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INNOVATIONS IN MANUFACTURING OF FLEXIBLE PACKAGING

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Abstract

This article provides overview of innovative approaches to engineering design and manufacturing of flexible packaging. Following research results are elaborated:

- *Fabrication of flexible films with predictable characteristics;*
- *Polymer films requirements definition to optimize utilization of flexible packaging machinery;*
- *Optimization of film pretreating mode to maximize ink layer resistance over the entire lifecycle of packaging;*
- *Engineering packaging design to optimize packaging material consumption and standardize packaging machinery.*

Key words: *flexible packaging, plastic film, packaging machines, surface preparation and printing on polymeric films.*

Modern packaging must be attractive to the buyer and convenient to use at all stages of the life cycle. Given the existing diversity of identical products today those producers win whose packaging optimally combines the functions of protection and promotion of goods.

But the packaging has the second side. Its cost should be small compared with the cost of the packaged product. Therefore the technology of its manufacturing must constantly evolve.

Flexible packaging includes pouches, bags, as well as semi-rigid tubes. Flexible packaging is made from flexible packaging materials such as plastic film, foil, paper, textiles and multilayer materials on their basis.

Flexible packaging has low resistance of form. Its shape may vary even for small loads at all stages of the life cycle. Pressure on flexible packing associated with the process of distribution of packaged products can be transmitted on the product itself. First of all this happens with bulk or spreads. This feature of flexible packaging requires from packaging material to correspond to a complex set of contradictory structural and technological properties. The formulation of these properties and finding ways of securing its predictability is an important direction of innovation activity of the modern researchers.

In the manufacturing of flexible packaging companies from various industries take part. They perform a variety of technological processes. Features of these processes must be considered when designing flexible packaging design and production technology. Each process has an impact on the properties of packing. It is obvious that the improvement of these processes, their innovations should be interrelated and focused.

Manufacturing of flexible packaging is mutually related movement of two material flows: the packaging material and the product being packaged.

In the flow of the packaging material, the main technological processes are: development of compositions plastics, obtaining of packaging material from this flexible plastic film, modification of its surface, applying text and graphic information, cutting off the canvas necessary width, winding it in a roll. Properties of the packaging material depends on each of these processes. In addition, these properties specify the nature of the interaction with the packaging machine and the packaged product. Two flows of packaging material and the product being packaged meet in a packaging machine. In the process of interaction of these flows flexible packaging is created.

To get flexible packaging of high quality it is necessary to conduct a complex of systematic and targeted research, some of which is carried out by teachers, graduate students and students of the Moscow State University of Printing Arts after Ivan Fedorov (MGUP). Let us consider the main directions of this research, having innovative character.

1. INNOVATIONS IN THE PROCESS OF DESIGNING A FLEXIBLE PACKAGING

The process of designing soft packaging is an important stage in the development of the packaging system. Under the packaging system the following is understood: it is a set of packaging construction, technologies and equipment for its manufacturing, packing and the formation of a transport unit [1-3]. The concept of the packaging system is fundamental. In fact, this concept includes a range of production processes, which are an important part of the packaging industry, aimed at obtaining high-quality and competitive packaged products.

When designing the packaging designer must take into account the peculiarities of the technology and equipment for its production and packaging. The engineering designer based on the characteristics from a packaging drawing can design the technology of manufacturing of the packaging and packaging technology. Design features and technologies for production of packed products dictate the technology of establishment of the transport unit, in which packed products are shipped from the factory.

A number of optimal solutions in complex interrelated problems should be taken in the process of designing a soft packaging. In those tasks, the designer must choose:

- material for soft packaging;

- volume or dimensions of soft packaging;

- form of soft packaging;

- constructive features of soft packaging;

- art design of soft packaging;

- technology of the production of soft packing;

- technology of packing;

- peculiarities of transportation, storage, distribution, sale and consumption of packaged products;

- technology of utilization of used packaging.

1.1. The choice of flexible packaging material

The choice of material for soft packaging is a multifactor optimization problem based on the complex of requirements to packaging from its main functions, packaged product, printing and packaging equipment. You must select the type and name of the packaging material.

