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DEVELOPMENT OF A GENERALIZED ALGORITHM FOR THE CREATION OF CONTAINERS FOR LIQUID USING COMPUTER-AIDED DESIGN OF PRODUCTS AND TECHNOLOGIES

В. Тігарєв, О. Лопаков, В. Космачевський. **Розробка узагальненого алгоритму створення ємностей для рідини з використанням комп'ютерного проектування виробів та технологій.** Проектування об'єктів для зберігання різних рідин (вода, олія, алкогольні продукти тощо) потребує застосування сучасних комп'ютерних технологій. Для підвищення ефективності, скорочення витрат на проектування та виробництво необхідно створювати оптимальні алгоритми на основі інформаційних моделей об'єктів, проектування ємностей різної форми. Запропонований підхід дозволяє скоротити час на розробку нових моделей об'єктів на основі існуючих прототипів, які враховують технологічний процес виробництва, що використовується. Реалізація цієї ідеї можлива лише за умови використання сучасних САПР на основі адаптивно-параметричних моделей об'єктів та засобів вбудованого програмування для створення спеціалізованих підсистем проектування. Такі можливості має САПР Autodesk Inventor. Для роботи з цим САПР було запропоновано узагальнений алгоритм (інформаційна модель) проектування ємностей для рідин. У роботі докладно розглядаються етапи виконання алгоритму з прикладу пластикової пляшки для рідини. У створеній моделі використовувалося табличне завдання параметрів ємності через Excel. Для створення параметричного ряду ємностей різної форми необхідно задати математичні залежності між розмірами об'єкта і об'ємом. Запропонована інформаційна модель може бути адаптована для ємностей різної конфігурації. Ємності можуть бути не тільки пластикові, а й скляні. Подальшим розвитком застосування інформаційної моделі проектування ємностей для рідин є створення підсистеми проектування на основі САПР Autodesk Inventor у середовищі ILogic.
Ключові слова: ємність для рідини, інформаційна модель, адаптивно-параметрична модель, узагальнений алгоритм

V. Tigariev, O. Lopakov, V. Kosmachevskiy. **Development of a generalized algorithm for the creation of containers for liquid using computer-aided design of products and technologies.** Designing facilities for storing various liquids (water, oil, alcoholic products, etc.) requires the use of modern computer technologies. To improve efficiency, reduce design and production costs, it is necessary to create optimal algorithms based on information models of objects, designing containers of various shapes. The proposed approach allows reducing the time for the development of new object models based on existing prototypes, which take into account the used technological production process. The implementation of this idea is possible only with the use of modern CAD systems based on adaptive-parametric models of objects and embedded programming tools to create specialized design subsystems. CAD Autodesk Inventor has such capabilities. To work with this CAD, a generalized algorithm (information model) for designing containers for liquids was proposed. The paper considers in detail the stages of the algorithm execution on the example of a plastic bottle for liquid. The created model used a tabular task of capacity parameters through Excel. To create a parametric series of containers of different shapes, it is necessary to set mathematical dependencies between the dimensions of the object and the volume. The proposed information model can be adapted for containers of different configurations. Containers can be not only plastic, but also glass. Using the proposed design information model, an adaptive-parametric model of a bottle filled with liquid was developed in CAD Autodesk Inventor.
Keywords: liquid container, information model, adaptive-parametric model, generalized algorithm

Introduction

The commercial success of alcoholic and non-alcoholic products largely depends on its presentation: the sophistication of the packaging, the shape of the bottle, and the aesthetic advantages of the label. Manufacturing companies, trying to protect their brand from counterfeits and at the same time not to get lost among a huge number of competing products, strive to design and manufacture bottles of various, sometimes the most cunning, shapes in the shortest possible time, as well as adjust or design equipment for supplying bottles for bottling. In the existing literature and Internet sources, various forms of containers for liquids are considered, taking into account their design features, technological processes of production and the capabilities of various CAD systems for designing bottles.

Computer-aided design is an important task. Creation of new computer models of containers every time increases the design time and cost. The use of adaptive parametric models allows solving many tasks.

