent), and "chip" form.

Traditionally, in Indian and Asian subcontinents, Vinyl acetate-Vinyl Chloride-vinyl alcohol terpolymer (popularly known as vinyl resin) and Ethylene Vinyl Acetate (EVA) based inks are known as vinyl inks.
9.3.6.1. Vinyl Ink is waterproof and smudge proof that has a lasting glossy look! It is essential to ensure basic ratio/blend of solvents into the ink following the TDS (Technical data Sheet) provided by the Ink Supplier. The use of other solvents and solvent blends are known to cause problems such as blocking, odor and reduced bond strength. In extremely severe cases the wrong solvent can cause "Ink Curdling or Chuck Out" problems. Recommended basic ratio:
Ethyl Acetate: Toluene: MIBK = 45: 45: 10 OR
Ethyl Acetate: Toluene: MIBK = 40: 40: 20 OR
Ethyl Acetate: Toluene = 60: 40
Ethyl Acetate: Toluene = 50: 50

9.3.6.2. PU ink is a non-reactive Polyurethane ink with low color and viscosity making it highly suitable for Flexographic and Gravure Inks and Laminating Inks. Its main applications are for flexible packaging and reverse printings. Recommended basic ratio
Toluene: MEK: Isopropyl Alcohol (IPA) = 40: 40: 20 OR
Toluene: MEK: Isopropyl Alcohol (IPA) = 50: 40: 10 OR
Ethyl Acetate: MEK: IPA = 40: 40: 20.

It is always better to mix the solvents before adding to the ink and always shake the container vigorously before emptying the ink.

9.3.7. Adhesives are designed for specific applications. Besides their role in the adhesion process, they can be used for other purposes, such as **sealing agents, in order to eliminate the effect of self-loosening caused by dynamic loads, sealing of areas to prevent oxidation and corrosion, waterproofing, etc**. An adhesive is a polymer mixture or polymerizable material in a liquid or semiliquid state that adheres substrates together (Petrie 2000). Adhesives may be composed of many components such as **polymer, oligomer, filler, and additives from either natural or synthetic sources**. This is a substance that is capable of holding materials together in a functional manner by surface attachment that resists separation. "Adhesive" as a general term includes cement, mucilage, glue, and paste terms that are often used interchangeably for any organic material that forms an adhesive bond. The advantages of adhesives:

Basic difference between adhesive and Glue is that **Glues are derived from natural sources (plant and animal byproducts), while adhesives are synthetic. Chemically, glue is composed of Carbon 49.1%, Hydrogen 6.5%, Nitrogen 18.3%, and Oxygen & Sulphur 26.1%.**

9.3.8. Hardener is **one that hardens** especially a substance added (as to a paint or varnish) to harden the film. Hardener molecules enable the resin molecules to connect to each other to form a three-dimensional network. There are many types of hardeners, but the most important ones are classified into **aliphatic and aromatic amines, anhydrides, and polyamides**. Polyamine hardeners are made up of **an organic molecule containing two or more amine groups**. Other types of hardeners include polyamide hardeners and anhydride hardeners, although these types react only with heat. Chemical hardeners are **used to make concrete surfaces denser and harder**. They are usually made of inorganic materials and come in dry or liquid forms that can be used on concrete surfaces.

In some mixtures a hardener is used simply to **increase the resilience of the mixture once it sets**. In other mixtures a hardener is used as a curing component. A hardener can be either a reactant or a catalyst in the chemical reaction that occurs during the mixing process. A hardener may also be known as an accelerator. **Formaldehyde** is an ingredient in some nail hardeners and nail polishes. It may be listed on the product label as formaldehyde or by different names, such as "formalin" and methylene glycol." In nail hardeners, formaldehyde bonds with the keratin that occurs naturally in the nails, making the nails harder.

Polyurethane adhesives are made by reacting a low molecular weight polymer with at least two –OH end groups with a di-isocyanate. The polymers can be polyether, aliphatic polyesters, or polybutadiene. The basic chemical reaction is:

$$\underset{isocyanate}{-\mathrm{NCO}} + \underset{ol}{-\mathrm{OH}} = \underset{urethane}{-\mathrm{NHCOO}-}$$

Figure 17: Polyurethane Adhesive preparation-1

In two-component polyurethane adhesive, the polymer and isocyanate are mixed and then applied to the adherends. Any hydroxyl groups on the surfaces (e.g., on paper, wood, or glass) will possibly react with isocyanate to form covalent bonds between adhesive and substrate. Detail reaction are as follows:

$$-\mathrm{NCO} + \mathrm{H_2O} = -\mathrm{NH_2} + \mathrm{CO_2}$$

$$-\mathrm{NCO} + -\mathrm{NH_2} = \underbrace{-\mathrm{NH}-\mathrm{CO}-\mathrm{NH}-}_{urea\ unit}$$

$$-\mathrm{NCO} + -\mathrm{NH}-\mathrm{CO}-\mathrm{NH}- = \begin{array}{l} -\mathrm{NH}-\mathrm{CO}-\mathrm{N}- \\ \quad | \\ \quad \underbrace{\mathrm{CO}-\mathrm{NH}-}_{biuret\ unit} \end{array}$$

Figure 18: Polyurethane Adhesive preparation-2

10. **Manufacturing Processes: Includes scope, Procedure/SOP (Standard Operating Procedure), Sample preparation (Optional), Analytical tests, Safety precaution.**

10.1. Multilayer Blown Film Process/making:

10.1.1. Scope: Three state-of-the art multilayer film blowing machine, Kung Hsing, a globally renowned company. These machines feature automated with thickness variation control (Auto Thickness Controller), Auto display monitoring Board and IBC (Internal bubble cooling) technology ensuring precision in film production.

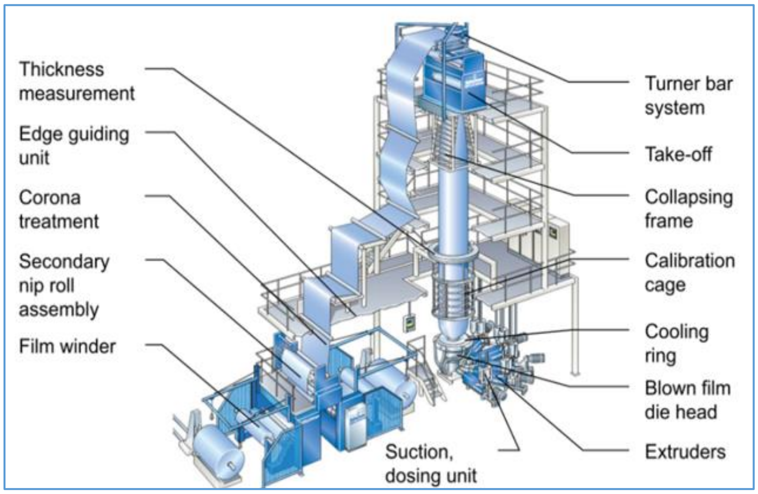


Figure 19: Extrusion of LDPE/LLDPE blown film

10.1.2. Procedure/SOP: In the blown film process, the polymer is molten and blown through a ring into the form of a long tube which is transported upwards, then folded and finally cut open into long sheets that can be wound onto reels. This process is most common for PE film. The polymer is extruded through a CIRCULAR DIE as a tube and blown into bubble. Air is used to cool and control film parameters. “Corona” is a treatment used to increase the surface energy of the film to help with bonding of adhesives or inks.

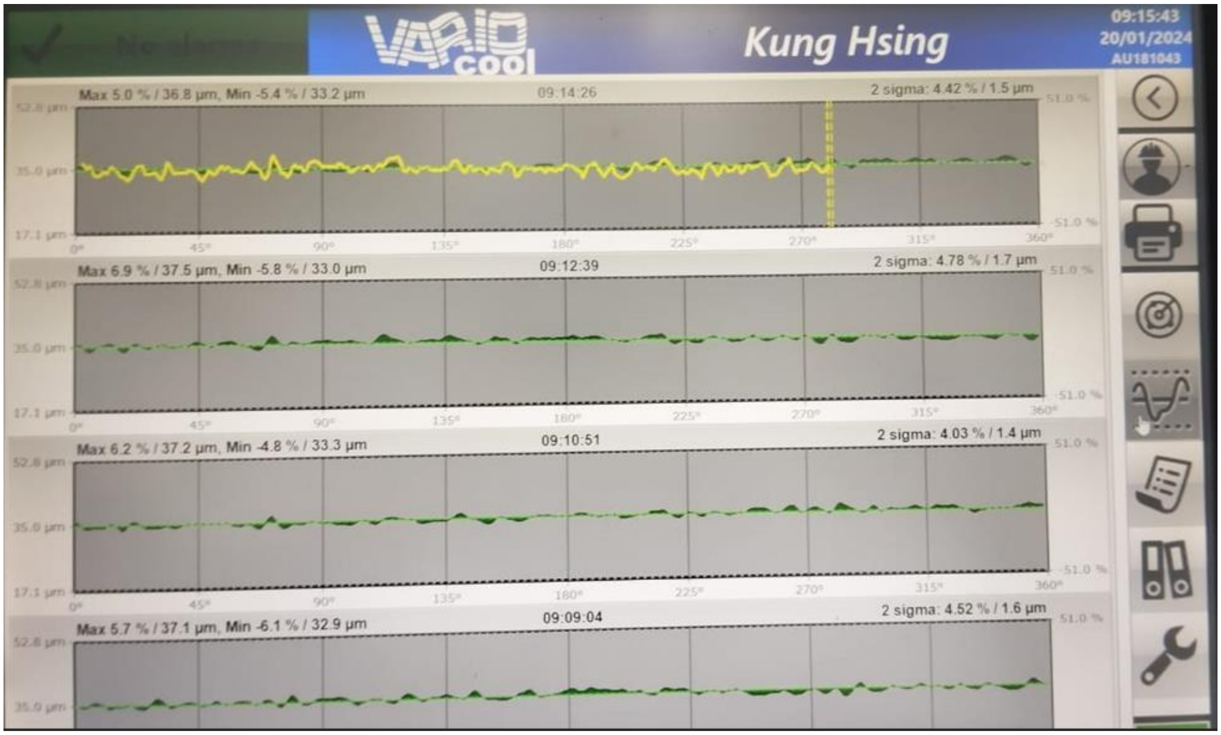


Figure 20: Auto Thickness controller

Figure 21: Auto display monitoring board

10.1.3 Corona treatment: "Corona" is a treatment used to increase the surface energy of the film to help with bonding of adhesives or inks. Corona is a high frequency electric discharge directed at a surface. It results in an improvement in the chemical connection (dyne/cm) between the molecules in the surface and the applied media/liquid. This surface treatment neither reduces nor changes the strength or appearance of the material.

10.1.3.1 Corona Equipment:

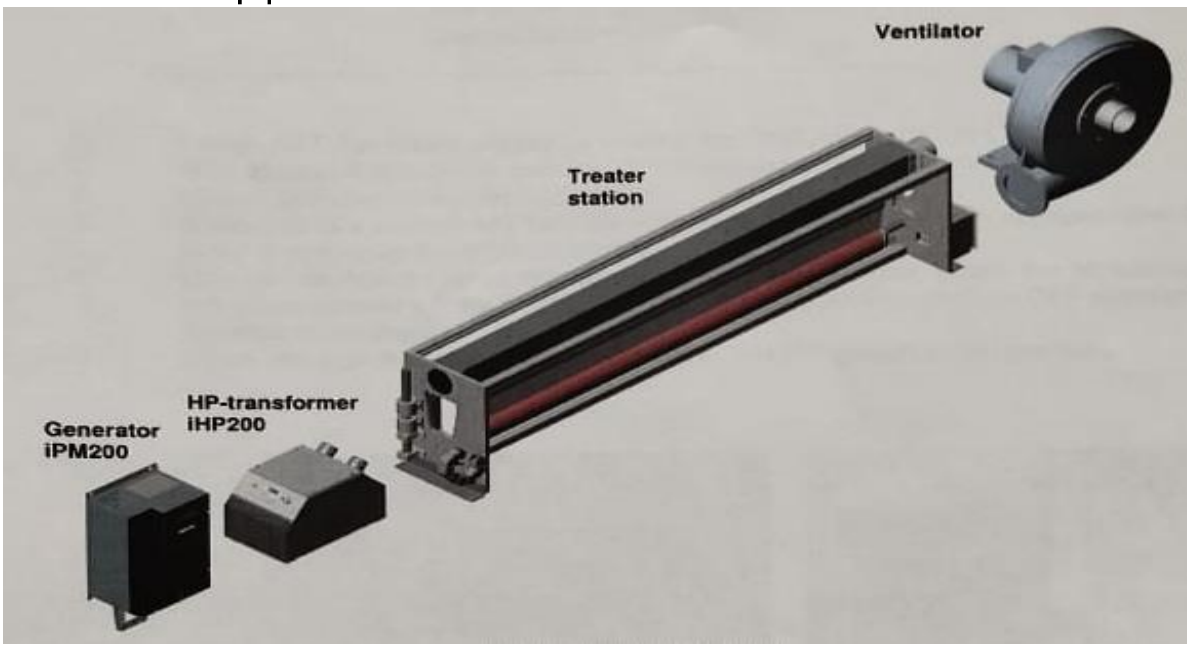


Figure 22: Example of a Corona Equipment

The equipment is composed of four basic parts:

a. A generator module (Power module): IPM 200
b. A high voltage transformer: IHP 200
c. Treater station and
d. An exhaust system (Optional): Ventilator

The pre-treatment itself is carried out in the treater station, where a system of electrodes gives an efficient electrical discharge on the film. The electrical power comes from the generator and the high voltage transformer. During the discharge in the treater station, heat and ozone are created and that's why an exhaustion of the air in the treater station is necessary.

The electrical system consists of a strong power supply, ensuring an efficient DC tension to the output stage. The output amplifiers are designed with IGBT (Insulated Gate Bipolar Transistor) in order to ensure a reliable working environment. The output signal from the generator is connected to the high voltage transformer which step up the power to the electrodes. The control and monitoring parts are taken care by a generator to which the remote control/BUS (A grouping of signals that share a common function) interface and the control signals are connected.

The electrical corona principle is centered on a resonant circuit. The working frequency of the electronic system is controlled automatically by a feedback system to a frequency between 10 – 40 KHZ. This ensures a maximum frequency and thus an optimal pre-treatment.

The corona effect comes from a specially designed IHP-transformer with a minimum power loss and optimum output voltage. The discharge emanates from the electrodes onto the film surface on the roll. The generator output power is controlled by a pulse-width modulation principle (PWM power). Keeping the power supply constant to the IGBT switch transistors and adjusting the power; i.e., the treating effect according to the time factor. This is the way how avoid the dangerous high tension potential which caused pinholes.

10.1.3.2 The electrical process of Corona Equipment altering the surface energy:
This can be performed in several ways. Plastic is a man-made synthetic material, which contains long homogenous molecular chains that form a strong and uniform product. The chains of molecules are normally joined end to end forming even longer chains, leaving only a few chain ends and free valences are formed. The free valences are then able to form carbonyl groups with the atoms from the ozone created by the electric discharge which offers the improved adhesion. The adhesion is further enhanced by the cleaning effect that the ozone causes, by oxidation of the surface of the material.

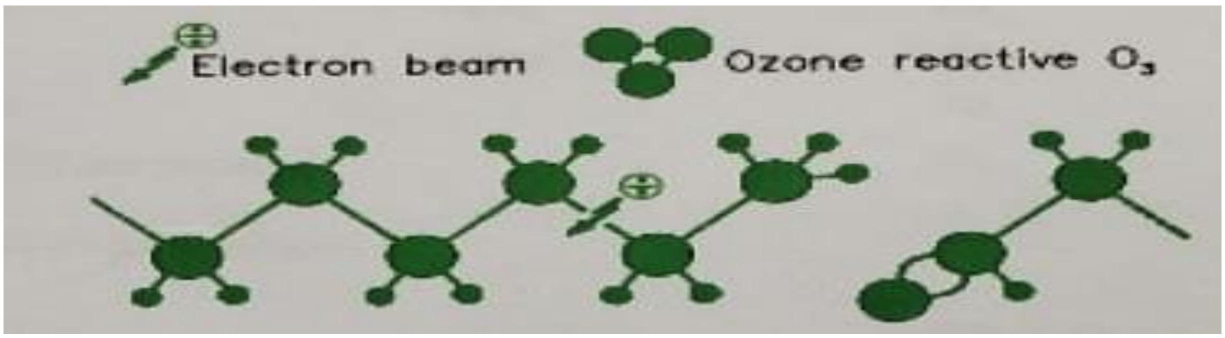


Figure 23: PE molecular chain ruptured by corona discharge
In spite of the fact that accelerated electrons cause rupturing of the surface, the strength of the material is not affected as the reactive force of the upper molecular layers dramatically reduces the acceleration. Thus the essential properties of the material are maintained and less than 0.1 µ of the material is penetrated.

10.1.3.3 Power calculation: Power (P) = T. S. W. M; where.
P = Total power required in watt
T = Number of sides to treat (single/double sided)
S = Line speed in meters per minute
W= Film width in meters
M= Material factor required watt / m^2 / minute; i.e., the number of watts required to raise the surface energy of a film to expected level. The factor typically varies between 10 – 50 for most of the materials depending on type of material, age, additive contents etc.

