Practice of the VOF Open Foam techniques aimed to parameters prediction of the « dampening solution – paper» interaction for the printing systems

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Abstract. The results of CFD research using the VOF method with Open Foam open source are presented. In the process of study, we built a digital model allowing us to analyze and predict the process of interaction of the dampening solution with substrate (paper) surface in the measuring cell of the PDA ultrasonic device. Discretization of the area for calculation was created using the blockMesh utility. A block-structural hexahedral computational grid has been constructed. The computational grid area is presented in such a way that the number of cells increases in the direction of the paper sample. The visualization of calculations in the ParaView package coincides with the time intervals obtained on the PDA ultrasonic measuring device. The practical significance of the study lies in the realization of the possibility to evaluate the dampening solution parameters, to control the modes of its supply, taking into account the use of modern papers and printing systems.

Keywords. Ultrasonic method, PDA ultrasonic device, dampening solution, offset printing systems, open source software

1. Introduction
Dosing when applying a dampening solution to a printing plate is carried out by the rollers of the humidifying machine by means of slipping or velocity adjustment of their rotation [1]. In order to establish feedback between the dosing of the dampening solution and its thickness, measurement systems have been developed on the printing plate. For the effective operation of new measuring systems [2], it is necessary to find quantitative relationships between the thickness of the layer on the humidifying machine rollers, its application to a printing plate, and an offset rubber fabric with subsequent minimal transfer to the printed material (paper). To assess the one-sided soaking of the paper surface, the most suitable is the ultrasonic method [3], it involves creating an acoustic contact through the liquid layer and measuring the decrease in the ultrasound intensity. The ultrasonic method for measuring the permeability of paper when interacting with liquids is widely used in the paper and printing industry for product quality control [4-10]. After immersing a paper sample in a container
with a dampening solution, the air in the ultrasonic measuring device is displaced from the surface of the solution which begins to penetrate into the paper pores [11]. The microgeometry of the paper surface influences the time when interaction of the fountain solution with paper begins [12]. To study the distribution of solutions taking into account the microgeometry of the paper surface, we can use images obtained with profilometers or scanning electron microscopes [13–17]. However, the PDA ultrasonic instrument does not record data in the first 8 ms from the start of measurements. This time interval could possibly be modeled in open source software. The Open Foam software package with the VOF solver (Version 7) simulates the process of air displacement and the initiation of interaction of the fountain solution with the paper surface after the sample is placed in the PDA cell. The volumetric fluid method is implemented in the Open Foam package and defines the boundary as a property of the fluid volume fraction field. The interphase boundary is blurred and represents the area where the volume fraction of the liquid is between 1 and 0 [18].

A schematic representation of the relationship between soaking and liquid penetration into paper and its effect on ultrasonic transmission is described by manufacturers [4]. At the time \( t = 0 \), when the paper is not wetted, there is a thin film of air between the water and the paper surface [19]. A small part of the signal is reflected by this film. Dry paper sample attenuates the transmitted signal. The received ultrasound intensity signal is defined as 100%.

For computer simulation, it is suggested to divide the process of paper interaction with a fountain solution into several steps which are: displacement of the air layer from the surface of paper, penetration and flow of liquid in the pores of the paper with the simultaneous compression of air in pores, formation of air bubbles and their movement in the opposite direction. Measurements on a PDA device made it possible to find the time, corresponding to \( t_{\text{max}} \), after which paper fibers swelling begins [12].

2. Problem statement
   The problem statement is the both advantages and effectiveness determination of the finite volume method in a double-phase mode at the process simulating of gases displacement from a substrate surface (paper) after its immersion into the dampening solution at the printing system components interaction.

3. Experimental technique
   The configuration of a two-dimensional model problem that simulates the squeezing out of the air trapped by a paper sample (as well as a certain volume of the air trapped in a liquid with the lower edge of the paper) has the following assumptions: a substructure supporting the sample, as well as the lower boundary of the liquid Figure 1 which coincides with the level of the lower edge of the substructure supporting the paper, Figure 2 are taken as the walls of the cell. The model is presented in the form of a tank 45.5 mm long and 92 mm high. On the right wall of the tank, a paper sample 0.14 mm thick is fixed, the lower edge of the paper sample is located at a height of 18 mm from the tank bottom. The area for calculation was created using the blockMesh utility and is presented in the form of three blocks - hexahedrons. The hexahedrons include 80 cells in the X and Y directions with a downward gradient on the X-axis from 0.1 to 0.5. The liquid phase is placed inside the cell. The liquid column height is set to 56 mm. The thickness of the air layer between the paper and the liquid phase for the computer simulation is taken as 0.05 mm. The thickness of the paper and the thickness of the trapped air layer under the lower edge of the paper sample are taken as 0.14 mm [20]. The boundary geometry file contains five boundary patches: leftWall is the wall of the cell, rightWall is the substructure with fixed sample, lowerWall is the level of the lower edge of the substructure supporting paper, atmosphere, the FrontandBack patch is marked as empty and is not resolved in this 2D case. The values of all velocity components are zero, because until point in time \( t = 0 \) there is no motion. The influence of surface tension forces of the liquid against the walls was not taken into account. In turbulence simulating, the Laminar type is set. Calculations are performed using the interFoam solver. Simulation end time – 0.025 s, simulation time step – \( 1 \cdot 10^{-3} \cdot 10^{-3} \) s and \( 1 \cdot 10^{-4} \) s. The kinematic
viscosity of the fountain solution is taken as $1 \cdot 10^{-4}$ m$^2$/s; density $\rho = 1 \cdot 10^{-3} \cdot 10^3$ kg/m$^3$.

