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CFD SIMULATION OF THE EFFECT OF GAS CONTENT IN HYDRAULIC FLUID ON THE INTENSITY OF CAVITATION PROCESSES

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Abstract

Hydrodynamic cavitation in hydraulic systems is strongly influenced by the gas content of the working fluid. This study investigates the effect of dissolved gas concentration on cavitation intensity using Computational Fluid Dynamics (CFD). A three-dimensional model of a throttle cavitator was developed and analyzed in Solid Works Flow Simulation. Numerical simulations were performed for water at 40°C with dissolved gas mass fractions ranging from 1×10^{-6} to 1×10^{-3}. The vapor mass fraction downstream of the throttling orifice was used as the primary indicator of cavitation development. The obtained results show that increasing the dissolved gas content leads to a higher vapor mass fraction and a larger cavitation region under identical hydraulic conditions. The findings confirm that gas content significantly affects cavitation dynamics and should be considered during the design and optimization of hydraulic equipment and cavitation devices.

Keywords: hydrodynamic cavitation, CFD simulation, dissolved gas content, hydraulic fluid, vapor mass fraction.

INTRODUCTION

Cavitation in hydraulic systems is a well-known yet insufficiently studied phenomenon that can play both positive and negative roles in equipment operation. The consequences of cavitation range from the destruction of hydraulic system components to a significant intensification of mixing and heat transfer. Studying the process of hydrodynamic cavitation is a complex task, as it depends on numerous factors that are difficult to account for in physical experiments. Observing the phenomenon of hydroluminescence—the light emission that can accompany hydrodynamic cavitation—presents an even greater challenge[1, 2].

One of the factors influencing cavitation intensity and cavity formation is the proportion of dissolved gases in the liquid. This issue has been addressed in numerous scientific studies. The influence of gas (both undissolved and dissolved) on cavitation processes in hydraulic oils and working fluids is a key topic in the modern analysis of positive-displacement and throttling hydrodynamics. Gas content significantly alters the formation mechanism, type, and destructive potential of cavitation phenomena. Hydraulic oils typically contain approximately 8–12% dissolved gas by volume [3].

The following mechanisms regarding the influence of gas content can be identified.

Change in the pressure value at which cavitation is observed. When local static pressure drops below the saturation pressure

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of the dissolved gas, gas bubbles are released (diffusive/gas cavitation). This process occurs much earlier (at higher pressures) than classical vapor cavitation, which requires a pressure drop to the liquid's saturated vapor pressure.

Damping effect of free gas (Reduction of collapse intensity) In case of low gas content or degassed fluid bubbles consist primarily of vapor. Upon entering a high-pressure zone, ultra-fast implosions occur, generating cumulative jets and shock waves of extreme amplitude, which leads to intense cavitation erosion [4]. The presence of undissolved gas inside a bubble acts as a damper. As the bubble is compressed, the gas resists—undergoing isothermal or adiabatic compression—and significantly reduces the peak shock-wave pressure, thereby diminishing destructive force and erosive wear. Comparative tests between degassed oils and air-saturated oils prove that partial gas saturation reduces material mass loss (cavitation wear) due to a damping effect.

Effect on the cavitation inception threshold. Gas microbubbles serve as the primary cavitation nuclei. An increase in free gas content lowers the critical cavitation number (σ); in other words, cavitation begins at lower flow velocities or higher static pressure values [4].

Changes in acoustic properties and the modulus of elasticity. Free gas dramatically reduces the fluid's effective modulus of elasticity and the speed of sound within the medium. This causes delayed hydraulic actuator response, self-excited oscillations, pressure pulsations, and low-frequency noise [4, 5].

Thus, the study of hydrodynamic cavitation is an important scientific and technical task that will enable the optimization of the operation of various technological systems.

EXPOSITION

Among modern methods for investigating cavitation phenomena in hydraulic systems and devices, the following areas can be distinguished: optical visualization and experimental studies and mathematical and numerical modeling (CFD).

Investigation of two-phase flows in throttle gaps and valves by using of high-speed imaging and optical methods to measure bubble size distribution demonstrate the distinction between gas degassing zones and vapor cavitation zones downstream of throttling elements [4].

