Life Cycle Assessment of Common Plastic Packaging for Reducing Environmental Impact and Material Consumption

Visvaldas Varžinskas[1], Jurgis Staniškis[1], Alis Lebedys[2], Edmundas Kibirkštis[3] and Valdas Miliūnas[3]

[1]*Institute of Environmental Engineering, Kaunas University of Technology, Lithuania*
[2]*Packaging Research Centre, Kaunas University of Technology, Lithuania*
[3]*Department of Graphic Communications Engineering, Kaunas University of Technology, Lithuania*

In order to sell production, the goods packaging must comply with the demands of the international market and the requirements of the corresponding legal acts.

In accordance with the EU regulations, member states have to ensure that a particular production packaging is used only when it complies with all the environmental regulations laid down in the EU Directives 94/62/EB and 2004/12/EB and the elaborated document system. One of the basic requirements is to produce packaging in such a way that its volume and weight are restricted to the minimum dimensions needed to meet the safety, hygiene and packaging demands acceptable for the consumer. With this aim, the main attention should be first of all focused on preventive measures. These measures refer to the reduction in the waste amount and harmful impact on the environment.

Research into that area was carried out in 2007-2008 within the framework of a joint Lithuanian-Ukrainian research and experimental development project "Study of special printing and packaging production technologies, considering their ecological and operational qualities.". It was done by a research group of the Graphic Communication Engineering Department at the Faculty of Design and Technologies, Kaunas University of Technology, together with packaging and environmental protection specialists of the University, and in cooperation with the Department of Printed Publications and Packaging of the Ukrainian Print Academy.

The present paper analyses certain basic findings of the study on the possibilities of improving the ecological level of packaging within the framework of the project. It is stated that appropriate investigation of packaging, its production and application has to be performed in order to prove that the packaging was produced in compliance with preventive and other principles; this investigation is related to a wide variety of package testing, some of which has not yet got methodology acknowledged at a sufficient level (the EU or groups of countries). Therefore, one of the research directions in the above mentioned project, discussed in the present paper, is related to developing a single system, recognized throughout the EU, which would enable researchers to perform the required tests confirming the packaging quality compliance with the environmental requirements. The paper analyzes the EU prevention regulations for reducing the amount of raw material and the system of checking the realization of the requirements based on identification of critical areas, aimed at reaching the lowest possible package weight and/or volume, consequently, the minimum waste amount, without increasing the amount of faulty products and product waste. The paper presents the findings of the research obtained in assessing the life cycle, when applying the Ecoindicator'99 qualitative analysis, concerning the impact of common plastic packages and processes on the environment during manufacturing, usage and disposal. Compression test results of common type plastic packaging construction are presented, which allow us to assess the impact of the package shape and construction upon the packaging reliability and minimization of its mass.

Key words: *packaging, environment, life cycle assessment, eco-design, packaging testing.*

1. Introduction

Product packaging complying with the international market requirements is a basic precondition for selling manufactured goods.

When designing ecological packaging, the following packaging functions are essential in ensuring competitiveness of manufactured goods:

– possibility of rational placement of a product in packaging;
– retaining the proper quality of the packaged product throughout its life cycle and the logistics process;
– compliance with the requirements of production realization;
– compliance with the requirements of production usage;
– possibility of appropriate disposal of used packaging.

The problems of packaging and package design were analyzed in Kaunas University of Technology in 2007-2008 within the framework of a joint Lithuanian – Ukrainian research project. During the work, special attention was given to the ecological aspect of packaging, mainly related to the implementation of the regulations of the EU system of regulatory documents based on the European Parliament and Council Directive 94/62/EB concerning packaging and packaging waste [1], and also the Directive 2004/12/EB [2,3], amending the former.

While trying to meet the requirements of the above mentioned EU systems of regulatory documents, complemented with new legal acts, the complexity of certain problems became evident and new urgent tasks were raised which needed an efficient and qualified solution.