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To solve such tasks, container developers use modern software from various manufacturers. Autodesk AutoCAD, Autodesk Inventor Professional, Autodesk Fusion 360, Dassault Systems SolidWorks are most often used. CAD Autodesk AutoCAD allows you to design design documentation and create non-parametric three-dimensional models of objects. CAD Autodesk Inventor Professional, Autodesk Fusion 360 and Dassault Systems SolidWorks create systems of three-dimensional parametric design. Autodesk Inventor Professional also allows you to create specialized design subsystems for various tasks based on programming technologies in the ILogic environment. ILogic allows you to create a design routine and user interface with the help of the necessary rules. The Autodesk Inventor Professional system is indispensable when designing plastic (PET) and glass containers.

Analysis of recent research and publications

In the reviewed literature [1, 2], materials for the manufacture of plastic containers of various configurations and purposes are considered in detail. In works [3–6] much attention is paid to the properties of materials and their influence on the contained liquid, and which of them can be used for food products. If there is an idea for a non-standard container, a consultation is offered with the possibility of solving the problem. However, algorithms for designing plastic containers of different configurations are not considered. Mechanical and digital rendering options are considered. There are several types of plastic containers. Some of the styles are Boston Round, Cylinder, Pitcher, Modern Round, Oblong, Packers, Square, Straight Sided Round, Flask, and Wide Neck Round. This versatility makes it the best choice for those with different storage needs. Plastic bottles are containers made of a polymer resin similar to polyester and used to store water or other liquids. The main reason why plastic bottles are preferred is that they are lightweight, which makes them easy to carry. Plastic bottles are also extremely strong, meaning they can be dropped without breaking. Plastics generally provide excellent thermal insulation. This means that liquids inside a plastic bottle can retain their temperature better than in containers made of other materials. This makes plastic bottles a great choice for storing cold or hot liquids. The development of the geometry of the mold for the production of bottles and canisters is in progress [7]. The paper [8] is intended for packaging technologists, scientists and engineers, students and teachers, packaging material suppliers, packaging processors, packaging equipment manufacturers, processors, retailers, and regulators. It does not offer optimal packaging design algorithms.

The book [9] is a step-by-step explanation of packaging design, materials and manufacturing applied to a wide range of industries. It shows how packaging is designed, manufactured and ultimately recycled. Particular attention is paid to machine details and finishing, as well as modern materials. Algorithms for creating and optimizing models of plastic bottles for various liquids based on an information model (IM) are not considered in the literature [10, 11].

The purpose and objectives of the research

The design of plastic containers in modern CAD using adaptive parametric models requires the development of the necessary algorithms. The purpose of the research is to create generalized product design algorithms based on an information model, which allows to reduce time and material resources. The use of an information model allows you to optimize the design process and production preparation. In the future, the proposed algorithms can be used during the creation of specialized subsystems for the design of containers for liquids of various purposes. Algorithmization of design increases the productivity and quality of manufacturing objects.

The method of creating generalized algorithms for the design of containers

Developers use modern software from various manufacturers to solve plastic container design tasks. To obtain qualitative indicators of interdependent objects, adaptive parametric models are used. When designing containers of different shapes, it is necessary accurately calculate their internal volume, which will be used in the future. The best option is to create adaptive parametric dependencies between the container and the internal volume of the liquid. Let’s consider in detail the container design algorithm in modern CAD using the example of a plastic bottle. It includes the following stages:

1. Determination of the type of shape of the created model (surface of rotation, surface of displacement along the trajectory).

2. Dividing the profile of the object into constituent elements and determining their shape and purpose (neck, main part, bottom).

3. Creation of parametric elements of profile sketches (profiles) of objects.

4. Creation of a parametric model of the container prototype.

5. Superimposition of dependencies, for the possibility of creating a number of parametric models.
6. Editing possible changes of parametric models.
7. Creation of parametric models by filling the object with liquid.
8. Creation of adaptive dependencies between the container and the liquid.
9. Verification of the created adaptive-parametric capacity-liquid model.
10. Determination of material consumption during the creation of containers.
11. Transfer of the created model for the design of technological equipment for the production of a container or the development of design documentation for a container.

Let's consider the implementation of the stages of the design algorithm, made in CAD Autodesk Inventor PRO. We will analyze in detail the sequence of creating an adaptive-parametric capacity model using the example of a bottle.

The bottle can represent, in the simplest version, a surface of rotation or, in a more complex example, a surface of displacement along a given trajectory.

In both cases we have the typical elements: neck and bottom. The main volume of the container is placed between them. Therefore, the volume of liquid consists of at least three elements:

$$V_{\text{general}} = V_{\text{mouth}} + V_{\text{basic}} + V_{\text{bottom}} , \qquad (1)$$

where V_{general} – full capacity;
V_{mouth} – neck volume;
V_{basic} – volume of the base (central) part;
V_{bottom} – base volume.

