KAUNAS UNIVERSITY OF TECHNOLOGY

Mechanical Engineering and Design FACULTY

Ilham Abbasov

Analysis of Application of Green Engineering Principles in Manufacture of Polymeric Packages

Master's Degree Final Project

Supervisor
prof. dr. habil.Edmundas Kibirkstis

KAUNAS, 2017

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Industrial Engineering and Management (code 621H77003)

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KAUNAS, 2017

KAUNAS UNIVERSITY OF TECHNOLOGY

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Industrial Engineering and Management, 621H77003

(Title and code of study programme)

" Analysis of Application of Green Engineering Principles in Manufacture of Polymeric Packages"

DECLARATION OF ACADEMIC INTEGRITY

24 May 20 17

Kaunas

I confirm that the final project of mine, **Ilham Abbasov**, on the subject "Analysis of Application of Green Engineering principles in Manufacture of Polymeric Packages" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Approved:
Head of
Production engineering
Department

____
(Signature, date)

Kazimieras Juzėnas
(Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Analysis of Application of Green Engineering Principles in Manufacture of Polymeric Packages

Approved by the Dean Order No.V25-11-8, 21 April 2017

2. Aim of the project

The aim of this project is to investigate the possible green engineering principles of flexographic printing in the manufacturing of food packaging proposing for printing house JSC “Aurika” more eco-friendly materials and their manufacturing technologies

3. Structure of the project

1.Analysis of packaging process in EU market
2.Principles of green engineering applied in manufacturing processes
3.Requirements, characteristics and properties of polymeric packaging materials for food products
4.Types of biodegradable polymers materials
5.The research of biodegradable polymeric films their properties, characteristics and equipment
6.Research of harm to environment of packaging manufacture process (ECO indicator methods)
7.Designing of manufacturing technologies of food packaging
8.Quality control of the technological process
9.Work safety and ecology
10.Competitor’s analysis in Baltic States and Europe
Conclusion

4. Requirements and conditions

Packaging printing machine- Fischer & Krecke Flexpress 16S-10. 6+0 partial matt varnishing. Wide Laminator equipment - Kodak FlexCel NX and technical characteristics. Exposure equipment- Dupont Cyrel DigiFlow 2000 EC. Kodak FlexCel NX Wide Imager (Gravure equipment). Green Engineering Principles

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2017 __06_ _09_st.

Student ________________________ ____________________
(*Name, Surname of the Student*) (*Signature, date*)

Supervisor ________________________ ____________________
(*Position, Name, Surname*) (*Signature, date*)

Ilham, Abbasov. Analysis of Application of Green Engineering Principles in Manufacture of Polymeric Packages *Master's* Final Project / supervisor prof. dr.habil.Edmundas Kibirkstis; Faculty of Mechanical Engineering and Design FACULTY, Kaunas University of Technology.

Research field and area: Technological Sciences, Production Engineering

Keywords: *Green Engineering , Polymeric Packaging, Biodegradable Materials*

Kaunas, 2017. 73 p.

SUMMARY

The analysis of packaging processes in EU market has been carried out in this work. The application of green engineering principles at company of flexographic printing technologies JSC "Aurika" has been investigated in this work. The review of biodegradable polymeric materials suitable for manufacturing of food packaging has been carried out to propose more ecological polymeric biodegradable films for food packaging. The researches of physical properties of these new biodegradable polymeric materials have been carried out and the results obtained have been compared with the physical characteristics of traditional LDPE polymer. The manufacturing technology of package was given which has a biodegradable additive also the equipment of manufacturing processes has been chosen. The methodology of quality control of technological processes, work safety has been proposed and the analysis of rivals in Europe of JSC "Aurika"has been carried out. The conclusions of the master's degree final project have been given.

Ilham Abbasov. Žaliosios inžinerijos principų taikymo analizė polimerinių pakuočių gamyboje *Magistro* baigiamasis projektas / prof. dr.habil.Edmundas Kibirkstis; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Mokslo kryptis ir sritis: Technologijos mokslai, Gamybos inžinerija

Reikšminiai žodžiai: *Žalioji inžinerija,polimerinės pakuotės, bioskaidžios medžiagos.*

Kaunas, 2017. 73 p.

SANTRAUKA

Atlikta pakavimo procesų Europos Sąjungoje rinkos analizė. Darbe ištirta žaliosios inžinerijos principų taikymas fleksografinės spaudos technologijų įmonėje UAB “Aurika“. Atlikta bioskaidžių polimerinių medžiagų, tinkančių maisto produktų pakuočių gamybai apžvalga ir atlikti tyrimai, tikslu pasiūlyti maisto produktų pakuotėms labiau ekologiškas polimerines bioskaidžias plėveles. Atlikti šių naujų bioskaidžių medžiagų fizikinių savybių tyrimai ir gauti tyrimų rezultatai palyginti su tradicinio polimero LDPE fizikinėmis charakteristikomis. Pateikta pakuotės, pagamintos su bioskaidžių priedu, gamybos technologija, parinkta gamybos procesų įranga. Pasiūlyta technologinių procesų kokybės kontrolės metodika, darbų sauga ir atlikta įmonės UAB „Aurika“ konkurentų Europoje analizė. Pateiktos baigiamojo darbo išvados.

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Introduction

The production volume and consumption of polymers, made from petrochemical raw materials are increasing constantly. The usage of polymer materials is increasing instead of paper, carton, metal, glass. In the meanwhile, the amount of production of polymer materials (mostly in the packaging area) are also increasing, however, these products go to the landfill site after usage. As is well known, the duration of polymers decomposition takes ten or hundred years, however, the landfill sites are limited. Therefore, this issue is becoming increasingly relevant. In some countries (Taiwan, Germany, Ireland) the usage of plastic bags is not allowed.

The ways to solve this type of problem as recycling and burning landfills are not so effective. Technological cycle of recycling is complicated and long, then quality of product decreases. Burning landfills bring more emission which causes air pollution, there are highly negative views on burning landfills in the most countries. Burying plastic waste from polymer materials make negative effects on natural environment-land, groundwater [1].

An analysis of green principles usage in the technological process of printing house JSC “Aurika” has been carried out in this work. Also, the proposals have been given how this company could develop more eco-friendly manufacturing technologies in the future.

Aim

The aim of this project is to investigate the possible green engineering principles of flexographic printing in the manufacturing of food packaging proposing for printing house JSC “Aurika” more eco-friendly materials and their manufacturing technologies.

Objectives

1. Carry out the analysis of packaging processes in EU market.
2. Carry out the analysis of request for materials used for food packaging and analyse the 12th principles of green engineering.
3. Carry out the researches of properties of more eco-friendly polymeric materials (surface treatment, resistance to tension, coefficient of friction, seal strength etc.).
4. Summarize the results of experimental researches and provide the methodology of selection of polymeric materials. Arrange the reasoning of technology of package manufacturing and carry out the designing of this technology.
5. Discuss the methods and tools which are used for control of manufacturing quality, work safety and ecology.
6. Carry out the analysis of rivals of JSC “Aurika” and prepare the conclusions of final project.

1. Analysis of packaging process in EU market

The Fig 1.1 shows the distribution of European (EU-28+NO/CH) plastics demand by segment in 2015. As can be seen in Fig 1.1. most plastics are consumed in packaging industry area. Packaging area leads for the plastic demand in Europe which is 39.9 %. Other area (goods, furniture, sport, health and safety) follows packaging area with 22.4 %. 19.7 % of plastics are required by building and construction area. Automotive area demands 8.9 % plastics. Less demand constitutes for electrical and electronic devices with 5.8 %. There are 3.3 % plastics demand in the Agriculture area. Total plastics demand constitutes 49 million tons in the Europe [2].

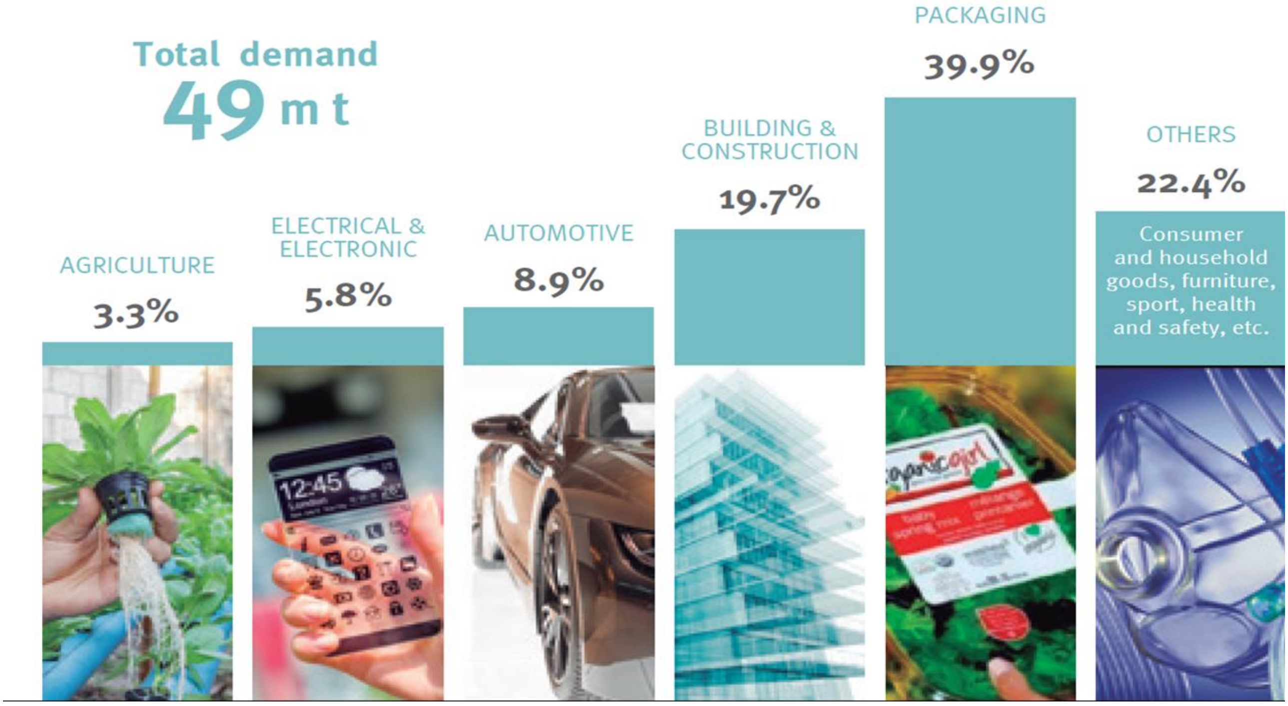


Fig 1.1. The distribution of European (EU-28+NO/CH) plastics demand by segment in 2015 [2]

The Fig 1.2 shows the European plastics demand (EU-28+NO/CH) by polymer type in 2015. Linear low-density polyethylene (LDPE) and Low-density polyethylene (LDPE) are mostly demanded for packaging according to European Plastics Statistics. The required rate of PVC (polyvinyl chloride) is higher compare to the other type of plastics for building and construction area. There is high demand for Polypropylene (PP) in Automotive as well as Electrical and Electronic area.

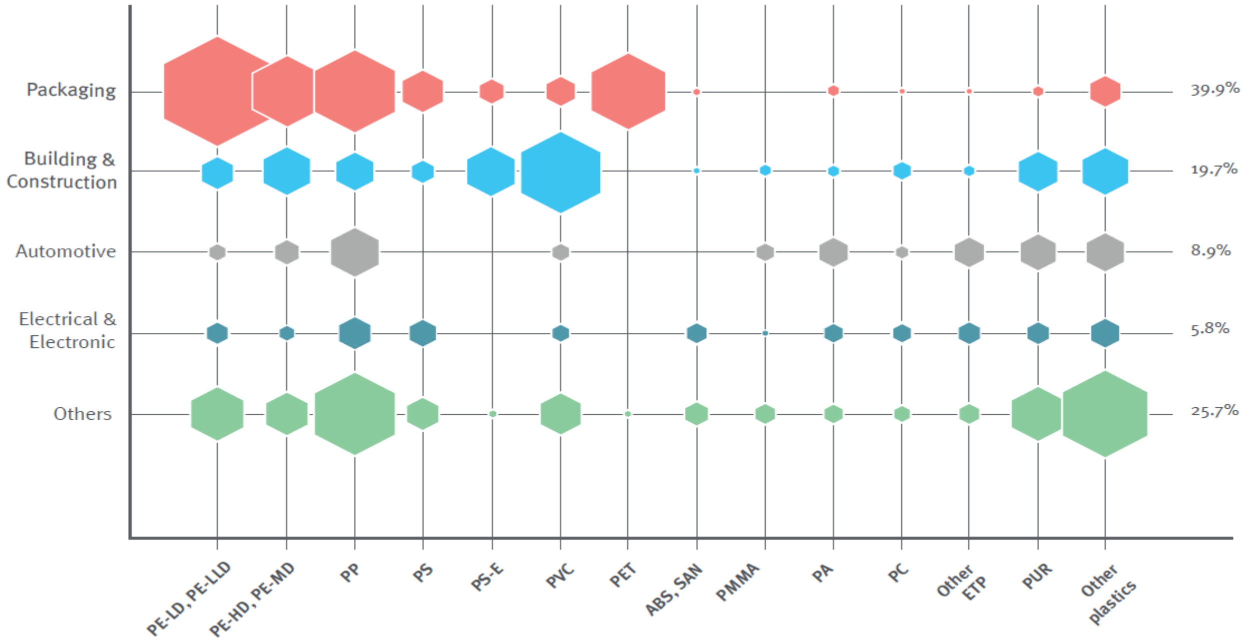


Fig 1.2. European plastics demand (EU-28+NO/CH) by polymer type 2015 [2]

The Fig 1.3 gives information about the percentages of treatment of post-consumer plastics waste 2014. There are three series in the chart. The recycle rate is represented by green colour, the orange one indicates the energy recovery rate and the landfill rate is represented by red colour in the Europe. From the Fig 1.3 it can be clearly observed that energy recovery rate in Switzerland is relatively high compare to other countries. There are 9 countries (Switzerland, Austria, Netherlands, Germany, Sweden, Luxembourg, Denmark, Belgium and Norway) with landfill ban in the bar chart. About 40 percent of plastics waste is recycled in Norway. From the Fig 1.3, it is clear that the landfill rates of 3 countries (Greece, Cyprus and Malta) are quite high. Energy recovery rates of 2 countries (Croatia and Bulgaria) contains approximately 5 %. If considering the Baltic states, Estonia exceeds other countries in more recycling and energy recovery rates. It can be seen that, the recycling rate and energy recovery rate are about 34 % and 44 % in Estonia. The treatment rate of post-consumer plastics waste in Lithuania exceeds his neighbour countries [2]. The recycling rate and energy recovery rate makes up about 24 % and 26 % in Lithuania. However, landfill rate is about 50 % much higher than other treatments in Lithuania. Only about 27 % of waste recovered through recycling while about 68 % went to landfill in Latvia.

Fig. 1.3. Treatment of post-consumer plastics waste 2014 (EU-28+CH/NO) [2]

Also, energy recovery rate is around 5% lower compare to other Baltic States. The treatment rates are much better than Latvia in Poland. About 25 % of waste is recycled and the energy recovery rate is 19 % in Poland. Approximately 56 % of waste went to landfill [2].

Conclusion

This analysis shows increasing demand of polymers and site fills are limited. So, we must concentrate on biodegradable polymers and eco-friendly production. JSC "Aurika" printing house invests on ecological issues.

In the following paragraph the green engineering principles and the explanations of them are discussed.

2. Principles of green engineering applied in manufacturing processes

Researchers, scientists have lately put the effort on the topic of decreasing the negative influences on the planet and making the life sustainable on the Earth. From these discussions, some specific aims have been formed, for example, decreasing waste, support recycling or approaching sustainability. The advantage of certain goals is that it can be very useful in providing a vision of what must be done. Further, many of these discussions are unhelpful in achieving this vision. Unfortunately, however, these approaches are neither systematic nor comprehensive now [3]

What is green engineering constituted of? Application of the principles of green engineering can create more sustainable development. The definition of green engineering from various sources:

- According to the date obtained from "epa.gov ", a quote "Green engineering is the design, commercialization and use of processes and products in a way that reduces pollution, promotes sustainability and minimizes risk to human health and the environment without sacrificing economic viability and efficiency "[4]
- According to the date obtained from "Design Through the 12 Principles of Green Engineering", a quote is "Green Engineering concentrates on how to build a culture of sustainability through science and technology "[3]

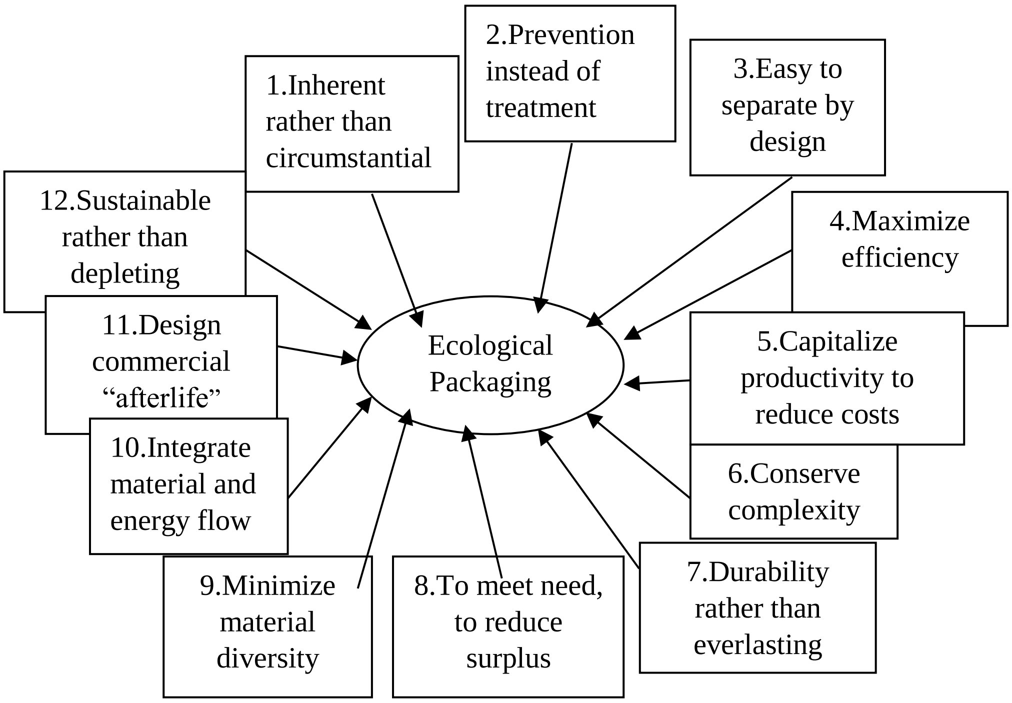


Fig. 2.1. Green Engineering Principles [3]

2.1. Principles of Green Engineering

Principle 1: Designers need to strive to ensure that all material and energy inputs and outputs are as inherently safe and benign as possible. However, the containment results of inherently hazardous substrates may be kept to a minimum, this process is only achieved thanks to more investment of capital, time and energy resources. If inherently hazardous inputs are already included to the process, there are many ways to decontaminate: one way is to remove or use purification step during process, or leave it for incorporation to final product. Engineers should put more effort to improve safety precautions in each movement [3].