Following the EU requirements, member states have to ensure that a certain package can be used for packaging production only if it complies with all the requirements laid down in the EU Directive 94/62/EB and its Appendix II. New packaging can enter the market only if the manufacturer has taken all the measures to reduce its impact on the environment without degrading its essential functions. Packages have to be manufactured by restricting their volume and weight to a minimum necessary to ensure the requirements of safety, hygiene and acceptable consumer goods. To reach this goal, the main attention has to be focused on preventive measures. In this case, preventive measures mean reducing the amount of materials in packages and packaging waste, as well as harmful effect on the environment. Further measures to reduce the amount of used packages in landfills include the following (in a descending order of priorities): package reusability, recycling, other technological processes for packaging waste application (recovery of materials, energy, etc.) The Commission is supposed to help the development of prevention by encouraging the formation of the appropriate European standards.

In order to prove that the new packaging was developed following the prevention and other principles, it is necessary to carry out particular investigation concerning the packaging, package manufacturing and application processes; this is a complicated task because of the wide variety of concrete package tests which often do not have commonly acknowledged (by the EU or groups of countries) methodologies. Therefore, one of the research directions in the above mentioned project, discussed in the present paper, is related to forming a single system, recognized throughout the EU, which would enable researchers to perform the required tests confirming the packaging quality compliance with the environmental requirements.

2. Prevention control: essence and characteristics of procedures

Packaging is meant for storing, protecting, managing, distributing and presenting products. Its main purpose is to protect the product against spoiling and/or losing it. Reduction in the initial amount of material is one of several ways how to reduce the ultimate amount of used packaging disposal. In order to save raw materials and reduce waste to a maximum, the whole system has to be optimized, packaging included.

The supplier has to ensure that the package system contains the smallest possible amount of the needed material. The basic principles of control procedures and methodology are laid down in the European Standard EN 13428 [4]. It provides general information on the guidelines for persons using the document, and then, while discussing methodology, describes separate phases of the evaluation process. It emphasizes that *when reducing the amount of raw materials*, the main aim in evaluating the prevention process, which can be documented by filling in a control sheet, is to achieve the smallest possible packaging weight and/or volume, thus the smallest possible amount of packaging waste without increasing the amount of spoilt product and product waste. Further aims are to ensure that:

– all the prevention possibilities for the same packaging material should be determined to reduce the amount of raw material and to achieve the smallest possible packaging weight and/or volume, and they should be taken into consideration;
– prevention when reducing the amount of raw materials should be reached before the necessary requirements for packaging are implemented;
– decisive characteristics, upon which the former statements are based, should be recorded.

In certain cases of packaging usage, detailed requirements may differ. During the process of package design, when prevention is taken into consideration while reducing the amount of raw materials, analysis of each requirement will influence the general requirements for the packaging. These

requirements may be classified in the control sheet. In order to achieve unified methodology, the document provides two examples of filled-in control evaluation sheets and protocols approving them, together with explanatory documents which help to complete the control sheets and which may contain major decisions about prevention in reducing the amount of raw materials. The documented market experience can be a significant source of data defining the acceptable limits. The marginal usage criterion can be registered as critical after it has been studied and tested by other operators of a packaging chain. Thus, prevention in reducing the amount of raw materials is a continuous process embracing the design and usage experience, which may provide useful information in determining critical areas.

It is generally considered that when designing some specific packaging or a group of similar packages, certain requirements determine the actual limits of reducing the package weight and/or volume without causing danger to the level of safety, hygiene and consumer acceptability.

In the second stage of the assessment process, the usage criteria restricting the possibility of reducing the packaging weight and/or volume are enumerated. It is known as the critical area. This identification should be based on testing and research meant for checking the validity of the possibilities in seeking further prevention when reducing the amount of raw materials needed.

