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Research Progress of Hydrodynamics in Hydraulic Engineering

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Abstract

Fluid mechanics is a complex and profound subject, and the knowledge it involves can be applied to many areas of our lives, from our drinking water to the bio-organic materials used to explore the universe, covering almost every aspect of human activity. Of course, in the aspect of hydraulic engineering, the relevant application of fluid mechanics is also essential, such as the relevant numerical calculation in hydraulic engineering, the flow pattern analysis and regulation effect analysis in waterway regulation engineering, and the interaction between fish and fluid, etc. In general, the relevant laws of fluid mechanics have broad application prospects and scientific value, and people are constantly exploring and innovating on the road of studying fluid mechanics, so as to better understand fluid mechanics and apply fluid mechanics.

Keywords

Hydrodynamics; Hydraulic Engineering; Waterway Regulation.

1. Introduction

Fluid mechanics is an ancient and full of vitality of the subject, its application in all walks of life is quite extensive, in the application of hydraulic engineering is too numerous to enumerate. At present, I have basically mastered the basic concepts, basic laws, basic physical phenomena in fluid mechanics and the corresponding basic methods to deal with problems in fluid mechanics. It is divided into four main parts, including field theory and tensors, which are important tools for the study of fluid mechanics related problems. The second part is to solve the problems related to fluid mechanics and establish the basic equations of fluid mechanics, whether it is to study computational fluid mechanics or some other interdisciplinary disciplines bordering on fluid mechanics, fluid mechanics equations are one of the most basic starting points. In the third part, the laws of the occurrence, development and extinction of some vortices in fluid mechanics are introduced, and Bernoulli's integral and momentum theorems, which are very useful in solving practical problems in fluid mechanics, are introduced. The fourth part deals with viscous fluids, ideal fluids, incompressible fluids and compressible fluids. Thus, I realized the development history and laws of fluid mechanics. After consulting the relevant research results of fluid mechanics in recent years and domestic and foreign literatures, combined with my research direction, I learned about fluid mechanics in hydraulic engineering and waterway regulation, and found that fluid mechanics is indeed a complex system.

2. Complex Fluid Mechanics

Raymond T. Pierrehumbert pointed out in his 2022 study that fluid mechanics constitute a typical complex system. In fact, the study of fluid mechanics existed long before the term "complex systems" was coined. In the case of incompressibility, we don't even need to introduce too many equations of state, it's just a matter of Newton's laws repeated many times at every point in space, along with Lagrange constraints that enforce incompressibility and molecular viscosity to remove fluid energy at small scales. There is no structure in this system, but it can spontaneously emerge with all kinds of amazing coherent structures and phenomena.

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Leonardo Da Vinci himself was fascinated by the almost organic forms created by fluid flow, as can be seen in his exquisite paintings of turbulent fluids. In his 2022 study on hydrodynamic diffusion of non-Newtonian fluids flowing in porous media, Senyou An explored the difference between solute transport and Newtonian limits in non-Newtonian fluid flows in porous media. The interaction between the complex rheology of non-Newtonian fluids and the disordered morphology of porous media shows that the escalation of the flow and transport of non-Newtonian fluids in this medium is much more complicated than that of Newtonian fluids. The final simulation results show that there is a striking non-monotonic relationship between the injection rate and the dispersion of the fluid. The dispersion of Newtonian fluids flowing in porous media is constant in the flow state they studied. However, they also found that the dispersion of non-Newtonian fluids in flow is related to shear. This also highlights gaps in existing theories of the transport of non-Newtonian fluids in porous materials, which can lead to misestimates of dispersion coefficients in porous materials when the rheological properties of fluids cannot be expressed in Newtonian mechanics.