Principle 2: Strive to prevent waste than to treat or clean up waste after it is formed. As mentioned in the article, "Zero waste "definition for manufacturing processes and services is often excoriated because this refutes the physical laws. Nature of materials or energy are not waste, people make waste them somehow people do not use it efficiently. It is fact that we should not waste wherever the process, however, sometimes It can generate accidentally. It is clear from the above article, power generation systems formed on fossil fuels make waste in each life cycle stage of production. However, fusion energy can be used because it is sustainable but still unrealized [3].

Principle 3: Easy to separate by design. Separation and purification operations should be designed to minimize energy consumption and materials usage. From the aspect of article, product separation and purification is problematic for some manufacturing process because it requires much material and energy during process. Thanks to advanced design, the self-separation of product can easily happen because of using physical chemical properties rather than special conditions and wasting. Poor economic and technical circumstances in separation process can be a protective factor for recycling factor. As mentioned from the article these problems can be solved by stopping permanent bonds between different material. Fasteners which are made to disassembly must include uncomplicated design strategy at all scales [3].

Principle 4: Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency. Product and life cycles often have broadly distributed consequences through but processes and systems often use more time, space, energy, and material than required, the results could be categorized as "inefficiencies" [3].

Principle 5: Products, processes, and systems should be "output pulled" rather than "input pushed" using energy and materials. Le Châtelier's principle states that when a stress is applied to a system at equilibrium, the system readjusts to relieve or offset the applied stress [3].

Principle 6: Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition. As cited from above article-the product complexity was based upon no matter which scale expend on cost, material and energy. High complexity should fit for later use because however minimal complexity is approved by sustainable approach [3].

Principle 7: Targeted durability, not immortality, should be a design goal. ranging from solid waste disposal to persistence and bioaccumulation which the product that will last well beyond their useful commercial life often result in environmental problems. To avoid immortality of undesirable materials in the environment which is therefore necessary to design substances with a targeted lifetime [3].

Principle 8: It is important anticipating the necessary process agility and product flexibility at the design. The material and energy costs can be high for overdesign and unusable capacity or capability. For allowance the same product or process to be used regardless of local spatial, time, or physical conditions, there is also a tendency to design for worst-case scenarios or optimize performance for extreme or unrealistic conditions [3].

Principle 9: Products which have multiple components as cars, food packaging, computers, and paint are very diverse. For avoidance additives at a later stage in the manufacturing process, at the process level, this is being done by integrating desired functionality into polymer backbones [3].

Principle 10: Products, processes, and systems must be designed to allow the existing framework of energy and material flows within a unit operation, production line, manufacturing facility, industrial park, or locality [3].

Principle 11: Occurrence in commercial end of life is a result of technological or stylistic obsolescence, rather than a fundamental performance or quality failure, in many instances. To reduce waste, the recovery of reusable or reconfigurable remains functional and valuable components are important [3].

Principle 12: Material and energy inputs should be renewable rather than depleting. Influence on the sustainability of products, processes, and systems can be a major by the nature of the origin of the materials and energy inputs. Whether a substance or energy source is renewable or depleting can have far-reaching effects [3].

Conclusion

Pre-designing of research, all principles of green engineering principles were considered. On these green engineering principles, I analysed that JSC “Aurika” printing house applies principles 1,2,3,4 and 12 on the production. Other principles do not totally apply on manufacturing.

The next paragraph will represent the requirements, characteristics and properties of polymeric packaging materials for food products

3. Requirements, characteristics and properties of polymeric packaging materials for food products

General required for food packaging materials and the functions of food packages are shown in the Fig 3.1.

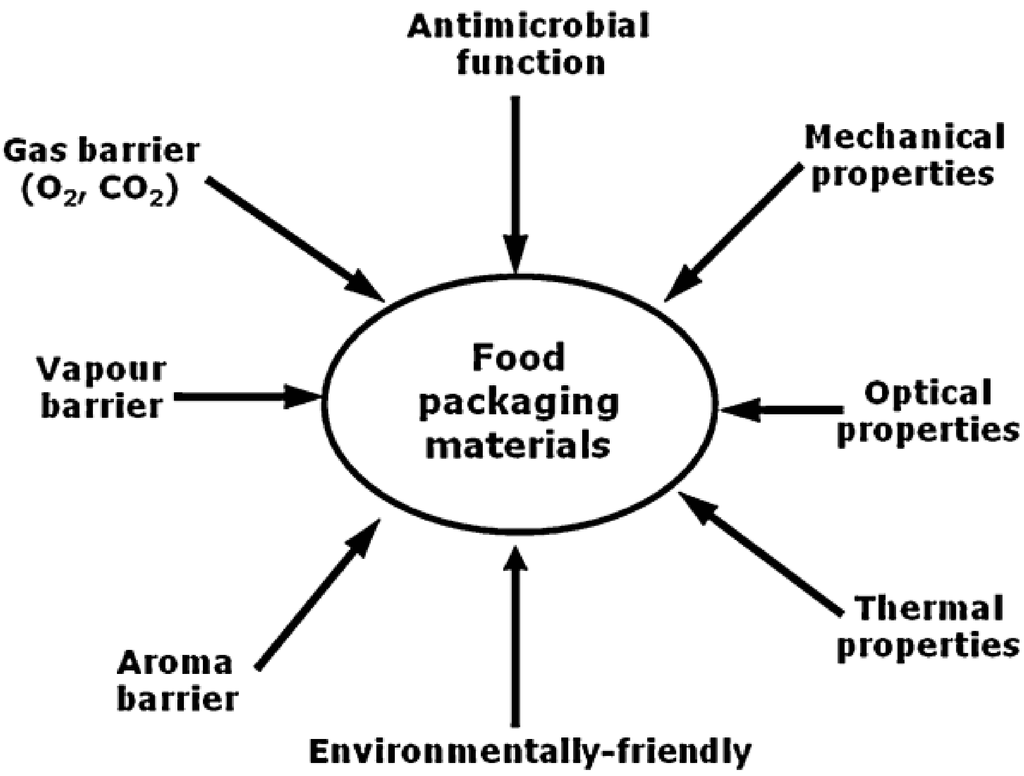


Fig. 3.1.General properties required for food packaging materials [5]

1. Printed Information(communication): "A package must protect what it sells and sell what it protects" as Judd reported in his book [6]. Although the idiom is very old, however, nowadays this expression assumes importance. Labels and packages play informative role in food packaging [7].

2. Physical Protection: It is one of the more important task which keeps food away from any environmental impacts (water, vapor, gas, odours, microorganisms and dust) and change can occur during transport or handling (damage, spoilage, leak) [7].

3. Containment: Also, called "agglomeration". This function is mostly related with easy transportation and handling. However, without this function, product loss and pollution largely expand. Containment function of food packaging keep environment from containment during countless food transportation from one place to another on special occasions.

4. Convenience: Makes consumers feeling more comfortable during using product way they want. Food packages can be designed to contribute easily portability. Two other aspects of convenience should take into consideration in designing package [7].

5. Barrier properties:

The determination of the barrier properties of a polymer is important to forecast the product-package lasting time. The specific final application of properties of package system depends on the characteristics of product. Plastics are usually relatively penetrable to small molecules of gases, water vapor, organic vapours and liquids under normal conditions. Water vapor and oxygen are two of the principal penetrators studied in packaging applications, as they may transfer from the internal or external environment through the polymer package wall therefore making the influence on the product quality and shelf-life (Germain, 1997) [8].

6. Gas barrier properties: Oxygen transmission rate (OTR) and Carbon dioxide transmission rate (CO2TR)

The oxygen barrier property of packed fresh food container (e.g. fruits, salad, ready-to-eat meals) plays a signification role on its conservation. The oxygen barrier is characterized by the oxygen permeability coefficients (OPC) which indicates the amount of oxygen that penetrates per unit of area and time in a packaging materials [kg mm^{-2} s^{-1} Pa^{-1}]. Once a polymer film packaging has a low coefficients of oxygen permeability, the oxygen pressure inside the container drops to the point where the oxidation process is delayed, resulting the extension of product life. Some authors like (Auras, Harte, & Selke, Auras and others have described in literature that the oxygen permeability coefficients of one of the most commercialized biodegradable polymer as the PLA The unit of oxygen transmission rate (OTR) is cc m^{-2} s^{-1}. The oxygen permeability coefficient (OPC) is determined by following formula:

$$OPC = OTR \times l / \Delta P \qquad (3.1)$$

where l is the thickness of the film (m), DP is the difference between oxygen partial pressure across the film [Pa]. $\Delta P = p_1 - p_2$, (3.2) where p_1 is the oxygen partial pressure at the temperature test on the test side and p2 is equal to zero on the detector side.

The carbon dioxide barrier is characterized by the carbon dioxide permeability coefficients (CO_2PC) which shows the quantity of carbon dioxide that penetrates per unit of area and time in materials for packaging. The unit of carbon dioxide permeability coefficient is [kg m m^{-2} s^{-1} Pa^{-1}]. The carbon dioxide transmission rate is expressed in cc m^{-2} s^{-1} (or g m^{-2} day^{-1}) Along with the permeability coefficient is given velocity of carbon dioxide transmission rate (CO_2TR). The carbon dioxide permeability coefficient (CO_2PC) has ratio to CO_2TR in equation (1).

7.Water vapor transmission rate (WVTR)

The water vapor barrier is characterized by the water vapor permeability coefficients (WVPC) which indicate the quantity of water vapor penetrating per unit of area and time in materials for packaging [kg m m^{-2} s^{-1} Pa^{-1}]. It is important for fresh food products to avoid dehydration, whereas bakery and delicacy needs to be protected against water permeation.

The unit of water vapor transmission rate (WVTR) is cc $m^{-}2$ $s^{-}1$ (or g m^{-2} day^{-1}). The water vapor permeability coefficients (WVTR) has ratio to WVTR as is described up in equation (1).

8.Mechanical properties

It is commonly known that the polymer architecture plays a key role in the mechanical properties, and therefore on the process utilized to modelling the final product (injection moulding, sheet extrusion, blow moulding, thermoforming, film forming) [9].

Tensile test analyses are carried out to find out the tensile strength (MPa), the percent elongation at yield (%), the percent elongation at break (%) and the elastic modulus (GPa) of the food polymer packaging material. These values are necessary to get mechanical information of the biodegradable polymer materials to compare with the commercial nonbiodegradable ones (ASTM D882-02, Standard Test Method for Tensile Properties of Thin Plastic Sheeting). Impact properties test is the ASTM D1709-03, Standard Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Method.The compression test is the ASTM D642, Standard Test Method for finding out Compressive Resistance of Shipping Containers, Components, and Unit Loads.

9.Chemical resistance properties

Products that could be packaged in this kind of containers may have weak or strong characteristics of acid; therefore, it is important to evaluate the performance and the suitability of biopolymers stored with common food packaging solution as a function of time. The chemical resistance is usually tested measuring the tensile stress, elongation at break and modulus of elasticity of sample submerged in weak and strong acid solutions as a function of time, simulating real conditions, at ambient temperature (23℃) and at −18 ℃, −23 ℃ and −29 ℃ [9].

Conclusion

Raw material is laminated from 3 to 7 layers in order that manufactured packages pay all of the above requirements in JSC “Aurika” flexo printing house.

Further we proceed to the eco-friendlier biodegradable polymer materials.

4. Types of biodegradable polymers materials

The classification of biodegradable materials is shown in the Fig 4.1. Biopolymers (the full name is biodegradable polymers) differ from the other plastics by the possibility of decomposition into microorganisms by chemical, physical impact or biological impact. These properties of biodegradable polymers will be solution for waste problem. There are four types of biodegradable polymers: Coming from agro-resources (Polysaccharides, Proteins) which is called biomass products, coming from microorganisms (polyhydroxyalkanoate), Polylactides (PLA) which is obtained by using biotechnology and synthesis from renewable resources. As it can be seen from Fig. 4.1 Polycaprolactone (PCL) is obtained through classical chemical synthesis way [10].

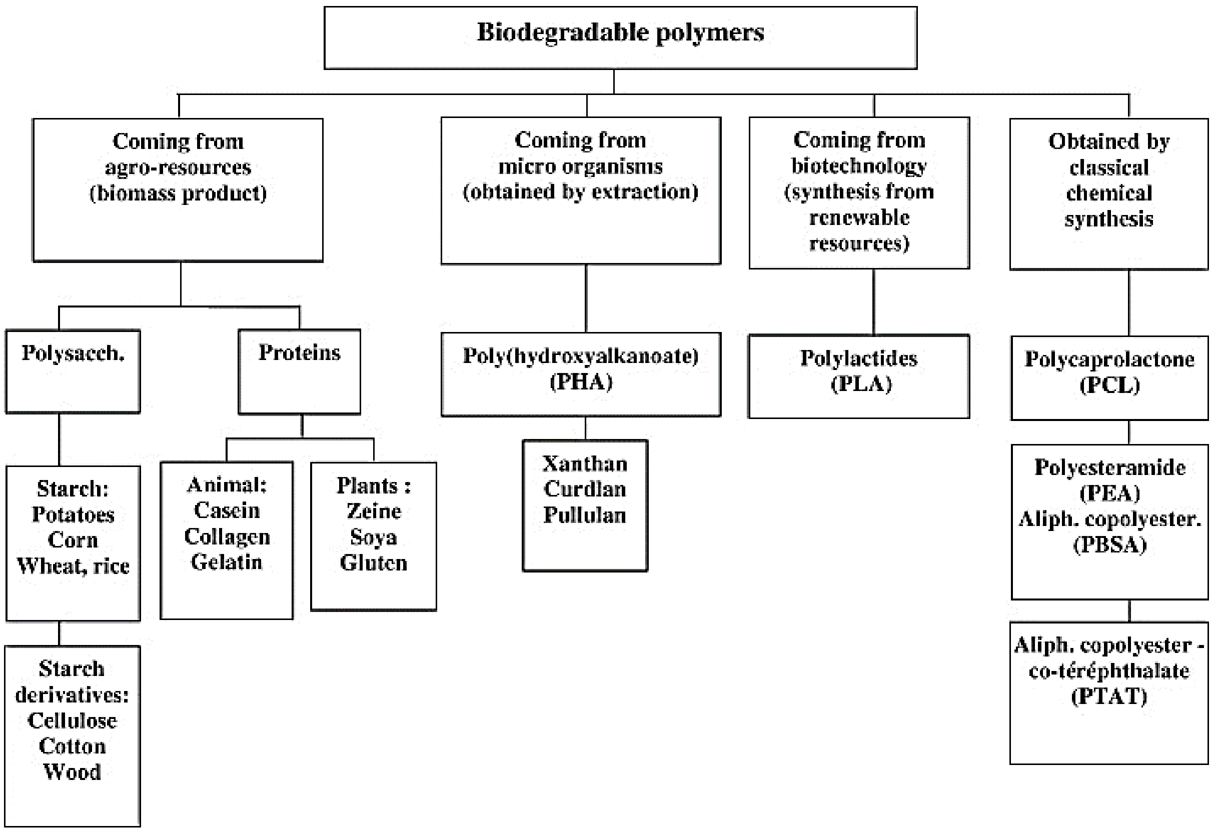


Fig. 4.1. The classification of biodegradable materials [10]

- **Polysaccharides**

Starch based polymers are obtained by extraction from plant raw materials with subsequent modification. Cellulose based polymers are obtained through modification of natural raw material or bacterial fermentation [11].

- **Proteins**

Natural high molecular weight organic compounds, built from the residues of 20 amino acids, which are linked by peptide bonds into long chains [12].

- **Polyhydroxyalkanoate (PHA)**

The other technological area biopolymers-the production of polyhydroxyalkanoates (PHA abbreviation) belonging to the type of aliphatic polyesters as the basis of Alpha hydroxy acid. American company Metabolix and Procter & Gambler are stressing out on this area [1]

- **Polylactides (PLA)**

One of the most perspective biopolymers are the polymers of milk acid-Polylactide (PLA), a raw material for the production of which is maize, Saccharum officinarum and rice etc. There are two ways to obtain PLA from Lactic Acid – direct polycondensation of lactic acid and the polymerization of disclosure of cyclic lactide [1].

- **Polycaprolactone (PCL)**

Polycaprolactone (PCL) is caprolactone polymers. It has a good resistance to water, oils and solvents. Moreover, it has low viscosity and easily processed. It can be blended with starch to reduce the cost and to increase the biodegradability. Also, PCL decomposes under physiological conditions (for example in the human body) and therefore received much attention as an implantable biomaterial [13].

Further we proceed to the research of biodegradable polymeric films their properties and characteristics.

5. The research of biodegradable polymeric films their properties, characteristics and equipment

5.1. Preparation of investigated specimens of biodegradable materials

All specimens are manufactured using extruder SJM 35-400. 36 specimens were obtained. The outer view of the extruder SJM35-400 is shown in the Fig. 5.1 [14].

Fig. 5.1 Outer view of the extruder SJM35-400

Polymeric films were manufactured using the following compositions [14]:

- Pure low-density polyethylene (referred as LDPE);
- LDPE + 3% potato starch + 1% glycerine (referred as LDPE1);
- LDPE + 3% potato starch + 1% glycerine + 10% itaconic acid (referred as LDPE2);
- LDPE + 5% potato starch + 1% glycerine + 10% itaconic acid (referred as LDPE3);
- LDPE + 2% molasses (dry) + 1% glycerine (referred as LDPE4);
- LDPE + 2% molasses (liquid) + 1% glycerine (referred as LDPE5).

The outer view of biodegradable materials is shown in the Fig 5.2 Low Density Polyethylene + Sorbitol (10 %), Low Density Polyethylene + Chitosan (3 %) and Low Density Polyethylene + Molasses liquid (3 %) are given in the picture

.

a)

b)

c)

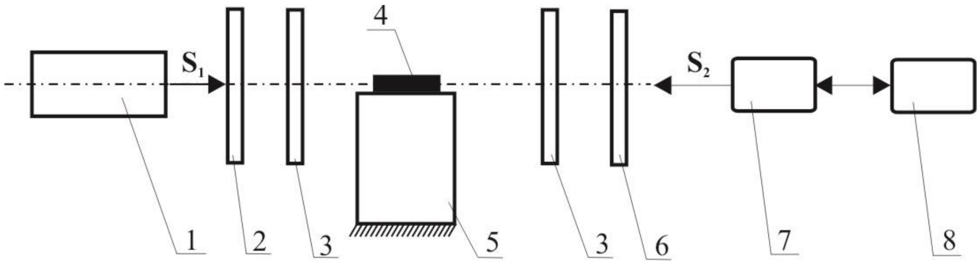
Fig. 5.2. The outer view of biodegradable materials: a) LDPE+ sorbitol 10 % ,b)LDPE+ Chitosan 3 %,c) LDPE+ Molasses liquid 3 %

5.2. Research equipment and methods of study of biodegradable polymers

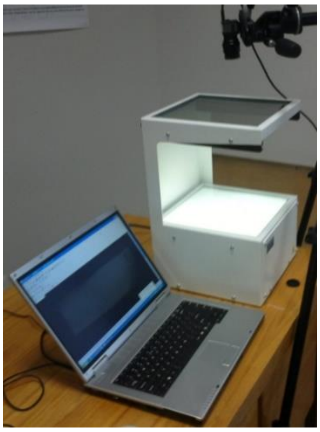
5.2.1. Photoelastic Stress distribution methods and equipment

The picture of the Sharples General Purpose strain viewer is shown in Fig 5.3 LDPE, Glycerine 1 %, Molasses (dry) -2%; LDPE, Molasses liquid 2%, Glycerine 1 %; Pure LDPE; PEVD + Chitosan (3%); LDPE + Sorbitol (10 %); LDPE+ Molasses liquid were used for the photo elastic method of the stress analysis. This method was applied to check the residual stress distribution in polymeric films.