Analysis of a concrete packaging conformance is carried out by evaluating an appropriate part of the life cycle in accordance with 10 common usage criteria presented below, which can be important for a certain package and each of which has a list of standard requirements (summarized below).

1. *Product protection.* The product has to be protected against damage and spoilage (including active packaging) caused by concrete mechanical, chemical, environmental and other factors, from the packaging moment to the final consumption moment.
2. *Manufacture of packaging.* Designers are provided with valid limits of packaging characteristics (size, thickness, etc.) which are determined in respect of the technological processes of packaging manufacture.
3. *Packing (filling).* Designers are provided with valid limits of packaging characteristics (mechanical strength, closure reliability, hygiene characteristics, maximum padding, etc.) which are determined in respect of the packaging technological processes.
4. *Logistics (comprising transportation, storage and arrangement).* A package (any combination of primary, secondary and tertiary packaging) has to ensure sufficient product protection and safety for the people managing and using the packed goods throughout the planned logistics process.

5. *Product presentation and trade.* Packaging has to enable the consumer to identify the product attributes (related to the image, trade mark, etc.), correspond to the goods' presentation systems, etc.
6. *Acceptability for the consumer.* The packaging size, shape, usability, reliability, attractiveness, ergonomic factors related to managing, opening, closing, storing, etc. have to be evaluated.
7. *Information.* The packaging has to provide all the necessary information concerning the product identification, characteristics, storage and maintenance instructions, etc.
8. *Safety.* The packaging has to meet all the safety requirements concerning the whole system of packaging, management and usage, as well as specific requirements (e.g., related to dangerous cargoes), in particular cases, ensuring inaccessibility to children, safe opening, showing unacceptable opening, warning about dangers, etc.
9. *Laws (legal acts).* The packaging has to comply with the regulations of national and international legal acts, rules, trade agreements, etc. (considering special requirements for food, medicine, chemical products, hazardous products, packaged goods in different means of transport, etc.).
10. *Security against counterfeiting, identification, etc.* If the above mentioned criteria do not spotlight the critical area, particular criteria are defined here for specific cases (e.g., related to economics, social environment, environmental protection, etc.), necessary for determining the smallest possible weight (volume) of the packaging.

The supplier of the packaging has to determine critical areas and to prove that the smallest possible packaging weight and/or volume have been achieved, considering all the criteria.

During the control, the crisis area of the packaging has to be determined. If it has not been done, it is concluded that the packaging does not comply with the requirements of the regulating document, and the possibilities of reducing the amount of materials used in manufacture require further research.

3. Investigation of plastic packaging life cycles

In order to determine the impact of plastic packaging on the environment throughout its life cycle, and to define the main environmental aspects, the analysis was carried out. The priorities in improving the product have to be determined in respect of characteristic aspects, and observed during eco-design.

For the evaluation of the impact of plastic packaging upon the environment and for defining priorities, the qualitative analysis method - Ecoindicators '99, based on the product life cycle – was used.

The functional unit – one plastic package – was determined. The initial data for assessing the plastic packaging are presented in Table 1.

Table 1.   Plastic packaging produced in a Lithuanian enterprise (2008)

Parameter	Measuring unit	Value
Type of plastic		PS
Amount of plastic with a lid	g/package	12.17
UV ink	g/ package	0.00625
Washing liquid	l/ package	$0.633*10^{-5}$
Print form	g/ package	0.000466
Negative	g/ package	0.000354
Water	l/ package	0.001005
Duration of manufacture	h/ package	0.00004955
Power required for: - printing machine - molding machine - plate making machine	kW	22.75 81.25 7.2
Type of packing		640 containers in a polythene bag packed in a corrugated paperboard box
Transportation distance	km	200
Recycling		0% recycling, 100% to landfills

