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NONSTATIONARY FLOW OF THE VISCOUS RAPID-CURING LIQUID ON THE SURFACE OF ROTATING CYLINDER IN GRAVITATIONAL FIELD

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Key Words and Phrases: cylindrical surface; flow rate; rate field; roll; rotational casting; viscosity.

Abstract: The article gives analysis of covering of rotated cylindrical surface by viscous rapid-curing polyurethane composition freely pouring from the jet. The found value of flow rate field on surface of rotated cylinder will allow to determine flow rate of composition through the jet of mixing head and obtain the coating of predetermined height.

Nomenclature

$\vec{G}$, $G_{\square}$, G_r – mass forces vector and its co-ordinate components;
g – intensity of gravity;
h – height of coating layer;
p – liquid pressure;
R – cylinder radius;
r, θ – co-ordinate axes;
t – time;
$\vec{v}$, $v_{\square}$ – velocity vector and its component on θ-coordinate;
$v_{\square r}$ – linear velocity of roll rotation;
φ – incidence angle of composition jet;
μ – viscosity coefficient;
ρ – density of liquid;
ω – peripheral velocity of roll rotation;

$$\xi = \frac{r}{R} - 1;$$

$$a = -\frac{\rho g \cos\varphi}{\mu}.$$

Abbreviations

DETDA – diethyl toluene diamine;
MDI – methylene diphenylene diisocyanate.

Rolls with polyurethane elastomeric coverings are widely applied in paper, printing, steel, wood and textile industries. Process of coating of polyurethane composition on roll's surface is one of the main processes in production technology of rolls.

It is necessary to consider flow of viscous liquid on the surface of cylinder under the gravity force to calculate volumetric flow rate through the jet.

Equation of motion of viscous incompressible liquid with mass forces taking into account in vector form [1] is:

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v}\nabla)\vec{v} = \vec{G} - \frac{1}{\rho}\operatorname{grad} p + \frac{\mu}{\rho}\Delta\vec{v}. \qquad (1)$$

Equation of indissolubility:

$$\operatorname{div}\vec{v} = 0. \qquad (2)$$

Stationary flow of layer of viscous liquid on cylindrical surface under influence of gravity field $\left(\frac{\partial \vec{v}}{\partial t} = 0\right)$ was considered in [2]. As a result of the problem-solving relations on determining field rate of flow on cylindrical surface and flow rate of composition through the jet was obtained:

$$v(\xi) = aR^2 \frac{\xi}{6}\left(2 + 2\xi - \left(1 + \frac{h}{R}\right)^3 \cdot \frac{2+\xi}{1+\xi}\right).$$

These relations were received for constant values of viscosity and density. But the real polyurethane system on the base of prepolymer Laprol-5003 + MDI and hardener DETDA is rapid-curing, and viscosity highly changes in time. We had carried out experimental research of curing rheokinetics of these systems. Processing of experimental data has allowed us to get relations of viscosity and density from time in form:

$$\mu(t) = 1{,}27e^{0{,}30t}\ \text{Pa}\cdot\text{s},$$

$$\rho(t) = 1074+23{,}6\,t\ \text{kg/m}^3.$$

We consider stable motion of layer of viscous liquid on cylindrical surface under the influence of gravity field. In this case solution $v = v_\theta(r, t)$ depends on only r and equation (1) of flow of viscous rapid-curing liquid in case of cylindrical co-ordinate system takes a form:

$$\left.\begin{aligned} \frac{\partial v_\theta}{\partial t} &= G_\theta + \frac{\mu(t)}{\rho(t)}\left(\frac{\partial^2 v_\theta}{\partial r^2} + \frac{1}{r}\ \frac{\partial v_\theta}{\partial r} - \frac{v_\theta}{r^2}\right), \\ -\frac{v^2}{r} &= G_r - \frac{1}{\rho}\cdot\frac{\partial p}{\partial r}; \end{aligned}\right\} \qquad (3)$$

where $G_\theta = g\cos\tilde{\varphi}$

Initial condition:

$$v_\theta = 0,\ t = 0. \qquad (4)$$

Boundary conditions:

$$v_\theta = 0,\ r = R \qquad (5)$$

– condition of adhering of viscous liquid on the surface of cylinder,

$$\frac{\partial v_\theta}{\partial r} - \frac{v_\theta}{r} = 0, \quad r = R + h \qquad (6)$$

– condition at the free surface.

