ПРОЕКТУВАННЯ ФУНКЦІОНАЛЬНИХ ЕЛЕМЕНТІВ ТЕХНОЛОГІЧНИХ КОМПЛЕКСІВ

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SCIENTIFIC RATIONALE FOR THE PARAMETERS OF VACUUM GRIPPING DEVICES FOR POROUS PACKAGES

The article presents the mathematical model of the air permeance of porous packing materials. Conformity of the mathematical model to real processes has been verified by the authors by means of experimental tests. The obtained test results are recommended to be used for calculation and selection of the elements of vacuum gripping devices of packing equipment.

Porous material, packing machine, sugekraft gripper.

I. Introduction

Today's packaging industry is characterized by development and employment of a large variety of packaging materials, which differ in their weight, physical-and-chemical and mechanical qualities, as well as the capability to enable manufacturing of a unique and functional consumer package for any kind of food product.

Robotic systems are used for forming load units from packing units of different types and sizes, and for fast switch-over of engineering systems in case of change of the shape, sizes, weight, cycle and structure of packing.

One of the main units of industrial robots used in the packaging industry is a gripping device. Gripping devices are used for gripping, holding and transferring loads in a predetermined path.

Gripping devices requirements can be theoretically divided into two groups: general and special. General requirements include damaging of marketable condition of packages and reliability of gripping and holding thereof. Special requirements are concerned with the specifications of manufacturing conditions of multiple packaging.

The conducted study of gripping devices has revealed that pneumatic devices are in most common use, of which prevalent are constructions using vacuum for holding packages [1].

Such devices are the most versatile in terms of shape and the material of the object of gripping, have a simple design and are easy to use. The device itself and its control system consist of only two main elements: suckers and a vacuum unit. The material for the suckers shall be selected based on the type of material of the package, the shape of its surface and the device operation mode. A compressor or a vacuum generator is used for receiving vacuum. The vacuum unit shall be selected based on the depth of vacuum and air flow. Thus, a large air flow rate is provided by the compressor, while the low rate – by the vacuum generator.

II. Materials and methods

The major functional disadvantage of most gripping devices as well as vacuum devices is that there is a probability that the package will come off the sucker while being handled. Detachment may occur due to excessive influence of dynamic load which exceeds the acceptable rates, and due to variations of retention force. To prevent detachment, either the values of kinematic and dynamic parameters of package transfer shall be restricted, which reduces the equipment productivity, or the air flow rate shall be increased, i.e. the retention force shall be increased. Without limiting the preceding factors, the intensity of retention force considerably depends on the type of package material.

The package, depending on its ability to keep the original shape, can be conventionally divided into two groups: hard and soft. The package which keeps original shape and sizes under the influence of external load is called a hard package. One of the most common materials used for hard packages is cardboard. One of the key qualities of cardboard as an object of transportation by gripping devices is its porosity, which can be determined by the air permeance coefficient.

Cardboard air permeance rate considerably affects the construction performance of executive devices of packing machines, especially when vacuum gripping devices are used.

Therefore, the object of this article is to present the test results of air flow through package materials with pore structure.

Herewith, the found air flow values shall be considered in the overall balance of air flow rate of the vacuum generator.

For calculation of the parameters of gas flow, which goes through a porous object, the following assumptions have been accepted: the real object (package) has been replaced with a plate of uniform thickness *b*, which is uniformly penetrated by a capillaries system (Fig.1); the plate is hard enough; air displacement in the object's pores is laminar; thermodynamic process of change of air state in the object's pores is isothermal.

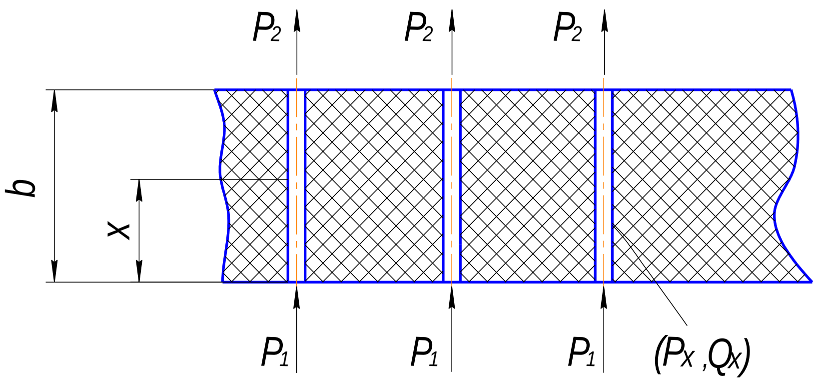

Fig. 1 Diagram for calculating air flow through a flat porous material

Volume flow rates Q_x of air through a capillary in the capillary point at distance *x* from the object surface can be determined by the formula which is equivalent to the expression for fluid movement [2]:

$$Q_x = -\frac{\pi \cdot r_\kappa^4}{8 \cdot \mu} \frac{dP_x}{dx}, \qquad (1)$$

where r_κ – the capillary radius, m; $\mu = 1{,}71 \cdot 10^{-5} + 4{,}94 \cdot 10^{-8} t$ – the coefficient of air dynamic viscosity, kg/(s·m); t – the air temperature, °C; $\frac{dP_x}{dx}$ – the gradient of air pressure in the capillary point *x*.