The impact of materials and processes on the environment during manufacturing, usage, and disposal has been calculated by Ecoindicators '99 and is presented in Fig. 1. The diagram shows that the greatest impact on the environment occurs during the manufacture (5.1 mPt).
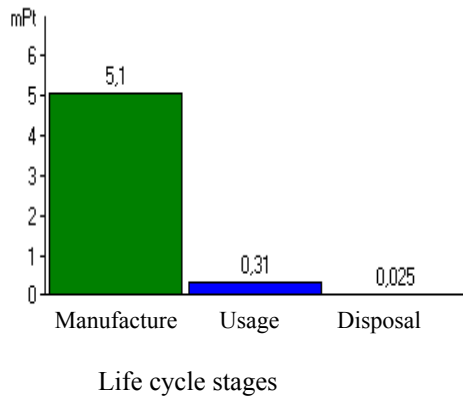

Life cycle stages

Fig.1.   Impact of plastic packaging on the environment during manufacture, usage and disposal

In manufacturing, various materials are used, therefore by applying Ecoindicators '99 software the manufacturing phase is divided according to separate materials, and the impact of these materials on the environment during manufacture is calculated (the findings are presented in Fig. 2). The greatest impact on the environment is made by plastic and its production (4. mPt).
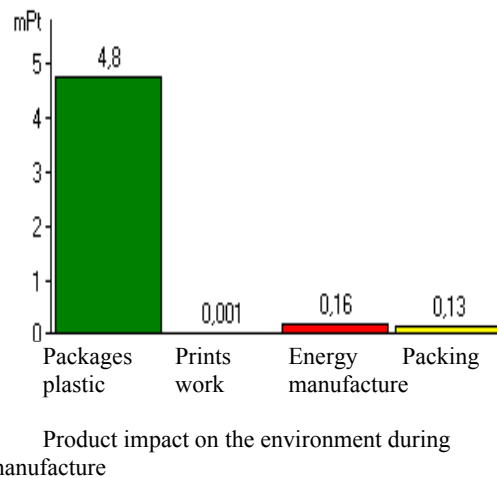

Product impact on the environment during manufacture

Fig.2.   Impact of plastic packaging components on the environment during manufacture

Analysis of the impact of packaging plastic on the environment has shown that the greater part of the negative impact on the environment is caused by polystyrene (PS), while the impact of the package formation processes is not so significant (Fig. 3). The impact of printing, energy and packing on the environment is relatively insignificant.
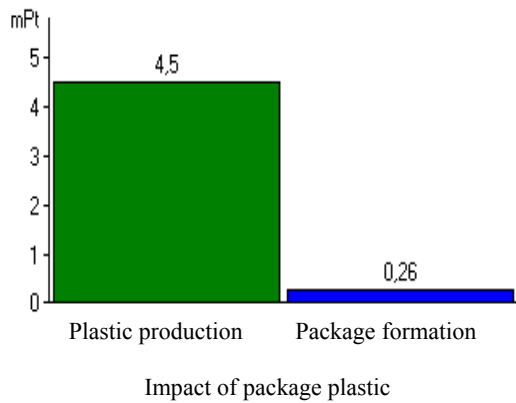
Impact of package plastic

Fig. 3. *Impact of plastic packaging material (plastic) on the environment during manufacture*

When analyzing the printing processes and the applied materials, it turns out that the most important environmental aspect in printing processes is organic printing ink. The Ecoindicator value is 720 nPt (Fig 4).
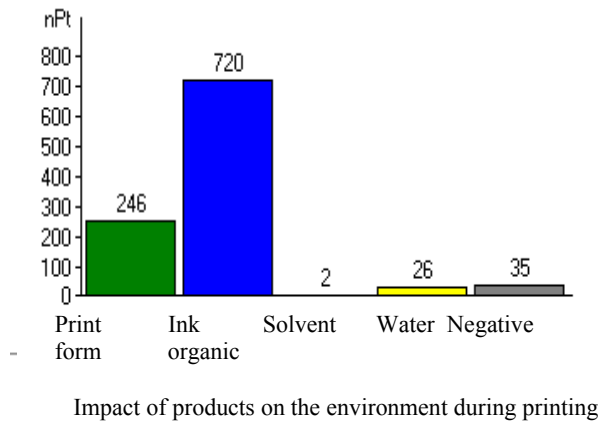

Impact of products on the environment during printing

Fig. 4. *Impact of plastic packaging during printing processes*

During the usage of plastic packaging, the environmental impact is made while transporting and distributing it among consumers.