The volume of the base part of the tank is determined by the formula:

$$V_{\text{basic}} = S_{\text{sect}} \cdot H , \qquad (2)$$

where S_{sect} – the cross-sectional area of the container;
H – height of the base part.

The minimum capacity is obtained when $V_{\text{basic}} = 0$

For a bottle of cylindrical shape, the volume of the main part is determined as follows:

$$V_{\text{basic}} = \pi r^2 \cdot H , \qquad (3)$$

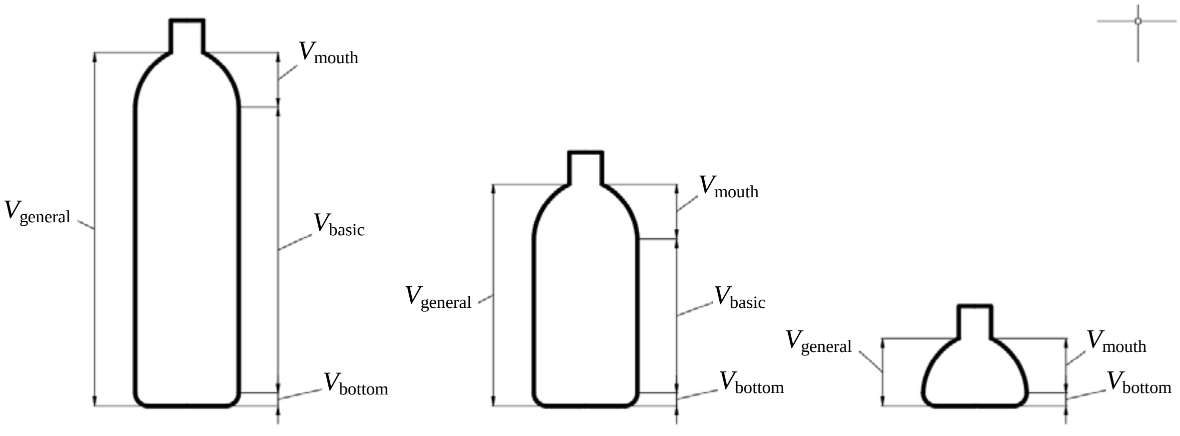
where r – the radius of the cross-section circle.

To obtain the required volume, set the height of the base part in the sketch profile parameters of the created container. When you want to create a container with different cross-sectional values, you add a volume equation correction factor that you specify separately for each container profile:

$$V_{\text{general}} = (V_{\text{mouth}} + V_{\text{basic}} + V_{\text{bottom}}) \cdot K_f , \qquad (4)$$

where K_f – the correction factor of the container shape.

Constructed sketch profiles for forming a cylindrical bottle of one diameter looks like (Fig. 1). Variants with the maximum height of the base (central) part (*a*), intermediate value of the base (central) part (*b*), with the absence of the base part (*c*) are considered.



a *b* *c*

Fig. 1. Profiles of sketches of a container of one diameter: *a* – the maximum height of the base (central) part; *b* – the intermediate value of the base (central) part; *c* – the absence of the base part

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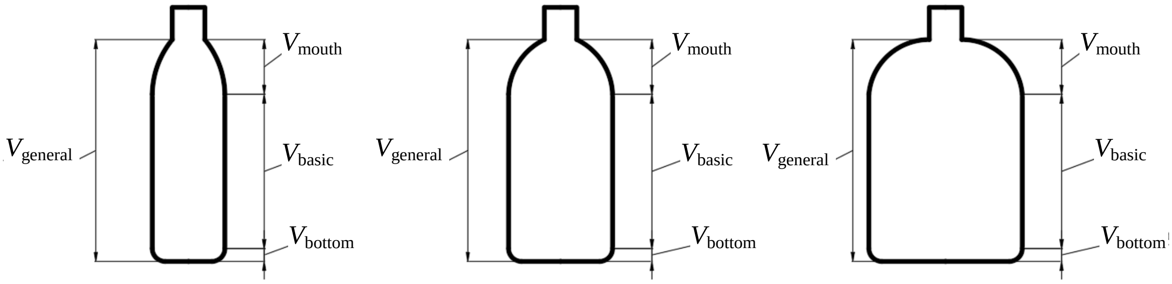
Sketch profiles for modeling a round bottle of different diameters look like (Fig. 2). Variants with the minimum value of the diameter of the base (central) part (*a*), the intermediate value of the diameter of the base (central) part (*b*), with the maximum value of the diameter of the base part (*c*) are considered.

