Numerical study of printing ink structuring

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Abstract. The computational experiment showing the structuring of the printing ink, being a highly-filled suspension and possessing the property of thixotropy. The areas of structuring are shown. It is proved that the center of rotation of the structured area, and consequently their radius is little dependent on the ink viscosity and the rotational speed of the ink fountain roller. The volume of the structured area rotating without stirring is calculated, which makes 20% of the volume of the ink can filled with ink by 70%.

1. Introduction
The quality of the printout in the offset printing depends, among other things, on the ink device operation. The supply of ink into an inker depends on the correct operation of the feeding group. The supply of ink into the inker feeding group is significantly influenced by its structuring, caused by the thixotropic character. It is difficult to visually estimate the influence of ink structuring in the ink can on its supply into the printing area. To estimate the impact of ink structuring, it is necessary to develop a mathematical model. Paulo R. de Souza Mendes developed a model of mechanical behavior of thixotropic fluids using equations for voltage and structural parameter [1]. It predicts voltage overshoot and viscosity bifurcation. A number of works are devoted to the study of structuring of printing ink in gravure printing. In particular, the transfer of the printing ink from the idealized cell of the form [2], the influence of the constricting shift on the ink transfer from the gravure print cell [3], the influence of the viscoelastic properties of ink [4, 5] is investigated.

During a flat offset printing machine operation, the circulating movement of ink is formed in an ink can (Fig 1). The figure shows that the ink roller rotates without ink stirring. This leads to a deterioration of the ink flow supply to the ink-distribution system.

In machines of relief offset printing there is also a problem of insufficient ink stirring which in technical literature is usually considered as a problem of ink non-rotation. If there is ink non-rotation,
the gap is formed between the ink fountain roller and ink body, and the ink supply into the ink-distribution system stops. The phenomenon of the ink non-rotation precedes the formation of the area, which moves without stirring. Due to the fact that this area has a tendency to grow, gradually increasing, it covers all the ink in the ink can.

2. Problem Statement
The ink movement in a can is rotational. The ink velocity at the flow boundary decreases from the periphery to its rotation axis. Tangent stresses are also reduced from the periphery to the axis of rotation. In the area close to the axis of rotation, the velocity of the ink flow and tangent voltages are equal to zero, that is, the ink is at rest (is static). In this case, due to the ink thixotropy character, an internal structure obtaining mechanical strength begins to form. The dimensions of this structure increase as long as the tangent stresses in the flowing ink do not exceed the shear stress limit. This leads to the formation of the area that rotates without stirring. The dimensions of this area depend on the ink properties. For example in UV dry ink, applied in relief offset printing, this area extends on all the ink volume. The task of the paper was the conducting of computational experiment, which shows the formation of the area rotating without stirring in the ink can of the flat offset printing machine.

3. Theoretical rationale
The dimensions of the area rotating without stirring depend on the of the ink rheological properties (viscosity, shear stress limit) and machine parameters (geometric parameters of the ink can, rotational velocity of the ink fountain roller). Since the transverse dimensions of the circulating ink flow are much smaller than its longitudinal dimensions (Fig. 1), the flow pattern in two parallel planes, located perpendicular to the axis of rotation, will slightly differ from each other. This allows to consider the flow in one plane perpendicular to the axis of rotation and located in the middle of the length of the ink roller.

To carry out the calculations, the following assumptions were made: ink flow is laminar; viscosity and temperature do not change over time; ink is incompressible and isotropic. Tangent stresses of thixotropic fluid are described by the following equation:

\[ \tau = \tau_0 + \mu' \cdot \varepsilon', \]  
(at \( \tau > \tau_0 \)), where \( \tau \) is the tangent component of voltage tensor (shear stress of moving ink); \( \tau_0 \) is the limit shear stress required to destroy the structure of the thixotropic fluid; \( \mu' \) is the dynamic coefficient of structural viscosity (viscosity of fluid with completely destroyed structure); \( \varepsilon' \) are tangent voltages.

In the case when the relative velocity of the neighboring ink layers is so small that the tangent voltages are less than the limit shear stress, i.e. \( \tau < \tau_0 \), the structure of the thixotropic fluid will begin to recover, which will lead to the formation of the area rotating without stirring.

The generalized Law of Newton for incompressible viscous fluid in the analytical form for a rectangular coordinates system has the following form:
\[ \tau_{11} = -\tau + 2\mu \frac{\partial u}{\partial x}, \]
\[ \tau_{22} = -\tau + 2\mu \frac{\partial v}{\partial y}, \]
\[ \tau_{33} = -\tau + 2\mu \frac{\partial w}{\partial z}, \]
\[ \tau_{12} = \tau_{21} = \mu \left[ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right], \]
\[ \tau_{23} = \tau_{32} = \mu \left[ \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right], \]
\[ \tau_{13} = \tau_{31} = \mu \left[ \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right], \]

where \( \tau_{11}, \tau_{22}, \tau_{33} \) are the normal voltages; \( \tau_{12} = \tau_{21}, \tau_{23} = \tau_{32}, \tau_{13} = \tau_{31} \) are the tangent voltages; \( \mu' \) is the dynamic coefficient of structural viscosity (viscosity of liquid with completely destroyed structure); \( u, v, w \) is the projection of the rate vector on the x, y, z coordinate axis.

