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Research on a new type of squirt gun for cleaning †

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Abstract

A new type of squirt gun, which is similar to a jet pump and can better induce formation of cavitating water jet, is presented. The scheme of design of this new squirt gun is discussed. An investigation of effect of different area ratio, length of throat pipe, standoff distance, nozzle type, and suction air amount on decontamination ability was made by experiments. This new squirt gun is experimentally compared with conventional one. Test data indicate that under the same operating condition the new type of squirt gun have the advantages of better decontamination ability, lower energy consumption and less water consuming over conventional one. The optimum operating parameters of this new device are put forward on the basis of test results.

Keywords: Squirt gun; Jet pump; Decontamination; Cavitation

1. Introduction

Human being is confronted with the threat of the serious lack of water resources. The population of China is one fifth of total population of the world, but the amount of water resources of China is only 7% of total amount of the world water resources, and meanwhile the coefficient of utilization of its energy is only 32%, whish is much lower than the average level of the world. With the development of the industry, the consumption of water is rapidly increasing. In the industry of decontamination, more consumption of water and lower utilization factor of energy is difficult problem to be settled urgently.

In general field of cleaning such as cleaning of car, the dirt is directly decontaminated by high-pressure water jet out of squirt gun. To enhance the ability of decontamination, people usually increase either pressure of water or discharge amount of water in a nutshell, which lead to squander seriously water resources and electric power.

For the purpose of saving on water and energy, the authors put forward a new type of squirt gun for cleaning after analyzing the mechanism of jet pump and cavitation. In contrastive experiment, the new squirt gun can save on water more 20% than ordinary squirt gun as shown in Fig.1 under the condition of

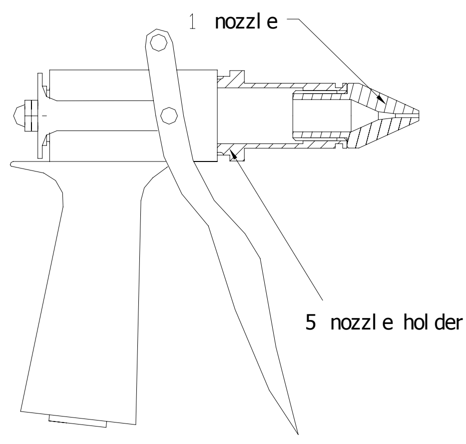

Fig. 1. Structure of ordinary squirt gun for cleaning.

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the same pressure source and the same effect of decontamination, and even its water saving is more than 40% under the optimal target distance.

2. Mechanism of the new squirt gun for cleaning

If the liquid pressure at any point within flow fields decreases to or below the saturated vapor pressure corresponding to the liquid temperature, liquid will vaporize. When the vapor bubbles produced due to liquid vaporization move to a high-pressure region with the liquid flow, the liquid steam will re-condense and become liquid. During this process the bubbles become deformed gradually and collapse at last. When the bubbles collapse a very strong explosive pressure occurs, which may reach hundreds even thousands of atmospheric pressure. If the bubbles collapse near the wall of material, so much big blast force is enough to clean the dirt or even to destroy the wall material. The so called cavitation is the process of formation, growing and collapse of bubbles. The effect of decontamination can be greatly enhanced by the action of cavitation.

The effective anti-tensility intensity of liquid can be greatly degraded by impurities including air nuclei dissolved in the liquid, and thus the process of formation and growing of bubbles can be speed up considerably. So it is a potent way to adjust cavitating that proper amount of air is entrained. Jet pump makes it possible to entraining proper air.

A new type of squirt gun, which is similar to a jet pump and can better induce formation of cavitating water jet, is presented. This device consists of first-stage nozzle, suction chamber, throat pipe (second-stage nozzle), as shown in Fig. 2 and Fig. 3. High-pressure water spurted out from the first-stage nozzle form a speedy jet flow. Because of entrainment of jet flow surface, ambient air is carried into throat pipe so as to make the pressure of suction chamber be lower than atmospheric pressure, thus air outside suction chamber will be drawn into suction chamber. If the quantity of air drawn into suction chamber is artificially controlled, the pressure in suction chamber will be very low, even equal to the vapor pressure of water. Cavitation bubbles and jet water are uniformly mixed inside throat pipe to form cavitating flow. Once the cavitating jet flow ejected from the second-stage nozzle impacts on the target surface, cavitation erosion will occur.

3. Design of the new installation

The hardcore of the new squirt gun is jet pump which has critical effect on the ability of its decontamination. So the design of the installation should be focused on jet pump [1].