During the disposal, the negative impact of plastic packaging is observed when disposing of the materials needed for printing. During the research an assumption gas been made that 100% packages of the market are disposed in landfills, therefore positive values of the plastic packaging and packing impact on the environment are obtained (Fig. 5). Negative factors of the impact on the environment during disposal have a positive effect upon the general product impact on the environment (due to the possibility of reusing it).
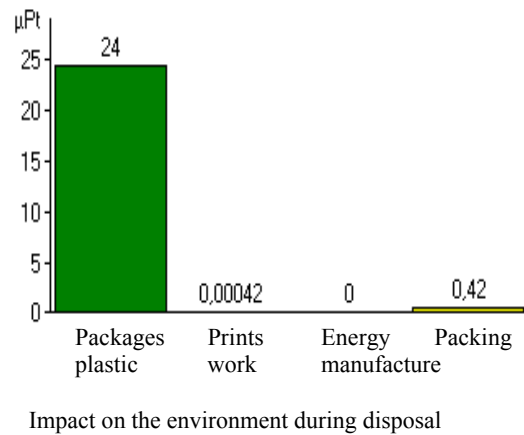

Impact on the environment during disposal

Fig. 5. *Impact of plastic packaging on the environment during disposal*

4. Study of mechanical resistance of plastic packages

Possible solutions of the problems concerning improvement in the ecological level of paper/paperboard packaging constructions were discussed in detail in the earlier stage of the research, and the major results were published in [23]

In the initial stage of the above mentioned project, experimental compression strength tests on widely used plastic packages of a truncated cone shape, tapered downwards, were carried out [24]. The tests were performed by using different specimens (plastic containers), made of polystyrene (PS), the image of which is presented in Fig. 6. The choice of such specimens for testing is explained by the fact that packages of this type are widely used in food industry of Lithuania and the Ukraine. While analyzing the geometrical variety of the package shapes, eight typical container types were chosen, with slight differences in the top and bottom configuration and sizes.
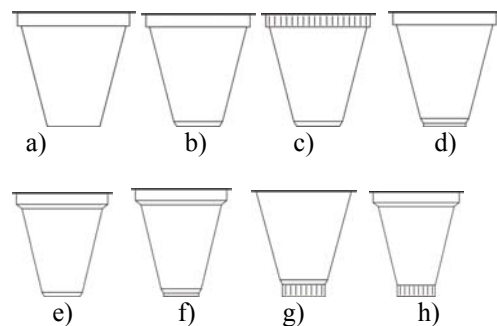

Fig. 6. *Types of polystyrene packages: a) Type 1; b) Type 2; c) Type 3; d) Type 4; e) Type 5; f) Type 6; g) Type 7; h) Type 8.*

The need for this type of study is predetermined not only by the demand to reduce the amount of materials used for packing, but also by the necessity to find efficient ways how to enable packaging suppliers to prove that they are keeping to the

requirements of *prevention in reducing the amount of raw materials*. As stated in Part 2, upon the basis of the study of plastic packaging life cycle, the greatest impact of the mentioned packaging upon the environment occurs during their manufacture, and the greatest impact on the environment during manufacture is made by the materials used, namely, packaging plastic.

Fig. 7 presents characteristic curves of compression resistance load and deformation dependences of the three above mentioned packages; they were obtained during compression tests on empty polystyrene containers under vertical load (more details in [24]).

The obtained test results led to further analysis, when the selected container types were studied to determine containers with similar geometric dimensions, thus trying to evaluate the impact of the package shape upon the possible maximum container compression load.