10.1.3.4 Material-Factor curves:
The increase in surface energy (Dyne/cm) that is induced into a film begins to decay immediately following treatment and again this depends upon the same factors mentioned in below Material-Factors curve with the additional considerations of the storage conditions and temperatures. But it is difficult to treat a material the quicker it is likely to decay with time. It has been established that film with very high slip additives (Over 1200 ppm) can be totally resistant to printing just 24 hours after treatment and it may be necessary to process the film immediately following treatment or boost the treatment in line with the printer. Aging of such film can render them impossible to treat if they are not treated during production.

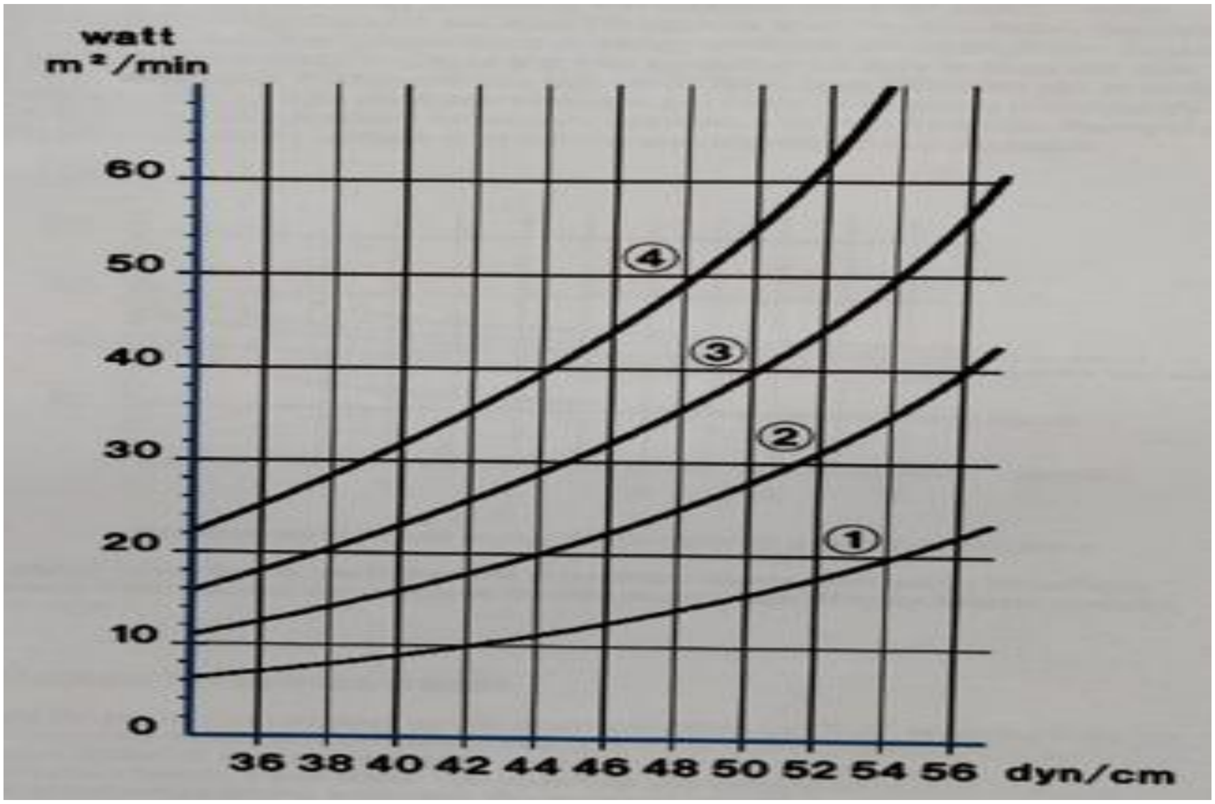


Figure 24: Material-factor curves

10.1.3.4 Tables showing required power for different materials:
Following the above material-factor curves, below is the table for different material vs. different condition vs. required power are as follows:

Material status	Material condition	Material	Applicable curve/Power
Low slip	Freshly extruded	Polyethylene (PE)	Curve 1
Medium slip	Freshly extruded	Polyethylene (PE)	Curve 2
High slip	Freshly extruded	Polyethylene (PE)	Curve 3
Low slip	Aged	Polyethylene (PE)	Curve 2
Medium slip	Aged	Polyethylene (PE)	Curve 3
High slip	Aged	Polyethylene (PE)	Curve 4
Embossed PE	-	Polyethylene (PE)	Curve 2
Post treated PE	-	Polyethylene (PE)	Curve 2
Polypropylene (Co-polymer)	-	Polypropylene (PP)	Curve 1
Polypropylene (Homo-polymer)	-	Polypropylene (PP)	Curve 3
Oriented Polypropylene	-	OPP	Curve 3
Biaxial-oriented Polypropylene	-	BOPP	Curve 4
Polyester Pure Material	-	PET	Curve 1
Polyester with additives	-	PET	Curve
Alu-Foil	-	Aluminum	20 watt m^2/minute

Kraft paper (Before coating)	-	-	16 watt m^2/minute
PE Foam (more than 3o kg/m^3)	-	Per 56 dyne/cm	50-200 watt m^2/minute

Table 4: Material vs. Curve type/Power

10.1.3.6 Durability of the treatment:
The level of treatment decays more quickly immediately following treatment and less rapidly as the time passes depending on different dyne/cm start levels.

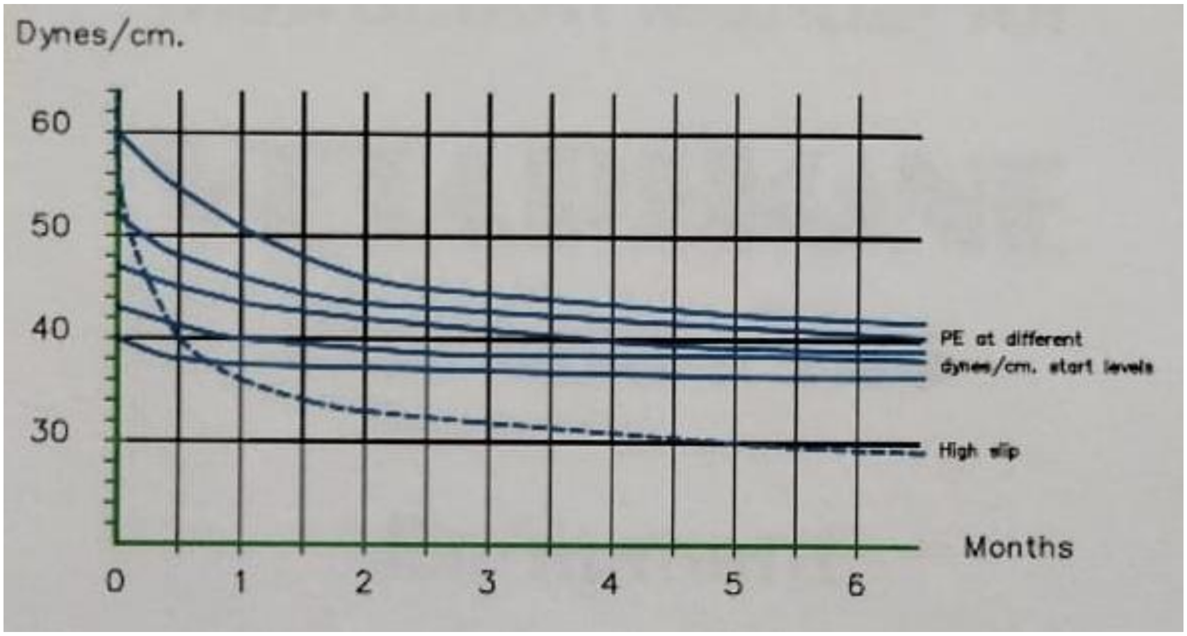


Figure 25: Typical delay in surface energy on PE materials over a 6-month period

10.1.3.7 Measuring the Surface Energy:
The surface energy is determined visually by estimating how the liquid (Dyne solution) reacts within the first two seconds following application. The test liquid can shrink and/or form itself into globules (Individual droplets) or it can remain unchanged. When a test liquid shrinks or forms into droplets, it indicates that the film has a lower surface energy. The test should be repeated as many times as necessary with a liquid of a lower surface tension until it remains unchanged for a period of two seconds or more. Once that has been achieved, the film can be said to have that level or surface energy at least equal to that of the liquid applied. Further applications should be made until shrinkage or droplets occur within two seconds. This last measurement should be taken as failure and the surface energy of the liquid used for the previous measurement should be taken to be the surface energy of the film. Sample prepared from a mixture of solutions-Formamide & 2-Ethoxyethanol (Cello solve) known as "Dyne". Mixing proportions are as follows:

Formamide	Ethyl Cello solve	Wetting Tension
0	100	30

10.5	89.5	32
26.5	73.5	34
42.5	57.5	36
54	46	38
63.5	36.5	40
71.5	28.5	42
78	22	44
83	17	46
87	13	48
90.7	9.3	50
93.7	6.3	52
96.5	3.5	54
99	1	56

Table 5: Dyne mixing proportions

10.1.3.8 Typical required dyne/cm and slip additives:

Manufacturing operation	Dyne value, dyne/cm	Applicable for items
Printing	40 -42	Solvent Inks
Printing	46 -48	Water based inks
Coating	44 - 54	Depending on coating type
Lamination	46 - 48	Solvent adhesives
Lamination	54 - 56	Water based adhesives

Table 6: Manufacturing operation vs. Dyne vs. Item

Slip additives, ppm from	Slip additives, ppm to	slippery status
0	400	Low slip
400	700	Medium slip
700	1200	High slip
1200	2000	Extremely high slip

Table 7: Slip Additives vs. Slippery status

10.1.4 Sample preparation: A transparent or Opaque Polyethylene (PE) film is produced in the "Blown Film Process". Ideally, a 3-layer PE (Polyethylene) consisting of Metallocene LLDPE/LDPE (Metallocenes are organometallic compounds that contain a metal atom; e.g., Fe, Cr, Ti, Mn, etc.), Normal LLDPE/LDPE, Master batch and/or Slip Agent following a specific Recipe. Recipe (s) vary from item to item as well as Customer to Customer. **2 (Two) Sample Recipe ae as follows:**

Outer		Middle		Inner	
Resin Name	**Percentage, %**	**Resin Name**	**Percentage, %**	**Resin Name**	**Percentage, %**
Metallocene LLDPE (Non-Slip)	70	Metallocene LLDPE (Non-Slip)	45	Metallocene LLDPE (Slip)	59.25
Normal LLDPE (Non-Slip), Grade 1	10	Normal LLDPE (Non-Slip), Grade 1	20	Normal LLDPE (Non-Slip), Grade 1	20
Normal LLDPE (Non-Slip), Grade 2	20	Normal LLDPE (Slip),	15	Metallocene LLDPE (Non-Slip)	20
		Metallocene LLDPE (Non-Slip)	20	Slip Agent	0.75
Total	100		100		100

Table 8: Sample Recipe -1 for Initial Atta pack Packaging, PE (Polyethylene Preparation).

Outer		Middle		Inner	
Resin Name	**Percentage, %**	**Resin Name**	**Percentage, %**	**Resin Name**	**Percentage, %**
Metallocene LLDPE (Non-Slip)	68	Metallocene LLDPE (Non-Slip)	40	Metallocene LLDPE (Slip)	68.50
Normal LLDPE (Non-Slip), Grade 1	20	Normal LLDPE (Non-Slip), Grade 1	35	Normal LLDPE (Non-Slip), Grade 1	25
Master Batch White	12	Normal LLDPE (Slip),	13	Metallocene LLDPE (Non-Slip)	5
		Master Batch White	12	Slip Agent	1.50
Total	100		100		100

Table 9: Sample Recipe -2 for Initial Shampoo laminate Packaging, PE (Polyethylene Preparation).

As per Recipe, all granules (Resins) are introduced inside each & every industrial mixer/Hooper of 3-layers (Outer/Middle/Inner) and finally through combination of all layers, expected blown film has been manufactured.

10.1.5. Analytical tests: All quality parameters of PE have been maintained as per requirements including Dyne test COF test, Dropping test and Dart impact value.

10.1.5.1. Dyne test results can be used to determine the suitability of a material for printing, coating, or laminating. A dyne level of 32 dynes/cm or higher is typically required for these applications. Dyne test results can also be used to determine the cleanliness of a surface prior to bonding or sealing.

10.1.5.2. COF test, Static coefficient of friction (SCOF) is the frictional resistance one pushes against when starting in motion. Dynamic coefficient of friction (DCOF) is the frictional resistance one pushes against when already in motion. The COF represents the resistance to movement between two objects, higher COF indicates greater friction and slip resistance.

10.1.5.3. Drop testing is a procedure used to evaluate how a package and its contents react to impacts such as free-falls, tumbles, and other types of handling during the shipping and distribution environment.

10.1.5.4. Dart value covers the dart impact (Impact resistance or impact failure load) of Polyethylene films is defined as the weight of a hemispherical shaped dart falling on the film held on a suitable clamp from a specific height that causes failure of specimens tested.

10.1.5.5. Quality standards:

Quality observations			
Quality parameter	**Category standard**	**Unit**	**As found in PE**
Dart value	5g x μ of PE	g	450
SCOF value, static	0.100 - 0.300,	μ (mu)	0.124-0.245
DCOF value, dynamic	0.100 - 0.300,	μ (mu)	0.097-0.188
Tensil displacement	350 minimum	mm	550
Tear Strength	≤ 5.0 N	Newton, N	5.2 - 5.5
Treatment dyne	minimum 40	dynes/cm	40

Table 10: Quality Standards of PE (Polyethylene)

10.1.5.6. Golden rule (s) are: the more the dart value, the more the drop ability achieves and the more the COF value, the less the slippery of the item.

10.1.5.7. Safety precautions: All Safety measures including PPE (Personal Protective Equipment) should be taken before starting the machine / operation.

10.2. Cast Film Process: In the cast film process, the polymer is molten and cast through a flat die into the form of a long sheet.

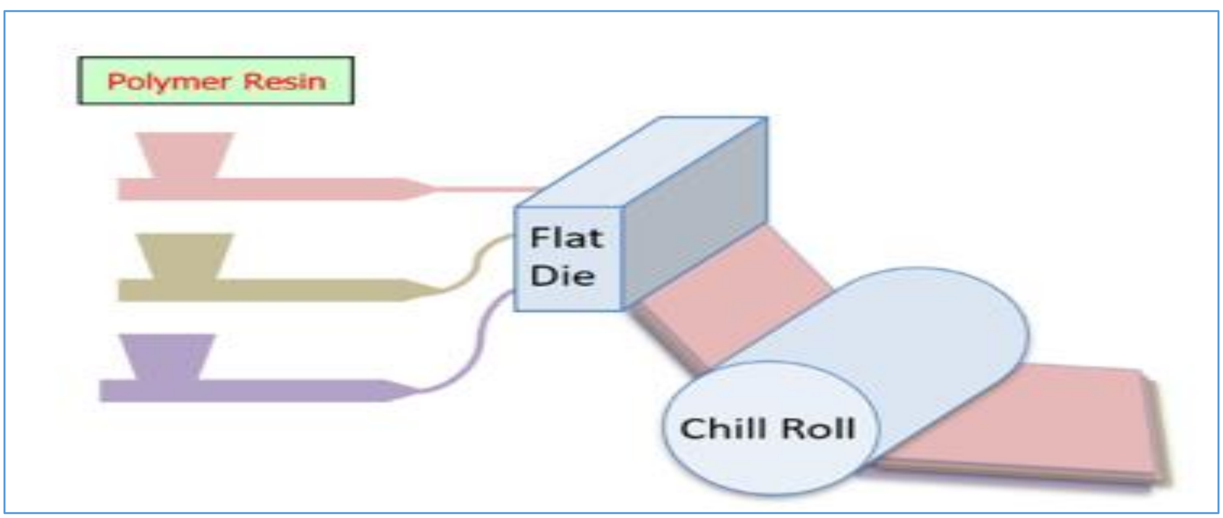


Figure 26: Cast Film Process

The polymer is extruded through a FLAT DIE either onto a chilled 'quenching' roll or into a water bath. Cast films generally have superior optical properties, are more common for thicker films and typically co-extrusion films, which means that different material layers are extruded (Fused) together.

10.3. Printing Process:

10.3.1 Scope: Rotogravure (or gravure for short) is a type of intaglio printing process, which involves engraving the image onto an image carrier. In gravure printing, the image is engraved onto a cylinder because, like offset printing and flexography, it uses a rotary printing press. Gravure printing is characterized by excellent print quality and high printing speed. Its further advantages are that it involves a simple printing process, accurate ink use, and the flexibility of printing machine structures. Gravure printing, due to several technological innovations, now belongs to innovative technologies. In many packaging applications, plastic films are printed to convey information to the user. When printing is desired, it is usually done on roll stock before packages, such as pouches, are formed. Printing on formed flexible packages is usually limited to date or lot coding.

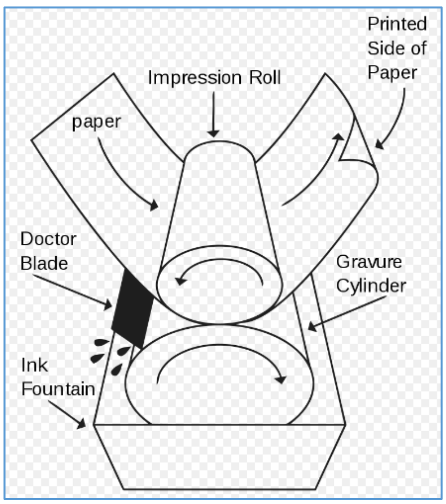


Figure 27: Printing Norm

Although the rotogravure printing process is not the most popular printing process used in flexible-packaging manufacturing, it does have the ability to print on thin film such as polyester, polypropylene, nylon, and polyethylene, which come in a wide range of thicknesses, commonly 10 to 30 micrometers. Other appreciated features include:

- printing cylinders that can last through large-volume runs without the image degrading
- good quality image reproduction
- low per-unit costs running high volume production

10.3.2. Procedure/SOP: There are BOBST with 10 colors, achieving speeds of up to 300 meters per minute without compromising on print quality and 8/10 color Long New and Worldly. The gravure ink is very low viscosity (12 – 20 cps), and there are two types - solvent-based and water-based.

