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Effects of the Coaxial-Assistant Air Stream on High-Pressure Submerged Water Jet

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Abstract

Currently, high-pressure water jet is mainly used in various applications such as paint peeling and cleaning of the surface of structures, fraying of concrete, cutting of materials, etc. in the atmosphere. Furthermore, the potential application of the water jet is expected to be used in underwater in order to develop marine industrial circumstances. In this paper, the authors have tried to maintain the performance of the water jet used in the submerged condition by the use of a specially developed water jet nozzle together with an air stream nozzle in order to avoid the decrease in the performance of the water jet. The water is ejected from a 1mm diameter nozzle, supersonic air flows in parallel around it. The injection pressure of the water was fixed at 12.7MPa and the stagnation pressure of the air was set at 0.5MPa and 0.7MPa. In case of the submerged water jet, the coaxial air stream has a large effect on the stagnation pressure on the impinging target plate. This effect suggest that the air stream surrounding the water jet behaves like the atmosphere even in the submerged condition. The stagnation pressure in the settling chamber of the air has almost no effect on the stagnation pressure on the target. Moreover, the stagnation pressure on the target is confirmed to decrease with the increase in the distance between the nozzle exit and the target.

1 Introduction

High-pressure water jet has been employed in a variety of industrial applications such as cutting, cleaning, surface reforming, etc. Eggers and Villermaux (2008), Annoni et al. (2017), Leu et al. (1998), Hashish (1988), Mohan et al. (1997) and Guha et al. (2011). Furthermore, from the practical engineering aspects, the use of water jet has a low environmental impact and excellent workability, further industrial application of water jet is expected in the future. It is well known that the high-pressure water jet into the still air is characterized by several distinct regimes such as nozzle flow, potential core, main flow, and diffused droplet regimes. However, the water jet into atmosphere still maintains its momentum because of the quite difference in density between the water and still air, which is quite applicable to industrial fields. It should be noted that the pressurized water jet is expected to penetrate targets because of its large density or large dynamic impact, which is however available only in an atmospheric condition. One the other hand, the demand for the application of the submerged water jet increases due to a maintenance or developments of marine structures or deep ocean resources. The flow fields around the water jet ejected into still water shows the typical flow structure as shown Fig.1 As shown in Fig.1, the velocity of the jet ejected into still water decreases as the jet moves downstream due to the momentum exchange between the jet and its surrounding water. The decrease in the jet velocity implies reduction in its performance. Therefore, in order to meet the recent potential demands for the submerged work, the velocity decay should be avoided in some ways. Referring to the flow field of the water jet and the atmospheric condition, the promising technique to maintain the submerged jet velocity is to simulate the atmospheric condition around the submerged water jet. Then, in order to achieve this kind of flow field, authors propose a special nozzle to discharge the water

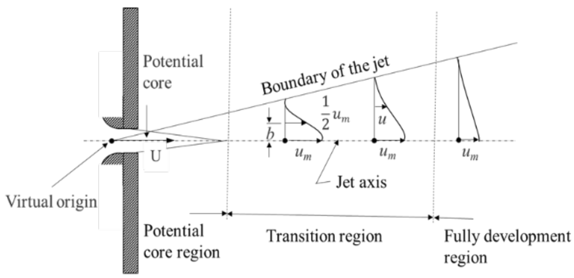


Fig.1 Basic structure of free jet

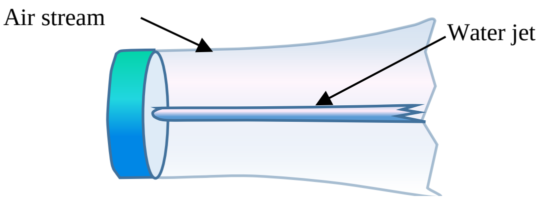


Fig.2 Concept of water jet with a coaxial air stream

jet and coaxial air stream. Fig.2 shows the concept of the flow field of the water jet and the coaxial assistant air stream that divides the water jet boundary and the still water. The coaxial air behaves like the atmosphere as shown in Fig.2, which is exaggerated air stream diameter. The water jet in Fig.2 is considered to moves downstream parallel to the main water jet. Then, if the air stream keeps to dividing the jet and the still water, water jet is supposed to keep its velocity as in the condition of atmosphere. In this paper, the effect of the air stream on the submerged water jet has been confirmed especially by means of measuring the stagnation pressure and comparing with the case of atmospheric condition as parameters of the distance between the nozzle exit and the impinging target plate and the stagnation pressure of the coaxial air.