The main packaging material for soft packaging are polymer films. They can be single - and multi-layer. The most important polymers for their manufacturing are low density polyethylene (LDPE), polypropylene (PP), polyethylene terephthalate (PET) and some others.

Feature of polymers in the film condition is that their characteristics are virtually formed 3 times: in the synthesis of polymer, during film production, and during in the manufacturing of packaging.

Typically, during the production of films various purposes additives are imposed in the base polymer synthesized. It should be emphasized that preparation of polymer compositions starts with defining the values of indicators of the properties that correspond to real conditions of operation of packaging. Usually when in the polymeric composition the starting point are the conditions of material usage, like an interval of operating temperatures, levels of physical and mechanical properties, the character of interaction with the packaged product and a number of other effects, in which the working characteristics of the material must maintain valid values within an acceptable period of time.

The composition can be understood from a chemical name of a film. For packing of food stuff the films must be recommended by the Ministry of Health of Russia. It should be noted that these recommendations take into account the processes of interaction of the packaging material and the product being packaged. But they do not reflect the whole complex of necessary service and technological properties of the packaging material.

An important innovation is the development of a technique for determining the operation properties of flexible packaging materials on the basis of analysis of emerging stressed states in different types of loads on the soft packaging for major groups of packaged products. This method allows the calculation to determine the required physical and mechanical properties of the packaging material and welds for the main types of soft packaging –

pouches and bags of different types. Understanding these characteristics allows to calculate the required thickness of packaging material.

For the practical implementation of innovative methods a database with recommended films for packaging of foodstuff polymer and requirements to its characteristics for different designs of pouches and bags was created.

1.2. Designing the optimal flexible packaging

Design of the main type of soft packaging - pouches from polymeric film and composite materials is given in two standards. In accordance with GOST 12302-83 and GOST R 52903-2007 flat and solid pouches are distinguished. [13]

Flat pouches – pouches of type I - 12A (Fig. 1, a) and type I - 12B (Fig.1, b) according to GOST 12302-83. There are the following types of flat pouches.

Three-seam - flat pouch received with one roll of flat film material by folding roll material, drawing three seams with subsequent package separation: type I - 12A (figure 1, a).

Four-seam - flat pouch received from one or from two rolls of flat film material by applying two transversal and two longitudinal seams; in the case of a single roll pre-cut is applied: type I - 12B (figure 1,b).

Flat pouches can be used for filling of almost all products and for packing of big nomenclature of bulk solids. In most cases the equipment can be applied (with minor exceptions) for a wide variety of products when changing doser or feeder.

Flat pouches are useful for filling a small dose of products when the volume of the dose is in the range from few cubic centimetres up to 300 cm3. When the dose exceeds 300 cm3 the consumption of packaging material in a conventional flat pouch is increasing disproportionately to the dose. In these cases either the extensive pouch or flat doy-pack type pouch should be used,.

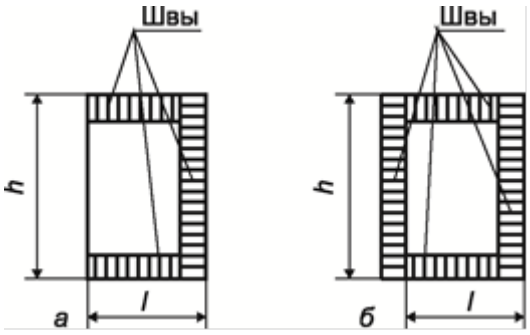


Figure 1. Types of flat pouches with direct bottom GOST 12302-83: a - type I - 12A, b - type I – 12

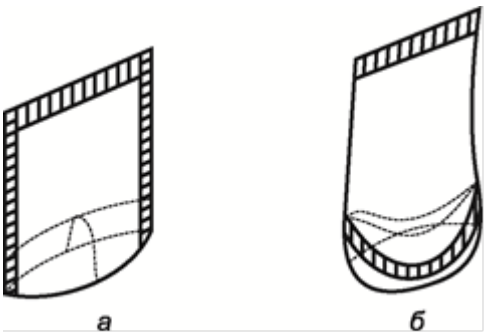


Figure 2. Flat doy-pack pouch: with a fold at the bottom; b - with a stable bottom

Flat pouch with a fold at the bottom (doy-pack). It is a flat pouch, obtained by adding the packaging material with formation of folds. So, if the fourth seam reduces the useful volume of the package, additional fold significantly increases the volume (figure 2). The maximum dose of the product packed in such a package is 1000 cm3. The principal difference of doy-pack pouch is its stability, ensured by the bottom of the form.