As a result of elastic properties of air, the volume flow rate and the derivative $\frac{dP_x}{dx}$ are values which vary in the capillary length. To determine the pressure gradient, we shall use mass flow continuity condition:

$$Q_x \cdot \rho_x = const, \qquad (2)$$

where ρ_x – the air specific gravity *d* at the capillary point at distance *x* from the object surface kg/m^3.

Fluctuations of air temperature moving through a porous test piece are insignificant, therefore, isothermal relation is true [3]:

$$\frac{\rho_x}{P_x} = \frac{1}{R \cdot T} = const, \qquad (3)$$

where P_x – absolute air pressure in the capillary section at distance *x* from the object surface, Pa;
R = 287.14 J/(kg·K) – the gas constant for air;
T – the absolute air temperature in the capillary section, K.

So, the formula of isothermal gas flow continuity in the capillary looks as follows:

$$Q_x \cdot P_x = -\frac{\pi \cdot r_к^4}{8\mu} \cdot \frac{dP_x}{dx} \cdot P_x = const, \tag{4}$$

i.e. the differential part of formula (4) can be expressed as:

$$\frac{dP_x}{dx} \cdot P_x = const. \tag{5}$$

Integration of formula (5) with account of initial conditions $x = 0$, $P_x = P_1$, and boundary conditions x = b, $P_x = P_2$ enable to find pressure distribution in the capillary length:

$$P_x{}^2 = \frac{P_2^2 - P_1^2}{b} \cdot x + P_1^2 \tag{6}$$

where

P_1 — the absolute pressure at the capillary input, Pa;

P_2 — the absolute pressure at the capillary output, Pa, i.e. this is the pressure created by the vacuum generator in the gripping element.

Then the derivate is equal to:

$$\frac{dP_x}{dx} = \frac{P_2^2 - P_1^2}{2 \cdot P_x \cdot b}. \tag{7}$$

By inserting expression (7) in formula (1), we shall find volume flow rate of the air through the capillary section at distance x from the object surface:

$$Q_x = \frac{\pi \cdot r_к^4}{16\mu \cdot b} \cdot \frac{P_1^2 - P_2^2}{P_x}. \tag{8}$$

From the last formula it may be concluded that the volume flow rate of air dQ_j at the output of surface element dS of the porous object is proportional to the difference of pressures squares at its input and output, and is determined by the following formula:

$$dQ_j = \frac{\xi}{\mu \cdot b} \cdot \frac{P_1^2 - P_2^2}{P_2} dS, \tag{9}$$

where ξ — the coefficient of the air permeance of packaging material, m^2.

Having been given the area of the test piece S, the air volume flow rate Q_S may be found from the following formula:

$$Q_S = \frac{\xi}{\mu \cdot b} \cdot \frac{P_1^2 - P_2^2}{P_1} \cdot S. \tag{10}$$

The coefficient ξ may be found by measuring the volume flow rate Q_S of air that goes through the porous test piece into the atmosphere, with the absolute pressure P_1 being created on its surface with area S. Under such conditions, from formula (10) the coefficient ξ determining the air permeance of material can be evaluated:

$$\xi = \frac{Q_S \cdot b \cdot \mu}{S} \cdot \frac{P_2}{P_1^2 - P_2^2}. \tag{11}$$

III. Results and discussion

Air volume flow rate Q for some types of cardboard has been determined by test using a laboratory apparatus Messmer Büchel K513 (Fig.2). The procedure of air permeance test is based on the Bendtsen method, which complies with the standards for such devices, in accordance with Standard ISO 5636-3.