10.3.3. Printing Principle: The rotogravure process is a direct transfer method for printing onto wood-pulp fiber based, synthetic, or laminated substrates, including Films such as polyester, OPP, nylon, Aluminum film and PE.

Figure 28: Printing Machine – BOBST, LONGNEW and WORLDLY

The modern day rotogravure printing press uses a printing cylinder which has been laser engraved with minute cells capable of retaining ink, the size and pattern of which reflect the required image. These cells are forced to transfer their ink directly onto the substrate by a combination of pressure and capillary action, so producing the printed image. The process, also commonly called gravure printing, is used in the manufacturing of food and non-food packaging, as well as labels, wall coverings, transfer printing, and has a variety of further applications in the security printing, industrial, and tobacco segments of industry. The whole process comprises of:

a. Printing Cylinder
b. Doctor Blade
c. Impression roller
d. Drying system

10.3.4. Process Description: During the gravure printing process the printing cylinder rotates in the ink pan where the engraved cells fill with ink. As the cylinder rotates clear of the ink pan, any excess ink is removed by the doctor blade. Further around, the cylinder is brought into contact with the substrate, which is pressed against it by the rubber covered impression roller.

The pressure of the roller, along with the capillary draw of the substrate, results in the direct transfer of ink from the cells in the printing cylinder to the surface of the substrate. As the printing roller rotates back into the ink pan, the printed area of the substrate proceeds through a dryer and onto the next printing unit, which is normally a different color or may be a varnish or coating. Precise color to color registration is made possible via automatic side and length register control systems. For a web-fed printing press, after each color has been printed and any coatings applied, the web is 'rewound' into a finished roll.

10.3.5. Analytical tests: Providing excellent adhesion levels on all substrates, when applied to BOPP and CPP films, it provides enhancement of oxygen (OTR) and water vapor (WVTR) barrier performance. For BOPP films, OTR values decrease to less than 10 $cm^3/(m^2\ d)$ and on CPP values of less than 5 $cm^3/(m^2\ d)$ can be achieved. On both substrates, WVTR levels of $< 0.1\ g/(m^2\ d)$ can be obtained. Moreover, this has also been shown to significantly increase dyne level retention, even at times of high humidity, which translates in improved ink wettability during printing.

Scotch tape test for print quality and treatment dyne test for dyne level retention should be performed as well as appropriate solvent ratio should be maintained. For instance, sample ratio (s) for Vinyl and PU Ink based on Ink Suppliers TDS are as follows:

Solvent Ratio							
Solvent 1	**Solvent 2**	**Solvent 3**	**Ratio 1**	**Ratio 2**	**Ratio 3**	**Grand Total**	**Ink Category**
Ethyl Acetate	Toluene	MIBK	45	45	10	100	**Vinyl**
Ethyl Acetate	Toluene	-	40	40	20	100	
Ethyl Acetate	Toluene	-	60	40	-	100	
Ethyl Acetate	Toluene	-	50	50	-	100	
Toluene	MEK	IPA	40	40	20	100	**PU**
Toluene	MEK	IPA	50	40	10	100	
Ethyl Acetate	MEK	IPA	40	40	20	100	

Table 11: Solvent Ratio for Ink

10.3.6. Tips for Vinyl Ink:

a. 6% BOPP Additive can be added to ink & medium by weight to enhance the application on corona treated BOPP film. (38-42 dynes/cm).
b. Ethyl acetate can be replaced by MEK (Methyl ethyl ketone) for relatively better graphic reproduction.
c. Recommended to use corona treated polyester film with surface energy approx. (≥48 dynes/cm), to achieve higher bond strength than that achieved by using normal polyester film.

10.3.7. Tips for PU (Polyurethane) Ink:

d. Solvent-based PU (Polyurethane) ink binder has the advantages of easy use, stable performance, strong adhesion, excellent gloss, good heat resistance, etc.
e. It can meet the requirements of various printing methods, especially for screen printing, plastic packaging and composite films, etc. aspect.
f. Excellent freeze thaw resistance: making the ink suitable for the extreme cold weather countries.
g. Extra-ordinary good dot-transfer properties.

10.3.8. Safety precautions: Due to potential health effects of chemicals used in printing process like solvents and inks can irritate the skin leading to dermatitis, appropriate all Safety measures including PPE (Personal Protective Equipment) should be taken before starting the machine / operation.

a. Eye & Face - Wear safety glasses with side shields or goggles when handling this material
b. Skin - Wear impervious gloves and appropriate protective clothing as required to minimize contact with skin
c. Respiratory - A half-face organic vapor respirator maybe worn for protection up to ten or full-face respirator.

Figure 29: Safety requirements @Printing

10.4. Lamination process (Common):

10.4.1. Scope: Lamination is the process of combining two webs of film together. In flexible packaging applications, lamination is often used to combine a plastic film with paper or foil, or to join paper and foil together. This involves bonding multiple layers of materials to enhance barrier properties, strength, and overall performance. These layers, often including films and foils, are combined using adhesives under controlled pressure and temperature, resulting in a durable, multi-layered structure that provides optimal protection and preserves the integrity of the packaged contents.

Another significant use of lamination is to produce a web with buried printing. In these materials, one web is reverse-printed, and is then laminated to a second web, either made from the same or a different polymer. The printing can be seen through the transparent plastic, and is protected against abrasion so it maintains a fresh attractive appearance much better than surface-printed materials.

Benefits of laminating different materials altogether are:

a. Ability to combine many properties at minimum delivered cost
b. Reduced packaging weight and
c. Available large print area compared to total surface.

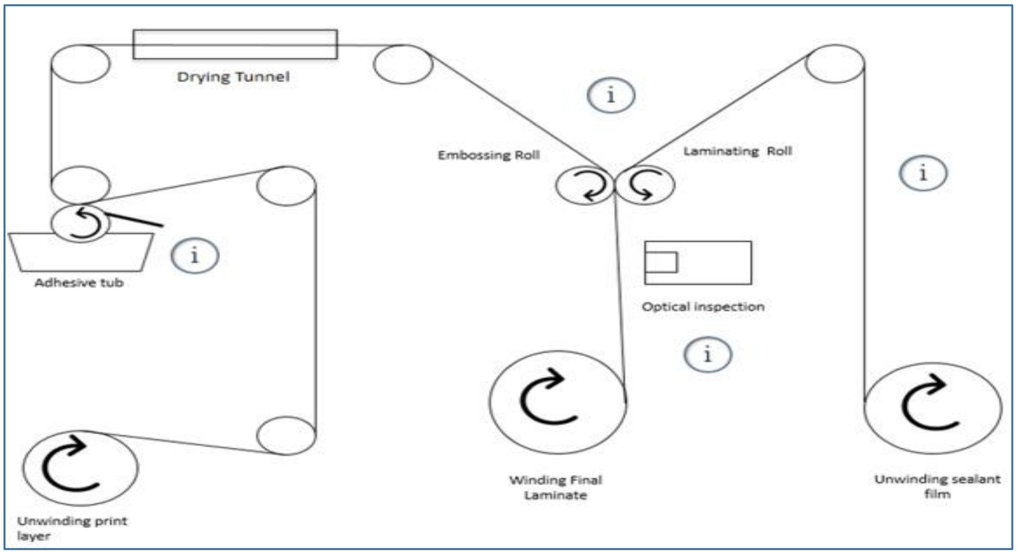


Figure 30: Lamination Norm

10.4.2. Ideal Procedure/SOP: An adhesive is applied to the less absorbent substrate web, followed by the pressing of the second web to form a duplex, or two-layer, laminate. The excess adhesive is removed by a blade, and the laminate is wound on a roll. The finished laminate can be used as a packaging material, a printing substrate, or a label. Simultaneously, proper curing time (At least 48 hours, 72 hours is preferable) should be maintained.

10.4.3. Safety precautions: Due to potential health effects of chemicals used in lamination process like solvents and Adhesive-Hardener can irritate the skin leading to dermatitis, appropriate all Safety measures including PPE (Personal Protective Equipment) should be taken before starting the machine / operation. To guard against injury, safety precautions must be observed in the installation and use of the laminator Keep hands, long hair, loose clothing, and articles such as necklaces or ties away from the front of the heat and pull rollers to avoid entanglement and entrapment.

10.5. Lamination process (Solvent Based-SB): Uses solvent as carrier for adhesive/glue transfer.

10.5.1. Procedure/SOP: Solvent-based lamination is the process of combining two or more different films to create a packaging material in flexible packaging. This process is accomplished using a solvent-based adhesive that requires high barrier properties. Solvent-based laminating adhesive is a type of adhesive that is dissolved in a solvent to create a liquid adhesive that can be applied to a wide range of materials. The solvent evaporates, leaving behind the adhesive, which hardens and bonds the materials together. The lamination process is based fundamentally on the below principles:

a. Thin-layered materials such as aluminum foil or sheets of foil are coated with adhesive and successively glued together layer by layer,
b. A mechanical cutter or laser is used to precisely cut the successive layers before bonding them together (which can be form-then-bond or bond-then-form).
c. The form-then-bond method allows the removal of excess material prior to bonding, which facilitates effective thermal bonding of ceramic and metallic materials and the fabrication of internal features.

d. Excess materials leftover after cutting can be used as support and subsequently removed or recycled.

Figure 31: Lamination Machine (SB) LONGNEW & WORLDLY

10.5.2. Analytical tests: Laminates are tested just like a metal or polymers sheets in tension, Temperature, compression, shear, torsion, thickness, GSM, elongation, heat seal strength, ink coating including coating pressure for reference, gum coating (**Thumb rule: Gum coating should be higher than ink coating by at least 0.5 gsm)** etc. But there are some testing unique to laminates. These are Bond strength/peel test, swell test, lap shear test, water resistance test, Curling test etc. Apart from these parameters, below are the essential features:

a. Lamination gum ratio/Adhesive-Hardener mixing ratio should be maintained following Supplier TDS.
b. Customized ratio can also be implemented based on appropriate R &D and long term testing/historical results/data. For instance, there can be the different ratio for air associated items like cake packaging and non-air associated items like biscuits packaging.
c. Similarly, this ratio can be the different for the items consisting of 40 μ and greater than 40 μ items.

10.5.3. Hardener dilution: Hardener has to be diluted under stirring with the corresponding solvent to the desired application solids (35 – 40%). Specimen dilution table can be as per below:

Hardener (OH Component), Kg	Adhesive (NCO Component), Kg	Solvent (Ethyl Acetate), Kg	Solid Content, %	Viscosity, cps
10	2.10	9.11	45	17 - 22
10	2.10	11.75	40	15 - 22
10	2.10	15.14	35	14 - 17

Table 12: Hardener dilution @SB Lamination

And specimen mixing ratio can be as per below:

Hardener (OH Component)	Adhesive (NCO Component)	Solvent (Ethyl Acetate), Kg	Solid Content, %	Viscosity, cps
5.5 parts by weight	100 parts by weight	69	40	23 - 24
5.5 parts by weight	100 parts by weight	94	35	20 - 22
5.5 parts by weight	100 parts by weight	126	30	18
5.5 parts by weight	100 parts by weight	178	25	16

Table 13: Hardener-Adhesive mixing Ratio @SB Lamination

10.5.4. Solid contents: Note that different Adhesive-Hardeners consists in different percentages of solids. For example, if an adhesive (NCO) consists in 66% solids, a hardener (OH) consists in 75 % solids and solvent (EA) consumption is 160 Kg, then the simple percentage calculation of solids should be is as per below:

NCO parts	% Solids of NCO	Total NCO	OH parts	% Solids of OH	Total OH	Solvent (EA), Kg	% NCO + % OH	Sum of (NCO + OH + EA	%Solids
100	*0.66*	*66*	*5.50*	*0.75*	*4.13*	*160*	*70.125*	*265.5*	*26.41*

Table 14: Adhesive-Hardener Solid calculation

10.5.5. Customized Ratio: Based on satisfactory R & D observations, I have been Sharing a customized mixing ratio, which can be as per below:

Sl.	Structure	Manufacturer's TDS Ratio					Customzsed Ratio					
		NCO, %	OH, %	Solvent (EA), Kg	Solid, %	Viscosity, cps	NCO, %	OH, %	Solvent (EA), Kg	Solid, %	Viscosity, cps	Justification for change
1	BOPP + MCPP items	*100*	*9*	*186*	*25*	*15 - 18*	*100*	*9*	*134*	*29.9*	*15 - 16*	*To remove Bursting/Sealing issue during lamination.*
2	PET + MPET /PET + Alufoil/PET + MCPP items	*100*	*13*	*190*	*25*	*15 - 18*	*100*	*5.5*	*160*	*26.4*	*13 - 14*	*To remove netal part separation issue during lamination.*
3	PET + LD upto 40 µ	*100*	*13*	*190*	*25*	*15 - 18*	*100*	*13*	*140*	*29.9*	*16 - 20*	*No change*
4	PET + LD, 40 µ +	*100*	*13*	*190*	*25*	*15 - 18*	*100*	*13*	*104*	*34.9*	*22 - 25*	*No change*

Tablec15: Customized Adhesive-Hardener Ratio

10.6. Lamination process (Solvent less-SL): Solvents are not used, uses 100% pure adhesive/glue.

Figure 32: 4 COMBI Lamination machine (SL) - NORDMECCANICA

10.6.1. Procedure/SOP: Solvent less lamination machines promote environmental sustainability by eliminating the use of harmful solvents, reducing emissions and creating a safer working environment. This eco-friendly approach aligns with modern manufacturing standards, delivering high-quality, laminated packaging solutions with minimal ecological impact. Solvent less lamination is a method of laminating different materials without using solvents. In the packaging printing industry, this method is becoming increasingly popular due to its environmental benefits and cost-effectiveness. Since solventless laminating adhesives do not require a carrier, converters that run solventless adhesives increase the sustainability of their operations, as they do not need to invest in driers that consume high energy and require less VOCs and HAPs emission and exposure control. Here are some of the pros and cons of using Solventless lamination in the packaging printing industry:

10.6.2. SL lamination Pros:

1. Environmental Benefits: Solventless lamination eliminates the need for solvents, which are harmful to the environment. This process reduces the emission of volatile organic compounds (VOCs) and helps to decrease pollution.
2. Improved Safety: Solventless lamination reduces the risks associated with the use of solvents. This process eliminates the risk of fire or explosion and ensures a safer work environment.
3. Cost-Effective: solvent less lamination is a cost-effective alternative to solvent-based lamination. This process eliminates the need for solvents, reducing the cost of raw materials, and the cost of waste disposal.
4. Improved Quality: solvent less lamination provides a high-quality bond between materials. This process ensures a stronger and more durable bond, reducing the risk of delamination.

10.6.3. SL lamination Cons:

1. Slower Production: Solventless lamination can be slower than solvent-based lamination. The process requires more time to cure, resulting in a slower production rate.
2. Limited Availability: Solventless lamination is not available for all packaging applications. Certain materials may not be compatible with solventless lamination, limiting its availability.
3. Limited Color Options: Solventless lamination is limited in terms of color options. This process does not offer the same range of color options as solvent-based lamination.
4. Higher Initial Investment: Solventless lamination requires a higher initial investment in equipment. This process requires specialized equipment and may require modifications to existing equipment.

In conclusion, Solventless lamination offers many advantages in terms of environmental benefits, safety, cost-effectiveness, and improved quality. However, there are also some drawbacks such as slower production, limited availability, limited color options, and higher initial investment. When considering whether to use Solventless lamination, it is important to weigh the pros and cons and determine if it is the right choice for your specific packaging printing needs.

10.6.4. Analytical Tests:

Solventless laminating adhesives contain 100% actives and do not have water or solvent carriers. These laminating adhesives are typically used in flexible packaging applications. They are specifically two-component adhesives consisting of an isocyanate and polyol that are mixed and react to form polyurethane. Solventless processes do not require the use of solvents at all. In most cases, means of mechanical separation, heat, and pressure are used to produce extracts.

The key difference in the final product is that solventless extracts will contain no residual solvents at all. As the process does not contain any solvent, therefore the process is also called a solid-state chemical reaction.

10.6.5. Adhesive Hardener mixing Ratio:

Adhesive (NCO Component) Solid Content, %	Viscosity, cps	Hardener (OH Component) Solid Content, %	Viscosity, cps	Mixing Ratio, by weight	
				Metalized	Non-metalized (Poly)
100	1000 - 2000	100	500 - 1500	100 : 80	100 : 60
100	1000 - 2000	100	2000 - 4000	100 : 75	100 : 60

Table 16: Hardener-Adhesive mixing Ratio @SL Lamination

Both components are mixed using the MMD (Meter, Mix and Dispensing) device, at a recommended ratio. Adhesive is fed through dosing gap on to the roller pre-heated at 35–45° C; proper tension controls are maintained. Few special guidelines are:

a. Ensure machine is cleaned by air pressure and wet cloth dipped in Ethyl Acetate
b. Left-over mixed adhesive drum should be closed tightly. Check the viscosity from time to time
c. Laminating substrate should have minimum 38 dynes level treatment
d. Check coating gsm on the laminating substrate, across the width
e. Ensure that laminate being produced, gives appropriate green bond, by putting sample in the oven for 30 min at 60°C.
f. Ensure that the laminates do not have issues such as speckling, orange peel effect
g. NCO Tank Temperature 42 - 45°C and OH Tank Temperature 42 - 45°C
h. R1 - R2 Temperature 40 - 45°C and Mixing and Transfer Roller Temperature 40 - 45°C.

