Diagnostics of paper – dampening solution printing system parameters for open source software applications

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Abstract. The paper parameters were selected for a computer model using open source software to predict their interaction with the dampening solution in an offset printing machine and in an ultrasonic measuring device. The indices characterizing the penetration of alcohol-free and alcohol dampening solutions with 5% and 10% content of isopropyl alcohol into the structure of offset coated papers on PDA c02 ultrasonic measuring device were obtained and analyzed. The surface profiles of coated offset papers are obtained on a Micro Measure 3D Station three-dimensional non-contact profilometer for constructing the surface geometry of papers in a graphical interface. A \( t_{\text{startswelling}} \) value was found characterizing the time of the beginning of fiber swelling in the paper structure, which will allow setting the time for calculating the numerical model. The obtained t95 and USI 70 indices are recommended for an indirect assessment of the identity of a computer model to the actual conditions for the onset of interaction and penetration of dampening solutions into the paper pores.

1. Introduction

Combined dampeners that work with alcohol and alcohol-free dampening solutions are used in modern offset printing machines. The ability to evaluate paper parameters when interacting with dampening solutions and control the operating modes of the dampener during the printing process allows to achieve the highest quality and reduce the rejects of printed materials. The OpenFoam open source software and the ParaView visualization package can be used to predict and analyze the interaction of papers with a thin layer of a dampening solution, to simulate the supply of a solution by dampeners.

The ultrasonic method implemented in the PDA 02 measuring device can be used to verify the identity of the computer model to actual conditions [1]. An analysis of the work performed in comparing the ultrasonic method for assessing the hydrophobicity of printed paper grades showed that this method is the most suitable for assessing the dynamic absorption of paper with a contact time of up to \( 10c^{-2} \), compared with the known methods (Cobb's angle 30, Cobb's angle 60, etc.) [2]. The ultrasonic method has been widely used in measuring the paper absorbency in order to improve print quality [3-6], when testing the effect of surface grinding and coloring on the physical properties of simulated paper [7], to control the quality of paper manufacture in paper production and to study...
factors of paper manufacture affecting the lateral position of the paper tape on web-fed printing machines with the Commercial Heat Set [8], as well as for computer simulation of the process of liquid penetration into the paper pores [9].

To study the structure and distribution of solutions, printing inks on the surface and in the pores of paper, images obtained on profilometers or scanning electron microscope are used. Methods of electron microscopy are intensively used in the printing industry to study the printed material and assess the influence of factors characterizing the interaction between the printing ink and the substrate surface [10-13].

For computer simulation in OpenFoam software, it is necessary to construct a computational grid for the simulated object, set the boundary geometry, initial conditions for the components of the fluid flow rate, establish the influence of surface tension forces, choose the type of fluid flow, etc. When using the software package, it is equally important to precisely select the time parameters for data input and output and the end time of the computer simulation. The accuracy of the calculation is also affected by the cell size of the model computational grid. The correct choice of these parameters allows the correct use of machine time.

2. Problem statement
Problem statement of research is to study and select indices obtained using an ultrasonic measuring device and a scanning electron microscope as applied to computer simulation of the process of interaction and penetration of dampening solutions into paper in offset printing machines.

3. Experimental technique
Paper samples of 5 × 7.5 cm in size, 10 pieces for each side, were selected to study the penetration of the dampening solution into the paper structure (Table 1). The presented types of papers are used in printing houses in Germany and Russia for offset flat and digital printing. Dampening solutions of the following composition were made: water+ 2% Wassertop DH+, water+ 2% Wassertop DH plus + 5% IPA, water+ 2% Wassertop DH plus + 10% IPA. The additive in the Wassertop DH+ dampening solution is universal and is used for sheet printing, for all types of water hardness and in osmosis systems, and is intended for both alcoholic solutions with an alcohol content of up to 12% and alcohol-free solutions in film and bag-type dampeners. The index of finished pH solution is 5±0.2.

Paper samples are brought into contact with dampening solutions in the measuring cell of the PDA c 02 ultrasonic measuring device. From the moment the dampening solution contacts the paper surface, high-frequency low-energy ultrasonic signals with a fixed frequency of 2 MHz are emitted in the Z-direction. The diameter of measuring section of the sensors is 10 mm. Signals are received by a highly sensitive sensor before they are processed in the device and transmitted to a personal computer. The level of the dampening solution in the cell is lower. Measurement time 30 sec.

The t95 index was recorded to assess the surface porosity of the paper when interacting with dampening solutions. The t95 index represents the period of time during which a decrease occurs in the ultrasound intensity from 100% to 95% passing through the paper sample. The rapid attenuation of the ultrasound intensity characterizes the presence of large pores, and the gently sloping curve of the graph from the measurement results may indicate a finer porous structure. The point of maximum change in the intensity of the ultrasonic signal was recorded to measure the top sizing / hydrophobicity of the paper tstartswelling. A later maximum point indicates a high degree of top sizing / hydrophobicity of the sample. To obtain information on surface roughness, a USI of 70 index was recorded, which refers to the ultrasound intensity of 70 ms after the start of the test. High values of USI 70 represent a higher roughness, which traps more air and requires a long time for liquid to penetrate the paper structure [2-5,8].