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**Figure 1.** Diagram of immersing a paper sample into a cell with a dampening solution of an ultrasonic measuring device. 1 – cell; 2 – source of ultrasonic signal; 3 – surface carrying the sample; 4 – sample paper

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**Figure 2.** Sketch for a computer model. 1 – the liquid boundary is represented as a wall

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4. **Experimental results and discussion**

At the time $t = 0$, the liquid column, which has a vertical limitation along the line with coordinates $(0 \ 0 \ 0) \ (0.4531 \ 0.056 \ 0.001)$, begins to move to the right side towards the sample, where an air gap is retained on the surface. Starting from time $0.007$ s, the liquid comes into contact with the sample surface. In the interval from $0.002$ s to $0.005$ s, air is displaced and a gas-liquid phase is formed. The interaction occurs over some areas in the time interval between $0.009$ s and $0.013$ s, when the paper fibers begin to swell according to the information of the ultrasonic device manufacturer [12].
Figure 3. Visualization of the interaction of a dampening solution with a paper sample in the ParaView package for time $t = 0.007$ s

Figure 4. Visualization of the interaction of a dampening solution with a paper sample in the ParaView package for time $t = 0.009$ s
Figures 6-13 show the numerical results for the scalar velocity $U_x$ and pressure $p$ when calculating with a step of 0.001 s and 0.0001 s. The diagrams of the scalar field $U_x$ representing the x component of the velocity along the vector drawn between the points of coordinates 1 (0 0.045 0.001) and 2 (0.0455 0.045 0.001) are constructed for a two-dimensional model Fig. 6-13. The vector runs parallel to the X axis and coincides with the centers of the transmitter and receiver of the ultrasonic signal.
Figure 8. Ux/cell width L diagram for time $t = 0.013$ s, calculation step 0.001 s

Figure 9. Ux/cell width L diagram for time $t = 0.013$ s, calculation step 0.0001 s

Figure 10. Pressure p/cell width L diagram for time $t = 0.009$ s, calculation step 0.001 s

Figure 11. Pressure p/cell width L diagram for time $t = 0.009$ s, calculation step 0.0001 s
Figure 12. Pressure p/cell width L diagram for time $t = 0.013$ s, calculation step 0.001 s

Figure 13. Pressure p/cell width L diagram for time $t = 0.013$ s, calculation step 0.0001 s

Velocity $U_x$ takes negative values between coordinates 1 (0.045 0.001) and 2 (0.0455 0.001). This change is possibly due to the reverse movement of the liquid after colliding with the paper surface. For the scalar velocity $U_x$, pressure $p$ and pressure $p_{rgh}$, the change in the calculation step from 0.001 s to 0.0001 s showed significant changes in the diagrams and calculation results for the time values $t = 0.002$ s, $t = 0.005$ s, $t = 0.013$ s, $t = 0.025$ s with similar visualization of the ongoing processes.

5. Conclusion
Simulation using the Open Foam software package is an informative numerical research tool. By changing the input data, it is possible to study and predict the process of the fountain solutions movement towards the surface of the paper sample and interaction with it in the measuring cell of the PDA device in a period of time that is not recorded. Numerical calculation showed that the specified thickness of the air film, which the sample captures with itself during immersion, is significantly small in relation to the dimensions of the cell and is inconvenient for calculation, since it gives mathematical errors when changing the calculation step from 0.001 s to 0.0001 s. With this model, it is difficult to take into account the microgeometry of the paper sample surface. It is recommended to simulate small areas where the liquid interacts with the sample surface, taking into account its roughness.

From the visualization of calculations in the ParaView package, it was found that the removal of the air layer adjacent to the paper surface occurs instantly and takes 0.006 s, and then a gas-liquid mixture is formed at the paper surface, which is gradually removed. Negative values of the liquid velocity imply its movement in the cell in the opposite direction after colliding with the paper surface in the
direction of the vector drawn between the coordinate points 1 (0; 0.045; 0.001) and 2 (0.0455; 0.045; 0.001). A numerical model of the interaction of a fountain solution at the liquid-air interface with a paper surface in a PDA measuring cell has been successfully tested. The model created in the Open Foam software package using the VOF method can be used to visualize and estimate the time of the beginning of the dampening solution interaction with the paper surface, but it requires additional verification of the mathematical accuracy.

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