10.7. Lamination process, Co-extruded-SL: Uses extruded (Melted) polyethylene (PE).

10.7.1. Procedure/SOP: Co-extrusion results in the production of a multilayer web without requiring initial production of individual webs and a separate combining step. The melted polymers are fed together carefully to produce a layered melt, which is then processed in conventional ways to produce a plastic film or sheet. When only plastics are being used in a flexible packaging structure, co-extrusion is generally preferred to lamination, unless buried printing is involved. Obviously, co-extrusion cannot be used to incorporate non-thermoplastic materials. The mechanical performance of the product for faster filling and scaling lines and also ensure better moisture barrier. In extrusion lamination, the molten polymer is applied as an adhesive layer between two substrates to form a laminated structure. Commonly used LDPE is Hanwha 955 with melt Index 7.7, well known for its excellent neck-in, draw-down and high quality assurance. Ideal layer structure: Pet, 12 μ / Print / LDPE, 20 μ / Aluminum-Foil, 7 μ / LDPE 955, 20 μ.

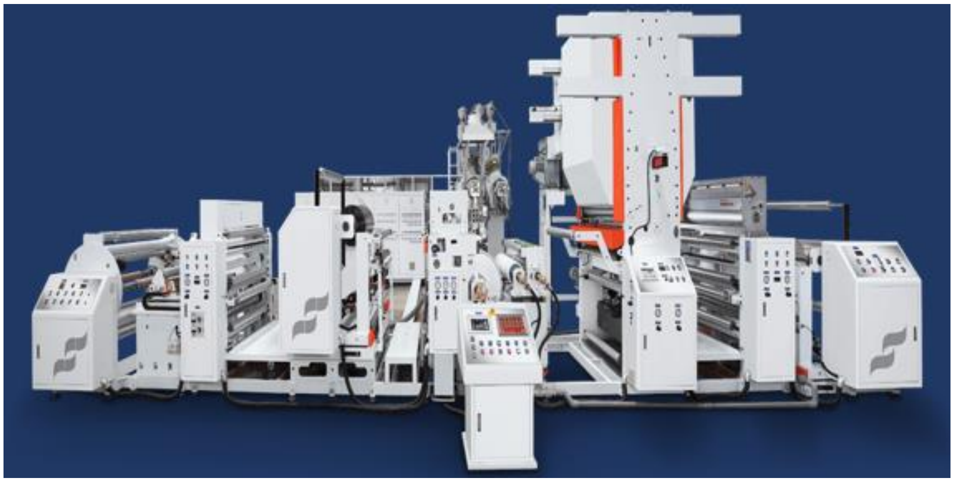


Figure 33: Co-Extrusion Machine

Extrusion lamination is one of the techniques used for laminating different materials, and is widely used as the manufacturing process for packaging films for products such as foods, cosmetics, and pharmaceutical products in order to obtain improved film properties such as gas barrier, heat sealing, and film strength. Extrusion lamination has a distinct advantage when thickness, stiffness, or puncture resistance are key considerations. This advantage lies in the bulk added by the molten resin.

10.7.2. Co-Extrusion Process: In the extrusion coating process, polyethylene is melted under heat and pressure in an extruder and the molten polymer is extruded through a slit die as a thin web. This web, at high temperature, is drawn down and coated onto a flexible substrate in a nip-roll assembly formed by a water-cooled chill roll and a rubber-covered pressure roll.
The substrate to be coated is fed continuously from an unwind reel over the rubber pressure roll into the nip where the laminate is formed by pressing the two layers together. The laminate is rapidly cooled by the chill roll and is taken up by a wind-up mechanism. A schematic drawing of a typical extrusion coating line is shown as per below:

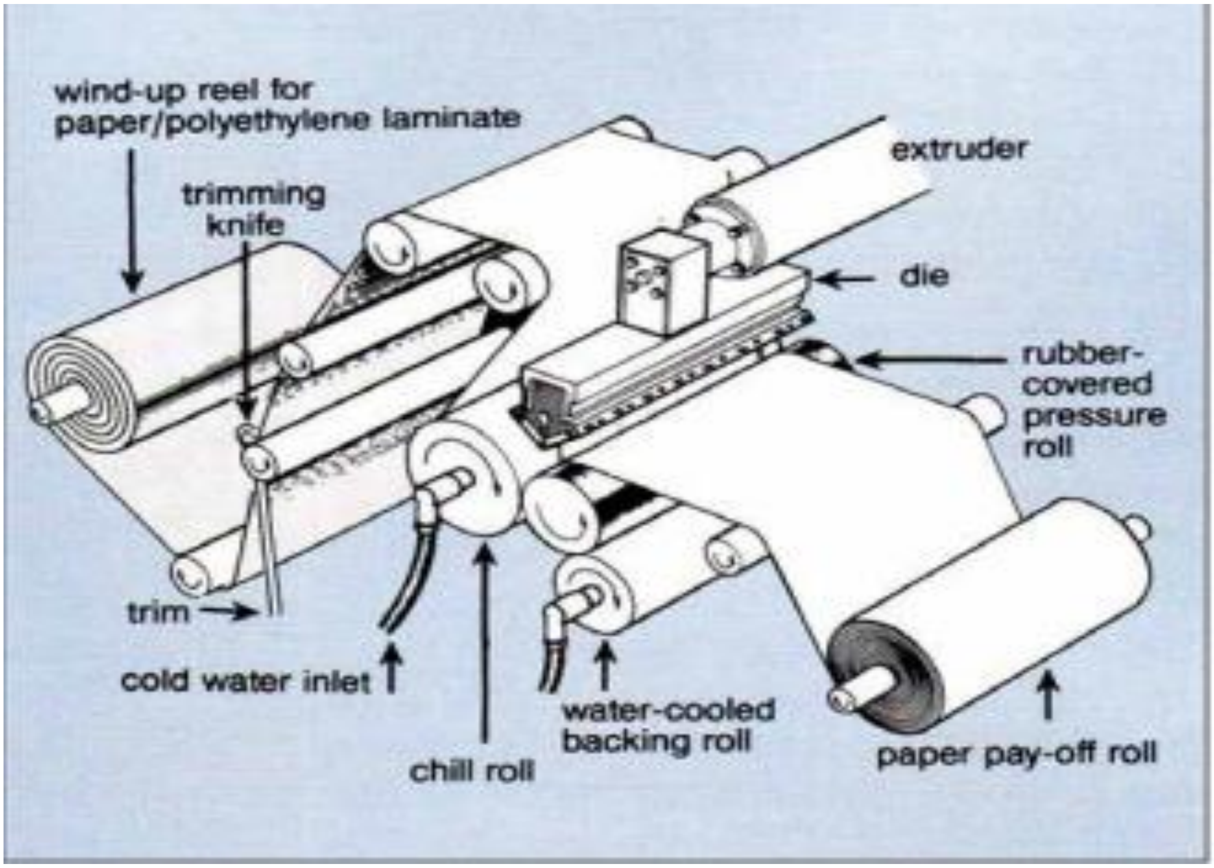


Figure 34: Co-Extrusion Operating Norm

10.7.3. Advantages of Co-extrusion:

A major advantage of co-extrusion over lamination is its ability to incorporate very thin layers of a material, much thinner than those which can be produced as a single web. This is particularly important for expensive substrates, such as those often used to impart barrier properties. The amount of the expensive barrier resin used need only be enough to provide the desired performance. The thinness of the layer is not limited by the need to produce an unsupported film and handle it in a subsequent lamination step. This enables the completion of multi-layer composite molding in a single process. Environmentally friendly, as it can be performed without the use of solvents or with low solvent content. The general benefit of the co-extrusion process is that every laminate ply imparts a required characteristic property like heat-sealability, stiffness, & impermeability, all of which are impossible to attain by using any single material. Some advantages are:

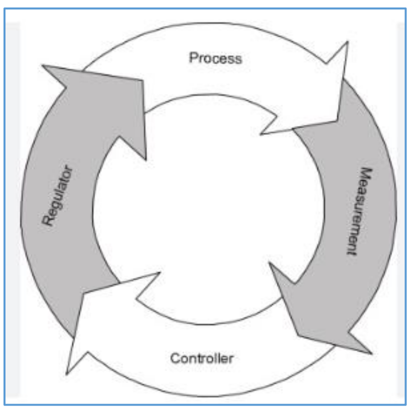
a. High quality mono-layer extrusion coatings in larger varieties of line speeds and widths
b. Use of lower cost materials for filling purpose, assists in saving on the amount of qualitative resins
c. Capability of making multi-layer as well as multi-functional structures that too in a single pass
d. Reduction in the number of steps required in general extrusion process
e. Provides targeted performance with the use of definite polymers in particular layers
f. Reduction in setup and trim scrap
g. Potential for use of a recycle layer

10.7.4. Disadvantages of Co-extrusion:

Requires skilled operation of the equipment. Few disadvantages are:

a. Minor differences in physical properties are responsible for making a combination desirable, but these differences are also responsible for making the combination incompatible
b. For this process, polymers must have similar melt viscosities to sustain a laminar flow. All the viscosity differences may be more or less tolerable, according to the material location inside the composite structure along with the layer's thinness
c. Requires more sophisticated extruder and its operator. This implies extra maintenance cost of the equipment.
d. Demands considerable planning as well as forethought in the system design

10.7.5. Analytical tests:
The main process parameters with the greatest effect on adhesion between the polymer and the substrate are: temperature of the molten polymer, thickness of the film deposited, Bond strength, Curling quality, treatment dyne, pressure of the rollers, extrusion speed, Extruder heat, die heat and air gap etc.



Extrusion lamination is achieved by unwinding two substrates, introducing an extruded polymer in between them (LDPE is common in our industry), and rewinding all three layers back together. In this process, the extruded polymer acts as the "glue", sandwiched between two other layers such as PET and LDPE.

Figure 35: Co-Extrusion Process

10.8. Lamination process (Water based-WB): Uses water-based adhesive for lamination.

10.8.1. Scope: Water-based lamination is a process of applying a water-based adhesive to a substrate and then applying a film or paper to the adhesive. This creates a laminated product that is environmentally friendly and has a clear, glossy finish. It is commonly used in the packaging industry for items such as food packaging and labels.

Figure 36: Water based lamination equipment

10.8.2. Procedure/SOP: The process comprises applying the water borne composition to a substrate, drying the composition, heating and softening the flexible material to be applied to the substrate, contacting the flexible material to the substrate, and vacuum forming the flexible material onto the substrate.

Water-based laminating adhesives use water as a carrier for their resins. These adhesives are subsequently dried after application to facilitate dry bond lamination. After drying, the adhesive resin system remains on the substrate to be bonded to a secondary substrate to form the laminate under heat and pressure. These water-based adhesives provide advantages in sustainability over solvent-based adhesives since they use water as their carrier; they do not release hazardous air pollutants or large amounts of VOCs (Volatile Organic Compounds) into the surrounding environment during the coating and drying process.

10.9. Inspection process:

10.9.1. Scope: Flexible packaging film inspection is the most comprehensive inspection solution for all types of flexible packaging. Small local defects are detected just as reliably as overall material property variations and corona treatment. Local defects are as follows:

a. Gels/Fish-eye defect detection
b. Pinhole defect detection
c. Scratch defect detection
d. Insect defect detection
e. Die line defect detection
f. Streak defect detection
g. Wrinkle defect detection
h. Air bubble defect detection etc.

Figure 37: Inspection Machine

10.9.2. Procedure/SOP: Inspection machine monitors 100% of the material surface to control the coating homogeneity on stretched film, the layers of metallized film, or the glue distribution of laminated film, and the transparency of BOPET/ BOPP film after stretching. It generates a homogeneity map of layer properties, i.e. coating regularity, surface structure, reflectance, and transparency, for the full width of the film. This allows identifying irregularities both in the base film and processed films, like metallized films and laminated films.

10.10. Slitting Process:

10.10.1. Scope: Slitting is a precision cutting process in which large rolls of material are transformed into narrower, tailored strips, enhancing flexibility and usability in various industries.

10.10.2. Procedure/SOP:

This technique ensures accurate width specifications and efficient handling of materials for diverse applications. In the slitting process, the big wide film rolls are unwound, cut into the right width and re-wound into multiple smaller rolls to the required dimension for the packaging forming machines. High speed Titan and DHA BHA are commonly used slitters.

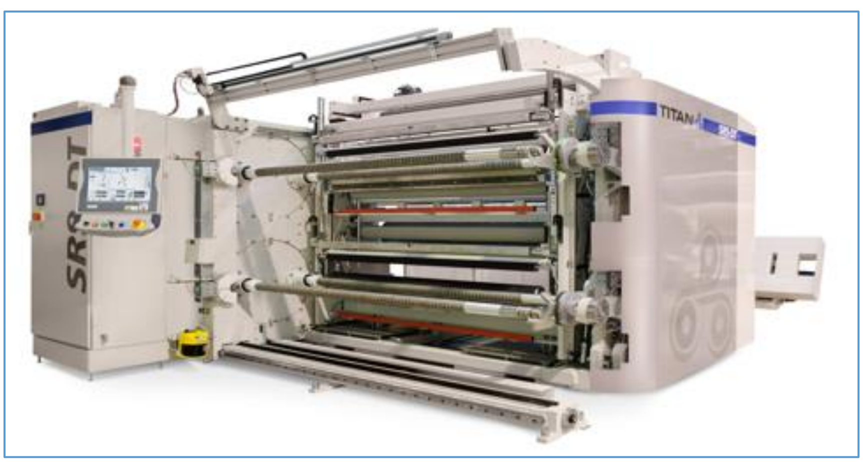


Figure 38: Slitting Machine

10.11. Finished Goods (FG) manufacturing Process:

10.11.1. Simple 2 ply laminate PET + PE and/or Multi-ply laminate:

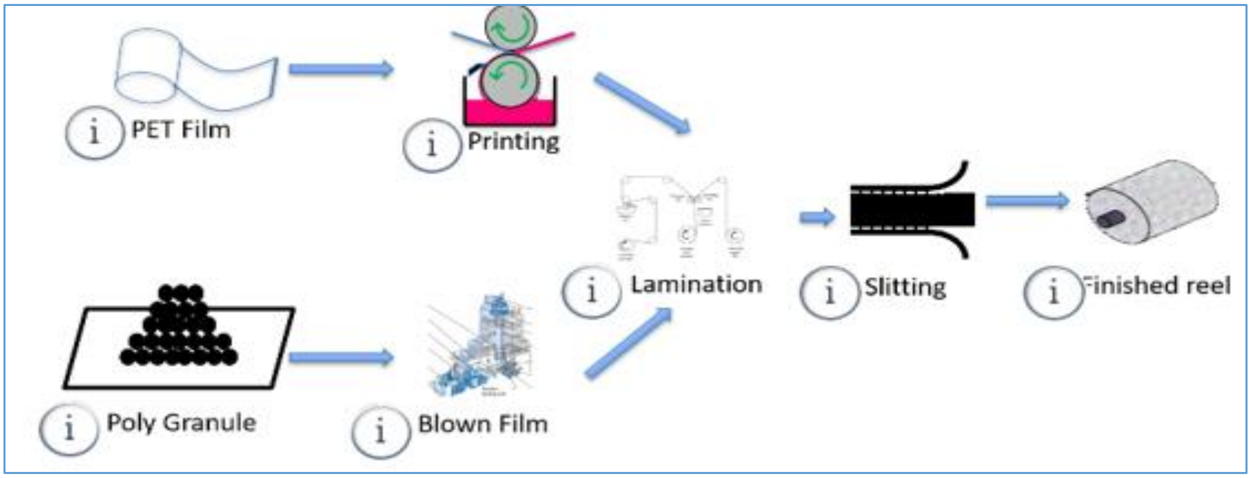


Figure 39: Finished Goods Manufacturing Flow chart

The packaging should be mono (one) layer or multi layers depending upon needs of the customer/consumer/functionality – e.g. glossy prints/barrier properties etc. The packaging layer are typically – Print layer + Barrier layer + Sealant layer. Note that the side that is later inside the laminate helps to avoid the color being scuffed or scratched off. Then PE and PET are laminated. They are glued together with the use of an adhesive. Few common composite structures are:

PET + PE (2 ply)
PET + MCPP (2 ply)
PET + MPET + PE (3 ply)
PET + PE (Co-extruded) + MPET + PE (4 ply)
PET + Aluminum foil + PE (3 ply)
PET + Aluminum foil + PET + PE (4 ply)
BOPP + MCPP (2 ply)
BOPP + MPET + PE (3 ply)
BOPP + Aluminum foil + PE (3 ply) etc.

