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To cite this article: Q Wang *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **240** 032033

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# Experimental study on the optimal range on nozzle-to-throat clearance of jet centrifugal pump

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**Abstract.** There has been a general recognition that the distance between the nozzle and the throat can affect the self-priming performance of the jet centrifugal pump. Although previous studies have been made to determine the range of the distance based on the method of numerical analysis, the approach of self-priming experiment has been seldom used. This paper presents the optimal range of this distance with the experimental measurements. A UJM100 jet centrifugal pump manufactured by a company in Zhejiang was used to complete the self-priming experiment. The nozzles with the diameter of 7mm, 8mm, and 9mm were used respectively to work with the the diameter of 15mm throat and the nozzle-to-throat clearance based on a original formula which denoted the relation between area ratio and the nozzle-to-throat clearance. The scheme with optimal self-priming and hydraulic performance was selected from the three schemes mentioned above. And this selected group should be adjusted the clearance of nozzle-to-throat to find out the optimal range. Finally, the changes of jet centrifugal pump's self-priming performance which were modified were analyzed within the usage of experimental measurement. As a result, the nozzle-to-throat clearance of this kind of pump exists a optimal range while the area ratio was in a certain scope. The scheme with the diameter of 9mm nozzle and the diameter of 16mm throat which can obtain the optimal self-priming performance was ascertained by experiment. Based on the tests, the value of the nozzle-to-throat clearance was selected at the range of 8.5mm to 9mm. According to the experiment, the relation between area ratio and the nozzle-to-throat clearance was modified to a new formula.

## 1. Introduction

Jet self-priming pump was developed by self-priming pump which widely used in agricultural irrigation. Self-priming pump is one of the important components of light small sprinkler. Jet self-priming pump consists of a jet and a centrifugal pump. Using the function of jet to improve the suction capacity of self-priming pump, with the aid of vacuum formed by the high-speed flow because of small diameter of nozzle to improve the suction capacity[1~2]. Compared with the traditional self-priming pumps, jet self-priming pump have the following advantages: user-friendly; reliable work; long service life; the secondary start dispense with irrigation and so on. Jet self-priming pump is also extensive used in drainage of agriculture; drinking water project in water depletion area; fire protection engineering; ship transport and other fields, especially in an application environment that needs to be restarted frequently jet self-priming pump has a bright application prospect[3~4].

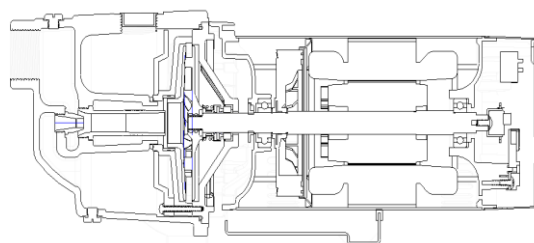


The operating principle of jet self-priming pump is slightly special, its suction capacity influenced by many factors, such as each component size of jet; impeller outlet width; impeller circle speed; gas-liquid separation chamber volume; the gap between the outer edge of impeller and the separation tongue of pump body and so on[5~7]. With the rapid development of computational fluid mechanics and its correlative software, many scholars have researched on the structure factors through numerical simulation[8~12] and some of them have given their optimal range on nozzle-to-throat based on numerical simulation studies. Hanxiang Hu deemed that the optimal rang on nozzle-to-throat clearance is between 0 to 2 times the nozzle diameter[13];Hongqi Lu thought that the best range on nozzle-to-throat clearance is between 0.5 to 1 times the throat diameter[14]; Xinping Long simulated the interior flow of jet self-priming pump by Fluent, according to the consequence he deemed that the optimal range on nozzle-to-throat clearance is between 0.5 to 1.5 times the nozzle diameter based on the efficiency result[15]. Changbin Wang holds that the optimal range on nozzle-to-throat clearance of jet pump is between 0.7 to 1.3 times the nozzle diameter based on the PHOENICS software[16] . Yanjun Ge simulated the liquid-gas jet pump by Fluent, on account of the efficiency curves he thought the optimal range of the nozzle-to-throat clearance located between 1.0 to 1.7 times of the nozzle diameter[17]. Because of the different operating conditions, there are slightly different between the each scholar's range. Also, the previous optimal range as regard the nozzle-to-throat clearance almost based on numerical simulation with less experiment results. Thinking the numerical simulation results reliable on account of the experimental data similar to simulation data in performance test, but in fact, the formula given by forefathers was used to test the self-priming performance, the height of self-priming did not achieve the ideal altitude and the time of self-priming did not shorten in that experiment. According to original formula the present study kept the original diameter of throat and altered the diameter of nozzle to testing the self-priming performance, comparing the three testing height results. Under the condition that guaranteed operating performance standards, adjusting the diameter of throat and the length of nozzle-to-throat clearance to work out the combination scheme that has attained the best hydraulic performance and the optimal self-priming performance. According to the self-priming experiment results, found out the optimal range on the nozzle-to-throat clearance closed to the facts.

