Experimental Investigation on the Effects of Particle Concentrations on Cavitation Development in the Venturi Tube

Xiangdong Han[1], Youchao Yang[2], Chao Wang[2,4], Pengjun Fan[3(✉)], and Jianqi Hu[3]

[1] School of Civil Engineering, Nanchang Institute of Technology, Nanchang 330044, China
[2] Chongqing Pump Industry Co., Ltd., Chongqing 400033, China
[3] Machine Industry Lanzhou Petrochemical Equipment Inspection Institute Co., Ltd., Lanzhou 730070, China
fanpengjub@lanpec.com
[4] College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin 150001, China

Abstract. Effects of different particle concentrations on cavitation development in the Venturi tube were experimentally investigated. The concentrations selected were 0.5%, 1.0%, and 1.5%. High-speed camera was used to observe shapes of cavitation bubbles and distributions of particles. Analyses on cavitation development degree at T_0 ms, $T_0 + 30$ ms, and $T_0 + 91$ ms moments were performed to determine the role of concentration. Results indicated that particles distributed in cavitation regions, which showed that they had a close relation with cavitation development. Cavitation regions became larger steadily with time. Under different moments, effects of the concentration on cavitation evolution were various. At T_0 ms moment, cavitation evolution was steadily promoted with the concentration increase; for $T_0 + 30$ ms and $T_0 + 91$ ms moments, cavitation development degree became more intense first and then, was weaker.

Keywords: Cavitation development · Particle concentration · Venturi tube · Experimental measurement

1 Introduction

Cavitation is one kind of multiphase flow, one common phenomenon in many fluid-handling types of machinery, such as pump, hydroturbine, nozzle, and propeller [1]. Cavitation occurrence and development show a closed relationship with local pressure and velocity, which are influenced by surface roughness, boundary condition, and other factors in turn [2]. A combination of numerical simulation and experimental measurement, these various impact factors have been studied deeply [3].

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Rivers and oceans in nature include solid particles and suspended sediments more or less and many fluid-handling devices are operated in this kind of environment. Therefore, cavitation onset and evolution are significantly affected by solid particles. That is solid particle-water cavitation flow, one complex solid-liquid-vapor and three-phase flow coupled with mass transfer [4–6].

Many scholars have performed discussions on the synergetic destruction of solid particle abrasion and cavitation erosion caused by solid particle-water cavitation flow towards different materials; however, the results they got were various. Representative literatures were as follows.

Huang et al. [6] discussed the effects of mean diameter, concentration, and hardness of four different kinds of solid particles which are quartz, aluminum, nickel, and molybdenum, experimental time, and specimen size on cavitation erosion. Jin et al. [7] analyzed the influence of solid particles on cavitation erosion of 18Cr-8Ni iron. One remarkable conclusion they got was that joint damage was more intense than the sole action of solid particle abrasion or cavitation erosion. Gou et al. [8] studied the synergetic destruction of solid particle abrasion and cavitation erosion on 1045 carbon steel under the particles with diverse diameters and densities. Madadnia et al. [9] got that cavitation erosion in the material surface was accelerated in particle-laden cavitation flow. Zhao et al. [10] investigated resistance mechanism on the joint damage of silt particle abrasion and cavitation erosion. Their results indicated that total mass loss was the weighted sum of mass loss of single solid particle abrasion and single cavitation erosion. Chen et al. [11] performed experiments to consider effects of solid particles with different sizes on cavitation erosion. The remarkable conclusion was that when the diameter was 500 nm, solid particles could induce the most intense cavitation erosion. Emelyanenko et al. [12] got that super hydrophobic coating on stainless steel surface could inhibit the joint damage of solid particle abrasion and cavitation erosion.

Although above investigation fruits were abundant, action modes of solid particles with different properties on cavitation evolution were not determined. Under this circumstance, the rig was designed and solid particle-water cavitation flow experiments under different concentration conditions were performed to achieve corresponding investigations.

2 Experimental Setup

2.1 Physical Model

The physical model employed was one Venturi tube. Primary sizes were that diameters of inlet and outlet are 30 mm and 50 mm, respectively; for the throat, it is 10 mm. Total length is 430 mm. Length of gradual reduce and expansion segments were 80 mm and 200 mm (Fig. 1).