The analysis has shown that the plastic container resistance to compression is mainly influenced by the following factors:

– formation of rigid edges on the outer surface of the package;
– choice of optimal cone angle value;
– rational choice of the top and bottom brim of the cone.
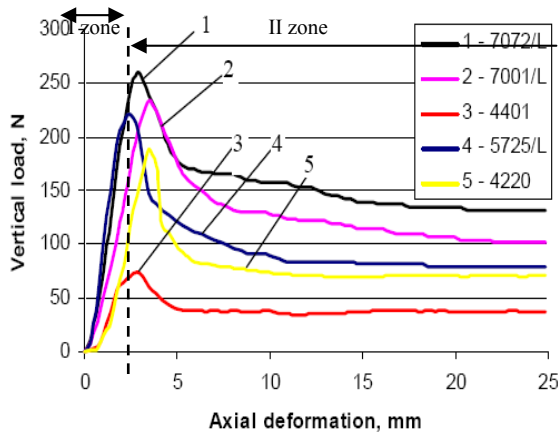

Fig. 7.   *Curves of compression resistance of polystyrene containers of Type 4 and 5 (codes 7072/L, 7001/L, 4401, 5725/L ir 4220)*

A characteristic package shape before the compression test and after it is shown in Fig. 8. As we can see, the configuration of packages and their elements, as well as their parameters, determine not only the values of their resistance to compression in relation to deformation, but also the characteristics of their side wall deformation.

Fig. 8.   *View of polystyrene containers before and after compression tests: a) Type 2, code 4250 (maximum compression load F_{max} =330.67 N, deformation under maximum compression load Δt = 3.50 mm); b) Type 8, code 5713/L (maximum compression load F_{max} =149.86 N, deformation under maximum compression load Δt = 2.45 mm);*

It is obvious that at the present choice of products determining the presented type of deformations, it is quite difficult to develop precise mathematical models for the evaluation the deformation process of the above mentioned packages. Therefore, we may say that experimental packaging resistance tests remain a relevant efficient approach in seeking possibilities to improve their construction and to assess their compliance with the EU environmental protection requirements, including control of prevention when reducing raw material consumption.

5. Conclusions

1. Implementation of the EU environmental requirements for packaging, regulated by the EU system of legal acts valid at different levels of obligation, encounters problems in practical application of the methodologies presented in these documents, and a large amount of work required (caused by a wide variety of packages and the dynamics in their changes), as well as significant labor input. Actually, each package needs specific technical control related to the applied packaging materials and structural package parameters, such as reliability, mechanical strength, etc. During eco-design of packages, it is necessary to evaluate the fact that they will also have to meet the requirements for safety, hygiene and consumer acceptability of the packaged product.

2. Following the requirements of the EU legal acts in the area of packaging, and the results of the analytical overview of the proposed solutions whose summary has been presented in the paper, the evaluation of the environmental impact of the most common plastic packages in food industry of Lithuania and the Ukraine - truncated cone shape, tapered downwards packages – has been carried out by using the quantitative analysis method Ecoindicators '99 based on the product life cycle.

It was determined that the most important environmental aspect of such packaging is the amount

of the plastic used, while in printing processes it is organic printing ink (containing solvent), and during disposal the negative impact is made by disposing of the plastic packages, the polythene bags used for packing, and the materials used for printing. Hence, reducing the amount of plastic needed for manufacturing packages is among the most efficient ways of reducing environmental pollution.

It has also been determined that:

- The greatest impact of the studied packages on the environment is made during their manufacture. The environmental impact of plastic packaging produced in Lithuania during manufacture is 16.5 times greater than during the usage phase.

- The greatest impact on the environment is made by the materials used. The main reason for that is plastic PS (4.8 mPt) used for making packaging. The environmental impact of other manufacturing processes (printing, packing, energy consumption, etc.) is relatively insignificant.