As the flat circulating ink flow around the axis of the perpendicularly to the considered plane is analyzed, then: \( \tau_{11} = \tau_{22} = \tau_{33} = \tau_{12} = \tau_{13} = \tau_{23} = 0 \). Then, the flow tangent voltages are recorded as follows:

\[ \tau_{12} = \tau_{21} = \mu' \left[ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right], \]

Thus, in order to find the tangent stresses, it is necessary to locate the projection of the rate vector on the coordinate axis U and V, and then the u and v change in the y and x direction respectively. For this purpose it is necessary to carry out numerical differentiation, defining partial derivatives from the following expressions

\[ \frac{\partial v}{\partial x} \approx \frac{v_{i+1} - v_i}{x_{i+1} - x_i}, \quad \frac{\partial u}{\partial y} \approx \frac{u_{i+1} - u_i}{y_{i+1} - y_i}, \]

where \( u_i, u_{i+1}, v_i, v_{i+1} \) are the rate projection values in the two adjacent grid cells in the y and x direction respectively. Further, using the viscosity values of the ink \( \mu' \) the values of tangent stresses \( \tau_{12} \) were obtained. Knowing the values of tangent stresses, the sectors in which \( \tau < \tau_0 \) where the areas where the paint rotates without stirring are formed, were found within the flow.

Thus, the computational experiment consists of the following stages.

1. Finding the velocity of the paint flow in a plane perpendicular to the axis of rotation of the ink fountain roller.
2. Finding tangent stresses in the flow.
3. Defining the areas that are rotating without stirring.

4. Conducting the experiment
To find the flow rate a specialized program FlowVision, which implemented a numerical solution to the Navier-Stokes equation and the equation of continuity were used. The calculation was carried out for the ink can of light-duty offset printing machine Gronhi 1800 YK. Fig. 2 shows the 3D model of the flow area.

Figure 2. Calculation area of the ink can: 1 – ink fountain roller; 2 – free surface; 3 – Ink knife

Figure 3 shows a calculation example for ink with viscosity of 30 Pa s, at the rotation velocity of the ink fountain roller equal to 4 rpm.

To find the tangent stresses and the area in which the condition \( \tau < \tau_0 \) is met, a custom designed program was used. The result is presented as a numerical matrix (Fig. 4), in which the cells where the condition \( \tau < \tau_0 \) is met do not have numerical values, the cells in which this condition is not met have the value of tangent stresses \( \text{n/m}^2 \), while the cells that go outside the flow area have zeros.

Figure 3. Current lines (a) and velocity fields with vectors of the same length (b) 1 – flow lines; 2 – ink fountain roller; 3 – free surface; 4 – ink knife; 5-velocity field
5. Results and discussion

According to the calculations results, the coordinate of the ink rotation center depending on the viscosity and rotation velocity of the ink roller was found. The difference in the coordinate values of the of the structured area rotation center was less than 4% for the same amount of ink. The calculated structured areas for the different viscosity values of ink and the rotation velocity of the ink fountain roller are shown in Fig. 5 and 6.

The figures show that with the increase in the ink viscosity and the decrease in the ink fountain roller velocity, the dimensions of the structured area increase, which, however, does not affect the size of the body rotating without stirring.

Although the area where \( t < t_0 \) has an irregular shape, the structured area is a circle (a cylinder in three-dimensional space) when moving. The radius of this area is equal to the minimum distance from the center of its rotation to the ink fountain roller. As the coordinates of the rotation center for different parameters are little different from each other, the radii of the structured area are not very different from each other. Thus, for inks with viscosity of 40 Pa s and 50 Pa s at the velocity of rotation of the ink fountain roller 1-4 rps the radius of the structured area is 8.43 mm, and for ink with viscosity 30 Pa – 8.11 mm. Thus, the volume of the body that rotates without stirring, is about 20% of the total amount of ink in the ink can. In this case, the body volume increases as the amount of ink decreases. So, fig. 1 shows a structured area with a small amount of ink, which is about 90% of the total amount of ink.
6. Conclusion

1. The coordinates of the rotation center of the structured area do not depend on the rotation velocity of the ink fountain roller and ink viscosity.
2. The dimensions of the structured area are directly proportional to the ink viscosity and inversely proportional to the ink fountain roller rotation velocity.
3. The dimensions of the structured area make up 20% of the total amount of ink in the ink can, when it is 70% full.

References

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