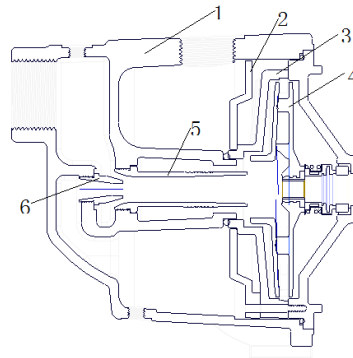
## 2. Experimental research on jet self-priming pump

### 2.1. Design parameters of the model pump and its structure

Selecting the model UJM100-2 jet self-priming pump as the object of this research, the main design parameters of this pump include the following: the rate of flow is  $5.5\text{ m}^3/\text{h}$ ; the hydraulic head is  $49.5\text{m}$ ; the rotate speed is  $3500\text{r}/\text{min}$ ; the external diameter of impeller  $120\text{mm}$ ; the outlet width of impeller is  $5.5\text{mm}$ ; the quantity of blade is 5.



**Figure 1.** Diagrammatic drawing of jet self-priming pump structure.



1.pump body 2.water baffle 3.diffuser 4.impeller 5.throat 6.nozzle  
**Figure 2.** Inside chart of the jet self-priming pump body.

The original parameters of jet device in this pump include the following: the diameter of nozzle is  $7\text{mm}$ ; the diameter of throat is  $15\text{mm}$ ; the distance of nozzle-to-throat is  $7\text{mm}$ . The highest self-priming altitude of this model pump is  $6.1\text{ meter}$  and the self-priming time is  $130\text{ second}$  based on the self-priming experiment. The result of self-priming did not yet achieve our goal parameters and far away from the design data. Through improving the self-priming performance to amend the value range of nozzle-to-throat clearance. In order to further improving jet self-priming pump provided experiment data for reference .

## 2.2. Improvement scheme

There are two main hydraulic components that influence the self-priming performance of this pump: the jet device and the impeller. The distance of the nozzle-to-throat and the diameter of nozzle and the diameter of throat influence the self-priming height and the time of self-priming in this type of pump. It is beneficial to optimize the parameter of jet device for improving the self-priming performance.

On the basis of the original equation of the nozzle-to-throat clearance and the value table of the nozzle-to-throat clearance with specific area ratio[18~19]:

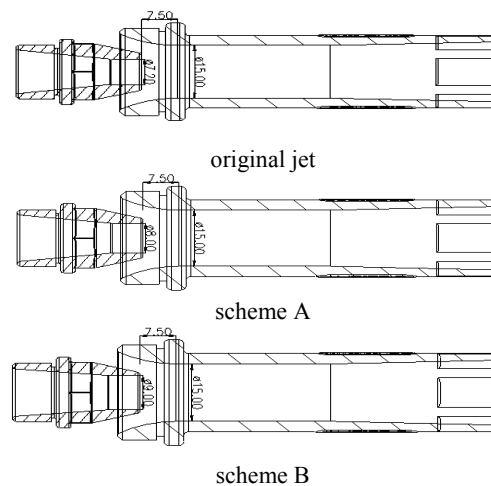
$$L_c = 0.5\sqrt{m}d_0 \quad (1)$$

where  $m$  is area ratio,  $d_0$  and  $d_2$  represent the diameter of nozzle and the diameter of throat respectively.