Photo elasticity is the display of optical anisotropy in isotropic solids under mechanical stress [16]. The non-destructive photoelasticity method was applied by testing the character of residual stresses distribution in polymeric film material.



a)



b)

Fig. 5.3. The scheme of polymeric film residual stresses analysis stand and outer view of the device: a) structural scheme of „General Purpose Strain Viewer “: *1* – light source; *2* – polarizer; *3* – quarter wave length plate; *4* – polymeric film; *5* – rigid base; *6*- analyser; *7* – digital camera EO-1312c; *8* – computer; S_1 – direction of light movement; S_2– view direction; b) outer view of the „General Purpose Strain Viewer” [15]

The views of the distribution of polymeric films residual stresses were captured using colour camera EO-1312c.The quantitative evaluation of the stresses, having in mind the mathematical point of view, was complex thus only qualitative analysis of stresses was carried out in this work [15].

5.2.2. Tensile and deformation testing methods and equipment

The main aim of this test is to determine the tensile force and elongation at break in the machine direction (MD) and cross direction (CD) of extrusion of the specimen by using a universal tensile/compression machine Tinius Olsen H10KT. The scheme for tensile test of experimental specimens was shown in the Fig 5.4 [14].

The samples of the polymeric films under the test were placed in the clamps of the tension machine. During the testing time, tension was applied to the polymeric films at the relative speed of 100 mm/min in the force scale 0 – 40 N using the interval up to 10 N and the elongation scale 1:1. The initial width b of the specimens was 15 mm, length l - 150 mm, and the length between the tension machine clamps (operation length) l_0 -100 mm (Fig.5.4.).

The horizontal optimeter IKG was used to measure the thickness of the films; each polymer type was measured 10 times,

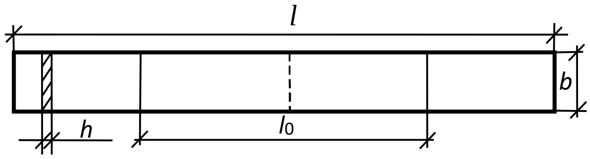


Fig. 5.4. Scheme for tensile test of experimental specimen: *l* is the initial specimen length, l_0 is length between the tension machine clamps (operation length), *h* is specimen thickness, *b* is specimen width [15]

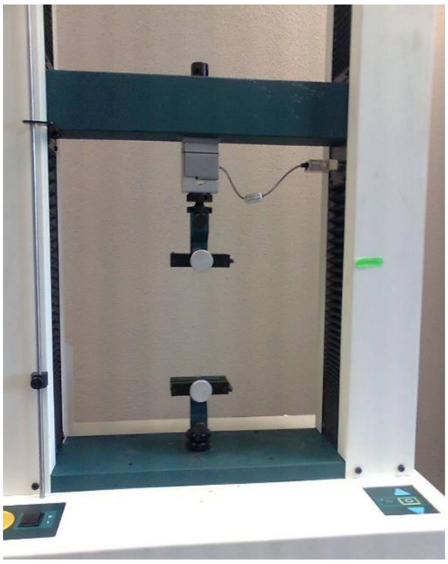


Fig. 5.5. View of tensile block of Tinius Olsen H10KT [14]

During the test the tension machine draws the dependence of tensile strength upon the specimen elongations. To replace tensile strength dependence on specimen elongation by stress dependence on deformation, cross section of the specimen has to be evaluated. The stress is calculated as the ratio of strength and cross-section area:

$$\sigma = \frac{F}{A} \tag{5.1}$$

where σ is stress, MPa; F is tensile strength, N; A is cross section area, mm^2, where h is thickness of the specimen, mm; b is width of the specimen, mm. A= b·h (5.2) The strain is calculated as the ratio of elongation and initial length: $\Delta\varepsilon = \left(\frac{\Delta\, l(0)}{l(0)}\right) \cdot 100\ \%$ (5.3), where ε is strain, %; Δl_0 is polymer elongation before it breaks, mm; l_0 is length between the tension machine clamps (operation length), mm. l_0 [17].

5.2.3. Printability Testing methods and equipment

100% ink colour patches on polymeric films were printed using "Flexiproof 100/UV" printing tester. The outer view of "Flexiproof 100/UV" printing tester is shown in the Fig 5.6[14]. First, the required anilox roll was selected and fitted [18].

Fig. 5.6. "Flexiproof 100/UV" printing tester [14]

Later, we placed substrate (105mm x 297mm) to impression roll using the self- adhesive sensitive strip. Set printing speed up to 99m/min. The ink was added using a pipette. Side dams fitted at each end of the doctor blade provide a reservoir holding sufficient ink for producing multiple proofs when required [18].

Table 5.1. The specifications of "Flexiproof 100/UV" printing tester [18]

Model	30-60-00-0001
Printing Speed	Variable 20-99m/min
Ink Types	Solvent based, water based, UV
Substrates	Flexible paper, board, film and foil
Substrate size	297 x 105 mm (11.7 x 4.1 in)
Maximum printing area	1.7 mm plus 0.5 mm, cushion mount
Standard Plate Thickness	260 x 90 mm (10.2 x 3.5 in)
Overall Plate Dimensions	In steps of 4 micron
Roller Adjustment	Hardened steel stepped edge
	92 x 12 x 0.15 mm (3.6 x .4 x .006 in)
Physical Specifications	
Bench Space	55 cm wide x 45 cm deep (21.6 x 17.7 in)
Weight	45 kg net 51kg gross (99 lb net, 112 lb gross)
Power Supply	100-115-200-230 volts 50/60 Hz
	N.B. UV POWER PACK REQUIRES 230 VOLTS MINIMUM

The specifications of "Flexiproof 100/UV" printing tester is shown in Table 5.1. After printing, the blade, blade holder and side dams were cleaned using a suitable solvent. The cleanliness of equipment was checked using the mirror [18].

5.2.4. Optical density testing method and equipment

Proof printing was carried out for samples without additional surface treatment (virgin surface tension) and with additional treatment by setting the power at 70 W/min/m2. Such value of power was selected considering the recommendations of flexographic printing machine operators from Lithuanian printing houses. The surface tension of polymeric materials was increased by using the corona discharge device "Vetaphone Corona-Plus". The densitometer "X-Rite Colour" was used to determine optical density and microscopic analysis was carried out using the optical microscope "AM2111 Dino-Lite basics" [19].

Fig 5.7. The outer view of optical densitometer "X-Rite Colour" [20]

The specifications of AM2111 Dino-Lite Basic is shown in Table 5.2. First, a unidirectional, perpendicular light beam was directed onto the polymeric film sample. The light that is transmitted through the film is collected, measured, and logarithmically amplified.

Table 5.2. The specifications of AM2111 Dino-Lite Basic [21]

Model	AM2111 Dino-Lite Basic
Interface	USB 2.0
Product Resolution	640x480 pixels (VGA)
Magnification Rate	20x~50x, 200x
Sensor	Color CMOS
Frame Rate	Up to 30fps
Save Formats	Image: DinoCapture2.0: BMP, GIF, PNG, MNG, TIF, TGA, PCX, WBMP, JP2, JPC, JPG, PGX, RAS, PNM DinoXcope: PNG, JPEG Movie: DinoCapture2.0: WMV, FLV, SWF DinoXcope: MOV
Lighting	4 white LED lights for illumination
Operating System Supported	Windows 10, 8, 7, Vista, XP MAC OS 10.4 or later
Unit Weight	100g
Unit Dimension	10.5cm (H) x 3.2cm (D)

The densitometer calculated and displayed the optical density of polymeric films. The optical density values are represented by the following calculation and relationship to % of light transmission. The following formula was used to calculate optical density of polymeric films:

$$\text{Optical Density (unitless)} = \log 10\left(\frac{\text{Incident light}}{\text{Transmitted light}}\right) = \left(\frac{100}{\text{Light transmission (\%)}}\right) \quad (5.4.)$$

After calculation, optical density values were reported into Table 5.6 [22].

5.2.5. HEAT SEAL TESTING method and equipment:

“Labthink Instrument Heat Seal Tester HST-H3” was used for welding the polymeric films. The outer view of “Labthink Instrument Heat Seal Tester HST-H3” is shown in Fig 5.8 [14].

Fig 5.8. Labthink Instrument Heat Seal Tester HST-H3 [14]

Technical specifications of Labthink Instrument Heat Seal Tester HST-H3 are shown in Table 5.3.

Table 5.3 Technical specifications of Labthink Instrument Heat Seal Tester HST-H3 [23]

Specifications	HST-H3
Sealing Temperature	Room temperature ~ 300°C
Accuracy	±0.2°C
Dwell Time	0.1~999.9 s
Sealing Pressure	0.05 MPa ~ 0.7MPa
Sealing Area	330 mm x 10 mm (customization available)
Heating Mode	Single heating surface or double heating surfaces
Gas Supply Pressure	0.5 MPa ~ 0.7MPa (outside of supply scope)
Port Size	Φ6 mm PU Tubing
Instrument Dimension	536 mm (L) x 335 mm (W) x 413 mm (H)
Power Supply	AC 220V 50Hz
Net Weight	43 Kg

Considering the equipment HST-H3, Heat Seal Tester is made up of upper and lower heat sealing jaws. Before starting the test, heat seal temperature was preset, pressured and dwelled time value, later the specimen was laid in between the upper and lower jaws, and then pressed start button. The whole sealing process can be finished automatically [23].

5.2.6. Study of coefficient of friction (methods and equipment)

Main aim of this test is to determine the static and kinetic coefficients of friction for polymeric films. The outer view of Friction/Peel tester Model 225-l is shown in Fig 5.9. First of all to start test, we need to tape the edges of the film specimen to the back of the sled, using adhesive tape and pulling the specimen tight to eliminate wrinkles without stretching it. For sheet specimens, we tape the sheet specimen or second substrate to the sled face with double faced tape. Keep the machine direction of the specimen parallel to the length of the sled (where such a direction exists and is identifiable).

Later, we need to start the driving mechanism (which has been adjusted previously to provide a speed of 150 6 30 mm/min (6.0 6 1.2 in./min)). As a result of the frictional force between the contacting surfaces, no immediate relative motion may take place between the sled and the moving plane until the pull on the sled is equal to, or exceeds, the static frictional force acting at the contact surfaces. Record this initial, maximum reading as the force component of the static coefficient of friction. In the case of conducting the test at temperatures above 23°C (the temperature of the plane), it should be ensured that sufficient time for the interface to reach the temperature of the plane has elapsed before starting the driving mechanism. Then we must record the visual average reading a run of approximately 130 mm (5 in.) while the surfaces are sliding uniformly over one another. This is equivalent to the kinetic force required to sustain motion between the surfaces and normally is lower than the static force required to initiate motion. After the sled has travelled over 130 mm (5 in.) stop the apparatus and return to the starting position. If a strain gage and load-displacement recorder are used, either draw the best straight-line midway between the maximum points and minimum points shown on the chart while the sled is in motion, or find out the average load by integration of the recorder trace.

Fig. 5.9. The outer view of Friction/ Peel Tester Model 225-1 [20]

The mean load is the kinetic friction force required to sustain motion on the sled. In the end, we must remove the film or sheeting specimen from the sled and the horizontal plane. And to continue with the next set of specimens. A new set of specimens shall be used for each run. No specimen surface(s) shall be tested more than once unless such tests constitute one of the variables to be studied.

- Calculation:

The static coefficient of friction μ_s is determined by following formula: $\mu_s = A_s/B$ (5.5.)

where: A_s = initial motion scale reading, g, and B = sled weight, g. 10.2 The kinetic coefficient of friction, μ_k is determined by following formula: $\mu_k = A_k/B$ (5.6.)

where:

A_k = average scale reading got during uniform sliding of the film surfaces, g, and B = sled weight, g. 10.3 Later the arithmetic mean of each set of observations was calculated and reported these values to three significant figures. 10.4 the standard deviation (estimated to be ± 15 % of the value of the coefficient of friction) is calculated by following formula: $s = \sqrt{(\sum X^2 - nX^2)(n-1)}$ (5.7.)

where: s = sample standard deviation, X = value of a single observation, n = number of observations, and X = arithmetic mean of the set of observations [24].

5.2.7. Contact Angle and wetting test method and equipment

Main goal of this method is to measure the contact angle. Wetting angle for was measured according to the standard ASTM D5946, using the device "Pocket Goniometer PG2". Wetting angle was converted to surface tension (ST) values in dyn/cm. The outer view of Pocket Goniometer is shown in Fig 5.10 [18]. Also, this equipment is used to understand used to understand how a liquid and a substrate surface interact with each other [25].

Fig 5.10 The outer view of Pocket Goniometer PG-2 [20]

For starting the test, the syringe was inserted the dispensing tip into the water and pulled the knob backward to fill the syringe. The next step was to activate the Pocket Goniometer to switch on the light source and access the specimen stage.

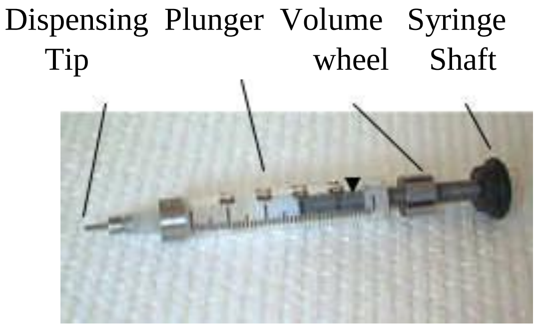


Fig 5.11 Syringe [26]

Flat Specimen was cut out and inserted it on top of the specimen stage. Then syringe was pressed at the end of the shaft and a small droplet appeared at the dispensing tip. Light pressure was applied and then the wheel was rotated (counter clockwise seen from above) until the droplet contacts the surface [26]

The built-in camera captured a video sequence of the liquid droplet applied on the surface to measure contact angle (wetting), volume (absorption) and base width (spreading) of the droplet as a function of time. Captive bubble method was used to measure contact angle of polymeric films [27].

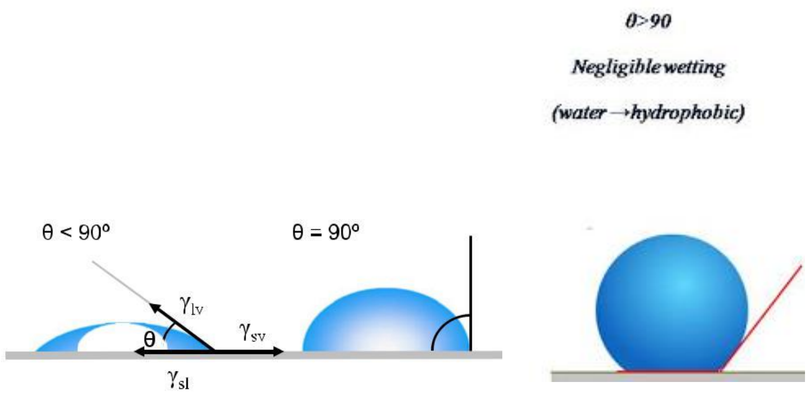


Fig 5.12. Illustration of contact angles formed by sessile liquid drops on a smooth homogeneous solid surface. θ is the contact angle [28] [29]

Wettability can help to determine the measurement of contact angles and surface tension. The contact angle is defined as the angle formed by the intersection of the liquid-solid interface and the liquid-vapor interface. By adding a liquid droplet on a specimen surface a contact angle is formed at the contact area. As shown in figure, high wettability was observed when small contact angles (<<90°), while large contact angles (>>90°) indicate to low wettability. For example, complete wetting happens when the contact angle is 0°, as the droplet turns into a flat puddle. “lotus effect” happen when contact angles are usually greater than 150°, indicating almost no contact between the liquid drop and the surface [28].

Fig 5.13. Surface Tension [28]

Furthermore, contact angles are not limited to the liquid vapor interface on a solid; they are also applicable to the liquid-liquid interface on a solid. The unbalanced forces of liquid molecules at the surface are the cause of surface tension (fig 5.13). The contact angle of a liquid drop on an ideal solid surface is determined by the mechanical equilibrium of the drop under the action of three interfacial tensions

$$\gamma_{lv} \cos\theta_Y = \gamma_{Sv} - \gamma_{Sl} \quad (5.8)$$

where γ_{lv}, γ_{Sv}, and γ_{Sl} indicate the liquid-vapor, solid-vapor, and solid-liquid interfacial tensions, respectively, and θ_Y is the contact angle. That calculation also referred to as Young's equation, and θ_Y is Young's contact angle. The wetting force f is determined as:

$$f = \gamma_{lv} \cos\theta \qquad (5.9)$$

Table 5.4. Ranges of wetting angles for conversion to surface tension level [27]

Nr.	Wetting angle θ, °	Surface Tension, mN/m
1	57-59	44
2	60-62	43
3	63-65	42
4	66-68	41
5	69-71	40
6	72-73	39
7	74-76	38
8	77-79	37
9	80-81	36
10	82-84	35
11	85-87	34
12	88-89	33
13	90-92	32
14	93-95	31
15	96-97	30
16	98-100	29

where γlv is the liquid surface tension, p is the perimeter of contact line (i.e., the same as the perimeter of solid sample's cross-section) and θ is the contact angle [28].

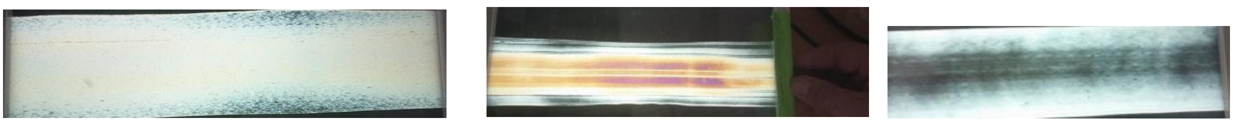
After finding the wetting angle surface tension was found from Table 5.4. For each range of wetting angle there is surface tension value.