Fig. 1. The physical Venturi tube.

Fig. 2. High speed camera.

2.2 High Speed Camera

High speed camera was utilized to observe the distribution of solid particles and evolution of cavitation bubbles. The type is FASTCAM SA5. In the experiments, the resolution setting was 1024 (horizontal) × 1024 (vertical). Photographic speed was 2000 fps. Total time was 5.495 s. Also, one LED light was used to make illumination supplement; therefore, brightness was sufficient (Figs. 2, 3 and 4).

Fig. 3. Nikon camera len.

Fig. 4. Led light.

2.3 Experimental Solid Particles

Solid particles used in the experiments were natural sea sands. Density is ρ_s = 2650 kg/m^3. Mean diameter was d_s = 0.1 mm–0.3 mm. The concentrations were α_s = 0.5%, 1.0%, and 1.5% (Fig. 5).

2.4 Experimental Rig

The whole experimental rig shown in Fig. 6 was employed to perform solid particle-water cavitation flow experiments.

Mixture of water and solid particles with different concentrations flew through water tank to the Venturi tube. Location of LED light could guarantee that high speed camera took clear images of cavitation bubbles and solid particles.

(1) α_s=0.5%

(2) α_s=1.0%

(3) α_s=1.5%

Fig. 5. Solid particles with different concentrations.

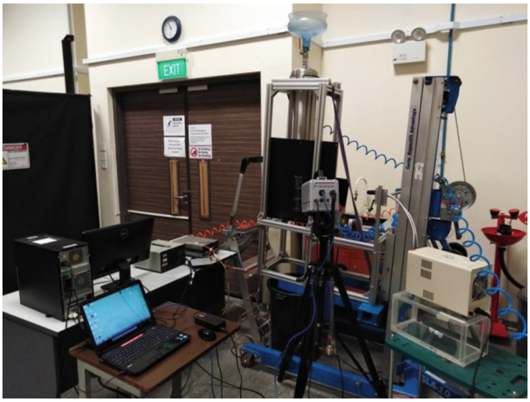


Fig. 6. Experimental rig of solid particle-water cavitation flow.

3 Results and Discussion

Three different moments: T_0 ms, $T_0 + 30$ ms, and $T_0 + 91$ ms were selected to analyze effects of different solid particle concentrations on cavitation evolution in the Venturi tube. Length of cavitation bubbles under diverse concentration conditions at T_0 ms moment was discussed. For T_0 + 30 ms and T_0 + 91 ms moments, the length and number of shedding cavitation bubbles were compared.

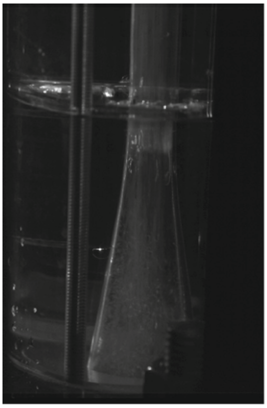
3.1 *T_0 ms Moment*

At T_0 ms moment, lengths of cavitation bubbles were different, which indicated that effects of diverse solid particle concentrations on cavitation evolution were various. For $\alpha_s = 0.5\%$, cavitation bubbles appeared at the end of throat segment and the distribution was symmetrical. While the length was particularly short. Therefore, corresponding effects of solid particle concentration on cavitation development were weak. At $\alpha_s = 1.0\%$, length of cavitation bubbles was obviously longer than in $\alpha_s = 0.5\%$. Increase of solid particle concentration significantly promoted the evolution of cavitation in the Venturi tube. Under $\alpha_s = 1.5\%$, the length was slightly longer than that of $\alpha_s = 1.0\%$. Effects of the increase of solid particle concentration continued facilitating the evolution of cavitation; however, the degree was especially weak (Fig. 7).

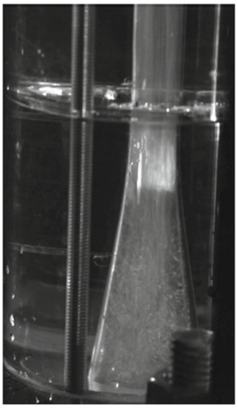
3.2 *$T_0 + 30$ ms Moment*

Compared with T_0 ms moment, cavitation under all concentration conditions had remarkable evolution. Cavitation bubbles began shedding in the gradual expansion segment.