Numerical modeling with classical cavitation models primarily describe vapor cavitation. Researchers adapt these models by incorporating mass transfer equations based on Henry's Law and the Rayleigh-Plesset equation to account for gas degassing [6].

This work continues research previously described in studies [7, 8] that involved the visualization of cavitation in a throttling device, flow modeling within that device, and the acquisition of qualitative results closely matching those obtained during physical experiments. Given that the physical experiment was accompanied by the phenomenon of hydroluminescence, this study examines the influence of various factors on cavitation intensity and seeks flow parameters that exhibit extrema in the regions where cavitation and light emission are observed.

Specifically, a modeling study was conducted to investigate the effect of dissolved gas content in the liquid on the vapor mass fraction in the flow downstream of the constriction.

The study was conducted using the 3D model discussed in the paper [7] and the SolidWorks 2026 Flow Simulation software package. A straight section was added at the cavitator outlet to stabilize the flow and improve solution convergence (Fig. 1).

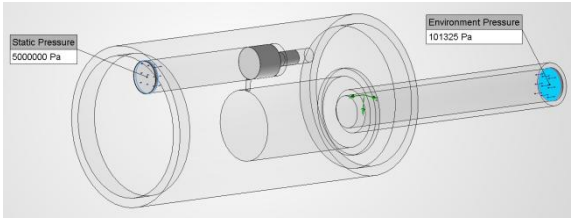


Fig. 1. *Three-dimensional model of the cavitator and the boundary conditions*

During the simulation, the "Dissolved gas mass fraction" parameter was varied within the simulation settings. Water at a temperature of 40°C was selected as the working fluid.

The computational mesh was refined within the orifice—where cavitation occurs—and in the region immediately downstream. In total, the computational mesh consists of 88469 elements (Fig. 2).

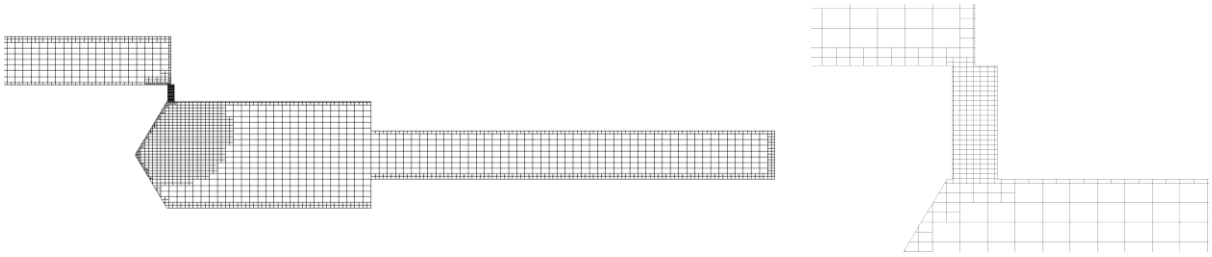


Fig. 2. *Computational domain meshing and local meshing in the orifice*

The "Dissolved gas mass fraction" values were set to 1×10^{-6}, 1×10^{-5}, 1×10^{-4}, and 1×10^{-3}. The average dissolved gas mass fraction in hydraulic drive working fluids is on the order of 1e-4, whereas the value of 1e-6 corresponds to a highly degassed fluid.

As a result, images were obtained showing the change in the vapor mass fraction within the flow at various levels of undissolved gas content in the liquid. Figure 3a shows distribution at Dissolved gas mass fraction" equals to 1×10^{-6}, 3b - equals to 1×10^{-5}, 3c - equals to 1×10^{-4} and 3d - equals to 1×10^{-3}.