The system (3) – (6) was solved numerically by running method [3] for

$$0 \le t \le 10\ \text{sec}, \quad 36 \le r \le 36{+}4{,}1\ \text{mm}.$$

As a result of solution the next field rate of flow was obtained:

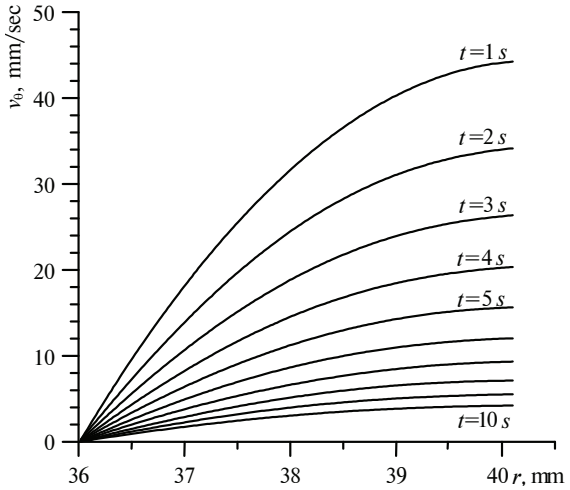

Fig. 1 Field rate of flow

Analyses of this field rate of flow shows that flowing on cylinder surface practically stops at curing time t = 10 sec.

In the real process of polyurethane coating roll rotates with some peripheral speed ω (fig. 2). In this case the boundary condition for the problem of flow of viscous liquid layer on the cylindrical surface under the influence of gravity field and shearing flow on account of peripheral speed of roll rotation on the cylinder surface is

$$v_{\varphi} = -v_{\varphi r}, \quad r = R \tag{7}$$

– condition of adhering of viscous liquid on the surface of cylinder.

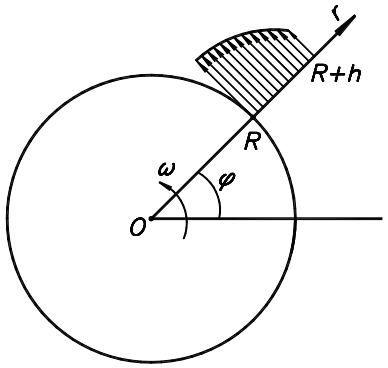

Fig. 2 Co-ordinate system

After solving system (3) with initial (4) and boundary conditions (6) and (7) by running method for

$$0 \le t \le 10 \text{ sec}, \quad 36 \le r \le 36+4{,}1 \text{ mm}, \quad v_{\varphi r} = 162 \text{ mm/sec}$$

we have obtained the next field rate of rapid-curing liquid flow:

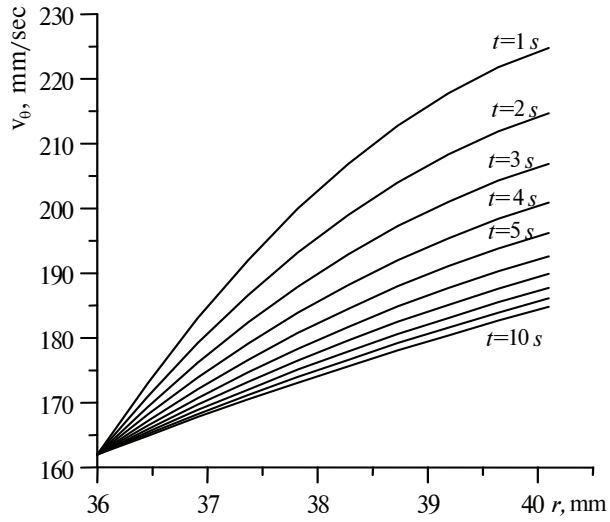

Fig. 3 Field rate of flow

The found value of flow rate field on surface of rotated cylinder allows to determine flow rate of composition through the jet of mixing head for obtaining the coating of predetermined height.

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Нестационарное течение вязкой быстроотвердевающей жидкости по поверхности вращающегося цилиндра в поле гравитации

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Ключевые слова и фразы: валок; вязкость; поле скоростей; скорость течения; цилиндрическая поверхность.

Аннотация: Рассматривается процесс покрытия цилиндрической вращающейся поверхности вязкой быстроотверждающейся полиуретановой композицией, свободно текущей из сопла. Найденное значение поля скоростей потока по поверхности вращающегося цилиндра позволяет определить расход композиции через сопло смесительной головки для получения слоя покрытия заданной толщины.

Unstationäres Fließen der zähen schnellverhärtenden Flüssigkeit durch die Oberfläche des drehenden Zylinders im Gravitationsfeld

Zusammenfassung: Es wird den Prozeß der Beschichtung eines drehenden Zylinderoberfläche mit der zähen Polyurethankomposition, die frei aus einer Düse fließt, betrachtet. Die gewonnene Bedeutung des Geschwindigkeitsfeldes des Stromes durch die Oberfläche eines drehenden Zylinders gestattet den Kompositionsverbrauch durch eine Düse des Mischkopfes für die Gewinnung der Beschichtung der angegebenen Dichte zu bestimmen.

Ecoulement non stationnaire du liquide visqueux à durcissement rapide sur la surface du cylindre tournant dans le champs de gravitation

Résumé: On examine le processus du revêtement de la surface cylindrique tournante par la composition visqueuse à durcissement rapide qui écoule de la tuyère. La grandeur trouvée du champ des viteses de l'écoulement sur la surface du cylindre tournant permet de définir le débit de la composition à partir de la tuyère de la tête à mélanger pour avoir une couche du revêtement de l'épaisseur donnée.