10.11.2. Backbone analysis of Finished Goods:

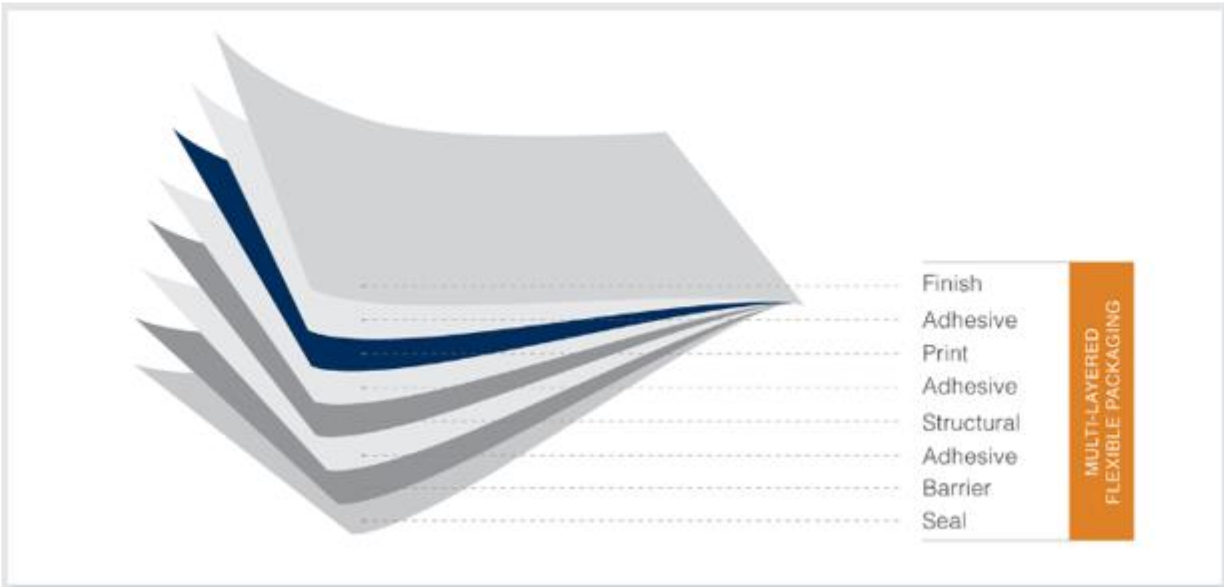


Figure 40: Backbone analysis of Finished Goods

In addition, a plasticizer (Low molecular weight substances) can be added to a polymer solution to promote its plasticity and flexibility. Therefore, the plasticizers make the polymer solution more suitable for the application of film coating. There should be chemical similarities between the polymers and its plasticizers. Most plasticizer additives used in inks and coatings fall within the chemical class of esters. Careful selection is necessary to provide the best plasticizer for a particular ink or coating formulation. Higher temperature and pressure will increase the rate of migration. As a rule of thumb, if the COF of a printed or coated film rises with time, plasticizer migration would be suspected. It is possible for the printed film to raise its COF from 1.5 to 3.5 or higher. The rate of migration is in the order of 8-24 hr depending on the film and plasticizer.

10.11.3. Turning flexible films into Packaging:

Now the reels are delivered to different customers and can form-fill-seal to pouches through converting machines.

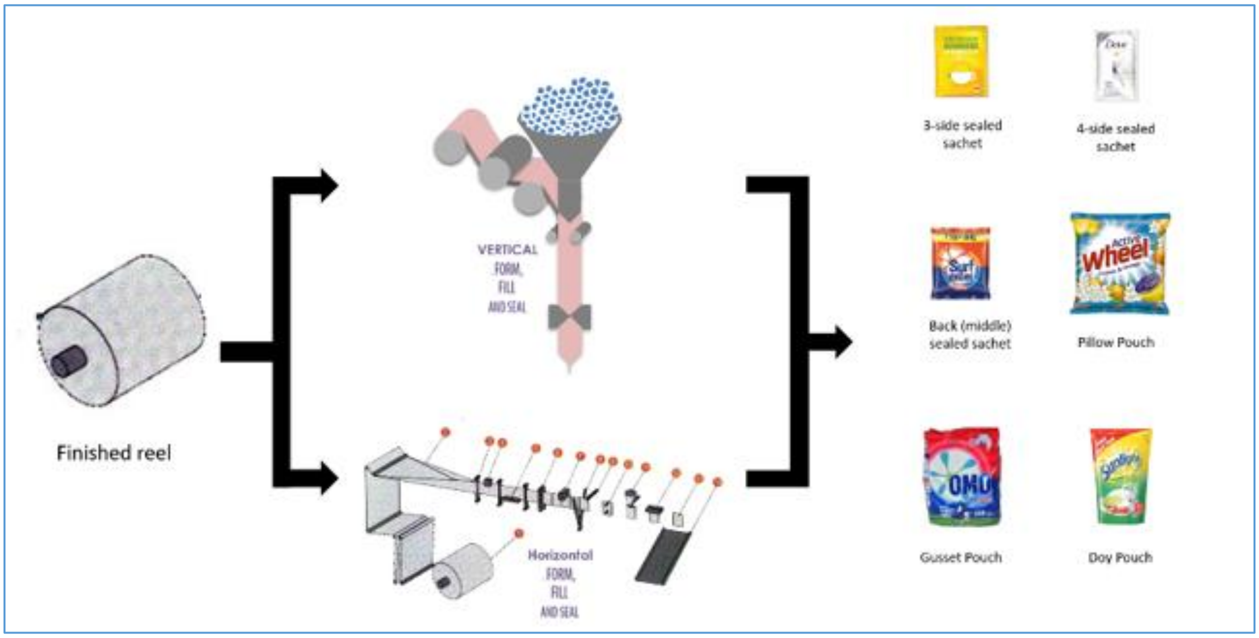


Figure 41: Flexible films to Packaging flow chart

10.11.4. Turning flexibles into Bags, Sacks and Pouches:

To make a bag, sack or pouch, two or more edges of a plastic film are sealed together, forming a cavity in which the product can be placed. In most applications, the opening is then closed so that the product is completely enclosed by the package. In some cases, such as merchandise sacks, one side remains open. The terms 'bag', 'sack' and 'pouch' can be confusing. According to some authorities, sacks are larger than bags, and both refer to packages in which the top is open, while pouches are smaller, and refer to packages that are totally sealed. However, these definitions do not conform to common use of these terms, which, in practice, are often used interchangeably.

Common styles of pouches include pillow pouches, three-side-seal pouches and four side- seal pouches. Pillow pouches are produced by forming the plastic film into a cylinder and sealing the edges together in what will become the back seam in the finished package. The bottom of the cylinder is collapsed and sealed, the product introduced, and then the top seam added. The shape of the filled package resembles a pillow – hence its name.

Three-side-seal pouches are formed, as the name indicates, by folding the film into a rectangle and sealing the three non-fold sides. In some cases, the fourth side is sealed as well, for additional strength. Four-side-seal pouches are formed from two pieces of material that are sealed together on all sides. Therefore, four-side-seal pouches need not be rectangular in shape. In contrast to pillow and three-side-seal pouches, the front and back of a four-side-seal pouch may be made from different types of plastic film. In any of these pouch styles, gussets may be added to expand the capacity of the pouch without increasing its width or height.

Pouches may be used alone, or may be combined with another package for product distribution and/or sale. One very common package structure is bag-in-box packages, which consist of a pouch inside a folding carton or corrugated box. The pouch material may be plastic film alone, or a multilayer material containing paper and/or aluminum foil. Paper may be used to add strength, rigidity, printability or bulk to the flexible package. Foil may be incorporated to improve the barrier to permeants such as oxygen, water vapor, odors or flavors. In the past several years, stand-up pouches have increasingly been used as substitutes for cartons or bottles. Stand-up pouches are designed to stand upright on the retail shelf. Their design involves gussets and special shaping of the bottom panel.

10.11.5. Finished goods pack analysis:

All finished goods (FG) pack analyzed before delivery and should be compliant all quality parameters, at least below mentioned parameters are accommodating. This is an specimen only including basic raw material, PE (Polyethylene).

Quality parameter	Category standard	Unit	As found in PE	As found in FG
Dart value	5g x µ of PE	g	450	1280
SCOF value, static	0.100 - 0.300,	µ (mu)	0.124-0.245	0.115-0.120
DCOF value, dynamic	0.100 - 0.300,	µ (mu)	0.097-0.188	0.090-0.100
Tensile Strength	≥ 14	Newton, N	-	24.0 - 25.1 N
Tensile displacement	350 minimum	mm	550	-
Tear Strength	≤ 5.0 N	Newton, N	5.2 - 5.5	5.2 - 5.5
Heat Seal Strength	12. 0 - 15.0	Newton, N	-	39.92 - 40.13
Bond Strength	≥ 1.5	Newton, N	-	Unable to separate
Treatment dyne	minimum 40	dynes/cm	40	-

Table 17: Finished goods pack analysis

N.B.: Tear strength and tensile strength were considered important factors because Tear Strength is the force needed to rip a material and to make the crack continue until it fails whereas tensile strength is a measurement of the force required to pull something to the point where it breaks.

10.11.4.1. Primary ways of pouching: There are two primary ways of using bags, sacks and pouches for packaging: as preformed / Auto-bag pouches, or in form-fill-seal operations. In a form-fill-seal (FFS) operation, the web stock (usually preprinted, if applicable) is fed into either a horizontal or vertical FFS machine, in which it is formed into a pouch, the product added and the final seal formed. If preformed pouches are used, the packages are formed and an opening left for product introduction. The product is added to the package in a separate operation, and then the package is sealed. Form-fill-seal operations are usually economically advantageous for large-scale production. Buying of preformed pouches is generally more economical if production quantities are small, or in cases where the material is difficult to seal and poses quality control problems.

The two form-fill-seal processes – Vertical form-fill-seal (VFFS) and Horizontal form-fill-seal (HFFS) are as follows:

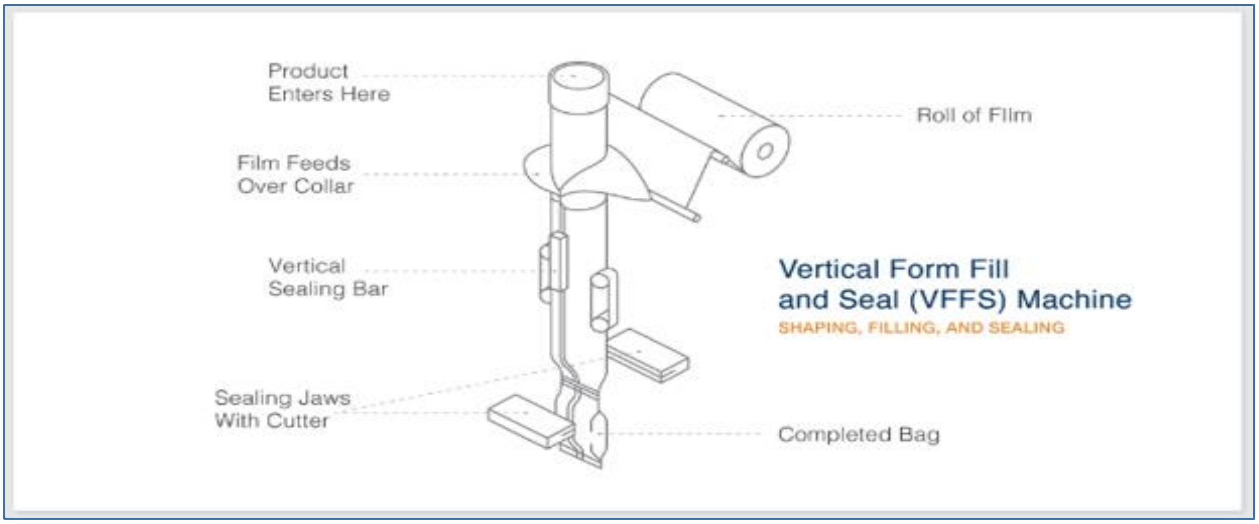


Figure 42: Vertical Form Fill and Seal (VFFS) Machine Specimen

10.11.4.2. The Art of Sealing:

Setting the machine parameters is important to ensure a tight and strong seam. Ideally, there are three key parameters which need to perfectly interact with the material.

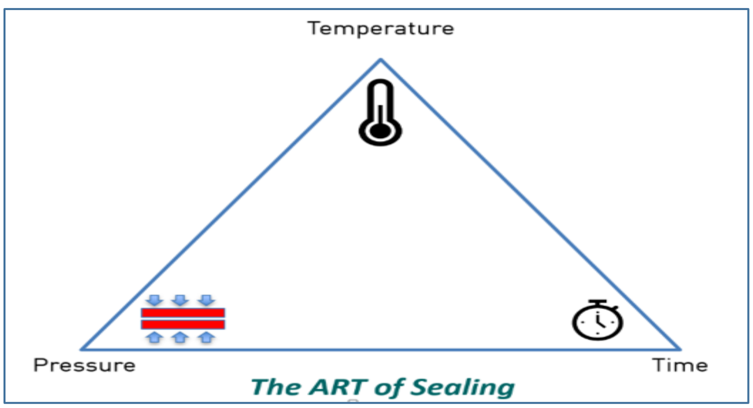


Figure 43: The Art of Sealing

11. Quality Analytical Laboratory:

11.1. Scope: Quality lab featured with an exclusive and advanced testing capability, employing cutting-edge technology to assess product integrity without compromising its structure. This distinctive ability allows to ensure the highest standards of quality while preserving the integrity of the tested items, setting quality control processes apart and guaranteeing superior product reliability for customers. **At a glance, Model lab and inside equipment's are as follows:**

Figure 44: Analytical Packaging Quality Model Lab.

Figure 45: Packaging analytical Equipment's (All)

11.2. Procedures/SOP vs. Lab Equipment:

In general, the physical and electrical properties of plastics and electrical insulating materials are strongly influenced by the temperature and stress history of the samples (used during their preparation) as well as the humidity. In order to make reliable comparisons, it is necessary to standardize the temperature and humidity conditions to which plastics are subjected prior to and during testing. For specimens thinner or thicker than 7 mm, condition the specimens for a minimum 40 h immediately prior to testing (or 88 h for the latter, over 7 mm thickness) in the standard laboratory atmosphere at 23 °C and 50% relative humidity (RH), whilst providing adequate air circulation on all sides. This can be achieved by placing the samples in suitable racks, hanging them from metal clips or laying them on wide mesh, wire screen frames with at least 25 mm between the screen and the surface of the bench.

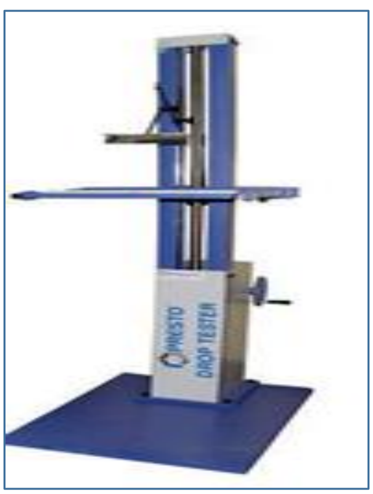
11.2.1. Tensile Tester: Packaging material tester

Scope: It is used to find out how strong a material is and also how much it can be stretched before it breaks. Tensile strength, Heat Seal Strength, Bond Strength (90^0 peel test) etc. can be performed by this instrument.
Procedure/SOP: A tensile strength tester works by holding a specimen in a pair of grips and then applying an increasing tensile load until the specimen breaks. If the original cross-section of the specimen is known as well as the rate of elongation (the rate of change in length), then the tensile strength can be calculated.

11.2.2. Dart impact tester: Packaging material tester

Scope: A Dart Impact tester or Dart Drop Tester is a lab testing instrument that is used to measure the Impact Resistance of Plastic film, coated paper, and Composite sheets. The dart weight expresses the energy required to tear or puncture the test specimen.
Procedure/SOP: Dart impact resistance of Polyethylene films is defined as the weight of a hemispherical shaped dart falling on the film held on a suitable clamp from a specific height that causes failure of specimens tested. The dart impact value depends on the film thickness. Since dart impact is not evaluated in any film direction, it is sensitive to orientation effects in both directions.

11.2.3. Drop impact tester: Packaging material tester



Scope: This test covers the ability of Pouches filled with products to resist impact in free fall drop from a predefined height onto concrete floor or flat metal plate, must be free from any sharp edges. The damages caused on the goods by drops, which are common during shipping & handling, include perforations or as tears and breakages.
Procedure/SOP: Once activated, the drop mechanism releases the package from the specified height, subjecting it to a controlled drop. The tester measures and records the impact forces experienced by the package during the drop, evaluate the package's durability and its ability to protect the contents.

11.2.4. COF (Co-efficient of friction) tester: Packaging material tester

Scope: The test is used to determine the kinetic (moving) and static (starting) resistance of one surface being dragged across another.
Procedure/SOP: A specimen is attached to a sled of specified weight. The sled is pulled across a second surface at a speed of 150 mm/minute. Mathematically, $\mu = F/N$, where F is the frictional force and N is the normal force.

11.2.5. Leak (water) tester: Packaging material tester

Scope: This test method covers the determination of leaks of laminated foil packs by bubble emission.

Procedure/SOP: A specimen is placed inside the distilled water filled jar. Set the timer and vacuum pressure. System automatically evacuates the chamber until it reaches the preset vacuum degree & time period, once starts the test.

11.2.6. Digital OD tester (Optical Density): Raw material tester

Scope: This test method covers the covers the measurement of Optical Density of any flexible films (MPET, MCPP etc.).

Procedure/SOP: A specimen is placed over the flat space of the instrument for test. Carefully move the lamp assembly until lamp filament is centered. Push & hold the button, once results display in the screen.

11.2.7. Leak & Seal Strength tester: Packaging material tester

Scope: This test method covers the determination of the Leak & Seal Strength (Burst Pressure) of any flexible packaging/laminated foil packs.

Procedure/SOP: Make three side sealed pouch by the pressed sealing machine and fix tightly to the probe of instrument. Set all the parameters including vacuum degree. System will automatically display the maximum pressure of all types of tests, once the sample bursts.