The proposed adjustment formulas are set as control parameters when creating a capacity model and can be presented in tabular form or in the form of formulas.

Using the proposed options for building sketch profiles, we will perform the following stages of container design and create a parametric model of the bottle in the Autodesk Inventor Professional system. The model is created as a solid and then transformed into a shell with a thickness equal to the thickness of the container walls.



a *b* *c*

Fig. 2. Sketch profiles of different diameters: *a* – the minimum value of the diameter of the base (central) part; *b* – the intermediate value of the diameter of the base (central) part; *c* – with the maximum value of the diameter of the base part

Experimental part of research

We create a three-dimensional model of a glass bottle using CAD Autodesk Inventor Professional. We impose parameterization on the created model. The obtained model of the bottle is presented in Fig. 3. To fill the inner part of the container with liquid, we create an object as a body, which is adaptively connected to the inner surface of the container. The form of liquid filling is shown in Fig. 4.

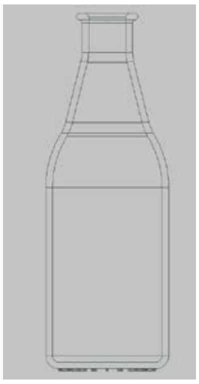


Fig. 3. Bottle model

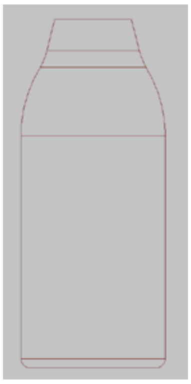
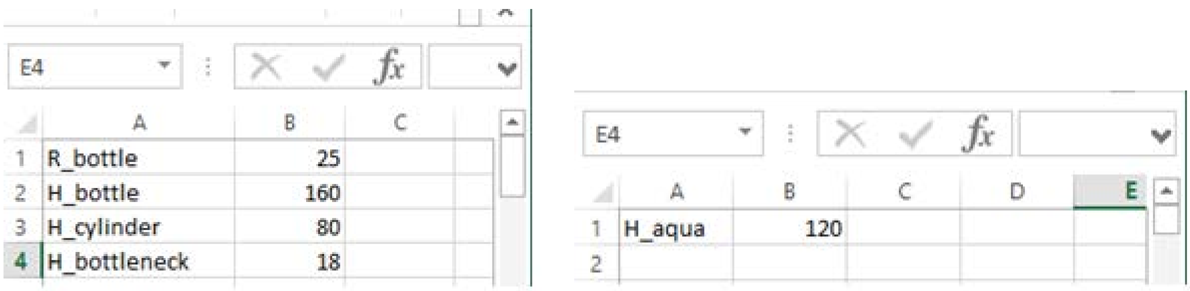


Fig. 4. The form is filled with liquid

We set the capacity and liquid parameters in a tabular way in the Excel program. Fragments of tables with values are presented in Fig. 5: capacity parameters (*a*), liquid parameters (*b*).



E4

	A	B	C
1	R_bottle	25	
2	H_bottle	160	
3	H_cylinder	80	
4	H_bottleneck	18	

a

E4

	A	B	C	D	E
1	H_aqua	120			
2					

b

Fig. 5. Tabular capacity and liquid parameters: *a* – capacity parameters; *b* – liquid parameters

Let's check the correctness of the adaptive parametric model of the created capacity with filling. The initial designed model of a bottle with liquid is presented in Fig. 6.

Let's change the parameters of the diameter of the container by increasing the initial value. We are updating the bottle and liquid models. At the same time, the liquid will automatically fill the changed capacity. This happens due to the adaptive connections imposed between the container and the liquid. The result is shown in Fig. 7.