Usually, doy-pack pouch is made from two-, three - or four films with a thickness of 80-160 microns. Most often a combination of PET and PA is used for outer layer, convenient for applying the ink layer flexo or intaglio printing with PE of different thickness (for internal layer, providing sustainability of packaging and thermal welding seams). As an intermediate barrier layer aluminum foil is applied.

These pouches are easier to obtain from one flat roll of film material. It should be noted that sterilization of products in the doy-pack is possible. The composite packaging material allows you to immerse the pouch in autoclave with a temperature of 120-130 ° for 30-60 minutes This increases the shelf life of the sterilized product up to two years or more.

Volumetric pouch – pouch of «pillow» type I - 11a (figure 3,a) and type I - 11b (figure 3,b) according to GOST 12302-83. Packages such as «pillow» is characterized by a simple form. There are following types of volumetric pouches.

Two seam - dimensional packets received from the sleeve of polymer film by applying two transverse joints and cut (figure 3).

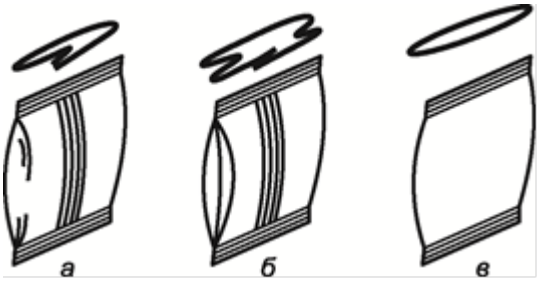


Figure 3. Volumetric three seam pouches with one longitudinal and two transversal seams (a, b); volumetric two seam pouch with two transversal seams (в)

Three seam - volumetric pouch with one longitudinal and two transversal seams, derived from a single roll of flat film material minimizing in cylindrical sleeve with the subsequent drawing of a longitudinal weld, two transverse joints and separation package. Can be of two types: without lateral folds: type I - 11a (figure 3,a) and lateral folds type I - 11b (figure 3,b).

Volumetric pouches are recommended for use in case the volume of doses of the product exceeds 200 cm3. If desired, this type of pouch can be used for volumes significantly below 200 cm3.

The standards mentioned above stipulate that the types and sizes of packages are defined in the technical documentation for pouches for specific types of products as agreed with the customer. The recommended width of welded seams should not exceed 10 mm, and the joints themselves should be located at a distance of 10 mm from the edge of a pouch.

The volume of the pouch can be defined as the product of the height of the of product layer h and width b and length l :

$$V_{\text{п}} = l \times b \times h$$

By these parameters, you can calculate the length L and width B required for the fabrication of polymer film:

$$L = l + 2(h + c)$$

$$B = 2(b + h + c)$$

where *c* - is the allowance for the bend and the width of the weld. Depending on the design of the weld and the peculiarities of the material of flexible packaging the allowance value for a fold is choosen in the range of 15-25 mm

The innovative methodology of calculation of the optimum sizes of pouches of specified volume on the criterion of minimum material requirements is developed. The width of blank *B* calculated according to this method is a very important factor. It is connected with an outer diameter of the product pipe of packing machine *Dnp*:

$$B - 2c = \pi \times D_{\text{пр}}$$

It is obvious that the unification of the optimum sizes of flexible packaging creates wide possibilities for standardization of packaging machines. It is the basis for the creation of standard technological processes of production of flexible packaging for various types of food products. Such processes would greatly improve the quality of flexible packaging and reduce its cost.

On the other hand, the width of the blank *B* significantly influences the cost of soft packaging. Standards for polymer film materials provide for their delivery to a customer in rolls of a certain width. As a rule, the size of the width of the roll is determined by the principle of absence of waste: roll width must be a multiple of the width, obtained on the film production unit. But standards provide for the possibility of delivery of the film with width of a roll, required by the customer. In this case there are wastes during film fabrication, the cost of which is included in the price of film supplied.