Roughness measurements were performed on a PPS L@W PPS TEST. The front and net sides were not detected for the tested papers, and the sides were indicated by numbers 1 and 2. The profiles of the surface areas of the paper obtained on a Micro Measure 3D Station three-dimensional non-contact profilometer [14].
4. Experimental results

The measurement results of the $t_{\text{startswelling}}$ parameter and $t_{95}$ for the selected paper samples are presented below in Table 1. The measurement results of the USI 70 parameter in Table 2, where the list of paper samples is presented by increasing roughness. The dependences of the intensity indicator change in % of the time of interaction with dampening solutions for 3 seconds for LumiSilkmatt and LumiArt papers and for 30 sec. for CHROMOLUX paper are shown in Figures 1-6.

**Table 1.** The time interval characterizing the change in intensity at the receiving device of the ultrasonic device.

| Paper sample: LumiSilkmatt 135 g/m² (PapierUnion) | $t_{\text{startswelling}}$ (s) | $t_{95}$ (s) |
|---|---|---|
| Dampening solution | Side 1 | Side 2 | Side 1 | Side 2 |
| Water+ 2% Wassertop DH+ | 0.013 | 0.013 | 7.406 | 5.556 |
| Water+ 2% Wassertop DH plus + 5% IPA | 0.013 | 0.013 | 5.4 | 6.360 |
| Water+ 2% Wassertop DH plus + 10% IPA | 0.013 | 0.093 | 4.013 | 6.043 |
| Paper sample No. 2: CHROMOLUX 700 250 weis 250 Bg 135 g/m² | | | | |
| Water+ 2% Wassertop DH+ | 18.417 | 5.097 | 28.651 | Not recorded |
| Water+ 2% Wassertop DH plus + 5% IPA | 0.541 | 4.393 | 18.512 | Not recorded |
| Water+ 2% Wassertop DH plus + 10% IPA | 0.221 | 1.497 | 9.140 | 5.857 |
| Paper sample No. 3: LumiArt 135 g/m² | | | | |
| Water+ 2% Wassertop DH+ | 0.017 | 0.069 | 3.670 | 3.707 |
| Water+ 2% Wassertop DH plus + 5% IPA | 0.029 | 0.041 | 3.283 | 3.634 |
| Water+ 2% Wassertop DH plus + 10% IPA | 0.069 | 0.033 | 3.490 | 3.436 |

**Table 2.** USI 70 index values.

| No. Paper sample, name | PPS Roughness | Water+ 2% Wassertop DH+ | Water+ 2% Wassertop DH plus + 5% IPA | Water+ 2% Wassertop DH plus + 10% IPA |
|---|---|---|---|---|
| USI 70 (%) | Side 1 | Side 2 | USI 70 (%) | Side 1 | Side 2 | USI 70 (%) | Side 1 | Side 2 |
| LumiSilkmatt 135 g/m² | 1.3/1.4 | 98.914 | 99.546 | 99.795 | 99.514 | 99.782 | 100.190 |
| CHROMOLUX 700 250 weis 250 Bg 135 g/m² | 0.552/8.89 | 100.153 | 115.646 | 100.15 | 114.171 | 100.381 | 110.13 |
| LumiArt 135 g/m² | 0.699/0.714 | 99.966 | 100.016 | 100.173 | 100.2385 | 100.410 | 100.007 |
Figure 1. The dependence of intensity index change in % on the time of interaction with dampening solutions: 1- Water+ 2% Wassertop DH+; 2- Water+ 2% Wassertop DH plus + 5% IPA; 3- Water+ 2% Wassertop DH plus + 10% IPA for side 1 of a sample of LumiSilk matt paper.

Figure 2. The dependence of intensity index change in % on the time of interaction with dampening solutions: 1- Water+ 2% Wassertop DH+; 2- Water+ 2% Wassertop DH plus + 5% IPA; 3- Water+ 2% Wassertop DH plus + 10% IPA for side 2 of a sample of LumiSilk matt paper.

Figure 3. The dependence of intensity index change in % on the time of interaction with dampening solutions: 1- Water+ 2% Wassertop DH+; 2- Water+ 2% Wassertop DH plus + 5% IPA; 3- Water+ 2% Wassertop DH plus + 10% IPA for side 1 of a sample of CHROMOLUX paper.

Figure 4. The dependence of intensity index change in % on the time of interaction with dampening solutions: 1- Water+ 2% Wassertop DH+; 2- Water+ 2% Wassertop DH plus + 5% IPA; 3- Water+ 2% Wassertop DH plus + 10% IPA for side 2 of a sample of CHROMOLUX paper.
Figure 5. The dependence of intensity index change in % on the time of interaction with dampening solutions: 1- Water+ 2% Wassertop DH+; 2- Water+ 2% Wassertop DH plus + 5% IPA; 3- Water+ 2% Wassertop DH plus + 10% IPA for side 1 of a sample of Lumi Art paper.