2 Experimental setup

Figure 3 shows the experimental setup and the detail of the nozzle, respectively. The high -pressure water pump(Kärcher HD 7/15 CX) supplies the high-pressure water at about 12.6MP, which is discharged into the atmosphere or into the water. The pressure at the stagnation chamber and the stagnation point on the target plate are measured by means of the pressure sensors(Valcom VESVM35) and digitized by LabView. The pressurized air at 0.7MPa and 0.5MPa are also introduced to the settling chamber of the nozzle. The flow meter is attached upstream of the high pressure water pump. The specially developed nozzle consists mainly of two chambers for the water and the air, respectively as shown in Fig.4. In Fig.4, three rods are for the precise alignment between the water jet exit and pressure measurement tap of the target. The nozzle diameter of the water jet is 1mm, the diameter of the coaxial air is 3mm. For the preliminary experiments, the water pressure is fixed at about 12.6MPa, whereas the stagnation pressure of the air is set at 0.5MPa and 0.7MPa. The distance between the nozzle exit and the target L/D is varied from 2 and 15, where L is the distance between the nozzle exit and the plate, D the diameter of the nozzle exit. The 0.3mm tap is drilled at the target plate for the pressure measurements in order to evaluate the water jet performance. The optical observations are also done by a high speed digital camera and high resolution still camera.

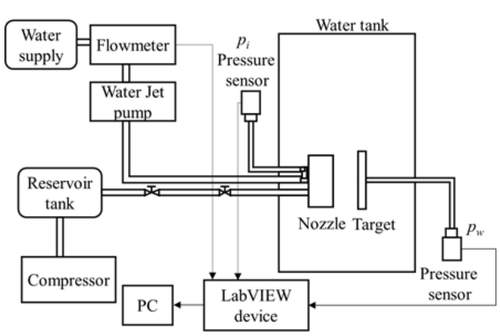


Fig.3 Experimental setup

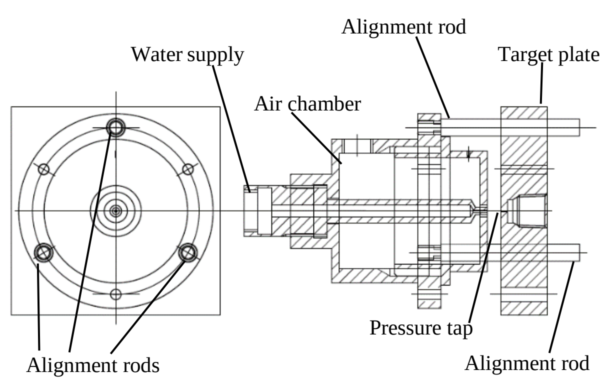
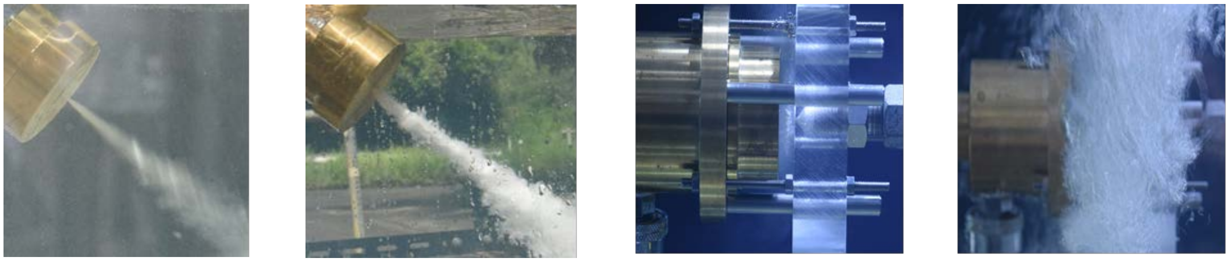


Fig.4 Detail of nozzle

3 Results and discussion

3.1 Optical observations

The optical observations are shown in Figs.5(a)~(d). Figures 5(a) and 5(b) shows the case of submerged free jet with and without coaxial air stream. In Fig.5(a), the cavitation cloud right after the nozzle exit is observed as many researchers have already reported: Sou et al. (2006), Nishimura et al. (2012) and Peng et al. (2016). Then, with the coaxial air steam, air bubbles discharged along the water jet which makes the jet



(a) Free submerged water jet without air stream

(b) Free submerged water jet with air stream

(c) Impinging Submerged water jet for L/D=5

(d) Impinging Submerged water jet with air stream

Fig.5 Optical observation from side view for injection pressure 12.7MPa

boundary unclear. Then, other technique such as a dye tracing for the visualization of this kind flow might be needed, which makes it possible to distinguish the jet from the surrounding water. Regarding the evaluation of the performance of a water jet, although the impinging flow field should be clarified. Figures 5(c) and 5(d) shows the impinging jet for L/D=1 with or without the surrounding coaxial air stream. It is found that the flow visualization might be quite difficult for this kind of flow especially from the side view.