5.3 Study Results and their analysis

5.3.1. Photoelastic stress results

The non-destructive photoelasticity method was applied to determine the residual stress distribution of specimens. To carry out this test „General Purpose Strain Viewer “was used and the following polymeric films were analysed [15] (a) LDPE, Glycerine 1 %, Molasses (dry) -2% b) LDPE, Glycerine 1 %, Molasses liquid 2% c) Pure LDPE d) PEVD + Chitosan (3%) e) LDPE + Sorbitol (10 %) f) LDPE+ Molasses liquid 3%). The images of colour patterns of stress distribution in specimen are shown in Fig 5.14.

a) **b)** **c)**



d) **e)** **f)**

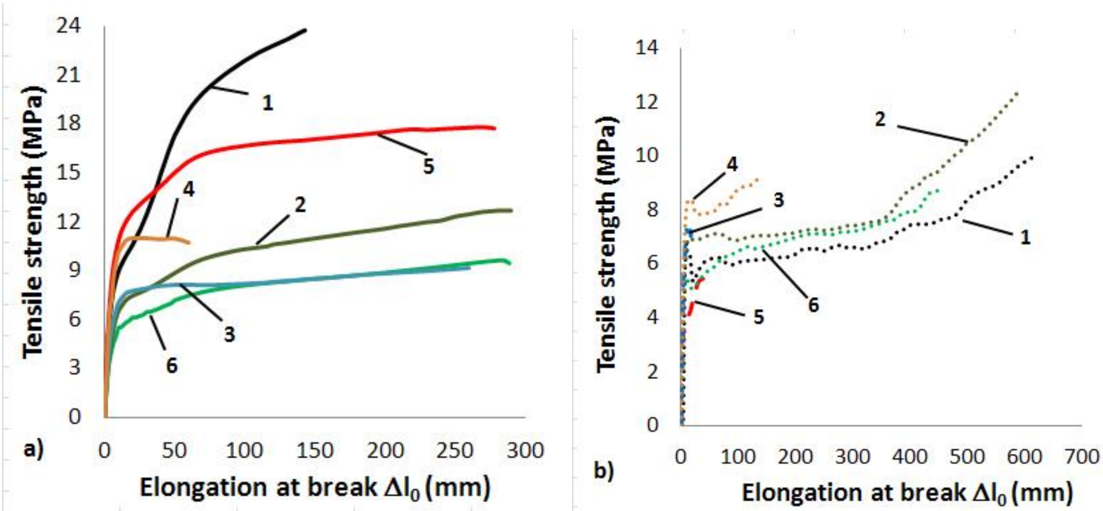
Fig 5.14. Distribution of stresses of specimen

a) LDPE, Glycerine 1 %, Molasses (dry) -2% b) LDPE, Glycerine 1 %, Molasses liquid 2% c)Pure LDPE d)PEVD + Chitosan (3%) e)LDPE + Sorbitol (10 %) f)LDPE+ Molasses liquid 3%

Residual stress level was noticed in “b- LDPE, Glycerine 1 %, Molasses liquid 2%, c- Pure LDPE and e- LDPE + Sorbitol (10 %)” specimen under „General Purpose Strain Viewer “compare to others. The highest level of residual stress was observed in “c- Pure LDPE” specimen. There was no sign of residual stress on the other films. Only in one type of the planned to be used polymeric films were observed the residual stresses the same level of residual stresses can be observed and in PET clear polymeric film which belongs to the group of the already in production used films. No residual stresses were observed in all other analysed films [15].

5.3.2 Tensile testing results:

The tensile strength and elongation at break in both machine (MD) and cross directions (CD) of polymeric films were determined with the universal tensile/compression machine called "Tinius Olsen H10KT". Graphical dependences of tensile strength and elongation at break in both machine and cross directions are shown in Fig 5.15. The values of tensile strength and elongation at break of polymeric films were presented in Table 5.5 [14].



Figure

Fig. 5.15 Tensile strength (MPa) and elongation at break (mm) of tested LDPE films: a) machine direction; b) cross direction; [14]

1 – LDPE; 2 – LDPE1; 3 – LDPE2; 4 – LDPE3; 5 – LDPE4; 6 – LDPE5

a) The clarification of graph in machine direction

Curve 1- shows the results of pure Low density polyethylene which have higher strength and low density properties. As shown in graph, at a tensile strength of $\delta 1$=24 MPA, the elongation at break $\Delta l = 150\ mm$. Moreover LDPE has less plasticity than materials used to make curves 2,3,5 and 6. It can be clearly seen from the graph that biodegradable materials that represent by the curves 2,3,5 and 6 have the same value of elongation at break. $\Delta l = 300\ mm$. Even though these materials have the same value of elongation at break, the tensile strength values are different. For example, curve 2 has $\delta 2$= 12 MPA, $curve\ 3\ has\ \delta 3$= 9 MPA , $curve\ 5\ has\ \delta 5$= 17 MPA $and\ curve\ 6\ has\ \delta 6$= 8.8 MPA. Tested Materials that represent by the curve 4 are fragile than other materials. Indeed, at a maximum tensile strength $\delta 4$= 11 MPA, the elongation at break equals to $\Delta l4 = 50\ mm$. This elongation at break value can be considered minimum among other tested materials.

Table 5.5. Tensile testing results [14]

Polymeric film	Tensile strength (MPa) MD/CD	Relative to LDPE (%) MD/CD	Elongation at break Δl_0 (mm) MD/CD	Relative to LDPE (%) MD/CD
LDPE	23.76/10.04	-	128.65/591	-
LDPE1	12.7/12.36	54/123	266/556	207/94
LDPE2	9.9/7.25	42/72	262.7/23.9	204/4
LDPE3	11.01/9.12	46/91	63.8/107.3	50/18
LDPE4	17.82/5.59	75/55	286.8/25.86	223/4
LDPE5	9.66/8.77	40/88	233.7/260.2	182/44

b) the clarification of graph in cross direction

Tested materials that represent by the curve 1 and 2 with high plasticity, the elongation at break values are same $\Delta l1 = \Delta l2 = 600 mm$. The tensile strength value of curve -2 equals to δ= 12 MPA. The curve -6 is located between curves 1 and 2. For this the elongation at break value can be equal to $\Delta l6 = 500\ mm\ and\ tensile\ strength\ value\ is\ \delta6$= 8 MPA. This material has lower plasticity properties compare to materials used to make curves 1 and 2. Tested materials considering to curves 3,4 and 5 are more fragile because the elongation at break values of these materials are relatively low. For example , $\Delta l4 = 150\ mm, \Delta l3 = 20\ mm\ and\ \Delta l5 = 30\ mm$ maximum tensil strength is applied for curves 4 $\delta4$= 9 MPA,3 $\delta3$= 7 MPA and 5 $\delta5$= 5 MPA.

In conclusion, in machine direction is recommended to use the material corresponding curve 5 and in cross direction is recommended to use material corresponding curve 2 having optimal characteristics.

Fig 5.16. The view of Polymeric material after testing

Tested materials that are represented by the curve 5 in machine direction and curve 2 in cross direction are more acceptable. It should be noted that LDPE 1 material that represent by the curve 2 has more stable characteristics in machine direction and cross direction as well.

Polymeric material was tested using universal tensile/compression machine called "Tinius Olsen H10KT" and the view of Polymeric sample was shown in Fig 5.16 after testing. It can be seen that, the sample was destroyed in order to measure the tensile strength and elongation at break.

5.3.3. Printability testing results

- **Printability testing results:**

Polymeric samples were printed using Flexiproof 100/UV" [14] printing tester and optical density was tested with the Spectrodensitometer "X-Rite Colour". Polymeric films were analysed under the optical microscope "AM2111 Dino-Lite basics" was used. The results of optical density analysis of the researched polymeric film prints are presented in Table 5.6. [19].

Table 5.6. Optical density results [14]

Polymeric film	**Optical density, D**	
	Without surface treatment	70 W/min/m^2 surface treatment
LDPE	1.23	1.23
LDPE1	1.22	1.22
LDPE2	1.03	1.03
LDPE3	0.83	0.83
LDPE4	0.78	0.78
LDPE5	0.95	0.95

The optical density value of LDPE 1 (D=1.22) polymeric film is the highest except LDPE (D=1.23) polymeric film under without and with 70 W/min/m^2 surface treatments. But, the values of LDPE 4 (D=0.78) polymeric film are the lowest compare to LDPE2 (D=1.03), LDPE3 (D=0.83) and LDPE5(D=0.95). [19] The microphotographs of 100% colour patch of microscopic analysis of all tested polymeric films without surface treatment is shown in Fig 5.17.

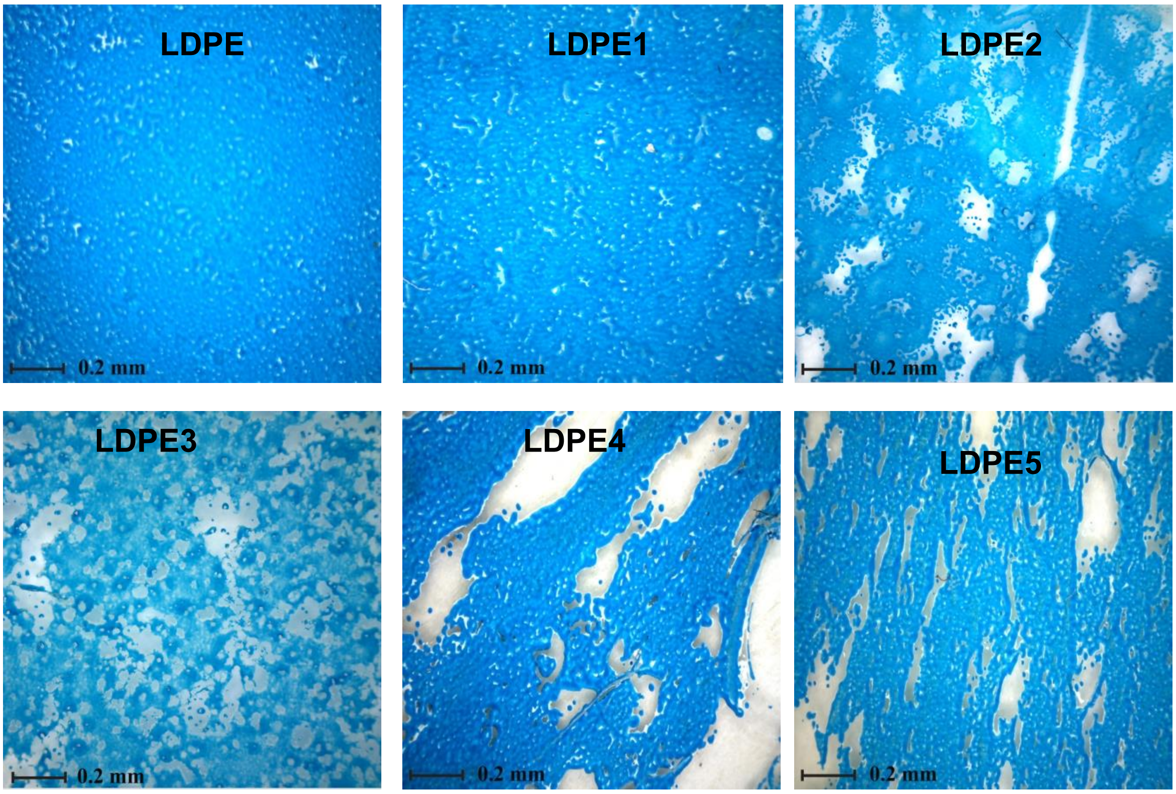


Fig. 5.17. The microphotographs of 100% colour patch of microscopic analysis of all tested polymeric films without surface treatment [14]

The microphotographs of 100% colour patch of LDPE 1 show that UV inks were inked on surface qualitative. The measured values of optical density of LDPE2 and LDPE3 samples were insufficient as recommended for UV flexography printing (see Table 5.6). As can be seen from microphotographs shown in Fig 5.17 and Fig 5.18 the inking quality of LDPE2 and LDPE3 surfaces was worse than LDPE1. Especially for LDPE3 as the UV inks did not form a solid layer but were tended to contract itself into the shape of a drop. Additional surface treatment increased optical density by 13% for LDPE2 sample and 35% for LDPE3 sample. Also, and the layer of inks on surfaces of LDPE 2 and 3 was more solid than before treatment (see Fig 6.3.4). But it could be stated that these two polymeric films still require improvement of the manufacturing process by changing the parameters of extruder, composition of material and concentration of additives. In conclusion, the optical density result of LDPE 1 is comparable to traditional BOPP polymeric films

Thus, the next step for using this polymeric film for flexography printing should be print quality assessment using the geometrical parameters criteria approach (accuracy of raster dots, the raggedness of graphic elements etc.).

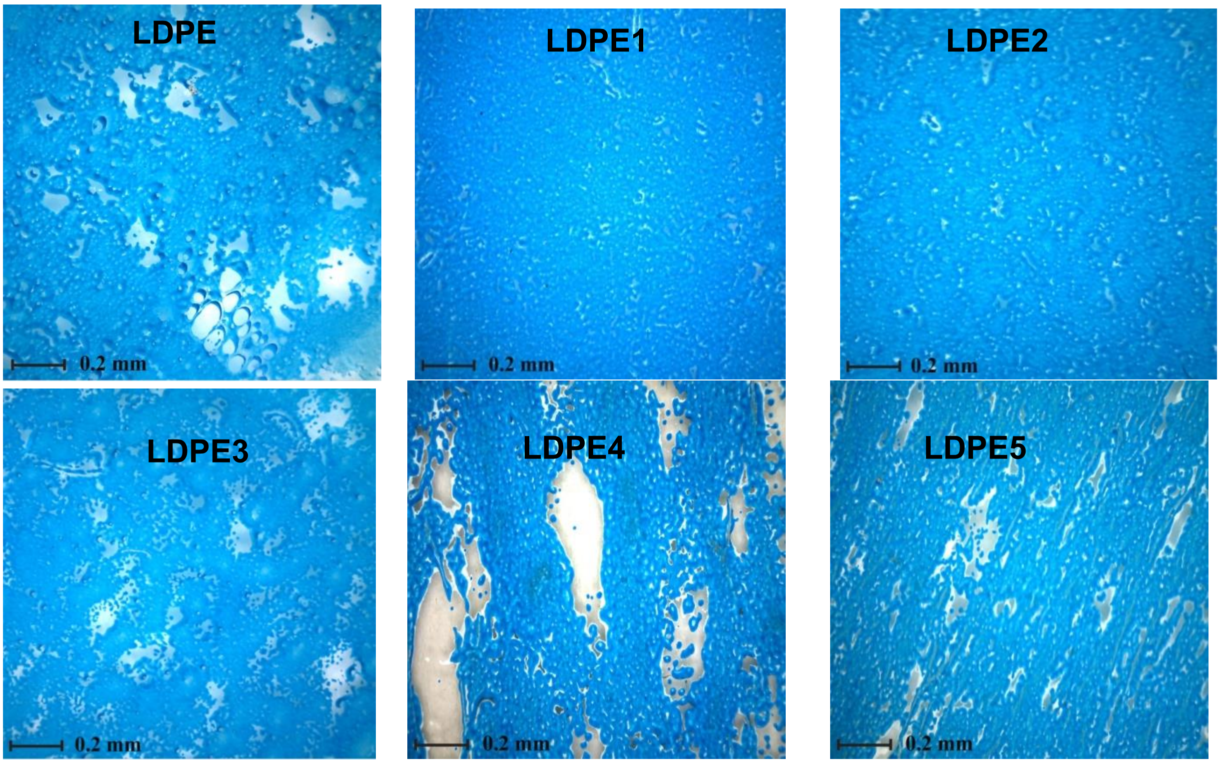


Fig 5.18. The microphotographs of 100% colour patch of microscopic analysis of all tested polymeric films with surface treatment 70 $W/min/m^2$[14]

Of course, the final optimization of this new polymeric film for packaging purposes requires more detailed researches considering to mechanical characteristics (tensile strength, elongation at break, seal strength, coefficient of friction and other), barrier properties (permeability to water vapour, oxygen, ink migration and other) [19].

5.3.4. Heat seal testing results:

Polymeric films were tested using "Labthink Instrument Heat Seal Tester HST-H3T" showed two characters of seal failure were distinguished as peeling failure or tearing failure. Simplified schemes of heat sealing failures in (Fig 5.19. a) PF - peeling failure; b) TF - tearing failure) and heat seal testing results of polymeric films were reported in Table 5.7. [14]. As shown in Table 5.7, LDPE 1,2 and 5 showed the peeling failure during the evaluation of seal with different welding temperature. However, (LDPE =11.41 N -115 °C, LDPE3=9.76 N- 145°C and LDPE 4 =8.91 N-115°C) showed the tearing failure with different welding temperatures

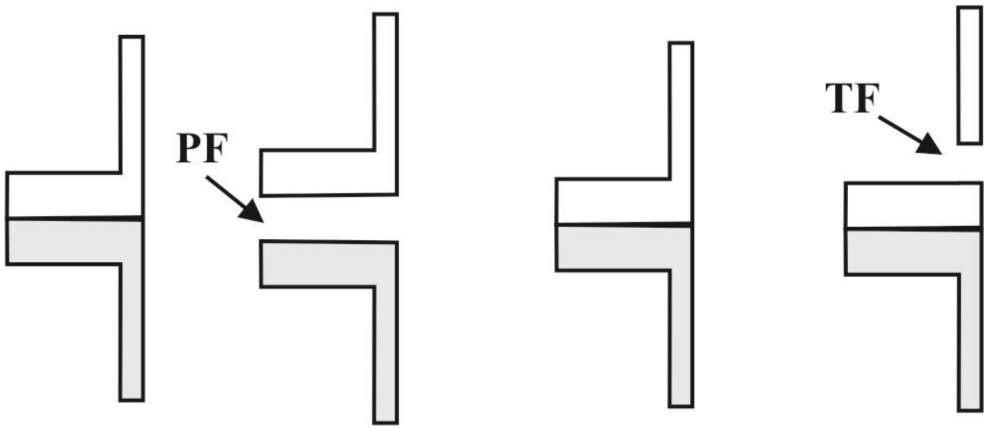


Fig. 5.19. Simplified schemes of heat sealing failures: a) PF - peeling failure; b) TF - tearing failure

Table 5.7. Heat seal testing results [14]

Polymeric film	Seal strength (N)	Welding temperature (°C)	Evaluation of seal
LDPE	**11.41**	**115**	**Tearing failure**
LDPE1	**4.23**	**135**	**Peeling failure**
LDPE2	**4.31**	**115**	**Peeling failure**
LDPE3	**9.76**	**145**	**Tearing failure**
LDPE4	**8.91**	**115**	**Tearing failure**
	16.45	**125**	**Tearing failure**
LDPE5	**1.95**	**115**	**Peeling failure**
	4.45	**125**	**Peeling failure**

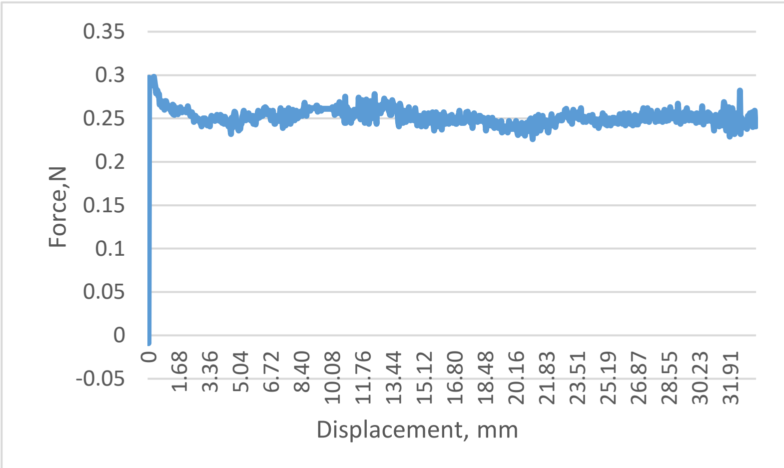
As shown in table 5, that seal strength values of (LDPE 1= 4.23 N and LDPE 2= 4.31 N) polymers made from 3% potato starch ,1% glycerine ,10% itaconic acid and + 5% potato starch + 1% glycerine + 10 % itaconic acid were approximately similar. There was tearing failure and peeling failure in (LDPE4= 8.91/16.45 and LDPE5=1.95/4.45 N) compare to others [14].