In a 2022 study, Tali Khain pointed out that the Stokes flow of three-dimensional fluids has odd and anti-odd viscosities. The Stokes equation describes that the inertia force can be ignored in comparison to the viscous force. Tali Khain investigated the effect of violating parity and non-dissipative viscosity on three-dimensional Stokes flow. The inverse singular viscosity refers to the coefficient that the viscosity tensor is not constant under the reflection of the space mirror image, while the singular viscosity refers to the coefficient that does not dissipate mechanical energy. They begin by systematically enumerating all possible odd-even violations of viscosity compatible with cylindrical symmetry, highlighting their connection to potential microscopic realizations. Then, the effects of the violation of odd-even viscosity on Stokes solution, on the flow of liquid spheres or bubbles, and on the settlement of multiple particles are analyzed by combining analytical and numerical methods. In all the cases obtained, even if the driving force is parallel to the axis of cylindrical symmetry, the violation of parity viscosity will cause the azimuth flow. Compared with the conventional Stokes flow, the azimuth flow bends the trajectory for a few settling particles. For particle clouds, the directional flow prevents the transformation of the spherical cloud into a torus, and the subsequent splitting into smaller parts.

In a 2019 study on mesoscale transport of viscous particle fluids, S. Lududing found that fluid mechanics and rheology involve many unresolved challenges related to the transport mechanisms of mass, momentum, and energy, especially when it comes to realistic, industrially relevant materials. Of interest are suspensions or particle fluids containing solid particle components, which have contact mechanics at the microscopic scale and thus affect the transport properties at the continuum or macroscopic scale. Each transport coefficient is related to the propagation and evolution of one (or more) of these quantities. For simple fluids, it is possible to bridge the gap between (macroscopic) hydrodynamics and (microscopic) atomic scales; For example, the diffusion coefficient quantifies mass transport mediated by microscopic fluctuations. At the same time, he also pointed out that the presence of durable aggregates in the presence of sufficiently strong cohesion is a fact used in wet granulation processes to make stable, larger particles with better processing and flow characteristics than the usual fine, viscous primary particles.

John W. M. Bush pointed out in his research on navigational wave fluid mechanics that the complex system of fluid mechanics, as a kind of quantum mechanics, has considerable limitations, but some limitations can be circumvented to a certain extent now. The hydrodynamic navigation wave system is a new type of dynamic system, in which the droplet used in the experiment realizes self-motion and self-propulsion through resonance with its own wave field. Its various characteristics allow us to associate it with single and double quantized

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orbitals, tunneling effects, quantum single particle diffraction, orbital energy splitting, spin and multimodal statistics, all of which can be explained by navigational wave mechanics.

3. Fluid Mechanics in Hydraulic Engineering

Water is an essential element for life on Earth, covering 71% of the planet's surface. In addition, humans associate water with the environment. Hydraulic engineers are at the forefront of scientific developments to provide water to communities and protect our society from water-related disasters. The technical tasks facing hydraulic engineers are formidable, and ongoing research work is essential to provide a basic understanding of different phenomena, as well as to provide predictions for design. In particular, the scientific challenges with respect to environmental fluid flow are significant. Hubert Chanson, in his 2020 study on Environmental fluid Mechanics for Hydraulic Engineering, notes that environmental fluid mechanics includes scientific studies broadly relevant to the natural fluid systems on our planet that affect the quality of the living environment. Understanding transport and diffusion processes in natural fluid flows, from the submillimeter scale to the planetary scale, is a driving force for the development of theoretical models, simulations, and predictions that ultimately lead to sustainable environmental management. Secondly, he also pointed out that the interaction between fish and fluid is an unsolved problem in the field of environmental fluid dynamics. Sediment transport and erosion processes also need more work and more in-depth research and understanding; The self-aeration of hydraulic buildings must also be embedded in the hydraulic design. To solve these problems, newer experimental techniques, numerical models, and joint modeling methods are needed to address these challenges. Future research must further include the implementation of new high-quality field measurements, in situ measurements at the full scale. In many applications, the main challenge of prototype-scale hydraulic flow is its two-three-phase nature, which may include water, air, and sediment.

The application of fluid mechanics in hydraulic engineering is very extensive. In the study of Cheng Yongguang and Yang Jiandong et al in 2005, three-dimensional computational fluid mechanics method was used to calculate the impedance coefficient of surge chamber. Because the water flow in the diversion system of most hydropower stations is mainly turbulent, the Reynolds number is generally high, and the hydraulic loss is mainly divided into two types: along the way and local. The hydraulic design of surge chamber is mainly based on the calculation results of hydraulic transition process. Secondly, the surge chamber is composed of many geometric flow channels of different shapes, and because the flow channels are usually close to each other or directly combined together, their hydraulic characteristics are always interrelated, resulting in its total hydraulic characteristics cannot be simply superimposed by the hydraulic characteristics of many single flow channels, which leads to inaccurate results. Up to now, fluid mechanics has become an important means to optimize design and replace most model tests. As long as the turbulence model is properly selected, the edge wall treatment is accurate, and the calculated mesh density reaches the corresponding value, the head loss coefficient can be obtained to meet the design needs.

