Investigation of Dense Wastewater Discharge Dynamics through Varying Diffuser Designs: An Integrated Experimental and CFD Study

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Abstract:

Domestic and industrial wastewater is often discharged—either treated or untreated—into large receiving water bodies such as seas, oceans, and lakes. Upon discharge, the wastewater undergoes horizontal and vertical dilution driven by density differences as it moves toward the surface. The extent of this dilution is significantly influenced by the design of the discharge system. Among the key design components are diffusers, which play a crucial role in determining how the effluent is released into the receiving body. Optimizing dilution performance is possible by adjusting various design parameters of the diffuser, including its shape, structure, height, and discharge angle.

This study comprises both experimental investigations and numerical modeling. In the experimental phase, critical discharge parameters—such as initial dilution and the impact point of horizontally discharged dense water—were evaluated using different diffuser designs. The experiments were conducted in a laboratory water tank measuring 150 × 50 × 60 cm. Three different diffuser configurations were developed, and a saline solution with a known density was discharged into the tank through these diffusers to observe horizontal and vertical dilution characteristics. The diffuser prototypes, representing the novel aspect of the study, were fabricated using a 3D printer (Anycubic Photon M3 Max). Rhodamine B dye was added to the discharge fluid to visualize the jet behavior in the receiving environment. High-resolution imagery was obtained using a digital camera to capture the dispersion patterns of the dyed wastewater.

Across the tested models, key external parameters—such as the number of outlets, discharge angle, and outlet diameter—were held constant, while only the internal geometry of the diffusers was modified. The density of the discharge fluid was also kept consistent throughout the experiments. Complementary to the physical tests, Computational Fluid Dynamics (CFD) simulations were performed for one diffuser geometry, incorporating various turbulence models and mesh densities. The numerical results were then compared with experimental findings in terms of density distribution and horizontal spread of the dense jet, both visually and quantitatively.

The outcomes of the study are expected to determine the precise location of the impact point, confirm the compatibility between experimental and numerical results, and demonstrate that the novel diffuser design enhances both jet trajectory and dilution efficiency.

Keywords:

Discharge, Dilution, Diffuser Design, CFD, Intensive water discharge.