- The greatest impact of the plastic packaging produced in Lithuania on the environment during printing is made by the ink, the polymer negative and the printing form.

- During the disposal, the negative impact on the environment is made by disposing of the plastic packages and the materials used for printing. The possibility of reusing plastic packaging materials has a positive environmental impact.

3. To preserve the relevant packaging parameters while reducing the amount of materials, it is necessary to choose appropriate constructions. At the initial stage of the above mentioned project, experimental mechanical strength compression tests of the widely used truncated cone shape, tapered downwards packages were carried out. The tests were carried out on different types of specimens (plastic containers) made of polystyrene (PS). When analyzing the variety of the package outer shape, the main aspects determining the container resistance to compression load were distinguished (rigidity of edges, choice of the optimal cone angle value, rational choice of the top and bottom brim).

4. It may be stated that the most efficient solution of ecological issues in packaging and other areas is by using complex measures related to the implementation of cleaner manufacturing, quality and environmental management systems, evaluation of life cycle and cost-profit ratio, eco-design principles; while in food industry – implementation of good practice. Since packaging products are known for their wide variety, concrete solutions are also different, taking into consideration the variety of technological processes and equipment.

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Dr. Visvaldas Varžinskas, lecturer at the Institute of Environmental Engineering, Kaunas University of Technology.
Main research areas: sustainable production and consumption, eco-design, life cycle assessment (LCA).
Address: K. Donelaičio str. 20,
              LT-44239 Kaunas, Lithuania
Fax: +370-37- 209372,
Tel.:   +370-37-300764,
E-mail: visvaldas@apini.lt

Prof. dr. habil. Jurgis Staniškis – Director of the Institute of Environmental Engineering, Kaunas University of Technology.
Main reseach areas: sustainable development, environmental management, cleaner production, financial engineering, integrated waste management.
Address: K.Donelaičio str. 20,
              LT-44239 Kaunas, Lithuania
Tel.:   +370 37 300760
Fax: +370 37 209372
E-mail: jurgis.staniskis@ktu.lt

Assoc. prof. dr. Alis Lebedys – senior researcher of the Packaging Research Centre, Kaunas University of Technology.
Main reseach areas: packaging, environmental management, packaging waste management.
Address: Karaliaus Mindaugo pr. 21,
              LT-44295 Kaunas, Lithuania
Tel.:   +370 37 323887
Fax: +370 37 323775
E-mail: alis.lebedys@ktu.lt

Prof. dr. habil. Edmundas Kibirkštis -Head of the Department of Graphic Communications Engineering, Kaunas University of Technology.
Main research areas: technology of printing, packaging, materials engineering.
Address: Studentų str. 56,
              LT-51424 Kaunas, Lithuania
Tel.:   +370 37 451684
Fax: +370 37 451684
E-mail: edmundas.kibirkstis@ktu.lt

Valdas Miliūnas - graduate student from Kaunas University of Technology.
Main research areas: printing materials, package characteristic.
Address: Studentų str. 56,
              LT-51424 Kaunas, Lithuania
Tel.:   +370 37 300237
Fax: +370 37 451684
E-mail: valdas.miliunas@ktu.lt

Būdingų plastikinių pakuočių būvio ciklo įvertinimas siekiant sumažinti jų gamybai naudojamų medžiagų sąnaudas ir poveikį aplinkai

Visvaldas Varžinskas[1], Jurgis Staniškis[1], Alis Lebedys[2], Edmundas Kibirkštis[3], Valdas Miliūnas[3]

1 *Aplinkos inžinerijos institutas, Kauno technologijos universitetas*
2 *Pakavimo tyrimų centras, Kauno technologijos universitetas*
3 *Grafinių komunikacijų inžinerijos katedra, Kauno technologijos universitetas*

Siekiant realizuoti gaminamą produkciją, būtina, kad prekių įpakavimas atitiktų tarptautinės rinkos poreikius bei atitinkamų teisės aktų reikalavimus.