11.2.8. X-Rite Spectrodensitometer: Packaging material tester

Scope: This test method covers the measurement of Ink density following GSM. Moreover, Ink shade made from drawdown samples can be stored for future reference to compare the shade against standard and spot color development.

Procedure/SOP: Keep the test sample under the machine and press the machine up to down. Record the data from display screen for density measurement. Again set the standard sample for comparing shade against light & deep. Record the deviations from display screen.

11.2.9. WVTR tester: Packaging material tester

Scope: This test method covers the water vapor transmission rate (WVTR) of films or sheets materials.

Procedure/SOP: Keep the test sample under the machine and start the button. Automatically display curves of transmission, water vapor concentration, temperature and humidity in real time. The curves with conceal function, support query function for background data. Measurement precise up to 0.001 g/m2·24h

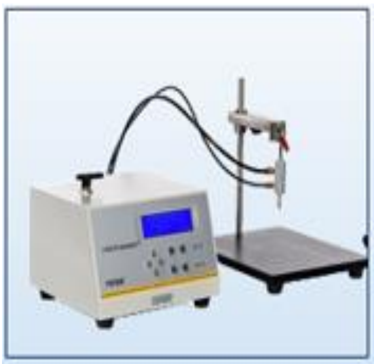
11.2.10. OTR Tester: Packaging material tester

Scope: This test method covers used to measure the oxygen transmission rate of barrier materials with high and medium barrier properties
Procedure/SOP: The pre-conditioned specimen is mounted between the upper and lower chambers. Oxygen molecules permeate through the specimen into the nitrogen side and are taken to the coulometric sensor where proportional electrical signals are generated. The oxygen transmission rate is then obtained by analyzing the signals and calculating the volume of oxygen measured by the sensor.

11.2.11. Light Fastness tester: Packaging material tester

Scope: Lightfastness is the measurement of how chemically stable a material is when exposed to light on a scale of 1 to 10, with 10 indicating the highest quality and 1, the lowest.
Procedure/SOP: Samples are exposed to an intense artificial light generated by a Xenon arc lamp. The light passes through a series of filters to ensure that its spectrum (wavelength make-up) closely matches that of natural daylight through glass. After 60 hours of exposure time, measured the light fastness quality based on 1 – 10 scale.

11.2.12. Bursting tester: Packaging material tester



Scope: This test method covers the determination of the burst Pressure of any flexible packaging/laminated foil packs.

Procedure/SOP: Make three side sealed pouch by the pressed sealing machine and fix tightly to the probe of instrument. Set all the parameters including vacuum degree. System will automatically display the maximum pressure of all types of tests, once the sample bursts.

11.2.13. Analytical balance & GSM cutter: Packaging material tester

Scope: This test method covers the measurement of the grammage of a paperboard or any flexible films – Mass in grams per square meter.

Procedure/SOP: Carefully cut around the sample, using a single cut, holding the cutter upright to ensure a straight edge. Weigh and calculate the GSM (Gram per square meter).

11.2.14. Digital Micrometer: Packaging material tester

Scope: This test method covers the measurement of thickness of a paperboard or any flexible films – Microns.

Procedure/SOP: Place the specimen in such a position that all points on the peripheries of the contact surface are in a fixed state. Release the foot and allow the reading to stabilize. Record the data.

11.2.15. Gas Chromatography: Raw material tester

Scope: This test method covers to detect organic solvents, the solvent residue of printed packaging materials and the purity or content of a single solvent.

Procedure/SOP: Place the specimen inside the machine. Adjust all the machine parameters. Manual button switch on and its function is equal to "Start collecting". Now display the working condition and chromatogram curves; curves can be zoomed and moved.

11.2.16. Karl-Fisher (KF) Titrator: Raw material tester

Scope: This procedure describes an electrochemical method for determining water content in raw materials and finished products.
Procedure/SOP: Empty the contents of the titration vessel, fill with methanol until the platinum rods of the electrode are fully immersed. Titrate the methanol until the endpoint is reached. Now weigh the sample and transfer to the titration vessel. Titrate the sample until the endpoint is reached. Calculate the Moisture content.

11.2.17. K Hand Coater: Packaging material tester

Scope: Provides a simple but effective means of applying paints, printing inks and other surface coatings onto many substrates including paper, plastic films, and foils.
Procedure/SOP: High quality proofs using gravure inks are produced instantly using the K Printing Proofer. Ink is transferred from an electronically engraved printing plate directly onto the substrate, which is attached to the rubber impression roller. Doctor blade and roller adjustments are made as well.

Safety Precautions: Appropriate all Safety measures including PPE (Personal Protective Equipment) should be taken before starting the testing / operation.

12. Discussion / Conclusion:

Flexible packages come in two basic forms: wraps, and bags or pouches. A wrap consists of plastic film that has not been formed into a package shape. The film is simply wound around the product or products to be contained, and held in place in some fashion. In a bag or pouch, some shaping of the plastic is done, either before or at the same time as the product is added. Most often, this shaping is done by heat-sealing the edges of the plastic together.

The global flexible packaging market size was valued at USD 178.12 billion in 2022. It is estimated to reach USD 256.83 billion by 2031, growing at a CAGR (Compound annual Growth Rate) of 4.15% during the forecast period (2023–2031). Like any industry, flexible packaging has developed its own unique terminology and phrasing borne from decades of growth and specialized knowledge. While much of this information is passed down from one converter to another, the advent of digital printing has enabled more and more people to step into the flexible packaging space from other industries without benefiting from a mentorship. For these flexible packaging newcomers, a deep understanding of the industry's language and shorthand will be absolutely vital to their long-term success.

13. Flexibles Sustainability Challenges:

We know Plastics are essential to our modern world. They protect our health in medical products, prevent foods from spoiling too quickly, make wind turbines more efficient, and are critical in enabling electric vehicles. And yet there is no question that plastic pollution is a growing problem that we must address.

Flexible Packaging also provides a challenge in sustainability and required to consider carefully the choices as Packaging Professionals need to ensure Sustainable Living Plan (SLP).

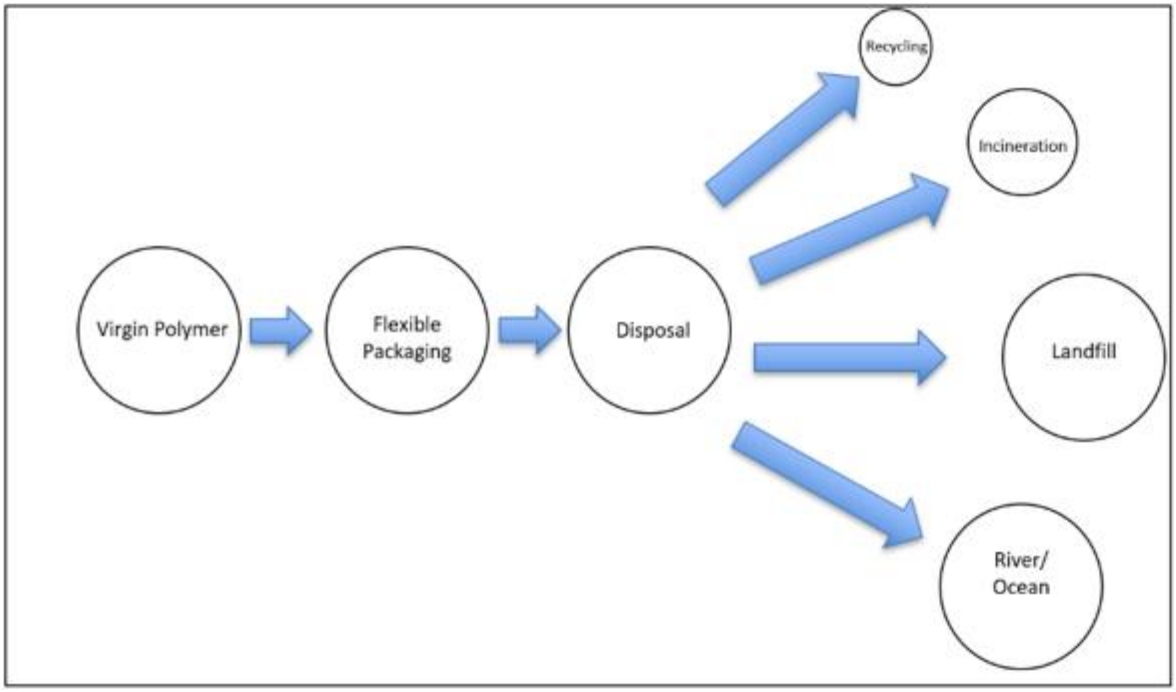


Figure 46: Flexibles Sustainability Challenge

Most of the flexible packaging ends up in landfill or oceans because of the following reasons:

a. Lack of waste collection system
b. Multi-layer flexible Packaging is not readily recyclable and
c. Lack infrastructure for Multi-layer Packaging recycling.

It is generally agreed that evaluation of the environmental impacts of a product or package requires consideration of the total life-cycle of the object. Such 'cradle to grave' analysis is commonly referred to as life-cycle assessment. Usually, when such analyses are carried out, the most influential life-cycle stage is that of production of the raw materials and packages, rather than transportation or disposal. Packages that minimize material use are therefore likely to have reduced environmental impact. Since flexible packaging systems usually (although not always, since distribution packaging must be included) use less overall packaging material, they often have reduced environmental impact, compared to the rigid packaging systems they replace. I have 2 (two) publications in two renowned journals based on the sustainability of flexibles. I have been sharing the DOIs for easy outreaching to everyone.

a. *"Sustainability of Flexible Packaging Industry across the Globe through the Eyes of Green/Sustainable Chemistry" – published in IJISRT. Volume – 7, Issue 3, March, 2022, DOI: https://doi.org/10.5281/zenodo.6474285 and*

i) *A brief study and one step ahead of Plastic sustainability across the Globe"- Published in Global Journal of Science Frontier Research: H Environment & Earth Science; Volume 23 Issue 4 Version 1.0 Year 2023; DOI of the article is:* https://doi.org/10.34257/GJSFRHVOL23IS4PG31

In examining the impacts of waste disposal, two general conclusions can be drawn. In most cases, flexible packaging is less likely to be recovered for recycling than rigid or semi-rigid packaging. Therefore, a higher proportion of flexible packaging is likely to require disposal. On the other hand, flexible packaging, as discussed above, usually means less total material requires handling. Unless recycling rates for the alternatives to the flexible packages are very high, use of flexible packaging is likely to mean less material requiring disposal. Also, flexible packages containing plastics are sources of recoverable energy in appropriate systems.

13.1. Flexibles vs. Circular Economy: We enthusiastically supports a solution that will eliminate plastic pollution from our planet by creating a socially inclusive, circular economy for plastics that recognizes the vital role these materials play in ensuring a low-carbon future. It's an audacious yet achievable goal. To ensure CIRCULAR ECONOMY, recycling of plastics must be ensured. To be effective, it will need to drive innovation, promote environmentally sound recycling, and build an inclusive financial model to enable a circular ecosystem. While recycling is important, it's no silver bullet. Just 9% of the plastic ever produced has been recycled with another 19% incinerated; 50% ending up in landfill; and 22% evading waste management systems entirely going into uncontrolled dumpsites, being burned in open pits or dropped into oceans, rivers, and lakes, especially in poorer countries.

The first priority is driving innovation through design. Using plastics sustainably requires making them with circularity in mind from the beginning. We must design more high-performance plastics that use fewer raw materials while maximizing durability, reusability, and recyclability. Countries can help by promoting smarter design standards and setting recycled content requirements so that waste can be more easily sorted, recycled, and put back into use.

Second, we must promote environmentally sound recycling methods under development and help bring them to scale. Traditional mechanical recycling can turn some plastic waste into everything from fleece jackets to weatherproof fencing. It will continue to be a key solution but is not effective for all uses. The good news is that recycling technologies are continuously evolving, offering additional ways to transform waste. These technologies will require significant investments to reach commercial scale. An agreement that encourages recycling targets for plastics and other materials will help drive a huge leap in the portion of plastics that can be diverted from landfills and given new life.

The third priority is the need to build a new, socially inclusive financial and risk model to power a circular plastics economy. Globally, an estimated 15 million people pick and sort urban waste. Building self-sustaining, modern waste systems globally won't be cheap. But it will drive the creation of new and better jobs, especially in parts of the world where waste management infrastructure can be upgraded. Our challenge is to preserve the enormous benefits of plastics while eliminating plastic waste.

In fact, there are substantial challenges in driving flexible packaging toward a circular economy which will require significant investment and a shift toward system understanding and collaboration. The initial investment in collection, sortation, and reprocessing will likely be geared toward rigid packaging because of its greater ease of collection as well as stronger end markets. However, much of the infrastructure and technology investment needed to make rigid collection more efficient will also apply to flexible packaging. It is critical that the industry collaborate with others and ensure that the sustainability benefits already achieved through flexible packaging are further enhanced as it strives to embed itself into a circular economy framework. To meet future state goals, it is critical that flexible packaging converters, as well as other value chains, initiate actions now to meet mid and long-term objectives and circular economy goals.

Figure 47: Sustainable Circular Economy

14. Few key information: Density of relevant Films, Resins and Chemicals

Film	Density, g/cc
PET	1.40
MPET	1.41
BOPP	0.90
MCPP	0.91
Matt BOPP	0.82
CPP	0.90
Nylon	1.12
Pearl BOPP	0.70
PVC Shrink	1.35
PET Shrink	0.98
Alu-Foil	2.70
Blister Foil	2.70

Granules/Resin	Density, g/cc
LLDPE	0.92
HDPE	0.94
LDPE	0.93
Master Batch	0.92
Zipper	0.92
Ink	1.00
Adhesive	1.00
Hardener	1.00

Chemicals	Density, g/cc
MEK	1.00
MIBK	1.00
EA	1.00
Toluene	1.00

14.1. Flexible Packaging Calculation without knowing Substrate: For instance, Film Length (L): 18000 m, Film Width (W): 890 mm and Ink GSM: 1.5,

Dry ink (Kg): (Film Length x Film Width x Ink GSM) / 1000000.

$$\text{Dry Ink (kg)} = \frac{\text{Film Length x Film Width x Ink gsm}}{1{,}000{,}000}$$

14.2. Another example, Adhesive consumed: 100 Kg, Laminated meter: 50000 m, Coil/Film size: 1200 mm

Therefore, Adhesive GSM: 100 x 1000000 / 50000 x 1200 = 1.666

So, Adhesive GSM: (Adhesive consumed in Kg x 1000000) / (Film size in mm x Laminated Linear in m)

$$\text{Adhesive gsm} = \frac{\text{Adhesive consumed in kg} \times 1000000}{\text{Film Size in mm} \times \text{Laminated Linear Meter}}$$

14.3. Convert Pouch Dimensions in Meter:

Pouch Height – 225mm / 0.225 M
Pouch Width (open) – 370 mm / 0.37 M
Pouch Area – 0.225 x 0.37
Printing Layer – 12µ PET
Film Density – 1.4
Therefore, GSM = 12 x 1.4 – 16.8
So, 1 (One) Pouch Weight in grams – 0.225 x .37 * 16.8 = 1.398 grams
If Order Quantity – 50,000 pcs / 50 Thousand, then
Total Printing Quantity – 0.225 x 0.37 x 16.8 x 50 = 69.93 (kg)

14.4. Mostly Salt Packs are of very basic Packaging structure:
PET + PE, PET Film Laminated with Poly, either Natural or White.
PET – 12µ
Poly – various microns, depends upon SKU and customer demand.

14.5. Structure of Retort Pouch:

- Polyester (PET) – printing layer /excellent printable
- Aluminum Foil – barrier layer / protect from sun light, grease, oil
- Nylon – 2nd barrier layer / high melting point, exceptional strength and toughness, and good oxygen barrier **properties**
- Polypropylene – sealing layer / direct food contact, heat seal surface, flexibility & strength

14.6. EVOH Barrier:
Ethylene-vinyl alcohol co-polymer or EVOH is a flexible, crystal clear, and glossy thermoplastic co-polymer with excellent flex-crack resistance, and very high resistance to hydrocarbons, oils and organic solvents.
It also has some of the best barrier properties to gases such as oxygen, nitrogen, and carbon dioxide making it especially suited for packaging of food, drugs, cosmetics, and other perishable or delicate products to extend shelf life. When compared to other common films, EVOH is considered to have superior barrier properties. However, when exposed to moisture, EVOH loses its good gas barrier properties. For this reason, EVOH is often used in a multi-layer co-extruded film structure with materials such as HDPE, PP and PET, all of which have superior moisture barrier properties.

15. Case studies:

15.1. Packaging discoloration & delamination of Salt packs (Iodized) at market places:
The outer pack became discolored, turning yellow following layer separation, delamination to a degree that would impact consumer acceptance at market places. Therefore, there was a need for an investigation to find out the actual root cause and possible remedy for this discoloration and delamination. To overcome these market place issues, applied **DMAIC (The problem-solving approach that drives Lean Six Sigma. It's a five-phase method - Define, Measure, Analyze, Improve and Control) for improving existing process problems with unknown causes.** For investigation purposes, we have collected more few Bangladeshi salt packs from

market places where different printing designs have been observed. Overall observations are as follows:

- This is crucial that during manufacturing/salt packing, dryer temperature should be maintained properly. This is because salt and its ingredients, especially Iodine can react with plastic materials and can be happened pack discoloration as well as layer separation/delamination if dryer temperature varies. So, this matter can be controlled at manufacturing end.
- Pack Sealing area of a salt pack, eventually the pack design contains ink/printed matter whereas no ink/printed matter has been present in another salt pack and during pack sealing this ink in combination with inside salt and it's ingredients can play a vital role in pack discoloration. This is because no pack discoloration has been noticed at the top/bottom sealing area, where there is no sealing/salt impact, only the salt filling packaging area is discolored. So, containing ink/printed matter over the pack sealing area predominantly plays a vital role in pack discoloration, manufacturers can avoid ink/printed matter at sealing area to stop this issue in future.
- Packed salt storage condition can also deteriorate the quality of packaging. To investigate the issue, few salt packs have been kept at lab and kitchen area for about 5 (Five) months for observation and after five months, no changes have been noticed in terms of Packaging and salt. On the contrary, same samples have been kept inside the industrial packing area and noticed pack discoloration and delamination simultaneously. This means due to the storing condition of salt packs, these changes can be happened.