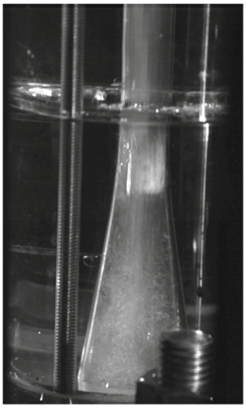
At $\alpha_s = 0.5\%$, length of cavitation bubbles became longer with the time increase. A few bubbles shed at the gradual expansion segment. From $\alpha_s = 0.5\%$ to $\alpha_s = 1.0\%$, the length became much longer. Number of shedding bubbles was more and the corresponding scope was larger. Cavitation evolution was promoted with the increase of solid



(1) α_s=0.5%

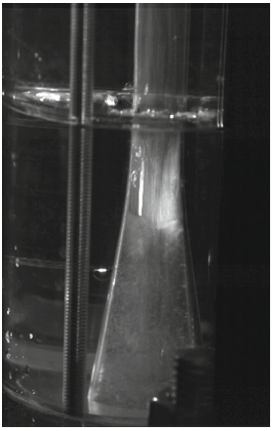


(2) α_s=1.0%

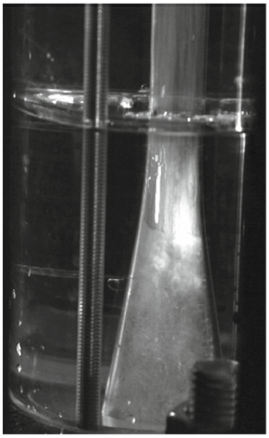


(3) α_s=1.5%

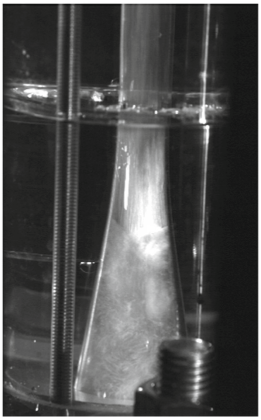
Fig. 7. Distribution of cavitation bubbles under T_0 ms moment in the Venturi tube.



(1) α_s=0.5%

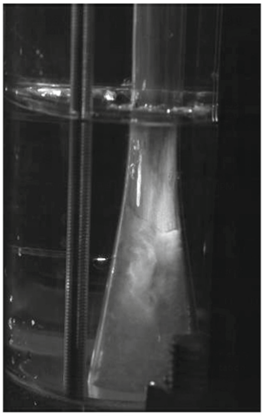


(2) α_s=1.0%

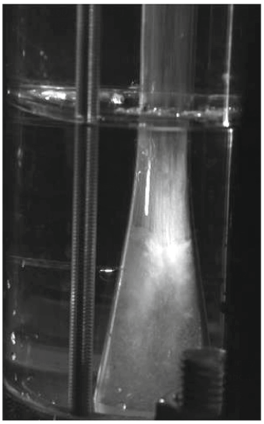


(3) α_s=1.5%

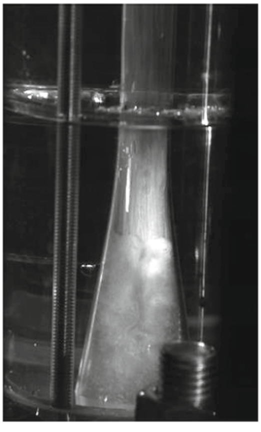
Fig. 8. Distribution of cavitation bubbles under $T_0 + 30$ ms moment in the Venturi tube.



(1) α_s=0.5%



(2) α_s=1.0%



(3) α_s=1.5%

Fig. 9. Distribution of cavitation bubbles under $T_0 + 91$ ms moment in the Venturi tube.

particle concentration. Under $\alpha_s = 1.5\%$, the length was slightly smaller than that of $\alpha_s = 1.0\%$; however, number of shedding bubbles became fewer and the shedding scope became smaller. The development degree of cavitation was weaker (Fig. 8).