5.3.5. Results of Coefficient of friction polymer materials

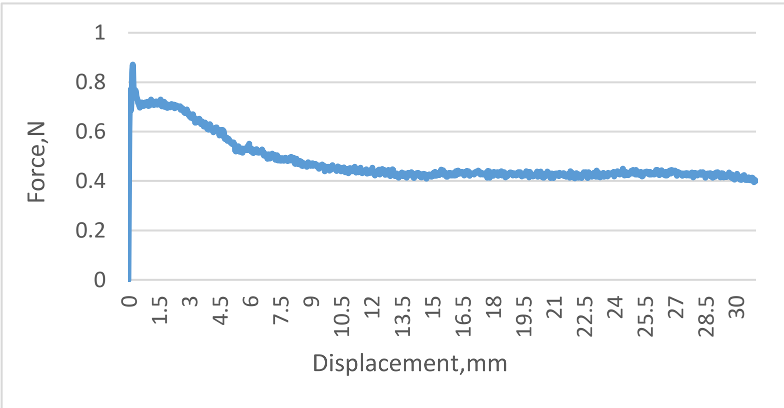
Friction/ Peel Tester Model 225-1 was used to determine static and dynamic friction of following polymer materials: (1 sample -LDPE, Glycerine 1 %, Molasses (dry) -2% ; 2 - sample LDPE, Glycerine 1 %, Molasses liquid 2%; 3-sample PEVD + Chitosan (3%) ; 4 -sample LDPE + Sorbitol 10 % ;5-sample LDPE+ Molasses liquid 3%). The static and kinetic friction were checked six times and average found in order to avoid maximum and minimum values. The results were reported in the following report:

Table 5.8. Results of Coefficient of friction polymer materials

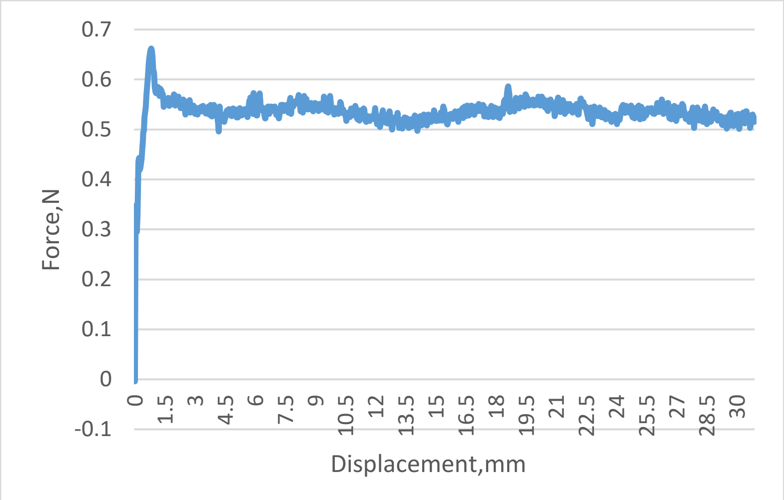
Name	Static Friction	Kinetic Friction
LDPE+ Glycerine food 1 %+Molasses dry 2 %	0.3197	0.1277
LDPE+ Glycerine food 1 %+ Molasses liquid 2 %	0.511	0.2103
LDPE+ Chitosan 3 %	0.436	0.264
LDPE+ Sorbitol 10 %	0.387	0,225
LDPE+ Molasses liquid 3 %	0.445	0.216



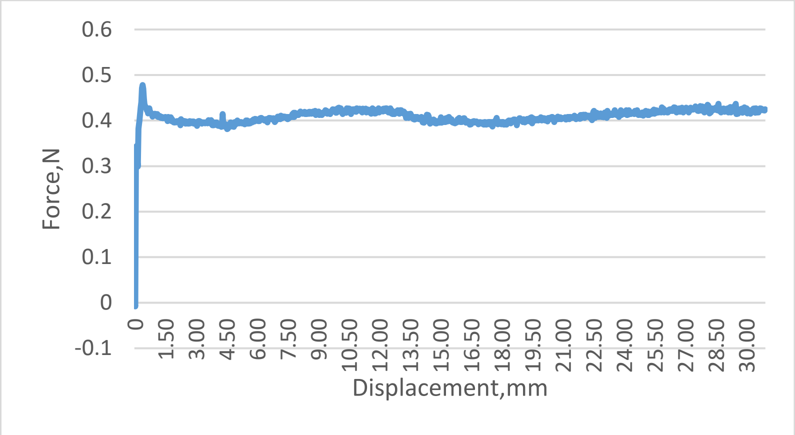
a)



b)



c)



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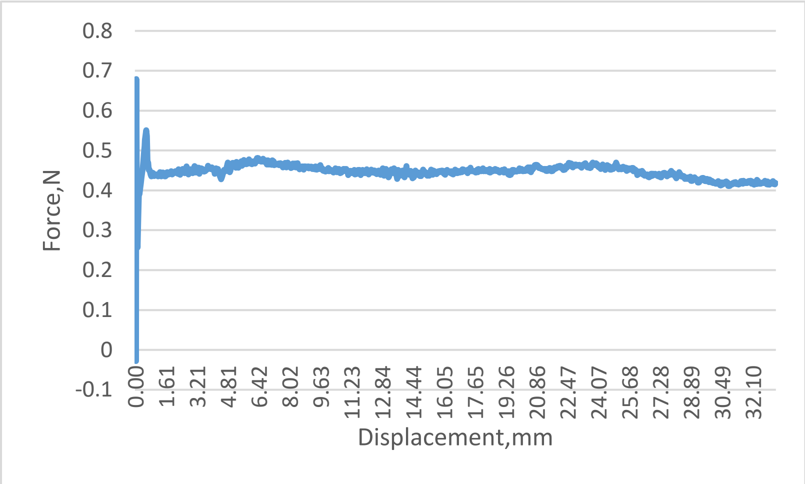


e)

Fig 5.20. Force and Displacement dependency **a)** (LDPE+ Glycerine food 1 %+Molasses dry 2 %) b) (LDPE+ Glycerine food 1 %+ Molasses liquid 2 %) c) (LDPE+ Chitosan 3 %) d) (LDPE+ sorbitol 10 %) e) (LDPE+ Molasses liquid 3 %)

It can be seen, second sample (LDPE+ Glycerine food 1 %+ Molasses liquid 2 %) showed the highest static friction result (Static =0.511 and Kinetic=0.2103). First sample (LDPE+ Glycerine food 1 %+Molasses dry 2 %) showed lowest static and kinetic result (Static= 0.3197 and Kinetic=0.1277). The kinetic value of 3 sample (LDPE+ Chitosan 3 %) was the highest compare to other polymer materials (Static=0.436 Kinetic=0.264). For each test speed value was equal to 100 mm/min and test time was 20 second. The value of test time was converted into minute (0.3333). The value of displacement for each test found in the following formula:

$$S= v \times t = 100\times 0.3333=33.33$$

5.3.6. Contact Angle and wetting results

"Pocket Goniometer PG2" was used to determine the wetting angle value of 6 samples (LDPE+ Sorbitol 10 %, LDPE+ Chitosan 3 %, LDPE+ Molasses liquid 3 %, LDPE+ Glycerine food 1%+Molasses liquid 2 %, LDPE +Glycerine food 1 %+molasses dry 2 % and LDPE).

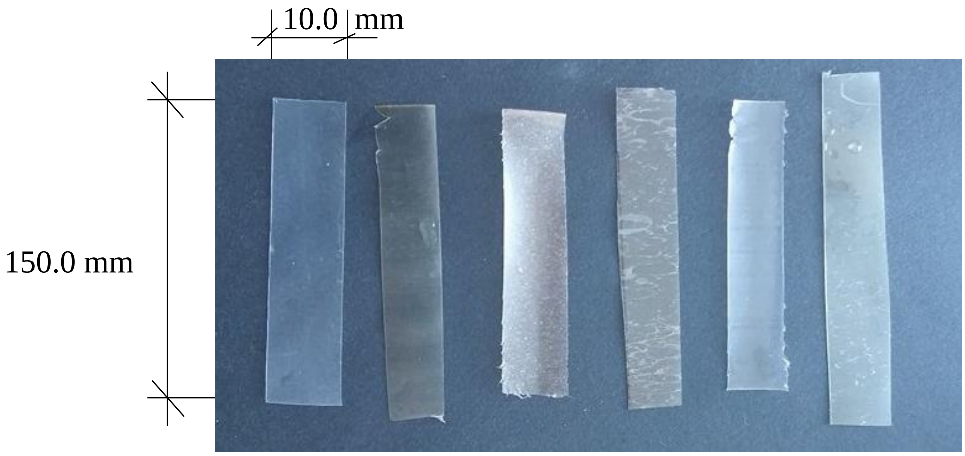


Fig 5.21. Outer view of samples

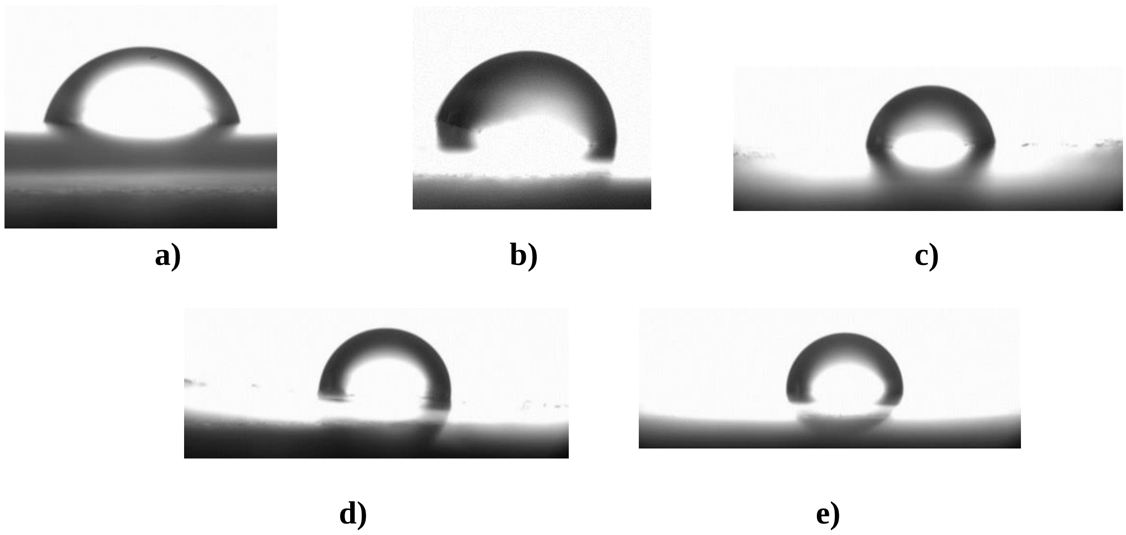


Fig 5.22. View of samples during drop a) LDPE+ sorbitol 10 % b) LDPE+ Molasses liquid 3 % c) LDPE+ Glycerine food 1 %+Molasses liquid 2 % d) LDPE+ Glycerine food 1% e) LDPE

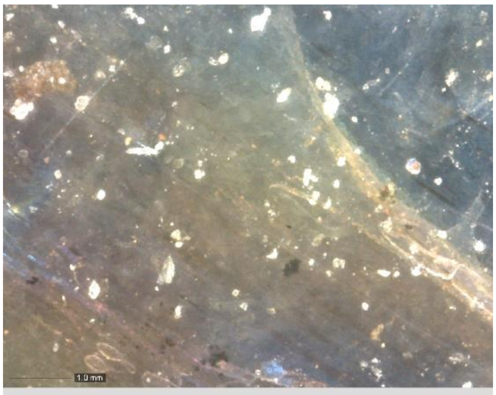
Table 5.9. Wetting angle and surface tension results

Polymer materials	Wetting angle, θ, º	Surface tension level, mN/m
LDPE+ Sorbitol 10 %	51	46
LDPE+ Chitosan 3 %	76.8	37
LDPE+ Molasses liquid 3 %	81.0	36
LDPE+ Glycerine food 1%+Molasses liquid 2 %	77.7	37
LDPE +Glycerine food 1 %+molasses dry 2 %	92.9	31
LDPE	87.32	34

The wetting angle value of each samples was measured 6 times and the average was reported in Table 5.9. Later Wetting angle was converted to surface tension. As shown in table, "LDPE +Glycerine food 1 %+molasses dry 2 % "sample showed lowest surface tension (31mN/m) result. However, the surface tension value of "LDPE+ Molasses liquid 3 %" sample (36mN/m) are like traditional film "Low-density polyethylene (LDPE)". The other 3 samples have different surface tension values (46,37 and 37 mN/m). If wetting angle value of sample is higher than 90º which means less wettability. If wetting angle value of sample is less than 90º means good wettability.

5.3.7. Results tests of surface of polymer materials

Microscopic analysis of polymeric films containing (a) LDPE + 2% molasses (dry) + 1% glycerine (LDPE4); b) LDPE + 2% molasses (liquid) + 1% glycerine (LDPE5)) without surface treatment and ink was done using "AM2111 Dino-Lite basics" equipment. Surface analysis using "AM2111 Dino-Lite basics" equipment showed following results in Fig 5.23:



a)

b)

Fig 5.23. Surface analysis results: a) LDPE + 2% molasses (dry) + 1% glycerine (LDPE4); b) LDPE + 2% molasses (liquid) + 1% glycerine (LDPE5)

The main aim of microscopic observation conducted in KTU laboratory was to determine the structure and properties of LDPE 4 and LDPE 5 materials.

In conclusion, the results of LDPE 4 and LDPE 5 polymeric materials showed that they do not have qualitative surface. Considering of the results, surface of LDPE 4 and LDPE 5 polymeric materials did not match standard requirements for food packaging.

5.4. Comparison of mechanical properties and characteristics between biodegradable and traditional polymeric films

Table 6.4.1 shows the table of characteristics of polymeric packaging materials which was collected by JSC "Aurika" printing house located in Lithuania area. Depending on kind of food The mechanical properties of PE 50 transparent and LDPE 4 were compared in Table 5.11 The mechanical properties of Polyethylene (PE) 50 transparent was taken from JSC "Aurika" Printing house

Table 5.10. Characteristics of polymeric packaging materials

No.	Production Name	Production format PxA, mm	Print run,pcs.	Number of repeat per year	Number of colors and varnishing	Production material
10	Sumuštinis "Baguette"	270x350	800000	5	6+0 partial matt varnishing	PE 50

Table 5.11. Comparison of mechanical properties and characteristics between biodegradable and traditional polymeric films

Polymeric Film	Tensile strength (MD/CD) N/mm^2	Elongation at break (MD/CD) %	Welding Temperature	Treatment Level (mN/m)	Coefficient of Friction (Static/Dynamic)
LDPE 4	17.82/5.59	286.8/25.86	115-125	31	0,3197/0,1277
PE 50 transparent	14,7/10,8	150/250	115-180	38	0,17±0,07 - 0,17±0,07

As shown in Table 5.11, PE 50 is used for packaging of Sumuštinis "Baguette". Tensile strength, elongation at break, welding temperature, treatment level and coefficient of friction values of two polymeric material are compared in table 6.6. It can be clearly seen that, some results of LDPE 4 (LDPE + 2% molasses (dry) + 1% glycerine) like PE 50 transparent. This shows that LDPE 4 has some potential to be used as food packaging material with some modification.

5.5. Conclusions

- Analytical review of packaging materials for food based on principles of green engineering was carried out
- Research of physical – mechanical characteristics and parameters of biodegradable polymer packing materials was carried out.
- The final optimization of this new developed polymeric films for packaging purposes requires more detailed researches for further use of these polymeric films in packaging processes and improvement of their manufacturing process. But considering to the already carried out researches, the LDPE 4 polymeric film containing dry molasses and glycerine additives has demonstrated the most encouraging results to be used as biodegradable packaging material.

The next paragraph will represent the researches of harm to environment of packaging manufacture process.

6. Research of harm to environment of packaging manufacture process (ECO indicator methods)

To find out the bad influences of plastic packages on the environment was the main aim of this research. To carry out this test, the life cycle was studied. Because of the demand for environmental contamination from packaging production, this investigation was related with processes as manufacture of the materials for packages, package manufacturing processes, power demand, transportation, product presentation, product handling, usage, and recycling, lean and waste management. The plastic influence on the environment was carried out using the special program ECO-INDICATOR 99 and its methodology.

6.1 Results and their analysis

The results of all stages of the life cycle are described in Fig 6.1. The huge influence is done in the production stage of polymeric packages (5.1 mPt) lifecycle to the environment [30].

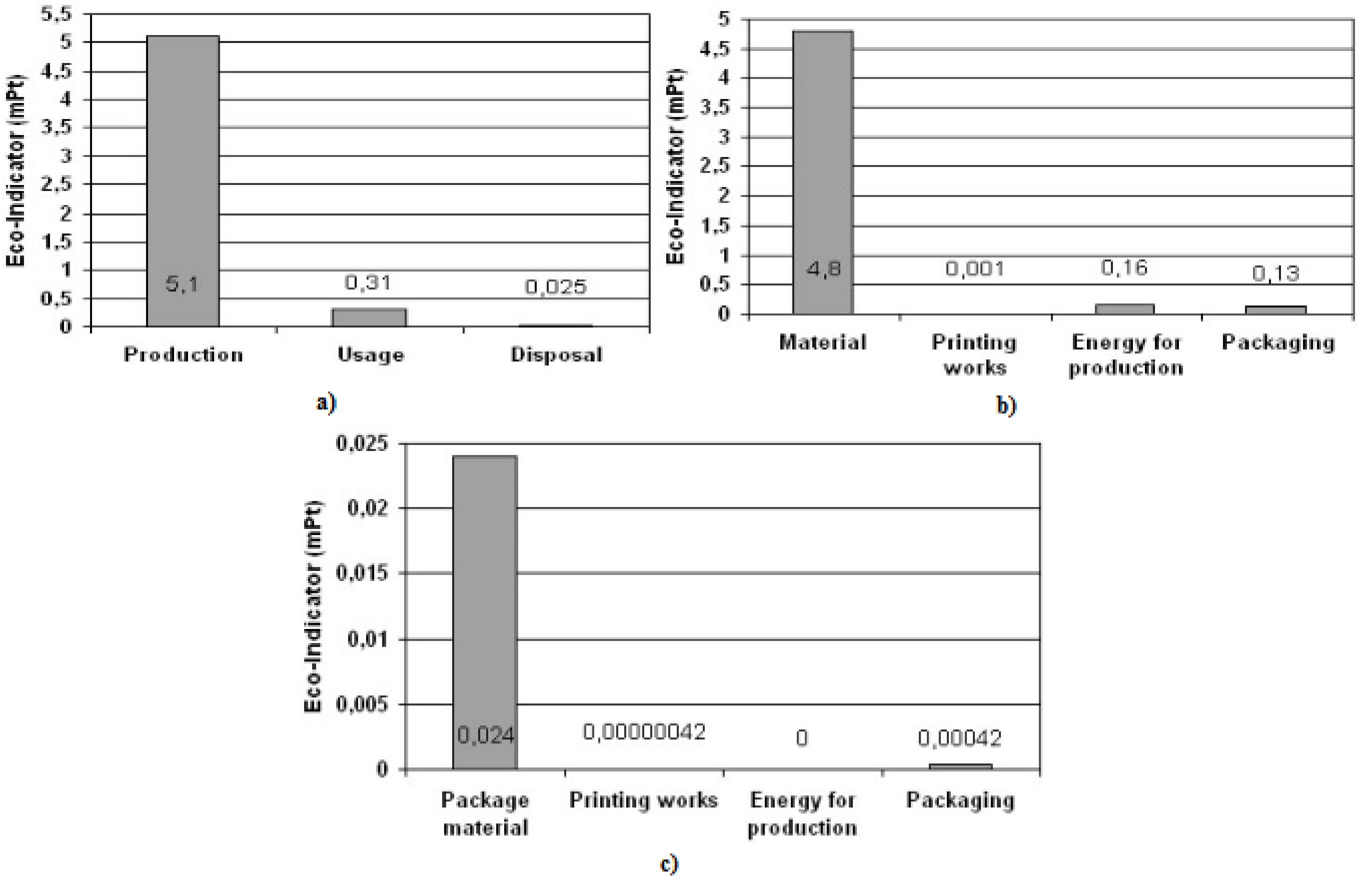


Fig 6.1 The results of plastic package influence on the environment: a) impact of all the package lifecycle stages, b) impact of package components during the production phase; c) impact on the environment during the disposal phase [30]

From the Fig 6.1 it is clear, used materials had the greatest influence on the environment. The explanation behind that is plastic PS (4.8 mPt) used for packaging manufacturing. It is comparatively unimportant the environmental influence of other manufacturing processes (printing, packing, energy consumption, etc.) [30].