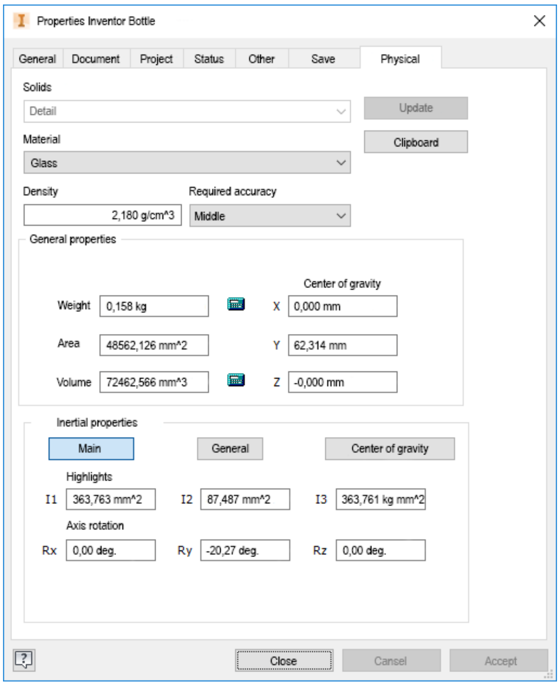
Let's change the height settings of the base part of the container. We will update the bottle and liquid models. The result is presented in Fig. 8.

Fig. 6. Initial model of a bottle with liquid

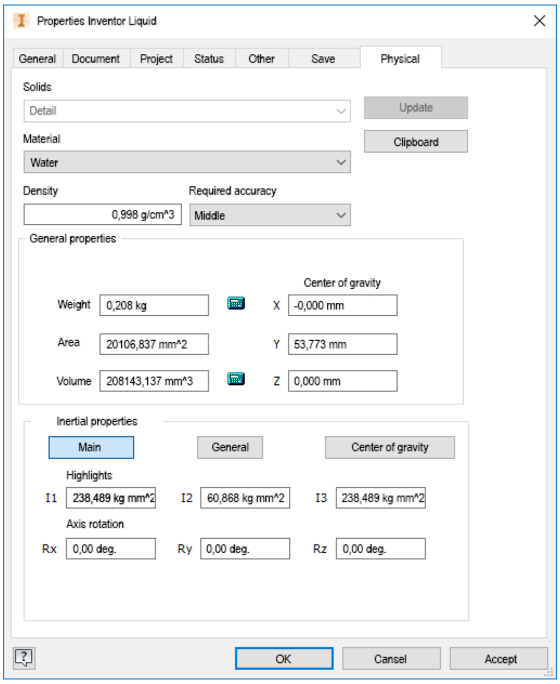
Fig. 7. Model of a liquid bottle with an enlarged diameter of the main part

Fig. 8. Model of a liquid bottle with an increased height parameter of the base part of the container

Using the capabilities of the Autodesk Inventor Professional system, we define the physical properties for the bottle and liquid objects. The results are presented in Fig. 9: physical parameters of the container (*a*), physical parameters of the liquid (*b*).



a



b

Fig. 9. Physical parameters of the objects of the bottle and liquid when the dimensions change:
a – physical parameters of the container; *b* – physical parameters of the liquid

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The obtained adaptive parametric model of the bottle can be transferred to create technological equipment for the production of containers, taking into account the properties of materials and technological processes.

A generalized algorithm for the design of containers has been created. We have considered in detail the sequence of all the proposed stages of designing an adaptive parametric model of a liquid container using the modern Autodesk Inventor Professional CAD system. The approach to the generalization of the characteristics of the formation of containers of different shapes is analyzed. Formulas are proposed for calculating the volume of liquid depending on the shape and size of the cylindrical container. For more complex forms of the container it is necessary to define formulas for calculating the volume of liquid, parametrically related to the external form.

Based on research, we offer a generalized algorithm for designing containers for liquids in the form of an information model, which is presented in Fig. 10.