Thus, plastic films for flexible packaging will have the minimum cost in case, if the width of the pouch blank *B* will be a multiple of a standard roll width. For solution of this optimization task of definition of blank width *B* a database of packaging film materials manufacturers is created, that contains data on standard roll width.

2. INNOVATIONS IN PROCESS OF FLEXIBLE PACKAGING PRODUCTION

The process of flexible packaging production is the interaction of two material flows (product being packaged and the packaging material) happening in packaging machines joined in a packaging line. Preparations for packing, dosing and mass transfer happens in the product flow. Processes of volume packaging forming, positioning, filling and capping happen in the flow of packaging material. [1, 3, 13]..

Processes of flexible packaging production are preceded by preparation of product for packing, when required with product cleaning and sterilization, etc. They are often classified as auxiliary packaging processes. [13].

The primary packaging processes include packaging formation processes and its positioning, dosing and positioning of product being packed, filling, capping, labelling and auxiliary packaging means application.

These basic and auxiliary processes determine the types and the number of packaging equipment required. The choice of the optimal type of packaging, auxiliary packaging means, technologies and packaging equipment are closely interrelated.

2.1. The choice of the optimal packaging machinery

Each product can be packaged with the application of various types of feeders and technological schemes of packaging equipment. As a result of their combination it is possible to use a wide range of packaging machines.

An innovative system for the selection of the optimal design of the packaging machine for various bulk packaged products is developed. The system is built on the basis of a thorough analysis and research of backward and forward linkages in chain: bulk product - packaging material - bulk product doser – packaging engineering design - packaging machine.

In the innovative approach a classification of bulk products by granulometric composition, volume weight, flowability, the ability to form stable structures was developed. Packed products are classified based on scoring method taking into account bulk product quality and conditions of its product processing in a packaging machine.

A separate database for packaged bulk products is created. It describes the characteristics of the products, which determine the choice of packaging material and enable the calculation of the basic packaging elements and the choice of the optimal structure of the packaging machine. A system of prioritization of these indicators is developed.

Product properties, packaging material properties, and packaging engineering design (pouch or bag) determine the choice of construction of packaging machine.

Structure of dosing machines used in the packaging industry includes four main mechanisms: product bunker; feeder, creating a steady stream of product from the bunker to the dosing mechanism; the dosing mechanism; output device. The structure and design of dosing machines depends on the properties of the packed bulk product, defining the process of product transfer.

The structure and design of the packaging devices depends on the properties of the packaging material and packaging engineering design. Currently there are packaging machines of vertical and horizontal principle. Different pouch types can be manufactured on it.

In vertical type machines a packaging material is unrolled from a roll, extended on working tract, rolled into a cylinder (sleeve) on the molding device. Sleeve of packaging material is moved top-down before filling or during filling.

In horizontal type machines packaging material after reeling from a roll and drawing on a working tract is collapsed in rectangular pipe with the help of forming mandrel and moved horizontally during filling and pouch sealing.

Based on a detailed analysis of kinematic schemes and technical characteristics a classification of modern packaging machines for food industry used in Russia (produced in Russia or imported) is developed. Machines of different classes are set in a correspondence to products of different classes. In each class machines ranked by applicability for use for different food bulk products. Ranking is made by the criterial and functional-cost analysis. Classification of ranked packaging equipment has been compiled in a database.

Application software for selection of the optimal design of packaging machines for different kinds of food bulk products, packaging materials and basic pouch types is developed. Because the selection is a multifactor optimization task, algorithm of multilevel database integration is created.

2.2. Definition of technological characteristics of packaging materials

Polymer film packaging materials produced in industrial volumes can have large range of values of operational and technological characteristics according to the technical conditions or standards.

Printing and packaging machines used in packaging industry has a variety of designs. In the process of passing through a printing machine packaging material does not change its flat shape and only changes the direction of motion. Packaging material is rolled into round or rectangular pipe with the help of special forming tools when passing through a packaging machine after reeling from a roll and drawing on the working tract.

Depending on the input angle, directional element form and surface properties various forming tools should allow for a smooth transaction of flow and forming a packaging without the collapse of the flow. A feed system has a great influence on the passage of the flow. A drive of this system can have a linear movement (with the use of tick-borne seizures) or rotational movement (friction rollers, belts, vacuum belts).