6.2. Conclusions

JSC "Aurika" printing house take into consideration the results of impact of plastic package on the environment not only in the production stage but also in the usage and disposal stage.

7. Designing of manufacturing technologies of food packaging

7.1 Reasoning of the proposed technology

Prepress for flexo printing plays key role. It is necessary to carry out some specific work for preparing project layout to get good looking print and as conceiving of designers. It is the responsibility of pre-press department to change the original idea into a printable artwork [31]. DuPont largo 2406 solution is used to produce contract proofs for flexo printing. Project Layout, Colour separation and rasterization is executed using Esko Graphics. Printing Form is prepared in the Department of making Printing Form. Thermal imaging procedure takes 3 minutes. The advantage of Kodak flexcel nx imager is better quality image on printing plate because of Kodak square spot Imaging Technology. Unimaged Printing plate is laid on the Flexcell Laminator equipment for laminating prior to exposure and processing. 1 minute 25 seconds is needed to carry out this process. Thermal imager layer is laminated onto the printing plate during this process. In addition, dust and oxygen is removed using flexcel laminator. DuPont™ Cyrel® 2000 PS with the attached brushes helps us to clean the printing plate in the next stage. The purpose of this process is to clean the printing plate from non-polymerized parts adding into special solvents. We need to place the plate to pin bar directly to realize this process. Dupont cyrel 1000d is preformed to dry printing plate. There are 6 drawers in this equipment. Printing plate is put to the one of these drawers and the drying time is adjusted depending on the thickness and type of printing plate [33-36]. According to the date obtained from JSC "Aurika" Printing House, technological process of printing was shown in the Fig.7.1.

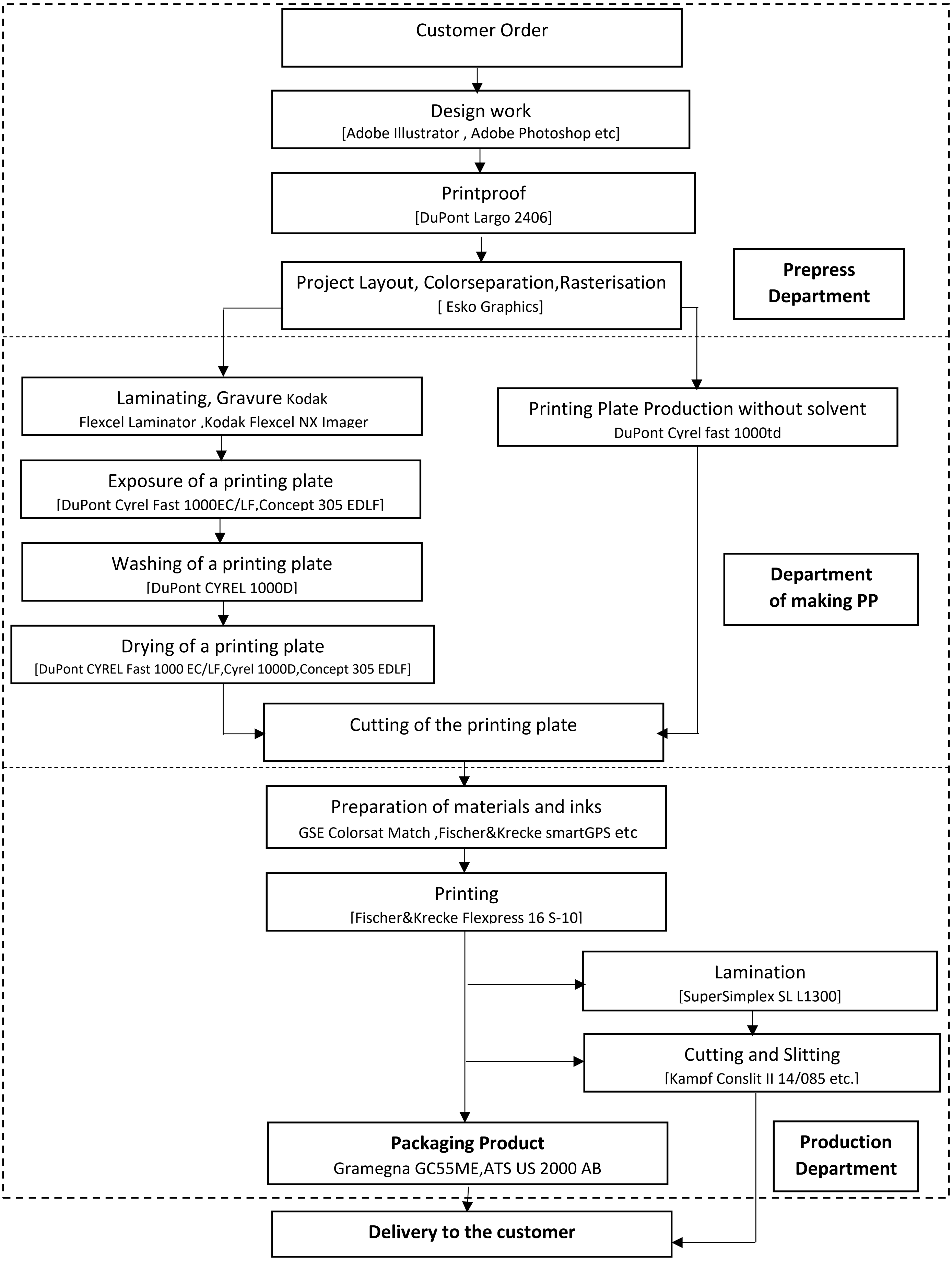


Fig.7.1. Technological process of Printing

7.2. Formation of the technological process

After testing material of product was chosen (LDPE + 2% molasses (dry) + 1% glycerine) because the properties of this material were similar to traditional PE 50 transparent material. Considering to the manufactured production, a technological scheme is created in which all technological process should be reflected. The characteristics of production are given in Table 7.1

Table 7.1. Characteristics of manufactured production [37]

No.	Name of production	Production format P x A, mm	Print run, unit	Number of orders per year	Number of colours and varnishing	Material of product
1	2	3	4	5	6	7
10	Sumuštinis "Baguette	270x350	800000	5	6+0 partial matt varnishing	LDPE 4 (LDPE + 2% molasses (dry) + 1% glycerine)

The task of manufacturing is given in Table 7.2. Further it is necessary to review shortly the technological processes of preparation of layout, manufacturing of printing plates, processes of printing and post-printing and to carry out the calculations [37].

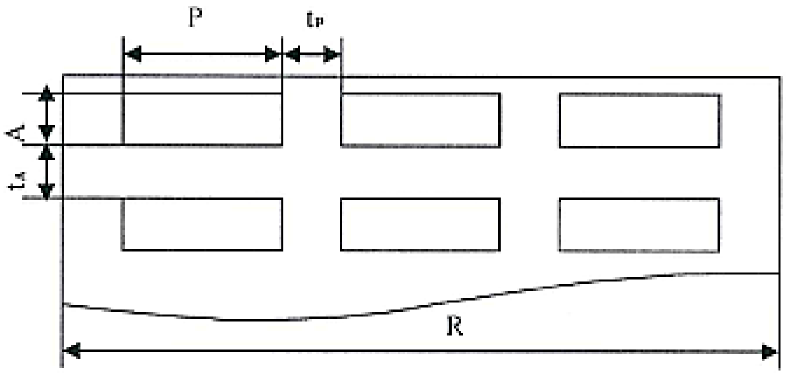


Fig 7.2 Layout for printing. P – width of printout segment; t_p – space between columns of printout segment; A – height of printout segment; t_A – space between rows of printout segment; R – width of print sheet, t_A=3 mm, t_p=3 mm, P=270 mm, A=350mm

Table 7.2. Task of manufacturing for printing of production

No.	Name of production	Production format P x A, mm	Print Run T, unit	Number of orders per year	Linear meters M_T, m	Amount of printed material M_K, m^2	Yearly amount of linear meters, m	Yearly amount of printed material, m^2
1	2	3	4	5	6	7	8=5x6	9=5x7
	Sumuštinis "Baguette	270 × 350	800000	5	71306	81003.62	356530	405018.1

Linear meters are calculated according to the formula:

$$M_T=\frac{T\times(A+t_A)}{S}\times k_s \qquad (7.1.)$$

Where

T=800000, A=0.35 m, t_A=0.003 m,

In order to find number of columns (S) we need to take max printing width date of printing machine $S=\frac{R}{P}=\frac{1250}{270}mm=\frac{1,25}{0,27}m$ =4.62~4 , k_s =1.01 (7.2)

A –height of printout segment, m;

t_A – space between rows of printout segment, m

S – number of columns;

k_s – coefficient evaluating the losses of printing material necessary for longitudinal colour register (1.01÷1.10). k_s depends on number of colours of edition and printout.

$M_T=\frac{800000\times(0.35+0.003)}{4}\times1.01=71306$ m (7.3.)

The amount of printed materials is calculated according to the formula:

M_K= R× M_T =1,136×71306=81003,616~81003,62 (7.4.)

Where

R – width of printing material for printing process, m and M_T= 71306

R = $(P+t_p)\times S\times k_n$ = (0.27+0.003) ×4×1.04=1.136 (7.5.)

Where

P – width of printout segment, m

t_P – space between columns, m

k_n – coefficient evaluating the losses of paper (1.04÷1.10). k_n depends on width of printing material and format of printed production.

Table 7.3. Calculation of yearly amount of printouts for printing

No.	Name of production	Production format, mm	Number of orders per year	Print run, unit	Number of colours and varnishing C	Time norm for preparation of inking unit t_D, h	Work demand for printing of one product	Yearly task for printing, h
1	2	3	4	5	6	7	8*	9=8x4
	Sumuštinis "Baguette	270 × 350	5	800000	6	0.17	3.604	14.41

*work demand for printing of one product is calculated according to the formula:

$$L = \frac{MT}{V} + T_D \times C = \frac{71306}{27600} + 0.17 \times 6 = 3.6035507246 \sim 3.604 \quad (7.6.)$$

V – average velocity of printing machine, V=460 m/min = 27600 m/h

Time norm for preparation of inking unit t_D = 10 min ~0.17 h

7.2.1. Calculation of Number of printing plates set:

Number of printing plates set (X_k) is calculated in the following formula:

$$X_k = T \times K \times C / E \times S \times \Delta \quad (7.7.)$$

Where T – Print run

K - Number of repeating per year

C – number of colours

E – number of rows in printing plate= (Drum diameter × π)/ (height of printing segment + space between rows of printout segment) = (3.14 × 1910)/353=16,989 ~ 16 units

Δ – resource of photopolymeric printing plate (Δ=1 × 10^6)

$$X_k = \frac{800000 \times 5 \times 6}{16 \times 1 \times 4 \times 10^6} = 0{,}375 \sim 1 \text{ unit} \quad (7.8.)$$

Table 7.4. Calculation of amount of printing plates

No.	Name of production	Format of production, mm	Number of repeating per year, K	Print run, thousands units	Number of colours C	Number of printing plates set X_k, units	Amount of printing plates X_f, units
1	2	3	4	5	6	7	8= 6*7
10	Sumuštinis "Baguette	270 X350	5	800000	6	1	6

The amount of printing plates has been calculated by multiplying the amount of printing plates set by number of colours

$X_f=X_k \times C=1 \times 6=6$ (7.9.)

Table 7.5. Calculation of duration of printing plates mounting

No.	Name of production	Format of production, mm	Amount of printing plates X_f, units	Time rate for mounting of one plate, t_{SF}, h	Yearly task for mounting of printing plates, h
1	2	3	4	5	6=4*5
10	Sumuštinis "Baguette	270X350	6	0.15 h	0.9

Time rate for mounting of one plate (t_{SF})= 0.15 h

Table 7.6. Calculation of duration of PANTONE inks preparation

No.	Name of production	Format of production, mm	Number of repeating per year	Print run, thousands units	Number of colours C	Amount of Pantone colours, units	Time rate for mixing of one colour inks t_{DM}	Yearly task for preparation of Pantone inks, h
1	2	3	4	5	6	7	8	9=8*4*7
10	Sumuštinis "Baguette	270X350	5	800000	6	2	0.2 h	2

Time rate for mixing of one color inks (t_{DM})=0.2 h

As shown in Table 8.2.6, 4 units of CMYK and 2 additional pantone colours units were used to prepare ink for packaging.

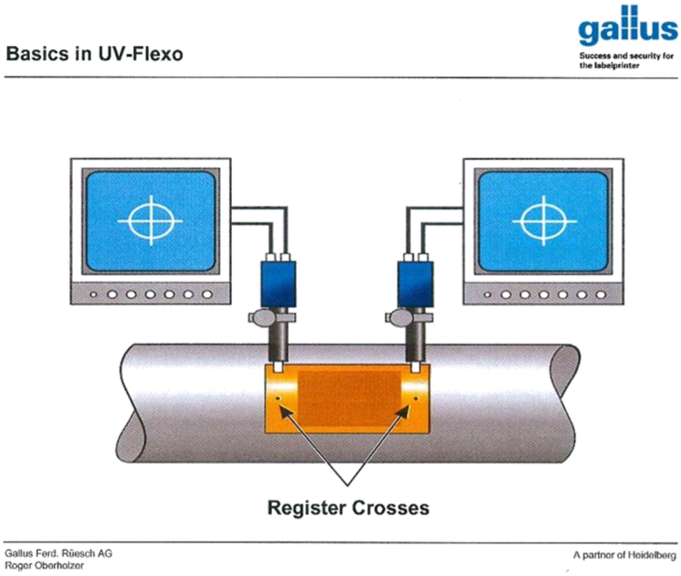
Table 7.7. Calculation of control of PANTONE inks

No.	Name of production	Format of production, mm	Number of repeating per year	Print run, thousands units	Number of colours C	Amount of Pantone colours, units	Time rate for control of one colour ink, t_{DT}, h	Yearly task for preparation of Pantone inks, h
1	2	3	4	5	6	7	8	9=8*4*7
10	Sumuštinis "Baguette	270X350	5	800000	6	2	0.03 h	0.3

Time rate for control of one colour ink (t_{DT})=0,03 h [37].

7.3. Technology of printing plates manufacturing

The scheme of plate mounter and outer view of plate mounter is shown in Fig 7.3 The photo of outer view of plate mounter was taken during internship in JSC "Aurika" printing house. Printing Plate mounting procedure is to bring printing plate onto the cylinder.



a)

b)

Fig 7.3. Plate Mounting a) The scheme of plate mounter b) Outer view of Plate mounter [38]

Plate mounting procedure consists of following steps [38]:

1. Cut the plate to the correct side
2. Clean backside of the plate with acetate (Never use greasy solvents)
3. Use a waterproof marker on the first and last 10mm on the backside of the printing plate (the printing plate will not lift anymore)
4. Clean the surface of the printing cylinder with acetate (Never use greasy solvents)
5. Chose the correct hardness of tape
6. Mount the tape onto cylinder without any bubbles and dust
7. Peel off the protection foil of the tape
8. Mount the printing plate without any bubbles and dust in correct position with the specific mounting system. The printing plate must not overlap in the gap
9. Surround the mounted plate with a plastic foil to avoid lifting of the plate

7.4. Formation and control of PANTONE inks

The Classification of Flexo ink is shown in the Fig 7.4 There are 3 types of flexo ink: Solvent Based, Water Based and UV inks.

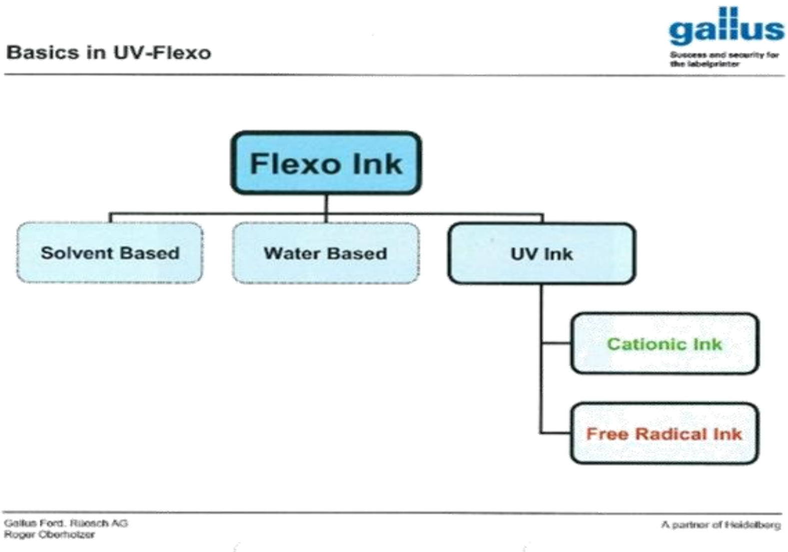


Fig 7.4. Flexo ink Classification [38]

Solvent Based Ink is one type of ink which contains solvents, pigments and some additives. But today eco -friendly companies are shifting into water based ink or UV ink because Solvent Based Ink contains 100 percent of VOC (Volatile Organic Compounds) that can damage to the environment [39].

Benefits of Solvent Based Ink

The main challenges of using water-based inks are related to press efficiency issues, such as limitations on press speeds. Problems occur especially with non-absorbent substrates such as films. The press efficiency is connected with the ease of drying solvent-based ink versus water-based ink. Most solvent-based inks contain 100 percent volatile organic compounds (VOCs) level. The flexo presses are capable of drying the solvent-based ink with conventional ovens and at even the highest press speeds. By definition, the level of water in water- based inks are high, VOCs level is low. The challenge of using water-based inks is simply related to time needed for the ink to dry. Problems occur on non -absorbent substrates. For example, Bread bags are a surface print application where gloss and a variety of resistance requirements are needed. Water based ink systems are commonly used for these applications [39].

In certain market segments, where high speed printing is demanded the usage of water based ink is limited. There is still growing demand for shorter print runs in many applications, and while run length decreases, press speed as the key operational efficiency requirement gives way to change over time. Within these segments, water-based products are certainly viable.

As with most businesses, converters nowadays keep searching for ways to diversify their business, especially into growing segments. As such, several converters that are currently using water-based technologies are pursuing flexible packaging markets that have historically been supported through solvent-based technologies [39].

UV Ink is the type of ink that is cured using Ultraviolet light [40]. Cationic and Free Radical Ink is two different kind of ink used in the printing industry [38].

Benefits of UV ink-UV inks do not become dry in the air because they have no evaporative properties. UV lamps are used to dry the UV ink. Therefore approximately 100% of the ink volume is used, reducing the cost of printing significantly. Additionally, there is no need for clean-up because the ink does not become dry until it is cured.

The other advantages of UV inks are: environmentally friendly, good opacity, light-fastness, resistance to smearing, sharp contrast, and a nice gloss.

Water- based inks contain chemical catalyst components so harsh cleaners is needed to remove the ink from printing equipment. Therefore, UV inks allow us to avoid time, money and environmental waste because it reduces greatly the need for cleaning.