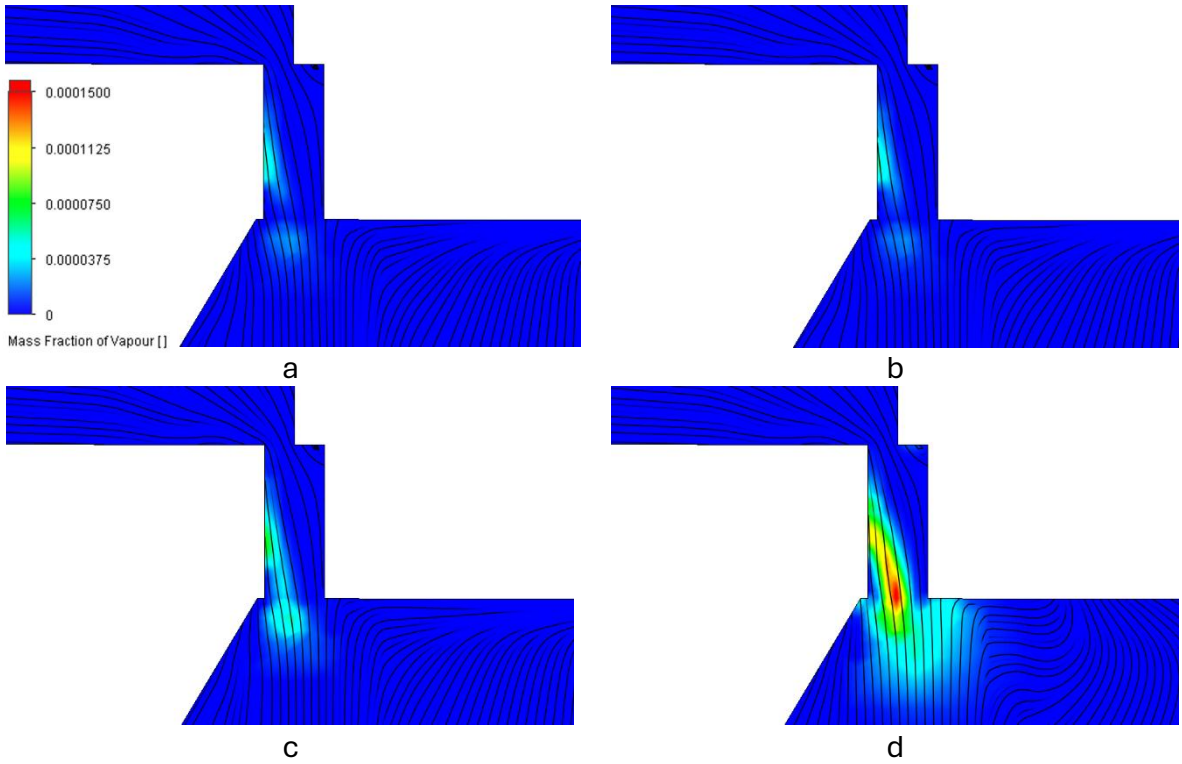


Fig. 3. *Mass fraction of vapor distribution in the throttling gap*

An increase in the vapor mass fraction within the throttling orifice is observed as the undissolved gas content in the liquid rises, with all other simulation conditions remaining constant. This may indirectly indicate a significant influence of this

parameter on the intensity of cavitation phenomena within the system.

The region of maximum vapor fraction in the presented figures coincides with the regions where cavitation and luminescence were observed during the physical experiment conducted under similar parameters. However, it should be noted that the physical experiment was performed using HLP-type hydraulic oil as the working fluid.

A more precise assessment of the phenomenon can be made using the cavitation number—a dimensionless similarity criterion for hydrodynamic flows that characterizes a fluid's susceptibility to cavitation.

$$\sigma = \frac{p - p_v}{\frac{1}{2}\rho v^2}, \quad (1)$$

where p — absolute static pressure of the liquid in the undisturbed flow (Pa); p_v — saturated vapor pressure of the liquid at the given temperature (Pa); ρ — liquid density (kg/m³); v — characteristic flow velocity (m/s).

CONCLUSION

The present study investigated the influence of dissolved gas content on hydrodynamic cavitation in a throttling device using CFD simulation. A three-dimensional numerical model was developed to analyze the distribution of vapor mass fraction under different levels of dissolved gas concentration in the working fluid.

The obtained results indicate that an increase in dissolved gas content promotes the formation of vapor cavities and leads to a higher vapor mass fraction in the flow downstream of the throttling orifice. These findings confirm that gas content is a significant factor affecting cavitation inception and development.

The study demonstrates the applicability of CFD methods for evaluating the influence of fluid properties on cavitation characteristics. The results may be useful for the design and optimization of hydraulic equipment operating under cavitating conditions. Future research should focus on quantitative validation of the numerical results through experimental studies and on identifying correlations between gas content and cavitation intensity.

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