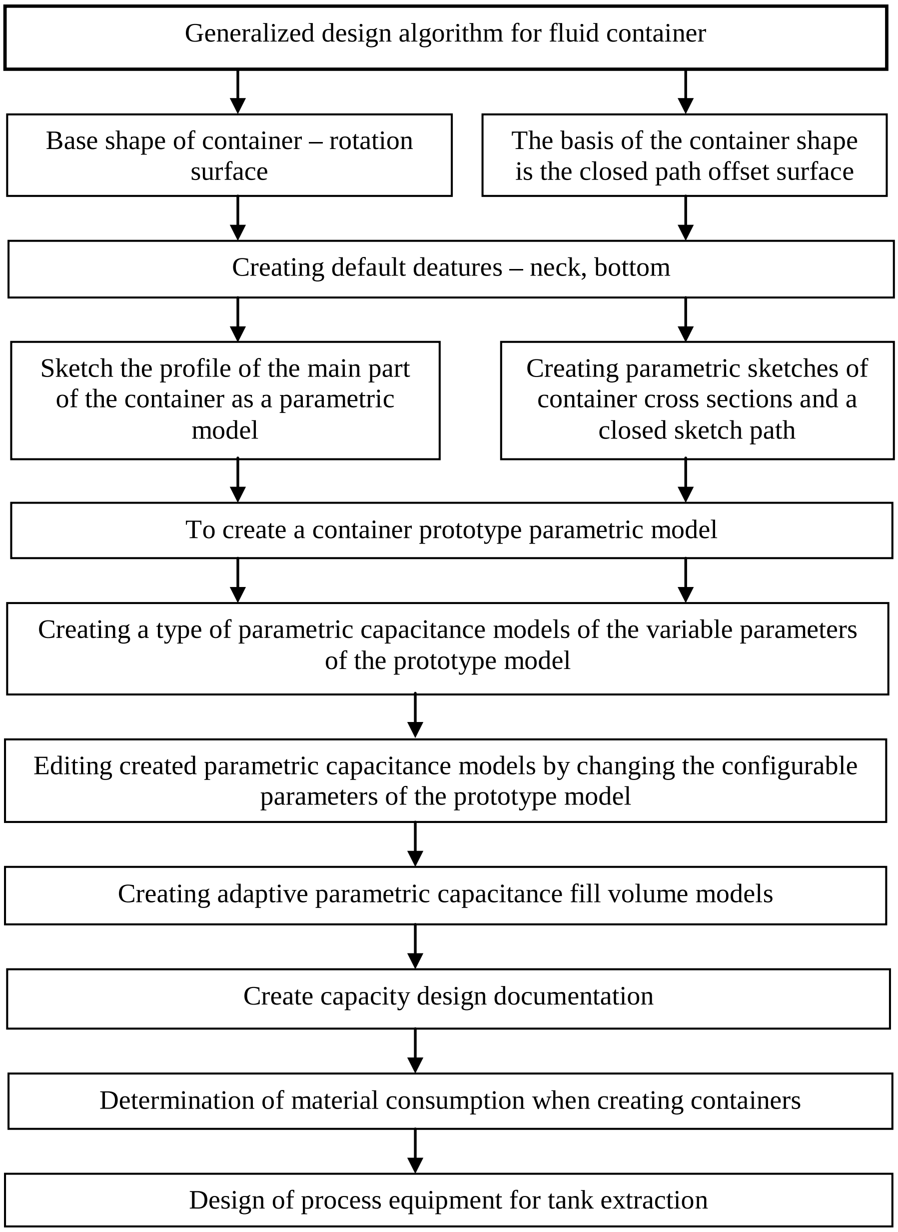

Fig. 10. Information model for designing plastic containers

The information model can be used in the design of modern CAD systems that use adaptively parametric models of the created objects. If necessary, it is possible to adapt the information model for a specific design and manufacturing process.

The proposed information model has two branches of solving the given problem for different variants of the bottle design. If necessary, you can add a new branch. When adding specific elements (for example, a company logo, the volume of a container or some other elements), you can add the corresponding blocks to the information model.

Conclusions

Adaptive parametric models of the container and liquid were created to check the information model of the container design. In the created models, a tabular assignment of the capacity and liquid parameters through the Excel program was used. Formulas for a cylindrical container are given in the work. To create a parametric series of containers of different shapes, it is necessary to develop mathematical relationships between the dimensions of the object and its volume. The proposed information model can be adapted for containers of different configurations. CAD Autodesk Inventor Professional allows you to create products from plastics. During the development of a PET container, special attention should be paid to the design of the preform: the quality of the future bottle depends on it. Containers can be not only plastic, but also glass. When creating models of such containers, it is necessary to take into account the technology of their production. Autodesk Inventor Professional allows you to estimate the mass, volume, surface area and a number of other physical characteristics of the designed preform, which helps qualitatively design the bottle itself.

Further development of the information model for the application of the generalized algorithm (information model) for the design of containers for liquids is the creation of a design subsystem based on Autodesk Inventor Professional in the ILogic environment.

With the use of the design subsystem based on Autodesk Inventor Professional, the time spent on designing the bottle and the mold kit for its manufacture is reduced tenfold – even if compared to flat design, not to mention manual design. The subprogram under development will allow to implement the most daring ideas of a constructor-designer in a minimum period of time.

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