Bifurcation is also a classic problem in fluid mechanics and river dynamics. In 2018, Zhang Wei, Fu Yujie, Guo Jinkan, Feng Haochuan et al. studied the impact of tidal wave movement on the diversion of the Yangtze River estuary by conducting three simulations of "no path", "no tide" and "radial tide" respectively, and quantitatively decomposed the impact degree of the interaction between runoff, tidal current and radial tide on the diversion. The influence of deep water channel regulation project in the diversion process is also discussed. The final verification results show that the tidal wave movement in the flood season and the dry season, 35.71% and 32.95% respectively, has the effect of restraining the uneven coefficient of the north-south port diversion, so as to achieve the effect of the diversion tends to be uniform.

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In hydraulic engineering, the erosion and deposition of the downstream river caused by the operation of the reservoir is also a focus issue. Zhang Wei, Wu Meiqin, Li Sixuan, Yuan Jing, Gao Yu et al. applied a lot of knowledge of fluid mechanics and river dynamics in their study on the adjustment mechanism of the erosion and deposition of the river from Chenglingji to Jiujiang after the impounding of the Three Gorges Reservoir in 2020. The characteristics and driving mechanism of the downstream channel erosion and deposition adjustment influenced by the reservoir are studied, and the distribution of the channel erosion and deposition and the characteristics of the cross section morphology change from Chenglingji to Jiujiang are analyzed accordingly. It is concluded that the erosion of the basic channel from Chenglingji to Jiujiang has intensified since the 175-meter experimental storage of the Three Gorges Reservoir in 2008, and the erosion and deposition changes of the channel are mainly concentrated in the basic channel, which accounts for more than 90% of the whole Pingtan channel. The change of section shows that the channel is scoured down and the section tends to narrow and deepen.

However, in waterway regulation engineering, the groin group of waterway regulation changes the local hydrodynamic conditions to a certain extent, which also has a great impact on the habitat of fish. This is also the problem of fish and fluid interaction mentioned earlier. Chang Liuhong, Xu Bin, Zhang Peng, Tang Wei et al., in their 2019 study on the impact of DAMS in regulation of deep water channel on fish habitat, pointed out the rule of "three fields and one channel" influence of DAMS in regulation of tidal channel on fish. The related research shows that there are relatively complex flow structure and slow flow area near the dam group, which provides a very suitable spawning ground for drift fish and sinuous fish. The bottom slow flow area and still water environment behind the groin dam provide a suitable wintering place for fish. It is because of the unique flow structure of the dam group that the plankton in the river channel is transported laterally to enrich behind the dam, which provides a rich feeding ground for fish to forage for food. After the completion of the dam group, the range of the nearshore slow flow area on the right margin of Shiye Island has obviously expanded, which provides a stable migration channel for the migration of fish eggs and larvae.

4. Conclusion

Fluid mechanics is an ancient and rich discipline, and the knowledge and energy contained therein will play a very important role in my future research, whether it is in the numerical calculation of relevant hydropower stations in hydraulic engineering, tidal wave analysis, bifurcation and regulation effect analysis in waterway regulation engineering, or in the ecological intelligent waterway. The interaction between fish and fluid and so on. I can use the knowledge and methods related to fluid mechanics to conduct experiments and model verification. Of course, as can be seen from the previous paragraph of this paper, fluid mechanics is a complex system after all. Whether it is from the most basic theoretical analysis to physical experiment verification, as well as based on big data and computer numerical calculation methods, people's relevant research on fluid mechanics is still moving forward. People use their wisdom to constantly understand fluid mechanics, understand nature, and finally live in harmony with nature. Therefore, the study of relevant laws of fluid mechanics has broad application prospect and scientific value.

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