**Table 1.** Optimal range of nozzle-to-throat clearance based on different area ratio.

$L_c$	$m$
$(0.5\sim1.5)d_0$	$1.5\sim3$
$(1\sim2.5)d_0$	$4\sim6$
$(1\sim9)d_0$	$7\sim26$

Based on the above-mentioned formula, the diameter of throat  $d_2$  is  $15\text{mm}$  and if we do not change the length of this diameter, the distance of nozzle-to-throat would not be altered. Only change the diameter of nozzle, according to the above-mentioned equation, modified the original model and tested the self-priming performance, for verifying the change of self-priming performance while the diameter of nozzle has been magnified.



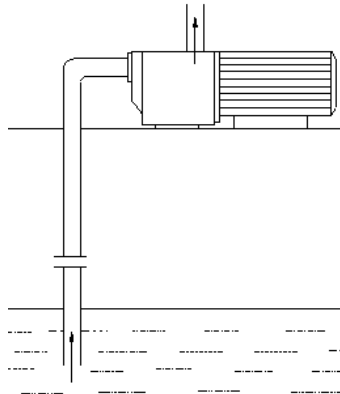
**Figure 3.** The improvement schemes of jet remodel.

As shown in the figure 3, the different structure of improvement schemes can be seen through comparing the original jet. Testing the self-priming performance of the improvement schemes via self-priming bed-stand in turn.

### 2.3. Performance testing

For testing their self-priming performance, this paper adopted three kinds of nozzle diameter including the following: 7.2mm, 8mm, 9mm. On the basis of simulating the actually operating situation, the model pump has been put on a professional self-priming test bench. Lifting this pump to nine meters high above the water level for simulating its operating performance at the actual usage. There are clear plastic tubing below the test bench, before these clear plastic tubing installed on the test bench, they need to be labeled each meter. Through above approach to make it convenient that the experimenter who record the data of the self-priming height and the self-priming time underneath the test bench. The pipe head before connected the pump inlet through using Teflon tape twining first in order to prevent air leakage, meanwhile, using Teflon tape twining the inlet of the pump for ensuring gas tightness, avoiding the testing error caused by air leakage. In the process of experiment, the water in underneath cistern should be replaced at regular intervals. The cistern water in long-term use lead to test error. Also, the temperature of laboratory should be controlled in normal to avoid the extreme temperature caused the testing error.

A simplified picture of the self-priming test bed is shown in figure 4. The test pump was placed on the self-priming test bench, and then the test pump was lifted to the design height through elevating apparatus, finally started the test pump. The inlet of the test pump was connected to the transparent pipe below the lifting platform, and the outlet pipe was used to drain the water from the pump back to the underneath pool. Because the height and time of self-absorption were mainly recorded in the process of self-absorption, there was no electronic monitoring in the test bench at the company where we completed the trial. In this paper, a parallel lifting test bench was used to manually record the time of water level reaching every meter in the transparent pipeline. There might be some error in the monitoring of self-priming time. In the future, the self-priming test bench could be improved to enhance the precision of the test.



**Figure 4.** Schematic diagram of the self-priming installation.

The confirmation prescription of self-priming height and the self-priming time influenced the experimental data, this paper defined the self-priming height as the maximum altitude that jet self-priming pump can achieve the highest altitude. This paper selected the height that inlet pipe water level held the same altitude for twenty seconds without large floating as the self-priming height. This paper also defined the self-priming time as that the jet self-priming pump reached each meter the time required and this pump achieved the self-priming height the time needed. Meanwhile, recording this pump reached each meter the time needed for comparing the different schemes.