Such a diversity of motion paths, form changes, contact with different working parts of the printing machines leads to the fact that each machine requires packaging material with specific technological properties with a narrow range of values. The range of change of these characteristics in the standard industrial polymeric film materials is much wider. That is why it is often that standard film does not provide operability of packaging machines.

An innovative methodology solves this problem in two stages: definition of the requirements to technological characteristics of packaging materials and printing and packaging machines; and development of technology of fabrication of polymeric film packaging materials with predictable characteristics.

2.2.1. Definition of the requirements to technological characteristics of packaging materials and printing and packaging machines

The innovative method of definition of the requirements to technological characteristics of packaging materials and printing and packaging machines is developed. The method includes the design of the kinematic scheme of the machine. The kinematic scheme distinguish the path of the packaging material. On this tract nodes of contact of packaging material with the working bodies of machines are analyzed.

For packaging machines these are units in the roll-out of the material from a roll, guides, leveling and pulleys, unit of forming packaging material into the pipe, product pipe contact unit, feed system, units of longitudinal and transverse joints welding.

In printing machines these include roll-out units, reeling units, guides, leveling and pulleys, sections of surface treatment, printing and drying.

Based on the analysis of powers happening in these nodes a mathematical model of motion of the packaging material is built. The model represents the system of the differential Lagrange equations, describing the motion of the packaging material without slipping and crumples, full braking and acceleration.

These mathematical models developed for a range of packaging machines of vertical and horizontal type, and also for a family of flexographic printing machines. Application software solving the system of equations included in these models is created. As a result, for a given kinematic scheme of the machine, packaging material roll characteristics (outer and inner diameters, length, width, thickness), design and size of pouch, and packaging material properties it is possible to define the nominal values of strength and technological characteristics of the packaging material and the range of valid deviations.

2.2.2. Development of technology of fabrication of polymeric film packaging materials with predictable characteristics

The most common method of fabrication of polymer films for packaging is blowing extrusion. 85% of films are fabricated using this method.

It is known that from the extrusion and subsequent operations mode substantially define physical and mechanical properties of films (tensile strength, elongation at rupture, shock load resistance etc). It is caused by the change of formed per molecular structure, as well as the range and direction of film orientation during its production.

As a result of the carried out complex studies using the methods of multivariate experiment planning a method of designing technologies of fabrication of film packaging materials with predictable characteristics developed.

To conduct this research a laboratory blowing extrusion equipment for polymeric films fabrication was made. Installation is small in size and reproduces structural and technological parameters of large industrial installations. At this installation experimentally obtained the system of equations connecting a set of operational and technological characteristics of LDPE films for packaging with the parameters of the technological process of their fabrication. It should be noted that the characteristics of the films may vary by more than 10 times. An application software is developed to solve this system of equations that allows to design technology of film fabrication and define all the characteristics of the technological process for a given complex of operational and technological characteristics of a film.

3. THE RESULTS

Practical implementation of the innovations described above helped to create a common methodological framework for several industries involved in the manufacturing of flexible packaging.

For the chemical industry a method of engineering the technologies of fabrication of polymeric film packaging materials with predictable characteristics is developed. A set of these characteristics is defined by a manufacturer of flexible packaging based on data provided by packaging designer, printing and packaging technologists.

Engineering designer defines a set of operational characteristics of polymeric film packing materials with the help of the developed application software. The software analyzes properties of the product being packed, pouch engineering design, product dosing.

In addition, engineering designers are provided with the method of designing a pouch with optimal dimensions and minimum material requirements for a given mass product dosing.

Printing and packaging technologists define the complex of the technological characteristics of polymeric film packaging materials. For this purpose methods developed for the analysis of kinematic schemes of packaging material path through printing and packaging machines are applied along with application software for the solution of a system of differential equations.

For packaging industry a methodology and application software for selection of optimal design of packaging machine depending on the type of product being packed, dosing, packaging material type and packaging engineering design is developed.

For packaging machinery manufacturers the methodological basis of unification and standardization of packaging machines for different classes of packed products is created.

The implementation of described innovative approach can have economic benefits of over 1 million rubles for a production of flexible packaging of only one nomenclature with a production volume of 500 thousand items.

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