3.3 T_0 + *91 ms Moment*

From $T_0 + 30$ ms moment to $T_0 + 91$ ms moment, cavitation in the Venturi tube continued developing. The most dramatically feature was that number of shedding bubbles was far more. Also, whole variation trend with the increase of solid particle concentration was identical with that in $T_0 + 30$ ms moment.

With solid particle concentration increase from $\alpha_s = 0.5\%$ to $\alpha_s = 1.0\%$, length of cavitation bubbles became longer. On the other hand, number of shedding bubbles was more and the shedding scope was larger. The concentration increase advanced cavitation evolution in the Venturi tube. Under $\alpha_s = 1.5\%$, difference of the length between that under $\alpha_s = 1.0\%$ was particularly small. Number of shedding bubbles became fewer and the corresponding scope was smaller. The evolution degree with the concentration increase was weaker (Fig. 9).

4 Conclusions

Experimental investigations about solid particle-water cavitation flow in the Venturi tube under $\alpha_s = 0.5\%$, 1.0%, and 1.5% was performed. Distribution characteristics of cavitation bubbles at T_0 ms, $T_0 + 30$ ms, and $T_0 + 91$ ms moments were analyzed. Main conclusions were as follows:

(1) At T_0 ms moment, solid particles continued promoting cavitation development in the Venturi tube with the increase of concentration.
(2) Under $T_0 + 30$ ms and $T_0 + 91$ ms moments, cavitation evolution degree became stronger first and then, was weaker.

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References

1. Li, S.C.: Cavitation of Hydraulic Machinery (2000)
2. Hammitt, F.G.: Cavitation and Multiphase Flow Phenomena (2008)
3. Washio, S.: Recent Developments in Cavitation Mechanisms (2014)
4. Han, X.D., Kang, Y., Zhao, W.G., Sheng, J.P., Li, D.: Silt particles affect cavitation flow: analyzing variations in silt mean diameter and concentration. Powder Technol. **356**, 671–690 (2019). https://doi.org/10.1016/j.powtec.2019.09.005
5. Zhao, W.G., Han, X.D., Li, R.N., Zheng, Y.J., Wang, Y.Y.: Effects of size and concentration of silt particles on flow and performance of a centrifugal pump under cavitating conditions. Mod. Phys. Lett. B **31**(34), 1750312 (2017). https://doi.org/10.1142/S0217984917503122

6. Huang, S., Ihara, A., Watanabe, H., Hashimoto, H.: Effects of solid particle properties on cavitation erosion in solid-water mixtures. J. Fluids Eng. Trans. ASME **118**, 749–755 (1996). https://doi.org/10.1115/1.2835505
7. Jin, H.Y., Zheng, F.Z., Li, S.Y., Hang, C.Z.: The role of sand particles on the rapid destruction of the cavitation zone of hydraulic turbines. Wear **112**(2), 199–205 (1986). https://doi.org/10.1016/0043-1648(86)90240-1
8. Gou, W.J., Zhang, H., Li, H.P., Liu, F., Lian, J.J.: Effects of silica sand on synergistic erosion caused by cavitation, abrasion, and corrosion. Wear **412–413**, 120–126 (2018). https://doi.org/10.1016/j.wear.2018.07.023
9. Madadnia, J., Owen, I.: Accelerated surface erosion by cavitating particulate-laden flows. Wear **165**, 113–126 (1993). https://doi.org/10.1016/0043-1648(93)90380-5
10. Zhao, K., Gu, C.Q., Shen, F.S., Lou, B.Z.: Study on mechanism of combined action of abrasion and cavitation erosion on some engineering steels. Wear **162–164**(Part B), 811–819 (1993). https://doi.org/10.1016/0043-1648(93)90082-W
11. Chen, H.S., Liu, S.H., Wang, J.D., Chen, D.R.: Study on effect of microparticle's size on cavitation erosion in solid-liquid system. J. Appl. Phys. **101**, 103510 (2007). https://doi.org/10.1063/1.2734547
12. Emelyanenko, A.M., Shagieva, F.M., Domantovsky, A.G., Boinovich, L.B.: Nanosecond laser micro- and nanotexturing for the design of a superhydrophobic coating against long-term contact with water, cavitation, and abrasion. Appl. Surf. Sci. **332**, 513–517 (2015). https://doi.org/10.1016/j.apsusc.2015.01.202