**Table 2.** The data of self-priming height in different nozzle diameter improvement project.

Testing pump	Nozzle diameter (mm)	Throat diameter (mm)	The nozzle-to-throat distance (mm)	Self-priming height (m)
1	7.2	15	7.5	6.3
2	8	15	7.5	6.6
3	9	15	7.5	6.8

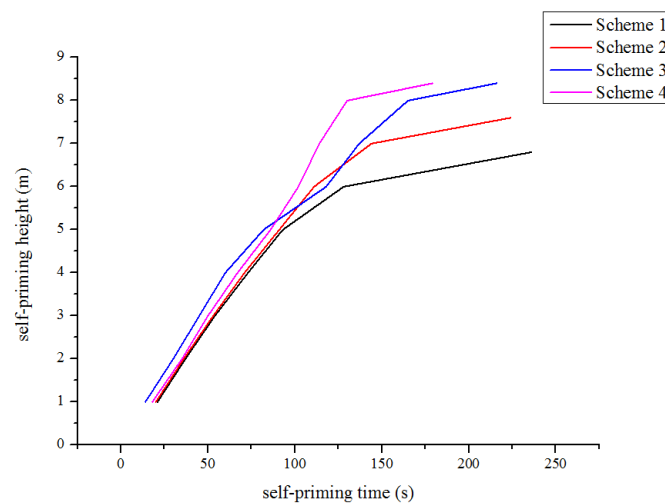
The self-priming height has been improved by changing the diameter of nozzle, but, on the basis of the original formula to amend the nozzle-to-throat distance have not achieved the design parameter and the self-priming performance did not get a large improvement, so that the parameters of the jet structure should be modified further. Amending the original formula in the self-priming experiment, based on the test data modifying the value range of nozzle-to-throat distance is closer to the actual application of this pump operating situation.

#### 2.4. The experiment of nozzle-to-throat distance value range

On the basis of the self-priming tests and the hydraulic performance tests of different nozzle diameter, comparing the experimental data the third plan that nozzle diameter is 9mm did not exceed the design parameters of hydraulic performance and held the best self-priming performance among the above three testing schemes. This paper selected the third schemes to modify the diameter of throat and the distance of nozzle-to-throat.

**Table 3.** The test data of different throat diameter and different distance of nozzle-to-throat.

Test pump	Nozzle diameter (mm)	Throat diameter (mm)	The nozzle-to-throat distance (mm)
1	9	15	7.5
2	9	15	9
3	9	16	9
4	9	16	8.5

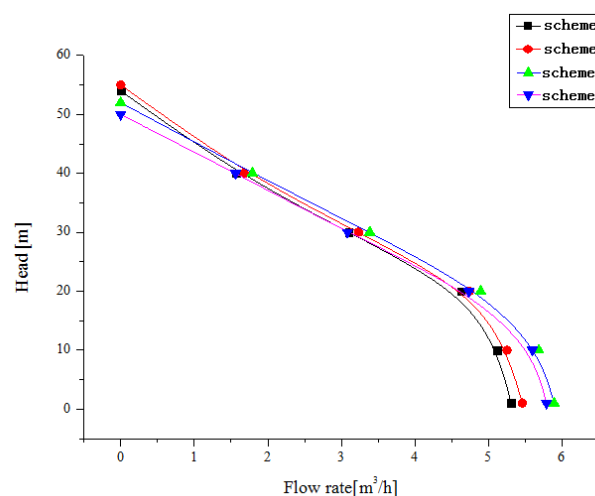


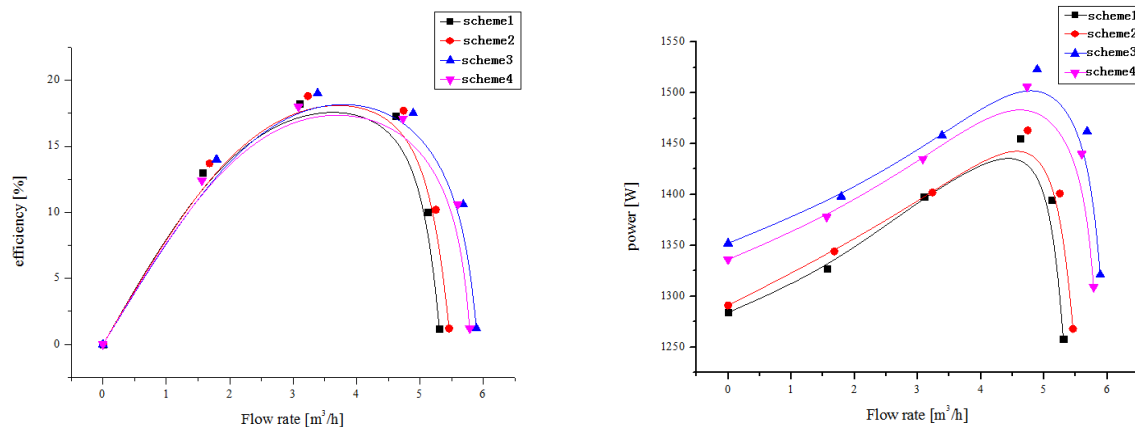
**Figure 5.** The comparison of self-priming performance in different schemes.