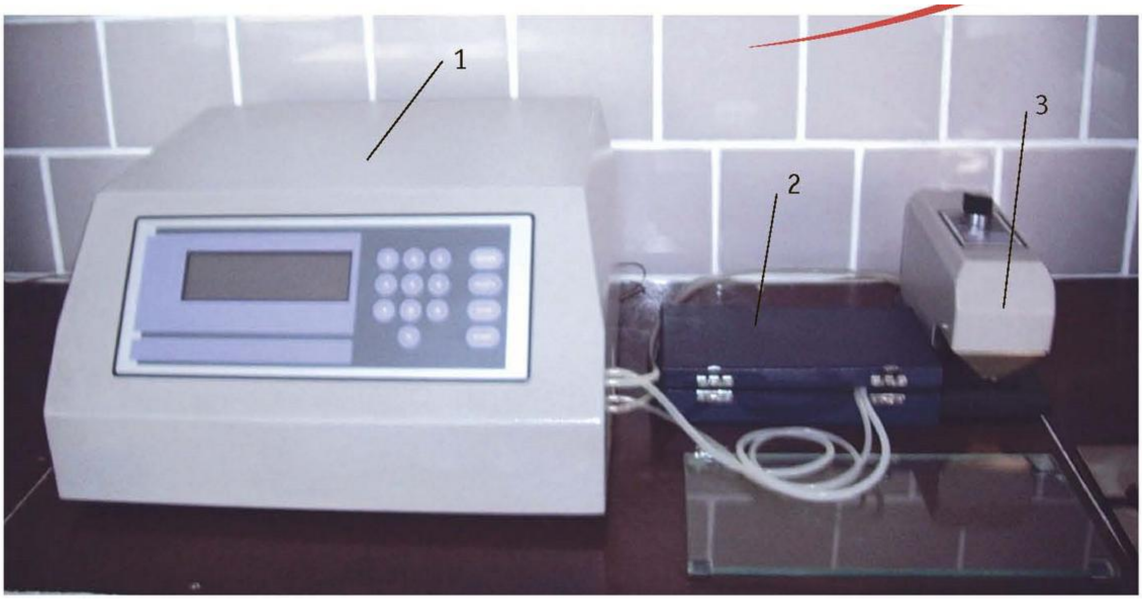

Fig. 2. Laboratory apparatus Messmer Büchel K513 for determining the air permeance of porous materials: 1- measuring instrument; 2- air supply device; 3 –measuring head

According to the Bendtsen method, the air permeance of cardboard was measured as a mean value of the air flow passing through a cardboard test piece clamped between a metal ring and a rubber gasket. The surface area of the cardboard tested was 10 cm^2. The metal ring was pressed against the cardboard surface by means of a special device, thus providing the pressure of 100 kPa. Then compressed air with pressure *P* of within 140-150 kPa was fed through the ring. The air was delivered through the thickness of the test piece, and then the amount of air was measured at the output.

The table provides the tests results of air flow through the surface of different types of cardboard, as well as the calculated values of air permeance coefficient ξ .

When design calculations of vacuum gripping devices are performed, all the factors determining the retention force of packing units shall be taken in the account. When the package is lifted up and handled by flat underformed surface, the retention force *F* can be calculated from the formula:

$$F = k_2 \cdot (mg + m\ddot{y}) \tag{12}$$

where

k_2 — the coefficient of the dynamics of device performance;

m — the weight of a packing unit;

y — the acceleration of a packing unit with the gripping device;

g — the gravity acceleration.

In turn, the retention force is formed by the attraction force of the package by gripping elements, which is calculated from the formula:

$$F = k_1 \cdot f_{ef} (P_a - P_2) \tag{13}$$

where

k_1 — the coefficient of the roughness of package surface and its nonflatness;

f_{ef} — the effective surface contact area of the gripping area and the package;

P_a — the atmosphere air pressure (air pressure of the ambient environment in which the gripping device operates);

P_2 — the absolute air pressure in the cavity between gripping elements and the package surface.

Therefore, to handle the package, with f_{ef}, k_1, $k_{2,}m$ and $\ddot{y}$ being available or constant, it is important to know the pressure difference:

$$(P_a - P_2) = \frac{k_2 \cdot (mg + m\ddot{y})}{k_1 \cdot f_{ef}}, \tag{14}$$

Thus, when values P_2, m, $\ddot{y}$, f_{ef} and ξ are known, using formula (10), it is possible to determine additional air flow in vacuum-generator in order to handle porous packages.

Table.

Air permeance coefficient

Type of cardboard	Air flow rate Q_s, ml/min	Air permeance coefficient ξ, $m^2 \cdot 10^{-4}$
Recycled imitation chromo board of H type, of first grade, TU U 05509659-008-2000	62	0.678
Recycled cardboard of HM type, TU U 21.1-05509659-008-2001	77	0.842
Recycled container board KT-25, TU U 21.1-5509659-026:2005	139	1.330
For flat layers of corrugated cardboard K-2, GOST 7420-89	122	1.170
Recycled cardboard of MM type, TU U 21.1-05509659-020-2001	78	0.854

IV. Conclusions

1. The performed tests of air penetration through porous packing materials have enabled to obtain the formula for calculating additional air flow rates in a vacuum generator, which enables to handle packages when making multiple packages.

2. The test values of the air permeance coefficient for the most widely-used types of cardboard have been obtained. They can be recommended to be used for design calculations of vacuum gripping devices.

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