Figure 6. The dependence of intensity index change in % on the time of interaction with dampening solutions: 1- Water+ 2% Wassertop DH+; 2- Water+ 2% Wassertop DH plus + 5% IPA; 3- Water+ 2% Wassertop DH plus + 10% IPA for side 2 of a sample of Lumi Art paper.

The profiles of the paper surface areas obtained by the non-contact method on the Micro Measure 3D Station profilometer are shown in Figures 7-9.

Figure 7. 3D profile of surface area of the CHROMOLUX paper sample.

Figure 8. 3D profile of surface area of the LumiArt paper sample.
5. Discussion of results
Sample LumiSilkmatt 135 paper r/m² is a pure cellulose matte, multiple coated paper. The addition of isopropyl alcohol to the dampening solution from 5% to 10% led to a decrease in t95 from 7.4 sec to 4.013 sec. For an alcohol-free dampening solution and a solution with a 5% alcohol content, instant interaction and penetration into this paper \( t_{\text{start swelling}} = 0.013 \) sec followed by a sharp drop in intensity. With an increase in the proportion of isopropyl alcohol in the composition up to 10%, there was a slight increase in intensity to 100.245% for side 2. Effect The addition of isopropyl alcohol did not affect the change in time to the maximum point and USI 70.

For the CHROMOLUX 700 250 weis 250 Bg 135 r/m² sample, the time values \( t_{\text{start swelling}} \) are quite high and reach 18 seconds for the glossy side and 5 seconds for the matte side when interacting with an alcohol-free dampening solution. The addition of isopropyl alcohol gave a sharp jump down \( t_{\text{start swelling}} \) to 0.2 seconds for the glossy side and \( t_{\text{start swelling}} = 1.5 \) seconds for the matte side. The time for changing the intensity of the ultrasonic signal to 95% on the glossy side decreases from 28 sec to 18.5 sec (5% solution) and to 9.1 sec (10% solution). The t095 index was not recorded in the interaction of the matte side of the paper and the non-alcohol and 5% alcohol solution. For a dampening solution with 10% isopropyl alcohol \( t95 = 5.85 \) sec. For side 1, with a PPS roughness of 0.552, the addition of isopropyl alcohol did not affect USI 70. For the matte side of paper with a PPS roughness of 8.89 μm, the addition of isopropyl alcohol reduced the intensity by 1% for a dampening solution with 5% isopropyl alcohol and 5% for a dampening solution with 10% isopropyl alcohol.

LumiArt 135r/m² sample is a glossy double-sided coated paper without the addition of wood fibers. This paper recorded an increase in the intensity of the ultrasonic signal from the beginning of the measurement. This means that the air layer [11] is kept on the paper surface and the signal is reflected, and, probably, the interference occurs when the ultrasonic waves reach the signal receiver in phase. The t95 index decreases with the addition of isopropyl alcohol, which indicates a more intense penetration of alcoholic dampening solutions into the coated layer. USI 70 has changed slightly, within 1% for alcoholic dampening solutions.

6. Conclusion
Based on the obtained measurement results of coated paper samples by the ultrasonic method, it is recommended to accept the following values of the computational model calculation time based on values \( t_{\text{start swelling}} \) from 0.013 to 0.07 sec. To simulate the interaction of CHROMOLUX paper with dampening solutions for a glossy surface with a PPS roughness of 0.5 μm, the calculation time must be increased to 18 sec.

The t095 index can be used indirectly in assessing the surface porosity of papers and, at the same time as measuring and calculating the pore radius, will help set the coefficients that determine the viscosity of the dampening solution through the permeability of the porous medium of the paper [12]. The t095 index also allows to estimate the flow rate of the dampening solution in the porous medium.
of the paper and helps to set the coefficient determining the inertial resistance of the flow. The selection of the above coefficients is necessary in the OpenFoam computer simulation to calculate the implicit channel for an incompressible substance with a stationary solver for an incompressible turbulent flow with implicit or explicit porousSimpleFoam porosity processing.

The obtained USI 70 is recommended to be used to assess the identity of the computer model under actual conditions during the interaction of the dampening solution with the rough surface of the paper in the measuring cell of the PDA or simulating the transfer of the dampening solution layer from the surface of the offset rubber cloth to paper in offset printing machines. It is recommended to set the height of the surface roughness column of the coated offset paper to build a computational grid from 0.5 to 1.5 as applied to the design case. Computer simulation can be implemented using the Volume of Fluid method implemented in the interFoam solver of OpenFOAM package.

Three-dimensional images of the paper surface profile will allow a comprehensive assessment of the effect of the paper surface geometry on the fluid flow parameters: surface dampening, fluid flow rate at the inlet and outlet of the calculated boundary. Profiles can also be used to build simple computational grids of two-dimensional models of rough surfaces using graphical interfaces.

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