On the basis of the data comparison chart, we can see the improvement of this pump in self-priming performance on account of modifying the diameter of throat and the distance of nozzle-to-throat. According to the figure 5, the self-priming height of this pump increased from 6.8 meters to 8.4 meters and the self-priming time has been shorten from 4 minutes to 3 minutes completing the self-priming process. Through comparing the data in figure 5, we can obtain that third scheme and forth scheme have achieved the 8.4 meters altitude, but the self-priming time of forth scheme is shorter than third plan, even so, both third plan and forth plan can be included in the value range.

## 2.5. Hydraulic performance

The regulation of the jet part has certain influence on the hydraulic performance curve of the jet self-priming pump, so it is necessary to test the hydraulic performance when the self-priming height of the jet self-priming pump was met. Comparing the test data with the design data to determine whether the hydraulic performance of the scheme with the standard self-priming performance is within the acceptable range.



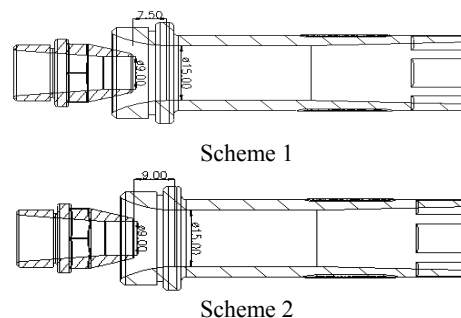


**Figure 6.** The comparison of the hydraulic performance in different plan.

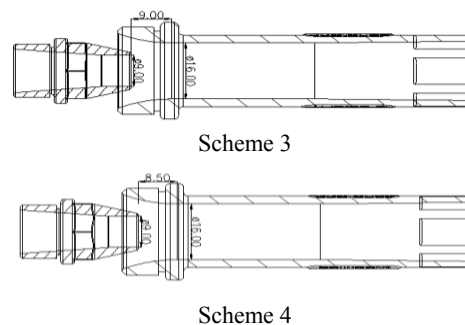
The hydraulic performance tests of the four schemes above were shown on the figure 6. Changing the nozzle-to-throat clearance has an effect on the hydraulic performance curve. After increasing the nozzle-to-throat clearance, the head dropped, the maximum flow rate and the head break point moved backward. Lengthening the nozzle-to-throat clearance did not result in the increase of the loss at the inner part of the jet. Lengthening appropriately the distance of the nozzle-to-throat is conducive to the mixing of the suction fluid and the working fluid. However, it can be seen from the comparison of flow efficiency diagram that the maximum efficiency points had little difference but still within the acceptable range. Without changing the diameter of the throat, only increasing the distance of the nozzle-to-throat, the axial power was slightly increased by comparing between schemes 1, 2 or 3 and 4. The comparison between two and three schemes showed that the diameter of the throat only increased without changing the distance of the nozzle-to-throat, and the axial power increased significantly. In the self-priming experiment of scheme 3 and 4, both can meet the design requirements, but scheme four with short self-priming time compared to scheme three, the efficiency of the scheme three also below the scheme four, input power scheme 3 was lower than scheme 4. Considering the self-priming performance and the hydraulic performance, scheme 4 was selected as the final structure parameter of the jet.