To further investigate the mechanism behind the discoloration, tests were done with potassium iodate in the presence of packaging film. The packaging film was melted in the presence and absence of potassium iodate to observe whether oxidation occurs at a faster rate with more color development. This would explain the yellowing in the layers of the packaged salt because they are melted when sealed. The test confirmed that in the presence of potassium iodate the oxidation of the packaging material was much faster with greater color development. Because discoloration was observed in parts of the pack/bag that were not melted (i.e. not on the layers), an investigation of discoloration without melting was conducted. The package is subjected to heat on the packaging line since part of the package is melted to form the layers. Packaging film with and without potassium iodate was heated in an oven. The packaging material was subjected to various temperatures over time and periodically inspected for change. The temperatures and times used were 60˚C for 20 minutes, 70˚C for 20 minutes, 80˚C for 20 minutes, 90˚C for 10 minutes, 100˚C for 15 minutes, 120˚C for 130 minutes, and 130˚C for 65 minutes. After this time both samples yellowed. The sample without iodine appeared slightly more orange / brown. Therefore, yellowing may occur in heated packaging that is not melted and may become orange especially in the presence of potassium iodate. So, this is proven that Iodine inside salt pack is responsible for pack discoloration as well as delamination of wrapper. This is one of my Research Articles has been published in **Research Square (A multidisciplinary preprint and author services platform)**.
DOI Link: https://doi.org/10.21203/rs.3.rs-3817812/v1
This Article also published in **SSRN (An open access preprint server)**.
DOI Link: https://dx.doi.org/10.2139/ssrn.4758445
Title: *A complete overview of Packaging discoloration & delamination of Salt packs (Iodized) at market places under conditions relevant to product packaging, ageing & stabilization of filled polymers and product storage.*

15.2. Puffed rice quality inside the poly-pouch – Bad smell noticed inside the Pouch

We have received Market complaint against Pouches of Puffed Rice pack. Bad smell noticed inside the pouch of Puffed Rice (Muri). There are a few potential reasons why rice puffs at marketplaces can develop a bad smell:

a. Improper storage: Rice puffs are very fragile and porous. If not stored properly, they can absorb moisture and odors from the environment which leads to quicker spoilage and bad smells. At busy market stalls, frequent temperature changes and exposure can contribute to this.
b. Oxidation of fats: Rice puffs contain oils and fats that can oxidize over time. This oxidation leads to rancid odors. Improper packaging that allows too much air exposure accelerates this oxidation and development of rancidity
c. Microbial growth: Like with any food, microbial contamination of rice puffs from handling, humidity etc. could result in the growth of spoilage microorganisms that give off unpleasant byproducts and metabolites leading to off smells
d. Use of old stock: Some vendors may continue to sell older rice puffs that are nearing the end of their shelf life or have already started emitting foul smells from one or more of the above factors
e. When the product/puffed rice sealed at high temperature causes burnt smell, leading to the product coming into contact can cause unusual bad/burnt smell.

Following good packaging, storage, stock rotation and overall hygiene is key to reducing chances of rice puffs turning foul smelling while selling at busy market stalls under variable environmental conditions in terms of humidity and temperature during different seasons. Strict quality checks can help in this regard. For further investigation purposes, we have kept the sample in our Lab and additionally, packed more puffed rice samples from market places to find out the actual root cause as per below patterns:

Pattern 1 - Collected fresh puffed rice from market place and packed & sealed in our pouches. For better clarity, same whitish puffed rice as good as the complaint sample has been collected,
Pattern 2 - Complaint puffed Rice sample once again packed in our pouches & sealed,
Pattern 3 - Empty pouch pack sealed and kept for observation
Pattern 4 - Empty pouch pack kept for observation and
Pattern 5 - Complaint Puffed Rice sample packed & sealed in a different pouch of same structure.
We have checked the above lab keeping samples after 7 days and 15 days respectively.
Overall observations are:

a. After 7 days, no abnormal/bad odor has been noticed inside all the patterns,
b. After 15 days, noticed tainted oily smell (Same as the complaint sample) inside the complaint sample packed pouches with running/existing pouches (Serial 2) and different pouches of same structure (Serial 5). No changes noticed in other (Serial 1, 3 & 4) conditioned samples. Details are as follows:

Serial	Pattern	Initial observation	Interim days	Observation (s)	Interim days	Observation (s)	Remarks
1	Collected fresh puffed rice from market place and	**Tainted oily smell noticed**	7	No bad smell noticed	15	No change	**Bad smell originated**

	packed & sealed in existing pouches						
2	Complaint puffed Rice sample once again packed in existing pouches & sealed		7	No bad smell noticed	15	Tainted oily smell noticed	
3	Empty pouch pack sealed and kept for observation		7	No bad smell noticed	15	No change	
4	Empty pouch pack kept for observation		7	No bad smell noticed	15	No change	
5	Complaint Puffed Rice sample packed & sealed in a different pouch of same structure.		7	No bad smell noticed	15	Tainted oily smell noticed	

Table 18: Case Study 2 – Bad smell inside Puffed Rice Pack investigation data

After 45 days, we have checked once again and noticed tainted oily smell in the above Serial 2 and Serial 5 bur no changes noticed in other (Serial 1, 3 & 4) conditioned samples. And same as the earlier observations of after 15 days. Finally, we have checked after 6 (six) months interval and found no change in the observations, same as the observations of after 15 days. Note that 6 (six) month is ideally the shelf life the product, puffed rice.So, this is proven that bad smell originated from puffed rice itself.

15.3. Bad smell and Microbial contamination of Shampoo Sachet at Market places:

In about 2016, there have been happened a market recall of Liquid Shampoo (Sachet) across Bangladesh. Shampoo manufacturer was one of the leading Multinational FMCG industry. Packaging structure of the sachet was PET + MPET + PE (Polyethylene). Respective team have investigated thoroughly the whole incidence starting from Raw & Packaging material to Finished Goods. Backward & Forward traceability also conducted and have been set up microbial tests for each and every ingredients including Finished Goods but observed no microbial colony growth/contamination. Later on, team have washed out a portion of laminated packaging material of the shampoo sachet and set up for microbial observation. Finally colony growth noticed including bad odor and find out the actual root cause of the incident.

Eventually, sealed polyethylene pouches/sachets/bags however modifies the atmosphere around, it reduces O_2 and increases CO_2 as well as relative humidity levels. In this investigation, team has been identified the sealant layer of the sachet containing Polyethylene (PE) as the offender. This is because this item has been kept for long time after manufacturing and ideally differences in chemical/physical characteristics, correct storage, and sanitizing of packing materials strongly affect the microbial loads present onto the packaging surfaces. In addition, differences in the abilities of various microorganisms to degrade plastics might be due to the differences in environments from where they are isolated. However, the main mechanisms for microbial degradation of PE plastics are oxidation of the PE surface and formation of carbonyl groups, which cause deterioration and fragmentation of the material. Microbial load on each produce was enumerated by plating 1 ml of 10^{-2} and 10^{-4} dilutions of the wash waters on the nutrient agar and the colonies counted after 24 h incubation at 37°C. Various scientific study also shows that different genera/species including Bacillus cereus (bacteria), Aspergillus and

Phoma sp. (fungi) degrades PE plastics. So, this is clear that bad smell and microbial contamination has been created due to long term storage condition of packing materials/Sachets and oxidation of PE plastics of sachet is liable for bad smell. That means flexible packaging is not directly associated with bad smell and microbial contamination at Market places.

16. Troubleshooting:

16.1. Voids, outgassing or bubbles during lamination: During solventless laminating, adhesive plays a crucial rule in flexible packaging applications. Below are the common run settings that are recommended for Adhesives to ensure the best result as well as to avoid visual appearance issues:

a. Adhesive puddle temperature in pan: 105 °F (41 °C)
b. Application roll temperature range: 122 °F to 140 °F (50 °C to 60 °C)
c. Nip temperature: 120 °F to 130 °F (49 °C to 55 °C)
d. Coat weight: 1 pound per ream (1.6 g/m2)

Over the years, production line speeds have increased and adhesive technologies have increased production efficiency. With this efficiency increase, there is a higher chance that laminates result in a mottled appearance that can be classified as having **voids, outgassing, or bubbles** as per below figures:

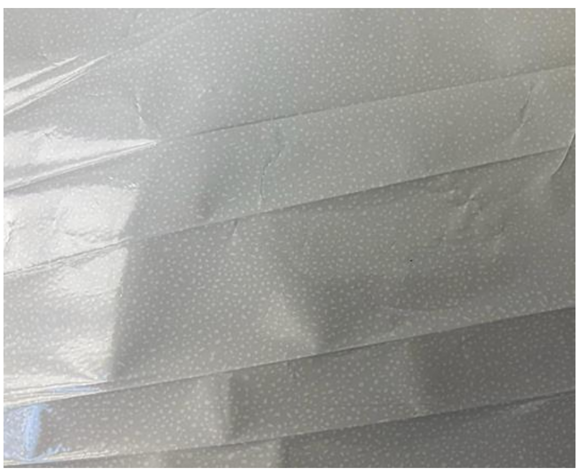


Figure 49: Poor Adhesive wetting, Mottled

Figure 50: Good Adhesive wetting, clear

These are typically caused by reduced flow and leveling of the adhesive onto the substrate. Most often, the root cause of this is an imbalance of the wet surface tension of the adhesive and the dry surface energy of the substrate, leading to reduced wet out. Faster line speeds exacerbate this issue since an adhesive has less time to level appropriately on substrates. Typical films used in food packaging laminates have dry surface energies of approximately 39–40 dynes/cm, whereas solventless laminating adhesives typically have 40 dynes/cm of surface tension. Therefore, film pretreatment is often required to increase surface energy to a level above adhesive surface tension to ensure good adhesive wet out. Other causes for these types of appearance issues may include using a nip pressure that is too low, using a nip roller that is too soft, or excessively agitating adhesives during mixing and circulation.

Description	Defects, Root causes and remedial actions

Quality issue	Voids, outgassing or bubbles during lamination
Actual root causes	a. Reduced flow and leveling of the adhesive onto the substrate. b. Imbalance of the wet surface tension of the adhesive and the dry surface energy of the substrate. C. Nip roller that is too soft, or excessively agitating adhesives during mixing and circulation
Remedial actions	a. Maintain the right flow and levelling of the adhesive onto the substrate. b. Correctly balance the wet surface tension of the adhesive and the dry surface energy/Dyne of the substrate. C. Use the right Nip roller that agitating adhesives correctly.

Table 19: Root cause following remedial action against voids, outgassing or bubbles during lamination

16.2. Tunneling during lamination: Tunneling creates an undesirable appearance and can result from several factors. Typically, manufacturers of solventless laminating adhesives will provide a suggested mix ratio for the isocyanate pre-polymer and polyol (NCO & OH). If an incorrect mix ratio is used or if residual ink solvent featuring a hydroxyl group is present, the adhesive may not cure properly and will result in tunneling. In addition, laminator run settings must be optimized. Tunneling can result if there is improper tension of the web being coated with the adhesive or during rewinding. In solventless systems, using an excessive coat weight may also contribute to tunneling. Both examples of tunneling as per below figures:

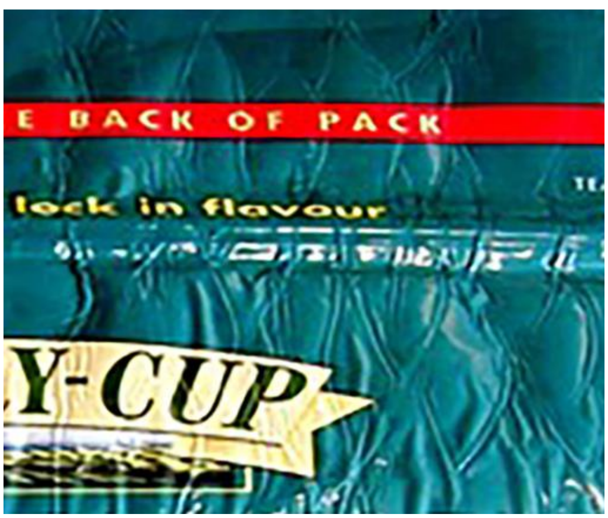


Figure 51: Tunneling due to lack of adhesion

Figure 52: Tunneling due to imbalance tension

Description	**Defects, Root causes and remedial actions**
Quality issue	Tunneling due to imbalance & lack of adhesion during lamination
Actual root causes	a. Incorrect mixing Ratio of laminating adhesive-hardener or the adhesive may not cure properly. b. Improper tension of the web being coated with the adhesive or during rewinding. C. Excessive coat weight during lamination.

Remedial actions	a. Lamination run setting must be optimized. b. Proper tension during adhesive coating as well as rewinding period should be maintained. C. Coat weight must be controlled and maintained within the standard.

Table 20: Root cause following remedial action against imbalance & lack of adhesion during lamination

16.3. Haze during lamination: Certain laminates used in packaging are optically clear and provide barrier properties to oxygen and moisture while maximizing transparency to display contained products. In these cases, haze is an issue that should be avoided. As shown in the below Figures, haze may result from air entrapment in the laminate, which may be caused by excessive agitation of the mixed adhesive prior to mixing or during circulation. Using an adhesive that has gone too far into its pot life/shelf life may also cause bubble entrapment and haze.

Figure 53: Clear laminate

Figure 54: Hazy laminate

Description	Defects, Root causes and remedial actions
Quality issue	Hazy during lamination.
Actual root causes	a. Optical Density (OD) of the laminate and/or film itself may cause the haziness. b. Haze may result from air entrapment in the laminate, caused by excessive agitation of the mixed adhesive prior to mixing or during circulation. C. Expired or near expiry adhesive may also cause bubble entrapment and haze.
Remedial actions	a. Laminates with optically clear and good barrier properties to Oxygen & moisture should be used. b. Avoid excessive agitation of the adhesive prior to mixing and/or during circulation. Proper mixing with proper ratio of adhesive is mandatory. C. Avoid to use near expiry adhesives during lamination process.

Table 21: Root cause following remedial action against Hazy during lamination.

16.4. Ink Bleed or Smear during lamination: High-definition print on flexible packaging is critical for manufacturers since it is required to accurately convey branding and other required information about the product. A common issue that distorts print quality stems from an incompatibility with the ink system used for printing, where the adhesive bleeds or smears the ink, as shown in the below Figure 50. In particular, solventless laminating adhesives are susceptible to incompatibility with the inks used in flexible packaging because their polymers are relatively low in molecular weight and have a high propensity to solvate inks. Additionally, solventless adhesives do not contain solvents and are not dried using conventional driers like solvent-based and water-based adhesives, so they remain in liquid form during the curing process, further contributing to potential ink solvation. For these reasons, it is critical to perform small-scale trials and determine ink compatibility prior to running at full scale.

Figure 55: Ink Bleed or Smear

Quality issue	Ink bleed or smear during lamination
Actual root causes	a. Incompatibility with the ink system used for printing, where the adhesive bleeds or smears the ink. b. Incompatibility with the ink arise for their polymers are relatively low in molecular weight and have a high propensity to solvate inks. c. In case of solventless adhesives having no solvents remain in liquid form during the curing process, further contributing to potential ink solvation - resulting ink bleeding/smearing.
Remedial actions	a. It is crucial to perform small-scale trials and determine ink compatibility prior to running at full scale. b. As adhesive bleeds ink, homogeneous ink spreading during printing should be ensured. c. Adjustments on the rewind portion of the laminator should also be ensured to overcome ink smearing.

Table 22: Root cause following remedial action against Ink bleed or smear during lamination

Adjustments on the rewind portion of the laminator have also been shown to improve flow, leveling, and appearance. When laminates are wound tightly and kept warm, the appearance of the laminate typically improves. A rewind tension between 30 and 40 psi, a lay-on-roll pressure at 30–40 psi, and a taper tension at or below 25% are optimal for many machines and solventless laminates.

17. New innovations of Adhesion, the latest Adhesion Science - Reversible Glue, Customizable Bio-adhesive patches and Soybean Protein Adhesives:

New research in adhesion science includes a reversible glue developed by scientists. As the needs of industry and the demands of consumers change, scientists are working to develop new adhesion technologies both within academia and business. The demand for more sustainable adhesive technologies is always increasing. Likewise, as medical science advances, the adhesives used within food and medicine also require new research and development. Presenting new research in adhesion science: a reversible glue developed by researchers; customizable bio-adhesive patches and a review of the use of soybean protein adhesives in wood composites.

17.1. Reversible Glue: Researchers developed a reversible, water-based glue that has good adhesion in the neutral pH range, but can be detached again in strongly acidic or alkaline environments. The novel adhesive system, which is based on electrostatic interactions, has bond strengths somewhere between those of structural adhesives and pressure-sensitive adhesives. The new adhesive also bonds "difficult" surfaces such as water-repellent polypropylene. Note that Structural adhesive systems, such as two-component adhesives, form chemical bonds when they react and cannot be separated again along the adhesive interface. Pressure-sensitive adhesives can be cleanly removed by pulling.