3.2 Pressure measurements

The pressure measurements are quite simple ways to estimate the effect of the air flow especially on the target plate. As a reference, the injection pressures of the submerged and non-submerged water jet are checked and shown in Figs. 6. It shows that the surrounding water and the target plate have no effect on the injection pressure. In addition, as shown in Fig.7, the flow rate keeps constant for submerged and non-submerged conditions. These results ensure that the injection pressure is not affect by the parametric conditions and that the high pressurized water is supplied under a quite constant flow conditions by the pump.

The higher pressurized water jet issued from the nozzle exit is supposed to cause more damages against the target. Figure 8 shows the stagnation pressures on the target plate as a parameter of the distance between the nozzle exit and the plate L/D=1, 5, and 7 for the submerged water jet. It is found that the

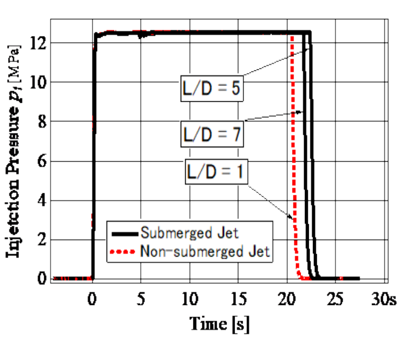


Fig.6 Injection pressure variations

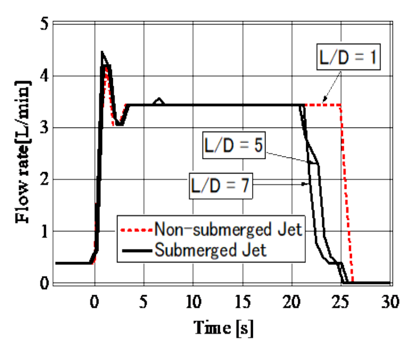


Fig.7 Flow Rate for injection pressure of 12.5MPa

pressures keep constant for all the distance L/D, whereas their values decrease with the increase in the distance L/D. It illustrates the decay of the velocity profile along the jet axis. Figure 9 shows the relation between the recovery factor and the injection pressure for the non-submerged water jet, where the recovery factor is defined by ratio of the stagnation pressure to the injection pressure. The recovery factor for the submerged without air stream denote by the symbol of open rectangular decreases with increase in the distance as a conventional structure variations. Moreover, it should be noted that the stagnation pressure

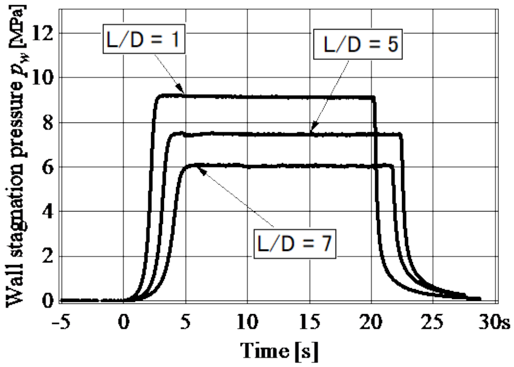


Fig.8 Stagnation pressure on the target plate for injection pressure of 12.5MPa for submerged jet without air stream

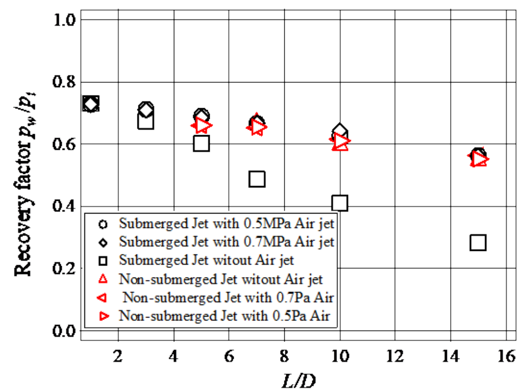


Fig.9 Relation between recovery factor and injection pressure

on the target plate denoted by open circle and diamond symbols considerably increase due to the existence of the coaxial air flow, which is almost the same as that for the case of non-submerged condition. These results suggest that the coaxial air stream around the water jet can generate a kind of atmospheric circumstances even in the submerged conditions. Therefore, the submerged water jet with the air stream has a quite important potential applications to future development of ocean industries and marine resources.

4 Conclusions

Submerged water jet with a coaxial air stream has been studied under the condition of the injection pressure of 12.7MPa and the stagnation pressure coaxial air of 0.5MPa and 0.7MPa. The summarizes are as follows:

1. The stagnation pressure on the target plate decrease as the increase in the distance between the nozzle exit and the target plate both in the submerged and non-submerged conditions.
2. The stagnation pressure of the coaxial air flow has almost no effect on the stagnation pressure on the target plate.
3. The coaxial air flow around the water jet considerably make stagnation pressure on the target plate increase, which indicate the atmospheric circumstances even in the submerged condition.
4. The increase in the stagnation pressure on the target plate suggests that there are promising potential application to the ocean industry and marine resources.

Acknowledgements

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