Pagal ES nuostatas valstybės narės turi užtikrinti, kad atitinkama pakuotė būtų naudojama produkcijai pakuoti tik tada, jei ji atitinka visas aplinkosaugines nuostatas, reglamentuojama ES direktyvose 94/62/EB ir 2004/12/EB ir jas plėtojančioje norminių dokumentų sistemoje. Vienas iš svarbiausių reikalavimų – pakuotes gaminti taip, kad jų tūrį ir svorį ribotų minimalūs dydžiai, būtini tam, kad pakuotės atitiktų saugos, higienos ir pakuojamam produktui keliamus bei vartotojui priimtinus reikalavimus. Siekiant šio tikslo, pagrindinis dėmesys turi būti skirtas pirmiausiai prevencinėms priemonėms. Prevencija šiuo atveju suprantama kaip pakuotėse ir pakuočių atliekose esančių medžiagų kiekio ir kenksmingo poveikio aplinkai mažinimas.

Šios krypties tyrimai buvo atliekami 2007–2008 metais vykdant bendrą Lietuvos ir Ukrainos mokslinių tyrimų ir eksperimentinės plėtros projektą „Specialiųjų spaudos būdų ir pakuočių gamybos technologijų tyrimai įvertinant jų ekologines ir eksploatacines savybes". Jį vykdė Kauno technologijos universiteto Dizaino ir technologijų fakulteto Grafinių komunikacijų inžinerijos katedros mokslo grupė, pasitelkusi KTU aplinkosaugos ir pakavimo sričių specialistus. Bendradarbiauta su Ukrainos spaudos akademijos spausdintų leidinių ir pakavimo katedra.

Šiame straipsnyje nagrinėjami kai kurie svarbesni pakuočių ekologinio lygio gerinimo galimybių tyrimo rezultatai, gauti vykdant minėtą projektą. Įrodant, kad kuriant nagrinėjamą pakuotę buvo laikomasi prevencijos ir kitų principų, būtina atlikti atitinkamus pakuočių ir jų gamybos ir panaudojimo procesų tyrimo darbus, kurie pasižymi didele reikalingų atlikti konkrečių pakuočių bandymų įvairove ir kuriems neretai dar nėra pakankamu mastu (ES ar šalių grupių) pripažintų metodikų. Todėl viena iš svarbių nagrinėtų krypčių vykdant minėtą mokslo projektą, kuri aptariama šiame straipsnyje, yra susijusi su dalyvavimu formuojant vieningą, ES mastu pripažintą sistemą, leidžiančią atlikti reikiamus tyrimus ir bandymus, patvirtinančius pakuočių atitiktį ES aplinkosauginiams reikalavimams. Straipsnyje nagrinėjama ES reglamentuojama prevencijos, mažinant pakuočių gamybai naudojamų žaliavų sąnaudas, reikalavimų vykdymo patikros sistema, besiremianti krizinių sričių nustatymu, kurios bendras tikslas – pasiekti mažiausią pakankamą pakuočių svorį ir (arba) tūrį, vadinasi, ir mažiausią pakuočių atliekų kiekį, nedidinant sugadinto produkto ir produkto atliekų kiekio. Jame pateikiami būdingų plastikinių pakuočių medžiagų ir procesų poveikio aplinkai gamybos, naudojimo ir šalinimo metu tyrimo rezultatai, gauti atliekant būvio ciklo įvertinimą ir taikant Ekoindikatorių '99 kiekybinės analizės metodiką. Apžvelgiami indelio pavidalo plastikinių pakuočių, būdingų konstrukcinių variantų atsparumo gniuždymo apkrovoms, tyrimo rezultatai, leidžiantys įvertinti pakuočių formos ir konstrukcijos įtaką pakuočių patikimumui ir jų masės mažinimui.