Researchers found an alternative route to achieving adhesion and separation: charge interactions promote structural bonding along the interface, which can be neutralized and thus dissolved again. To obtain the charge interaction, they developed two separate water-based polymer dispersions to be applied to surfaces. In both dispersions, the base polymer was a copolymer composed of the inexpensive, commercially available components styrene and butyl acrylate.

a. For one dispersion, the researchers coated the particles with the surfactant lauryl sulfate and polymerized acrylic acid, which together provide a negative charge in the neutral to alkaline pH range.
b. For the other dispersion, they coated the particles with the polysaccharide chitosan, which contains positively charged amino groups in neutral or acidic environment.

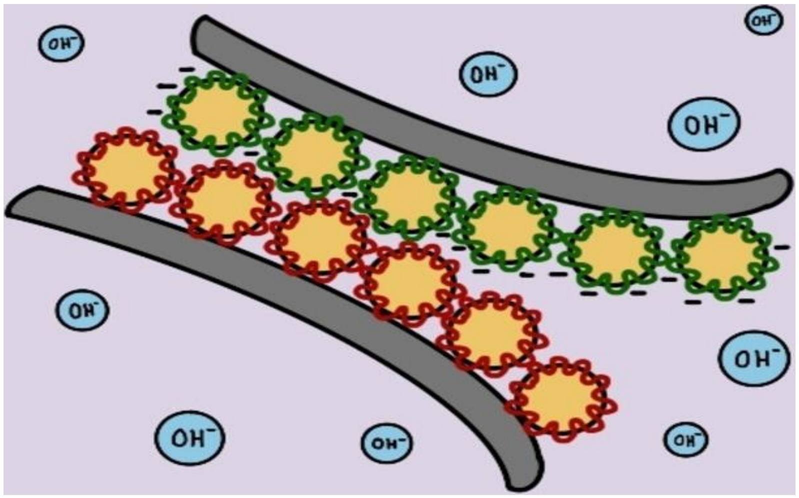


Figure 56: Reversible adhesive functioning. This kind of adhesive would be useful for the recycling and dismantling of products.

Both polymer dispersions formed sticky coatings on a variety of surfaces. The researchers then observed that, when brought into contact, the coated surfaces stuck tightly together due to the electrostatic interactions between the positive and negative charges within the films. This was even true in humid or wet environments, which usually have a detrimental effect on water-based adhesives. However, when the pH was adjusted to one extreme or the other, by adding either a strong acid or base, the negative or positive charges within the glue were neutralized, and the adhesion disappeared. Researchers said that the pH-sensitive adhesive system could serve as a novel, and recyclable, middle ground between structural adhesives with fixed chemical bonds and peel-off adhesive films that bond using physical interactions. They also emphasized that their novel electrostatic glue adheres well to highly water-repellent polypropylene surfaces, which are otherwise difficult to treat with aqueous adhesive systems. Finally, they proposed in integrating a bio-based material from soybean oil into the base polymer, taking a further step toward environmentally friendly, recyclable bonding systems.

17.2. Customizable Bio-adhesive patches: The researchers created three types of customized adhesive patches and applied them in animal treatments and implants. These patches maintained high adhesion even in highly mobile organs such as the heart and bladder. They also conducted successful experiments in adjusting biodegradation times and flexibility during the transplantation of muscle regeneration electronic devices.

17.3. Soybean Protein adhesives: The Researchers explored the use of soybean protein as a potential material for the production of eco-friendly wood adhesives. Techniques used to improve bonding properties and to functionalize soybean protein adhesives include molecular modification, cross-linking modification, organic-inorganic hybrid system construction, and biomimetic design. These include application requirements, including water resistance, low viscosity, fast curing, desired pre-pressing bonding properties, anti-bacterial properties, cost effectiveness, and flame resistance, among others. Also discussed in the paper are the structural properties of soybean protein molecules and bonding mechanisms of these adhesives when used in wood composites.

18. Abbreviations and Acronyms:

LDPE – Low Density Polyethylene

PE – Polyethylene
LLDPE – Linear Low Density Polyethylene
HDPE – High Density Polyethylene
LCA – Life Cycle Assessment
SDG – Sustainable Development Goals
OPRP – Operational Pre-requisite Program
PP – Polypropylene
PVC – Poly Vinyl Chloride
PA – Poly Amide
MFI – Melt Flow Index
WVTR – Water Vapor Transmission Rate
OTR – Oxygen Transmission Rate
PET – Polyethylene Terephthalate
BOPP – Bi-axially Oriented Polypropylene
MCPP – Metalized cast Polypropylene
MIBK – Methyl Iso-butyl Ketone
EA – Ethyl Acetate
MEK – Methyl Ethyl Ketone
COF – Co-efficient of Friction
SCOF - Static Co-efficient of Friction
DCOF – Dynamic Co-efficient of Friction
ARSR – Alkali Resistance Soap Resistance
CMYK – Cyan Magenta Yellow Black
PU – Polyurethane
NCO used for Adhesive
OH used for Hardener
SB – Solvent based
SF – Solvent free
SL – Solventless
WB – Water based
VOCs – volatile Organic Compounds
VFFS – Vertical Form-Fill-Seal
HFFS – Horizontal Form-Fill-Seal
CAGR – Compound Annual Growth Rate
HAPs – Hazardous Air pollutants

19. References:

i) https://www.adhesivesmag.com/articles/100489-improving-appearance-with-solventless-laminating-adhesives

ii) https://books.google.com.bd/books?hl=en&lr=&id=qrGXBZiiMMcC&oi=fnd&pg=PA5&dq=Handbook+of+Plastic+Films,+Rapra+Technology+Limited&ots=mE7xEhQZaV&sig=6WjwKB1PqYC6xJZTAj8XtluHKC8&redir_esc=y#v=onepage&q=Handbook%20of%20Plastic%20Films%2C%20Rapra%20Technology%20Limited&f=false

iii) https://fortune.com/2024/04/16/dow-ceo-company-major-plastic-producer-end-plastic-pollution-leadership-environment/

iv) https://www.globalcitizen.org/en/content/global-plastics-treaty-explainer-fossil-fuels/?utm_source=Iterable&utm_medium=email&utm_campaign=Recurring%20%7C%202024-04-18%20%7C%20ROW_AutomatedContentDigest
v) https://www.forbes.com/sites/sap/2024/04/17/earth-day-2024-planet-vs-plastic/?sh=67e7cace2352
vi) https://www.adhesivesmag.com/articles/100947-reversible-glue-and-customizable-bio-adhesive-patches-the-latest-adhesion-science
vii) Different Internet/Goggle sources
viii) Long term Practical experience at Factory level as well as shop floor level.

20. Table of Contents:

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Biography – Azizul Haque

Pic. Azizul Haque

Personal Life:

This is Azizul Haque. I was born in a Muslim aristocratic family on 15th May, 1966. My Father is late Moulvi Hossain Ahmed and my mother is late Khodeza Begum. I am the 5th son of my parents. My birthplace is Chittagong, Bangladesh. I have started my matrimonial journey on 13th March 1999. My better half is a wonderful homemaker. We have been blessed with 2 (Two) lovely kids. We are a happy family and we always sincerely grateful to our Creator, Almighty Allah.

Education:

From my early boyhood, I assumed researchers/scientists as the wisest person in the world and I believe that they usually look alike. I have completed my primary education in a government primary school of our village and secondary education from a high school nearby our village. After that I have finished my higher secondary education from Chittagong College, Chittagong. Consequently, I have completed my B. Sc. (Honors) graduation and Masters (M. Sc.) from the University of Chittagong, Bangladesh from Chemistry and Organic Chemistry respectively. My CU Batch is 20th.

I have completed the online course "Introduction to Assessment & Management of Chemicals" organized by Stockholm University. This course includes Eco toxicological effects of chemicals on the environment and human health (Oct'2022).

I am a certified Lean Six Sigma White Belt, trained by Prof. Marcelo Machado Fernandez (11 Jan 2023)

I have been certified for Responsibility of Safety Committee organized by FBCCI (Federation of Bangladesh Chambers of Commerce & Industry) in collaboration with ILO (International Labor Organization) and DIFE (Department of Inspection for Factories & Establishments).

Career:

After finishing my Masters, I have started my career in 1993 at Youngone corporation, a 100% export oriented RMG industry. After completing of about 2 (Two) years in Youngone, I have joined in 1995 at Unilever Bangladesh limited, an FMCG, a sister concern of Unilever PLC, UK in Quality function. I have worked for more than 25+ year in, I have left Unilever and joined in 2020 in NRG Printing and Packaging limited. About 1 year, I have worked here and joined in 2021 in Consort Flexipack limited. I am leading Quality, R & D and Compliance function at Consort.

Specialized areas:

I am an enthusiastic & high energy-driven professional targeting assignment in FMCG Operation / Packaging Development / New product development / Project Management / Research & Development / Compliance / Manufacturing Excellence) TPM / Quality Management System implementation with an organization of high repute. I have an extensive academic background along with 28+ years' experience that will have formed solid foundation for the goal. I have lead SAP (ERP) Make QM function in Unilever Bangladesh Limited from design phase (2010). Apart from my Job, I have been independently working with Flexible Packaging and its sustainability. At a glance, specialized areas are:

a. QMS
b. SAP Make QM (ERP)
c. Packaging Development
d. Flexible Packaging
e. Research Article/Content writing

Interests:

My keen interest is to research, write research papers/articles and analyze. My hobby is learning and I love to learn, investigate and study anything new. Many times, I have been selected as Top learner of the month in my Unilever career.

Publications:

I have 3 (three) publications in three different renowned journals, 2 (Two) conference papers, 1 (One) Innovation and multiple articles are waiting for publish. Published articles are:

i) *My paper "Sustainability of Flexible Packaging Industry across the Globe through the Eyes of Green/Sustainable Chemistry" – published in IJISRT. Volume – 7, Issue 3, March, 2022, DOI: https://doi.org/10.5281/zenodo.6474285.*

ii) *My science Article "A brief study and one step ahead of Plastic sustainability across the Globe"- Published in Global Journal of Science Frontier Research: H Environment & Earth Science; Volume 23 Issue 4 Version 1.0 Year 2023; DOI of the article is: 10.34257/GJSFRHVOL23IS4PG31;*

iii) *My research paper "A complete overview of Packaging discoloration & delamination of Salt packs (Iodized) at market places under conditions relevant to product packaging, ageing & stabilization of filled polymers and product storage" – Published in Research Square* ***(A multidisciplinary preprint and author services platform)****; DOI: 10.21203/rs.3.rs-3817812/v1; Pre-print link: https://www.researchsquare.com/article/rs-3817812/v1.*

iv) *My research paper "A complete overview of Puffed rice quality deterioration at Market places, usually bad smell across Bangladesh under conditions relevant to* *product packaging, ageing and storage." – Published in Research Square **(A multidisciplinary preprint and author services platform)**; DOI: https://doi.org/10.21203/rs.3.rs-4360660/v1; Pre-print link: https://www.researchsquare.com/article/rs-4360660/v1*

v) *My paper "A brief study & assessment of chemicals & waste and its impact on the environment and human health"- Published in SSRN **(An open access preprint server);** DOI: https://dx.doi.org/10.2139/ssrn.4758906; URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4758906*

vi) *My paper "Challenges and solutions of Water and Wastewater Treatment / Water and Wastewater Treatment Challenge; Resource recovery in Water and Wastewater Treatment"- Published in SSRN **(An open access preprint server);** DOI link: https://dx.doi.org/10.2139/ssrn.4758952; URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4758952*

vii) *My paper "Resilient and Sustainable Food Production Systems / End hunger, achieve food security and improve nutrition and promote sustainable Agriculture"- Published in SSRN **(An open access preprint server);** DOI link: https://dx.doi.org/10.2139/ssrn.4802103 URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4802103;*

viii) *My paper "Sustainability of flexible packaging industry across the globe/sustainable path for the flexible packaging industry sectors & global community to Green / Sustainable Chemistry Education" has been accepted for the technical program for **ACS (American chemical Society)** fall 2022**. Joined ACS Speaker Directory (2024)***

ix) *My abstract "Sustainable Path for the Chemicals & Materials Sectors towards a Global Community of Transformation in Green Chemistry Education" has been accepted for the Atlantic Basin Conference on Chemistry (ABCChem) in Morocco by December 2022. **(ACS (American chemical Society) Joined ACS Speaker Directory (2024)***

x) *My Innovation "A small GREEN project and right usage of plastics for sustainable future into the school culture" - Stop choking the earth, unleash from plastics and incorporate this simple idea into education system has been submitted in HundrEDorg – A Finland based Education Research organization. Website: www.hundred.org*

Below are the multiple articles are in processing:

i) *"We have only one earth; don't let it burst a day! Combat climate change and cool the earth with greenery and save it from global warming heat"- Waiting for publish.*

ii) *My paper "Climate change, Plastic Paradox and conversion of CO_2 "- A brief study. Waiting for publish.*

iii) ***My Book "Flexible Packaging Foundation: An exclusive Hand book of Flexible Packaging" – waiting for publish***

Personal Attributes:

I am a native speaker of Bengali, fluency in spoken & written English. I am able to communicate effectively with entire team & with the community at large. I can deliver clear & concise oral presentation to both technical and non-technical audiences and able to comprehend other viewpoints as well as convey information.

I am well Expert with windows operating environment. (MS-WORD, POWER POINT, MS-EXCEL, MS ACCESS, INTERNT) and Sound & well expert in (U2K2) SAP MAKE QM Module.

*"I have recently joined the **ACS Speaker Directory**". **Subject matter - "Ideas on environmental issues, plastics recycling, climate relevant topics, carbon capture etc."*** Link: https://communities.acs.org/t5/media/gallerypage/user-id/79062/image-id/9205iC138E9C397F43FCA/tab/all;

My E-mail: azizul.haque6602@gmail.com, Cell: +8801313032712; +8801912520492

Trainings/Workshops attended:

I have trained on managing safety techniques via "Du – Pont" – The miracles of science, organized by Du Pont safety Resources Asia Pacific held in Chittagong.

I have grown with hands-on training on Artwork management (Blue Project) from Hindustan Unilever Limited, Mombay, India in 2010

I have joined in workshop for SAP (U2K2) implementation in Pakistan Unilever Limited, Karachi in 2020 – 2011. Also joined in "BIG BANG" – A Global project on SAP QM Harmonization at Unilever Vietnam limited, Ho Chi Minh City, Vietnam in 2016.

Career achievements:

I have achieved CIA (Compass into Action) Awards of Quarter 03, 2011 for successful implementation and smooth execution of (U2K2) SAP Project from Unilever. Also achieved Chairman's award, 2011 for successful roll – out of SAP (U2K2) in Bangladesh jointly with Pakistan Unilever Limited.

I have achieved good and glorious service award for completing 15 years of service with the company in July 2011. Again, in 2020, I have achieved good and glorious service award for completing 25 years of service with the company in July 2020.

I have achieved recognition from functional Director in 2013 for successful implementation of CRQS & SNCR in SAP (U2K2).

Social and professional links:

i) *Facebook: https://www.facebook.com/azizul.haque.3572846/*
ii) *Twitter: https://twitter.com/Azizul6602*
iii) *Instagram: https://www.instagram.com/azizul689/*
iv) *LinkedIn: https://www.linkedin.com/in/azizul-haque-47506638/*
v) Research interest in ResearchGate: *https://www.researchgate.net/profile/Azizul-Haque-13*
vi) *Gold Loyalty Level:* https://www.globalcitizen.org/en/profile/83af3d77-4955-4cd2-a0c6-0981b3ef8a08/
vii) *Registered evaluator of Mystery Shopping Company:* https://www.bareinternational.in/.
viii) *Joined Op-Ed community – write to change the world (October, 2023)*
ix) *Community member, FIEVRR: https://www.fiverr.com/azizul6602?up_rollout=true*

x) *Community member, Upwork: https://www.upwork.com/freelancers/~01095a6f8feef1c3fa*

xi) My ORCID ID: 0000-0002-7514-7256; https://orcid.org/0000-0002-7514-7256

xii) Web of Science Researcher ID: JOK-1923-2023: https://www.webofscience.com/wos/author/record/JOK-1923-2023

xiii) *Lens. Org ID:* https://www.lens.org/lens/user/profile

xiv) *PubMed ID: https://www.ncbi.nlm.nih.gov/myncbi/*

xv) *Dimensions ID: https://app.dimensions.ai/discover/publication*

xvi) My Author page @ SSRN (An open access preprint server of Elsevier)): https://ssrn.com/author=6580839

xvii) ***My profile @ Research Square (A multidisciplinary preprint and author services platform):*** *https://www.researchsquare.com/profile*

Abroad tour:

a. Attended Training on Artwork management (Blue Project) at Hindustan Unilever Limited, Mumbai, India on February 15 – 20, 2010
b. Attended Workshop on SAP U2K2 implementation at Unilever Pakistan Limited, Karachi, Pakistan on August 09 – 28, 2010
c. Attended ITC1 (Integrated Testing Cycle 1) on SAP U2K2 implementation at Unilever Pakistan Limited, Karachi, Pakistan on February 21 – March 19, 2011
d. Availed a family tour to Thailand in 2012.
e. Attended “BIG BANG” – A Global project on SAP QM Harmonization at Unilever Vietnam, Ho Chi Minh City, Vietnam on June 23 – June 24, 2014