Disadvantages to UV inks as well. UV inks do not dry without curing, as mentioned above, and thus if they are spilled, it is a challenge to clean them up. The initial startup costs for UV inks are higher because of the need for UV curing equipment. And a variety of anilox roles are needed to adjust print colour. Finally, UV inks may cause allergic irritations when operators touch [41]. The contents of Flexo inks are shown in the Table 7.8

Table 7.8. Flexo ink contents [38]

UV ink	**Solvent and WaterBased Inks**
Pigments 12-16%	Pigments 10-12 %
Monomers & Oligomers (=Binding Agent) ~ 75%	Solvents / Water ~ 70 %
Photoinitiator 6-10 %	Binding Agents ~15 %
Additives 2-4 %	Additives 3-5 %

Compare to Solvent and Water Based inks, UV ink contains more monomers and oligomers but less additives. Eco-friendly flexo inks which is provided by sun chemical company is shown in the Table 7.9

Table 7.9. Eco-friendly Inks [42]

Product	Application	Sustainability Benefit
Synergy "Display UV Inks"	Plastics Printing	Manufactured without VOC's
Water Based Inks for Packaging(Multiple Products)	Flexible Packaging	Environmentally Friendly
Wetflex "Uniqure"	Packaging EB Cured Ink	Manufactured without VOC's

7.5. New technologies in printing packaging

Printed Solar Cells- are one of the steps for sustainability renewal energies that taken by Aalto University, Swiss Federal Institute of Technology in Lausanne and engineers from Massachusetts Institute of Technology(MIT). Solar Cells are cells which

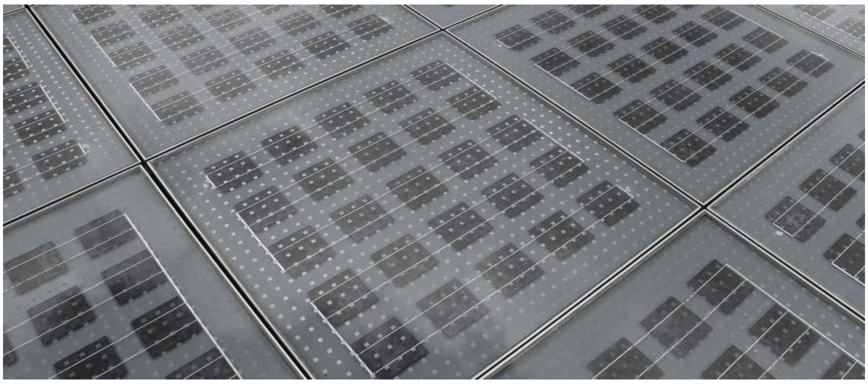


Fig 7.5. Printed Solar Cell [43]

are printed using photovoltaic inks on all materials. Unlike usual photovoltaic cells on glass substrates, printed solar cells are very thin and light. This property makes them applicable in many areas where weight plays key role for example on space-crafts [43]. Micro-perforated Packaging is the type of modern packaging which help keeping fruits and vegetables fresh for much longer and reducing food spoilage. The other benefit of Laser Cut micro-perforation technology is to help a meal with meat and vegetables be heated simultaneously.

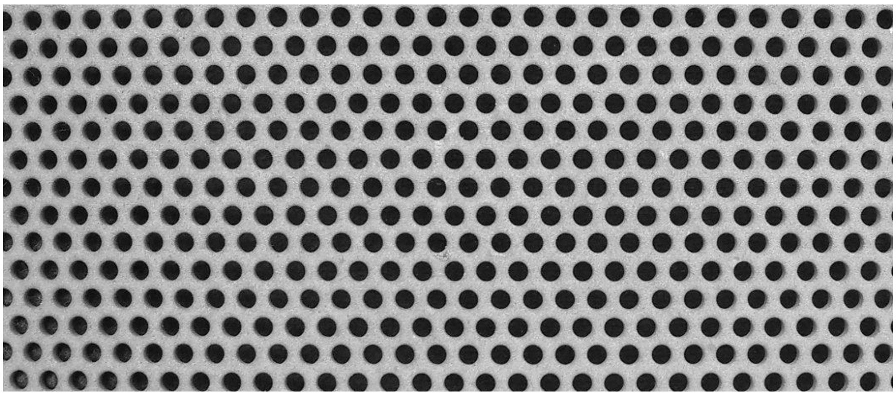


Fig 7.6. Micro-perforated Packaging [44]

Precise Perforation Patterns enables the opportunity to control the level of steam and pressure in different compartments individually. When products like tomatoes or bananas make their way onto a shelf in a supermarket they already came a long way. Consumers expect fresh products that won't go off immediately after purchasing them. In the past stores struggled with keeping fresh products fresh. Smart packaging that use microperforation offer a solution to this issue [44].

8. Quality control of the technological process

According to the date obtained from JSC "Aurika": Quality assurance is very important criteria and integral part of each process. Thus, the processes were distinguished which are important ensuring the excellent quality of product.

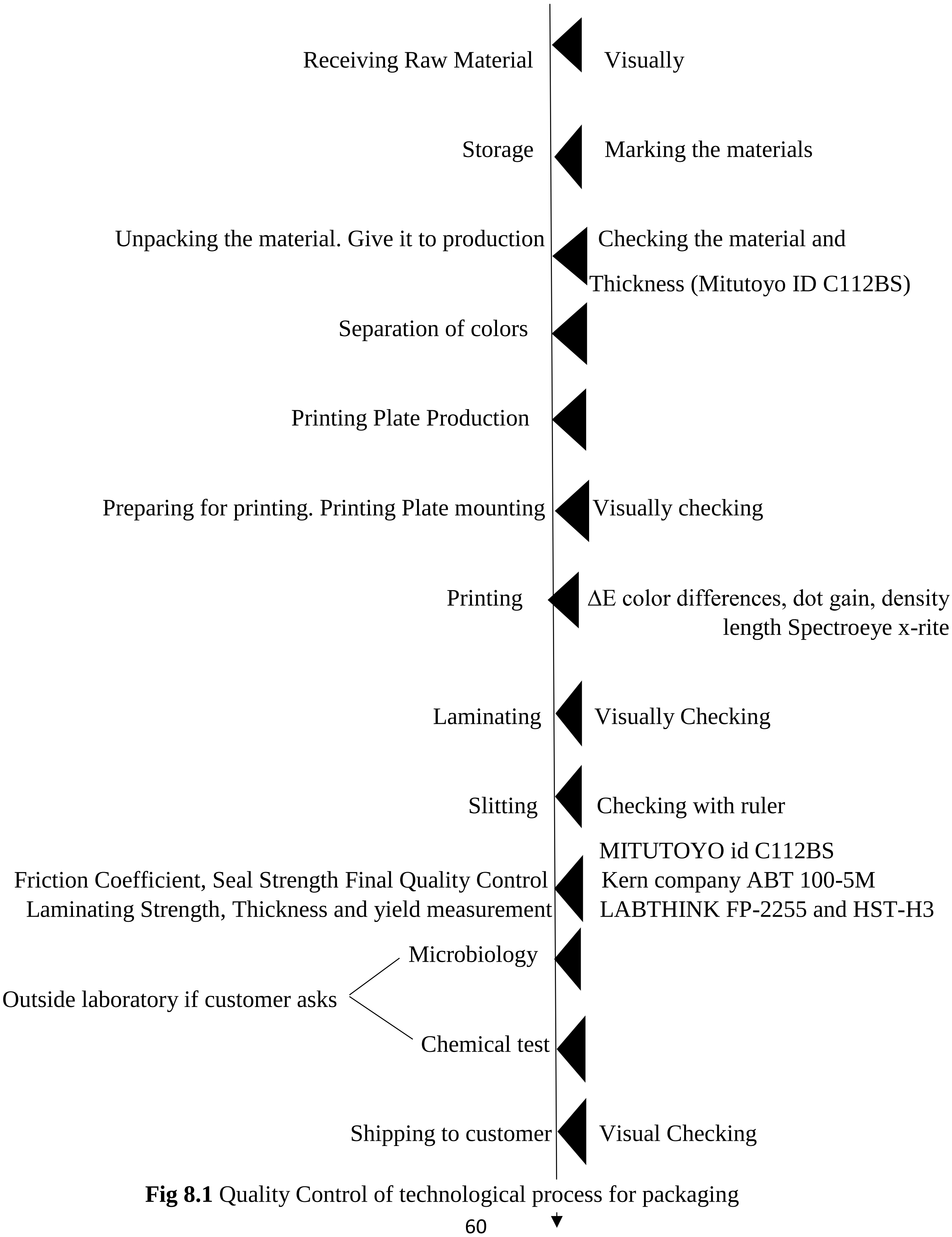


Fig 8.1 Quality Control of technological process for packaging

In the plan of quality assurance, the stages are provided which are important in the process of product manufacturing and in which physical and visual parameters are checked and controlled (raw resources and materials, semi manufactures and products).

In the plan of assurance of information transfer the stages are provided which are important in the process of information movement of product and in which non-material results and information provided in themes are checked and controlled (request, calculation, layout preparation, planning and electronic documents). Periodicity: the quality parameters are checked and controlled for each product. More details about it in the plans of quality assurance. The data are recorded in CERM system or in other selected place and are saved for all life cycle of product or for a minimum of two years. The view of quality checking equipments are shown in the Fig. 8.2

a) **b)**

Fig 8.2. Quality checking equipment a) Spectroeye X-rite b) Mitutoyo ID C112BS

According to the date obtained from JSC "Aurika" the stages of quality assurance of product are shown in Table 8.1. As we can see from Table 8.1, there are 11 stages in the quality assurance. Also, the person in charge is described for each stages of quality assurance of product

Table 8.1. The stages of Quality Assurance of product

Stage of process	Brief description	Person in charge	Related document, records
1. Acceptance of raw materials	The acceptance of main and subsidiary materials. The state of arrived transport is assessed and accordance of documents.	Warehouse manager	Control plan of acceptance of raw materials

2. Storing of raw materials	The storing of main and subsidiary materials, marking of production and providing the places of location	Warehouse manager	Control plan of storing and disposal of materials
3. Unpacking of materials/releasing to manufacturing	The unpacking of materials, releasing to manufacturing according to the prepared manufacturing plan		
4. Manufacturing of printing plates	The manufacturing of printing plates according to the planned dates of manufacture.	Head of Repro department	Control plan of manufacturing of flexo printing plates
5. Pre-press	The is work is arranged according to the set plan of manufacturing: search of necessary envelope, plate mounting on printing rollers, preparation of necessary inks.	Head of manufacturing	Control plan of pre-press
6. Printing	The printing process according to the technological sheet and order sheet	Head of manufacturing	Control plan of printing of flexible packages Control plan of printing of aluminum closures
7. Laminating	Joining to monolithic material of two or more materials using the adhesives appointed in the order sheet	Head of manufacturing	Control plan of non-solventic laminating
8. Cutting/die cutting	The cutting of semimanufacturers into the rolls according to the technical parameters appointed in order sheet. Packaging of products and recording in CERM system. The die-cutting of aluminum semimanufacturers, selection of embossing type. Packaging of products and recording in CERM system.	Head of manufacturing	Control plan of cutting and packaging of products Control plan of die-cutting of aluminum closures
9. Final control/laboratory	The quality control is carried out in these stages: in pre-press,	Quality manager	Plan of final control (control, laboratory)

	printing, laminating and cutting/die cutting processes. The assessment of task accordance of semimanufacturers and products according to the order sheet and internal standards.		
10. Made-up production warehouse/ acceptance and storing of production	Acceptance of made-up and checked production from manufacturing, placing of it in the appointed location places.	Warehouse manager	Control plan of acceptance and storing of made-up production
11. Microbiology	The researches are carried out in external laboratories in order to assess the appointed standards of air, water, subsidiary materials, production, surfaces and hygiene.	Head of laboratory	Control plan of microbiology
12. Chemical researches	The researches are carried out in external laboratories in order to assess the accordance of products to laws and regulations, standards of customers and company.	Head of laboratory	Plan of chemical researches
13. Sending for customer	The sending of manufactured production to customer according to the prepared collection sheet. All necessary documents are attached together with production. The state of arrived transport is assessed.	Warehouse manager	Control plan of production sending

Conclusion:

The printing house JSC “Aurika” has created a quality control system that ensures us to provide good quality manufacturing of packaging thus manufactured products are high quality

9. Work safety and ecology

System of work safety at JSC "Aurika"

According to the data obtained from JSC "Aurika". To reduce or completely avoid the risk of accidents and occupational diseases at workplaces the system of work safety is applied in the company. Thus JSC "Aurika" in its manufacturing and administrative facilities applies all tools defined be the laws and sub-statutory acts for safety at workplaces.

The printing house pays high attention to the education of employees. 396 employees are working in the company. All staff is instructed to work safely with equipment and has attended a fire safety instruction. Technical manager is responsible for work safety. All instructions should be registered in special journal. A good spread of information helps not only to avoid accidents, occupational diseases but also ensures high qualification of employees and successful activity of company. For additional prevention of accidents in workplaces the protective cases and walls are mounted in the printing machines and other devices. The device stops after removing them. Also, the emergency stop buttons are mounted for the stopping of technological process. Protecting the employees against potentially harmful effects of electric current, the cut-outs of short-circuit are mounted, technological equipment is grounded and the electrically conductive bodies of it are neutral connected.

A fire safety system is also important, because the employees in printing house are constantly working with flammable materials - paper, inks, varnishes, solvents and cleaners. The territory should be neat, constantly cleaned; the waste of manufacturing should be removed to the special arranged places. The approaches to the buildings and firefighting equipment should be free. Also, the parking and materials storing places should be determined in the territory. The fire extinguishing system is mounted in the JSC “Aurika”; the facilities are equipped with moveable firefighting tools; the constructions of buildings are chosen according to their fire resistance.

The air conditioners and humidifiers maintain the 20°C temperature and 50% air humidity in the manufacturing facilities of JSC “Aurika”. This is optimal values of thermal environment for technological processes of printing industry. This means that in the company is generated such thermal environment that ensures a sense of satisfaction of thermal environment and do not evoke any stress of systems that regulate body heat of employee and discomfort, even it long and systematically affects the employee.

The printing machines and other devices are designed in such way that they emit a minimum of noise. But the noise is unavoidable thus the employees are equipped with personal noise protection tools –

earplugs. The administrative facilities are screened with noise isolating walls from the manufacturing facilities. In order to burn volatile organic compounds RTO (Regenerative Thermal Oxidizer) is used in JSC "Aurika". Company. The effectiveness of this equipment is 98 %. Left solvents is reused to clean machines. After that, solvent is recovered and distilled. JSC “Aurika” Company meets the requirements of ISO 9001:2008 and ISO 14001:2004.ISO 9001:2008 is certified to the companies which meet the customer satisfaction and regulatory requirements. Unlike ISO 9001:2008, ISO 14001:2004 specifies requirements to focus on environmental management systems. These certificates are attached to Appendix.

10.Competitor's analysis in Baltic States and Europe

Main aim of this analysis is to investigate JSC "Aurika" printing house competitors in Lithuania and other nearby countries. Results of analysis in Lithuania, Poland, Germany, Belarus, Latvia, Estonia and Scandinavian countries were reported in Table 10.1.

Table 10.1. Competitor's market analysis [45-47]

No	Company Name	Product	Country	Sales Turnover
1	Baltic Pack ,JSC	For Dairy, bakery ,fish, meat, fruits and vegetables	Lithuania	5000 K€-9999 K€
2	IOCO Packaging JSC	For Dairy,Free-Flowing,Bakery, Confectionary,Meat and Meat Products, Fish packaging	Lithuania	10000 K€-49999 K€
3	ACHEMPAK, JSC	Polypropylene big bags for grain,flour,sugar,various vegetables.	Lithuania	
4	Reprodukcijos spalvos	Flexible Packaging for confectionery, food, dairy products	Lithuania	
5	Pack mark	Shrink Sleeves ,Banding labels	Lithuania	10 000 K€ - 20 000 K€
6	FlexPro	Label printing	Lithuania	1 000 K€- 2000 K€ EUR
7	VELPLEV SIA	Bakery and Confectionary bags	Latvia	Less than 999 K€
8	Plastrum OÜ	Bakery products	Estonia	
9	Folflex	Meat, fruit and vegetables, bread wrapping	Poland	Less than 999 K€
10	Alupol Packaging	Vegetables packaging	Poland	More than 50000 K€
11	Formika	Packaging for dairy (aluminium lids)	Poland	
12	BISS S.C.	Packaging for deep frozen products,sweets,baked products	Poland	
13	Grupa Pakum	Packages for frozen food,bread and sweet	Poland	

14	Uniflex	Web flexible Packaging for Ice cream, Confectionary and burgers	Belarus	
15	HELMUT SCHMIDT VERPACKUNGSFOLIEN GMBH	POLYPROPYLENE CROSS BOTTOM BAG	Germany	
16	Beuckegroup	Labels for juice and baked goods (flat gusset bag), coffee, tea, nuts, baking mixes, sweets (standup bag)	Germany	
17	Aluminium Féron GmbH & Co. KG	Self adhesive labels for alcohol beverage	Germany	
18	HEYNE & PENKE VERPACKUNGEN GMBH	Flexible package for bakery ,confectionary products	Germany	10.000 K€ - 49.999 K€
19	LEEB GmbH & Co. KG	Label and Packaging for dairyproducts , confectionary ,snack ,bread	Germany	Less than 999 K€
20	Nordex-flexibles	Packaging for dry goods, meat ,bread	Norway	
21	Huhtamäki	Flexible packaging and labels for snacks, chocolates, ice cream, coffee, juices, soups, pet food, and ready meals.	Finland	
22	4R PRODUCTION HB	Food and beverage labels	Sweeden	

About 6 companies produce package and label in Lithuania: ‘Baltic Pack ‘provides packaging for dairy, bakery, fish, meat, fruits and vegetables products. Sales Turnover is about 5000 K€-9999 K€. ‘IOCO Packaging JSC’ company provides services for Dairy, Free-Flowing, Bakery, Confectionary, Meat and Meat Products, Fish packaging. And Sales turnover higher than Baltic Pack (10000 K€-49999 K€). JSC “Aurika” printing house produce very high-quality package and label. ‘VELPLEV SIA’ is located in Latvia and provides Bakery and Confectionary bags. ‘Plastrum OÜ’ company is situated in Estonia and produces packaging for bakery products. As shown in table 11.1 5 Polish companies produce package and label for food (‘Folflex ‘,’Alupol Packaging’, ’Formika’, ’BISS S.C’, ’Grupa Pakum’).‘Uniflex’ company is located in Belarus and produces web flexible packaging for Ice cream, Confectionary and burgers. 5 German companies (‘HELMUT SCHMIDT VERPACKUNGSFOLIEN GMBH’,‘Beuckegroup’,‘Aluminium Féron GmbH & Co. KG’, ‘HEYNE & PENKE VERPACKUNGEN GMBH’, ‘LEEB GmbH & Co. KG’) was found and reported in table. There are 3 Scandinavian companies (‘Nordex-flexibles’,‘Huhtamäki’,‘4R PRODUCTION HB’) was found and reported in table.