### 3. Result and discussions

Modifying the original formula through the self-priming performance tests because of the exiting value range nozzle-to-throat almost based on the numerical modeling and prediction of computational fluid dynamic simulation software. But there were some assumed condition when we used the numerical modeling to simulate gas-liquid two-phase flow, so that the value range of nozzle-to-throat distance might exist some errors in final. According to the original formula this paper on the basis of the actual self-priming experiment to amend the value range of nozzle-to-throat clearance formula.







**Figure 7.** Testing schemes of jet self-priming pump.

As the figure 7 indicated, comparing the record results we can obtain that magnifying the diameter of nozzle and throat properly and adjusting the distance of nozzle-to-throat were beneficial to improving the performance of self-priming. Considering the structure characteristics of jet self-priming pump, the influencing factors of the ejection part concluded the diameter of nozzle, the diameter of throat, the distance of nozzle-to-throat and the angle of suction chamber and so on. The length of nozzle-to-throat has been adjusted influencing the mixture of the suction air and the high-speed ejecting flow by nozzle. Differential pressure between vacuum caused by nozzle and barometric pressure outside resulted in the air suction, however, the diameter of nozzle should not be shortened blindly. The diameter of nozzle, the diameter of throat and the distance of nozzle-to-throat need to be combined to consider for improving the self-priming performance of this type of pump. We analyzed the last two plan in the self-priming tests to obtain that the distance of nozzle-to-throat was 8.5mm and distance was 9mm both can reach the design altitude, but the self-priming time of the two plan was different. Holding 8.5mm clearance scheme four was slower than holding 9mm clearance scheme three at the first five meters, but scheme four was faster than scheme three at the maximum altitude and reached each meter stably. At the practical application, scheme three and scheme four both can be selected in value range, but by comparing two of them in self-priming time, scheme four was more reasonable than scheme three. on the basis of above discussion of amending the nozzle-to-throat clearance, there was a optimum distance existing, but different pump had their own evaluation. This paper was proper to give a value range of nozzle-to-throat clearance, according to the result of self-priming tests we selected the scheme three and scheme four as the nozzle-to-throat clearance value range of this type of pump, modifying the original formula into:

$$L_c = (0.53 \sim 0.56) \sqrt{m} d_0 \quad (2)$$

There are some errors between the actual tests and the numerical modeling because of the assumed conditions when simulation software simulated the self-priming process. But actual test still has its drawbacks that it only can test the normal situation appropriate for the optimization design of engineering application. By combining with the results of simulation previous, it might be helpful to optimize this type of pump.

#### 4. Conclusions

(1) The jet self-priming pump has complex construction result in the self-priming performance of this type of pump influencing by many factors. The dimension parameters of ejector affect the self-priming ability of this pump. The relationship among the diameter of nozzle and the diameter of throat and the diameter of throat and the distance of nozzle-to-throat is extremely important factor to improving the self-priming performance of this pump and guiding the optimization design.

(2) The result of experiment indicated that testing model pump had absorbed to 8.4 meters when the construct parameters of nozzle diameter was 9mm and throat diameter was 16mm with the distance of nozzle-to-throat ranged from 8.5mm to 9mm, the self-priming time was 3 minutes and it hydraulic performance reached the standard. The self-priming time was 82 seconds when the self-priming altitude reached to 5 meters. The property meets state requirements that the self-priming time must shorter than 120 seconds when the altitude reach 5 meters. The relational expression among the

diameter of nozzle and the diameter of throat and the distance of nozzle-to-throat can be summarized by the self-priming experimental consequences.

(3) On the basis of the experimental results, the original formula has been amended into  $L_c = (0.53 \sim 0.56)m^{1/2}d_0$ . Comparing with the original one, the amending formula was more proper for engineering application and the results provided the testing data to improving this type of self-priming pump.

(4) At present, there are still some errors on account of the monitor of the self-priming height and the self-priming time based on the manual timing and visual measurement. In the future, the self-priming test bench can be improved and retested to improve the accuracy of the experiment. This paper only carried out a limited quantity of experiment on one type of self-priming pump. Further experiments could be focused on different structure and precision.

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