Conclusion

Although JSC “Aurika” printing house has many competitors in Europe, high quality labels and packages produced by JSC “Aurika” as well as requirements for food packaging allow JSC “Aurika” export his products to countries such as Germany ,Poland and Scandinavian countries

Conclusions and proposals

Overall, following stages were analysed and 7 steps were suggested as a conclusion of final degree project:

1. Packaging process was analysed in the Europe market. Total plastics demand constitutes 49 million tons in the Europe and Packaging area leads for the plastic demand which is 39.9 %. However, landfill rate is about 50 % much higher than other treatments in Lithuania.
2. All green engineering principles were analysed and it was realized that JSC “Aurika” printing house applies principle 1 (Inherent rather than circumstantial),2(Strive to prevent waste than to treat or clean up waste after it is formed) ,3 (Easy to separate by design),4 (Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency) and 12 (Sustainable rather than depleting) on the production
3. Raw material is laminated from 3 to 7 layers in order that manufactured packages pay all general properties requirements in JSC “Aurika” flexo printing house.
4. Considering to the already carried out researches, the LDPE 4 polymeric film containing dry molasses and glycerine additives has demonstrated the most encouraging results to be used as biodegradable packaging material.
5. Research of harm to environment of packaging manufacture process was done using (ECO indicator methods) and the greatest impact (4.8 mPt) on the environment is made by the used polymeric materials for manufacturing of packages.
6. Designing of manufacturing technologies of food packaging was described detailly. After testing material of product was chosen more eco-friendly LDPE4 (LDPE + 2% molasses (dry) + 1% glycerine) because the properties of this material were almost similar to traditional PE 50 transparent material for Sumuštinis "Baguette.
7. The analysis of rivals in Europe of JSC “Aurika“has been carried out and it was determined that JSC “Aurika” printing house export its 63 % products to EU countries such as Germany ,Poland and Scandinavian countries. So, it can be stated, that packaging production of JSC “Aurika” meets high requirements for packaging manufacturing that are set in various EU countries and is competitive printing house in this field

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Annexes

Lloyd's Register
LRQA

CERTIFICATE OF APPROVAL

This is to certify that the Management System of:

UAB AURIKA
Taikos ave. 129A, LT-51127 Kaunas
Chemijos str. 29F, LT-51333 Kaunas
Lithuania

has been approved by Lloyd's Register Quality Assurance
to the following Quality and Environmental System Standards:

ISO 9001:2008
ISO 14001:2004

The scope of this approval is applicable to:

Design, pre-printing services and production of flexible packaging, self-adhesive labels, non-adhesive labels and lids.

Approval
Certificate No: LTQ0002808

Original ISO 9001 Approval:	29 April 2003
Original ISO 14001 Approval:	29 April 2009
Current Certificate:	29 April 2015
Certificate Expiry:	28 April 2018

Issued by: UAB LRQA Lietuva
For and on behalf of Lloyd's Register Quality Assurance Limited

UKAS
MANAGEMENT SYSTEMS
001

Lvovo str. 25, LT-09320 Vilnius, Lithuania
For and on behalf of: 1 Trinity Park, Bickenhill Lane, Birmingham, B37 7ES United Kingdom

Lloyd's Register
LRQA

CERTIFICATE OF APPROVAL

This is to certify that:

Aurika, UAB
Kaunas Packaging factory
Chemijos str.29 F, LT-51333 Kaunas, Lithuania

has been audited by Lloyd's Register Quality Assurance
and found to meet the requirements set out in:

BRC Global Standard for Packaging and Packaging Materials
Issue 5, July 2015
High Hygiene
Announced

And has attained certification at Grade B for High Hygiene Risk Category
Product categories 05 & 07 applicable to

Manufacture (slitting, lamination, and printing) of flexible plastic packaging and aluminium foil lids cutting.

Approval
Certificate No: LTQ0002808/B
BRC site code: 1591080
BRC Auditor No: 108159

Audit Date	:	30 November 2016
Certificate Issue Date	:	25 January 2017
Re-Audit Due Date From	:	2 November 2017
To	:	20 November 2017
Certificate Expiry	:	11 January 2018

Issued by: Lloyd's Register EMEA Klaipedos Filialas
For and on behalf of Lloyd's Register Quality Assurance Limited

UKAS PRODUCT CERTIFICATION
001

BRC CERTIFICATION BODY

If you would like to feed back comments on the BRC Global Standards scheme or the audit process directly to us, please email enquiries@brcglobalstandards.com or call the TELL BRC hotline +44 (0)20 7717 5959.
'Visit the BRC Directory www.brcdirectory.com to validate certificate authenticity'

Nemuno 2A, LT-91199 Klaipeda, Lithuania
For and on behalf of LRQA Ltd, 1 Trinity Park, Bickenhill Lane, Birmingham, B37 7ES, United Kingdom

Analytical review of energy requirements of electronic prepress, printing and laminating equipment

According the date obtained from JSC “Aurika” Printing House. The view of Kodak Flexcel NX Wide Imager is shown in Fig 13.1. This equipment is used to gravure printing plate. Technical characteristics of equipment is shown in Table 13.1.

Fig 13.1. Kodak FlexCel NX Wide Imager (Gravure equipment)

Table 13.1 Technical characteristics of Kodak Flexcel NX Wide Imager (Gravure equipment)

Equipment measurements (H × W × D)	120×323×234 cm
Weight	1760 kg
Negative size	• 640 × 838 mm, you get 610 × 762 mm printing form; • 838 × 1097 mm - 800 × 1,067 mm; • 1097 × 1554 mm - 1067 × 1524 mm
Productivity	13,4 m^2/hour
Number of laser heads	16
Power, kW	9,66 kW

Fig 13.2. Wide Laminator equipment - Kodak FlexCel NX and technical characteristics

Equipment measurements (H × W × D)	*87 × 273 × 133 cm;*
Weight	*700 kg*
Printing form sizes	*610 × 762 mm;* *800 × 1067 mm;* *1067 × 1524 mm*
Power, kW	*3,45 kW*

The view of Dupont Cyrel DigiFlow 2000 EC is shown in Fig 13.3.This equipment is used to exposure printing plate.Technical characteristics is shown in Fig 13.3 as well.

Fig 13.3 Exposure equipment- Dupont Cyrel DigiFlow 2000 EC and technical characteristics

Max. printing from width	*1070 mm*
Max. printing from lenght	*1530 mm*
UV-A waves lenght	*360 nm – 380nm*
Voltage	*208-240 V / 50-60hz*
Power	*10 kW*
Tempetarture	*Nuo 17°C iki 27°C*
Equipment measurements (H × W × D)	*2080 mm × 1990 mm × 2250 mm*
Weight	*800 kg*
Power	*21 kW*
DuPont Cyrel 2000D Drying machine power 2014	*11,7 kW*

Fig 13.4 Washing equipment -Dupont Cyrel 2000 PS

Table 13.2. Technical characteristics of Washing equipment -Dupont Cyrel 2000 PS

Max. printing from width	*1070 mm*
Min. printing from width	*200 mm*
Max. printing from lenght	*2000 mm*
Printing form thickness	*from 0,5 mm to 7,0 mm*
Min. liquid quantity for operation	*70 l.*
Max. liquid quantity for operation	*90 l.*
Voltage	*220 / 230 V – 50 / 60 hz*
Power	*8.5 kW*
Temperature	*From 15°C to 30°C*
Compressed air supply	*Min, 6 bar*
Equipment measurements (H × W × D)	*4420 mm × 1730 mm × 940 mm*
Weight	*1190 kg*

Fig 13.5 Packaging printing machine- Fischer & Krecke Flexpress 16S-10

Table 13.3. Fischer&Krecke Flexpress 16S-10 technical characteristics

Sections number	10
Max. material width, mm	1300
Max. printing width, mm	1250
Printing speed, m/min	460
Power	280 kw
Drying	Hot air system
CI drum diameter ,mm	1910

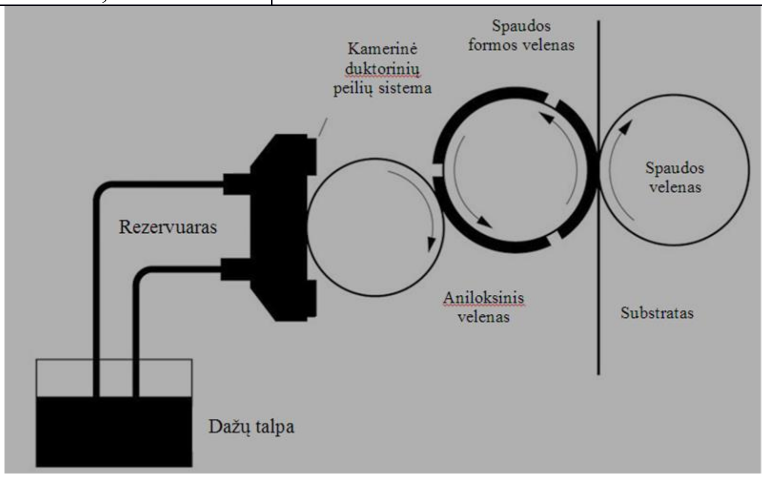


Fig 13.6. Principle scheme of ink apparatus

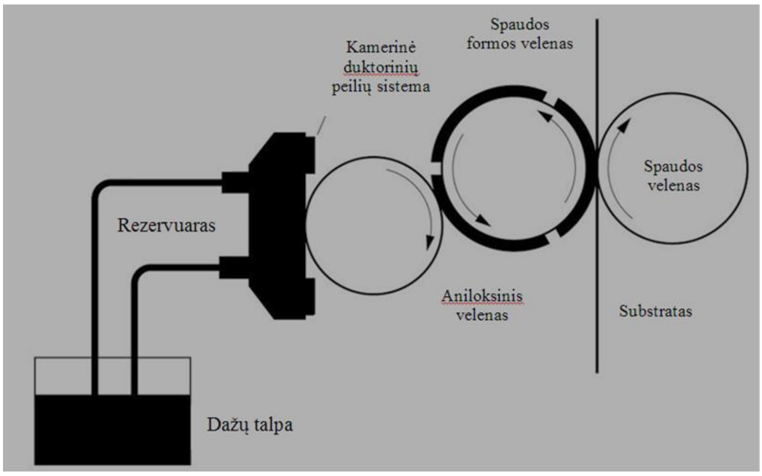


Fig 13.6. Principle scheme of ink apparatus

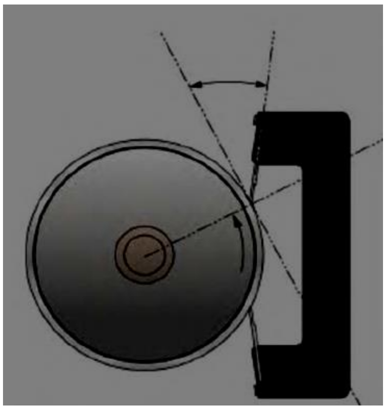
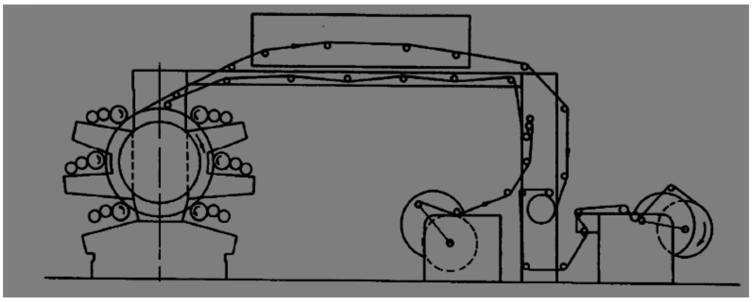


Fig 13.7 Scheme passing ink to



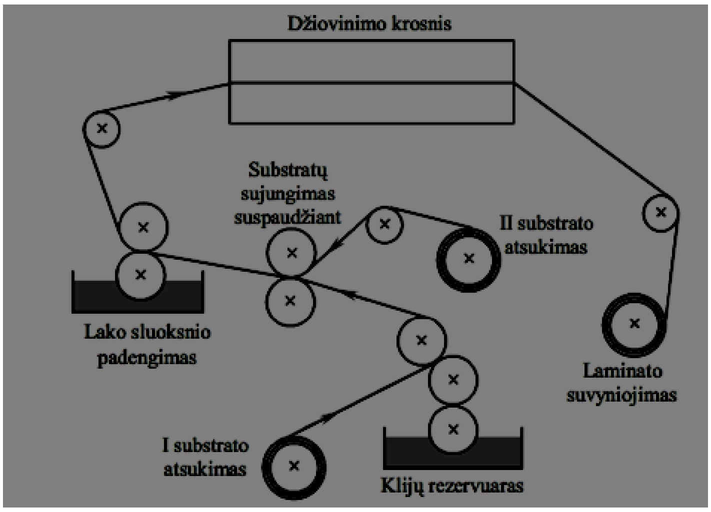


Fig 13.8. SuperSimplex Technological process of lamination

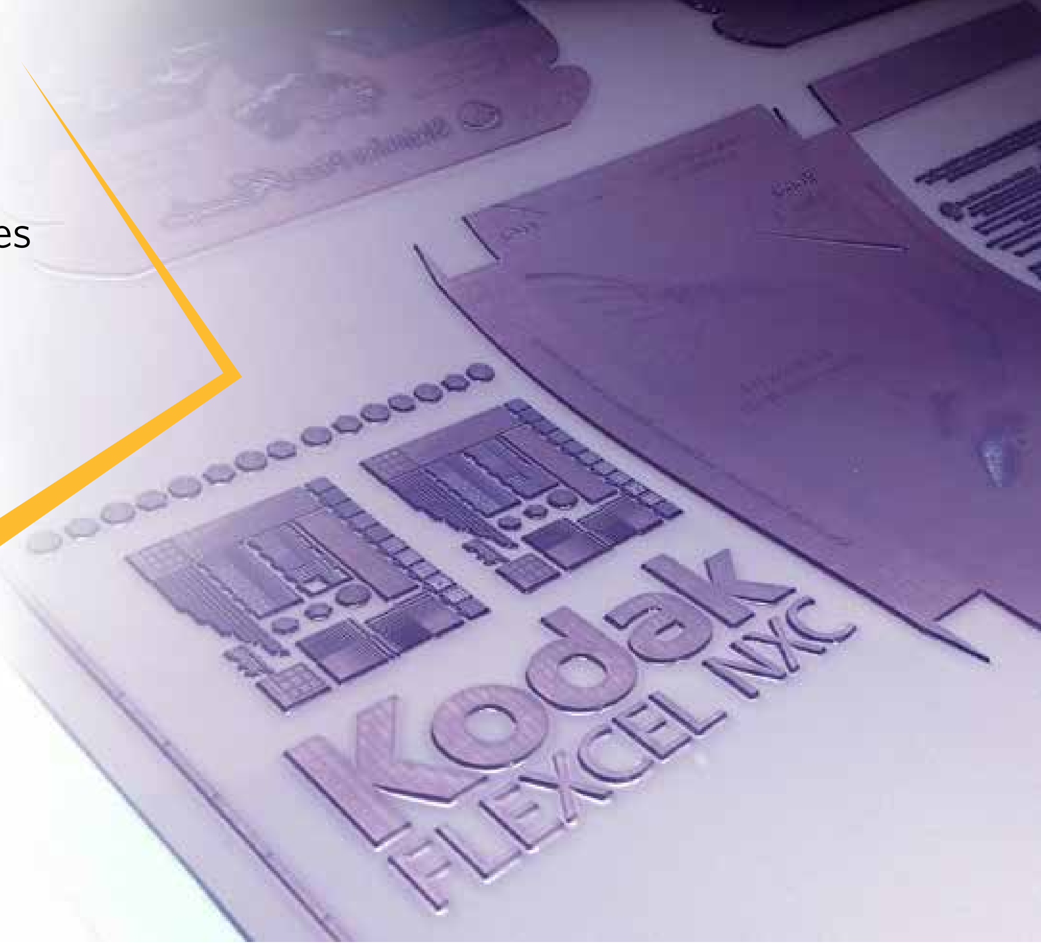
Table 13.4. SuperSimplex technical characteristics

Parametras	Reikšmė
Laminating material width, mm	650÷1330
Max. speed, m/min	350
Corona system	+
Power	80 kw
Material thickness	7 ÷ 300

Fig 13.9 Equipment of lamination- „SuperSimplex“

Kodak Flexcel NXC Plates

Kodak Flexcel NX Thermal Imaging Layer-R



Do more with less

The award-winning **Kodak Flexcel** NX System uses unique imaging technology and plate materials to drive outstanding shelf impact at the lowest total delivered cost. Users benefit from more impactful graphic reproduction with less complexity and downtime on press.

Unique technology

For post-print corrugated applications Kodak offers two uniquely formulated materials. The **Kodak Flexcel** NX Thermal Imaging Layer-R is designed to provide rapid, high-resolution imaging on the **Kodak Flexcel** NX Imager, utilizing **Kodak SQUAREspot** Imaging Technology to ensure stable and predictable results. Lamination ensures intimate optical contact between the imaged layer and the **Kodak Flexcel** NXC Plate, allowing 1:1 dot reproduction onto the plate.

Exceptional quality and performance

Flexcel NXC Plates are high-quality, lower durometer flexographic plates providing full tonal reproduction, low dot gain, and robust on-press performance. Higher line screens are possible with existing press equipment, and excellent ink transfer and coverage minimizes fluting and increases visual impact even on lower quality liner materials.

Maximum versatility

Flexcel NXC Plates are designed to print with aqueous (water-based) inks on post-print board with a wide variety of liner and flute types. They are suitable for a broad range of graphic reproduction requirements from simple line and tone work to complex full process color content.

Speed and ease of use

Flexcel NXC Plates offer wide exposure latitude with efficient drying times, necessary to meet your demanding print quality requirements and production schedules. In addition, the plates are easy to mount and are highly resistant to ozone, wear and abrasion, so you realize increased consistency, productivity and enhanced print quality.

Complete solution for packaging

The **Flexcel** NX System forms part of Kodak's broad portfolio of graphics workflow and printing solutions for packaging. From packaging concept to creation, no other partner brings a more complete solution to printer-converters, trade shops and the brand owners they serve than Kodak. Our strategic vision is to enable product innovation with simplified, standardized and automated production processes.

Kodak Flexcel NX Thermal Imaging Layer-R

Sizes	1097 x 1554 mm (43.2 x 61.2 in), 1283 x 2062 mm (50.5 x 81.2 in)
Thickness	6.5 mil (0.0065 in)
Safelight recommendations	Prolonged exposure should be under process yellow or UV modified fluorescent light.
Handling and storage	Handle the layer by the corners. Avoid scratching and kinking the layer. Store flat and use in a controlled environment of 17 - 30°C (63 - 86°F) and at 40 – 60% RH.
Distinguishing characteristics	For use in the manufacture of **Kodak Flexcel** NXC Plates of all sizes. Media color: Blue

Kodak Flexcel NXC Plate

Plate sizes	1067 x 1524 mm (42 x 60 in), 1270 x 2032 mm (50 x 80 in)
Ink compatibility	Aqueous
Washout solution	Compatible with most washout solvents
Safelight recommendations	Prolonged exposure should be under yellow or UV-modified fluorescent light.
Handling and storage	Handle the plates carefully. Store flat and use in a controlled environment of 17 - 30° C (63 - 86°F) and at 40 – 60% RH.

Technical specifications for a finished **Flexcel** NXC Plate

Thickness	2.84 mm / 0.112 in	3.18 mm / 0.125 in	3.94 mm / 0.155 in
Durometer	36 - 40 Shore A	34 - 38 Shore A	33 - 37 Shore A
Resolution	1% at 150 lpi		
Minimum dot	20 µm minimum (0.8 mil)		
Isolated dot reproduction	75 µm minimum (3 mil)		
Fine line reproduction	50 µm minimum (2 mil)		

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Or in North America, call +1-866-563-2533

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