The theory of design of jet pump, which consist of optimal performance Eq. (1) and basic Eq. (2) as followed, may be applied to the new squirt gun. These equations are obtained by experiments.

$$m_y = \left(\frac{0.981\Delta p_0 + 0.32}{0.66}\right)^{1.02} \quad (1)$$

$$\frac{h}{\varphi_1^2} = \frac{2\varphi_2 k_i}{m} - \frac{A_i(1+q)}{m^2} \quad (2)$$

When $m \le 5$

$$k_i = \frac{1.96m^{-0.14}}{\varphi_1^2 \varphi_2} \quad (3a)$$

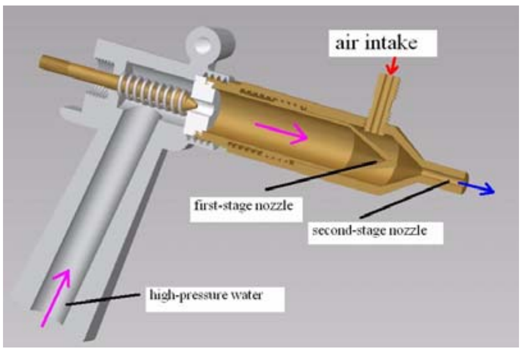

Fig. 2. Mechanism of the new squirt gun for cleaning.

Fig. 3. Outline of the new squirt gun for cleaning.

$$A_i = (91.75e^{-0.182m} + 0.1)\frac{m}{\varphi_1^2} \quad (3b)$$

When $m > 5$

$$k_i = \frac{1.82m^{-0.137}}{\varphi_1^2 \varphi_2} \quad (4a)$$

$$A_i = 4.34\frac{m^{-0.87}}{\varphi_1^2} \quad (4b)$$

where, $\Delta p_0 = (z_0 + \frac{p_0}{\rho_0 g} + \frac{\alpha_0 v_0^2}{2g}) - (z_s + \frac{p_s}{\rho_s g} + \frac{\alpha_s v_s^2}{2g})$.

The main dimensions of squirt gun as shown in Fig.4 are given by the following equations.

$$D_0 = \sqrt{\frac{4Q_0}{3.14\mu_1\sqrt{2g\alpha\frac{\Delta p_0}{\rho_0 g}}}}$$

$$D_3 = D_0\sqrt{\varepsilon m_y}$$

$$L_c = (1 \sim 2)D_0$$

For shorter throat pipe, $L_k = (1 \sim 2)D_3$
For longer throat pipe, $L_k = (7.77 + 2.42m)D_3$

When the pressure difference between before and after the nozzle is 8 MPa, the flow rate of the nozzle is 9.8 L/min. The diameter of the nozzle is 1.2~1.25 mm. The divergent angle of jet within suction chamber is $17 \sim 19°$. There are two diameters i.e. 2.4 mm and 3.6 mm of the throat pipe to be respectively adopted. The flow rate of air entrained is about 23~25 L/min. The location where there is lowest pressure and the bubbles are formed largely is 2.5~3 cm away from the inlet of the throat pipe.

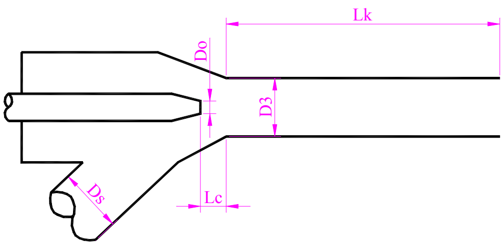

Fig. 4. Main dimensions of the new squirt gun for cleaning.

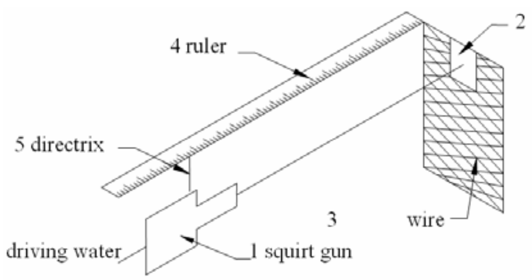

Fig. 5. Sketch of installation for testing.

4. Method of test

The target 2, which is a cardboard made of asbestos fiber, is fastened on the wire netting 3 as shown in Fig. 5. The ruler 4 is used to determine standoff distance and directrix 5 is used to localize the squirt gun 1. Measure and write down the standoff distance L firstly, and then start to clean and record the time interval t from the incipience of decontamination to target being punctured, and finally scan the hole on the target into computer and figure out area S of erosion.

Once the target is holed, the larger the total amount of water consumption is, the worse the effect of cleaning is. Similarly, the larger the amount of water consumption per square millimeter is, the worse the effect of cleaning is.

5. Results and analyses

It can be seen from Fig. 6 that the new squirt gun can save on water up to 70% compared with ordinary squirt gun when the standoff distance is 50 cm, and the average is 40% when the standoff distance is within 30-60 cm . It is showed that the time interval of target being holed by the new squirt gun is much shorter than that of target being holed by traditional

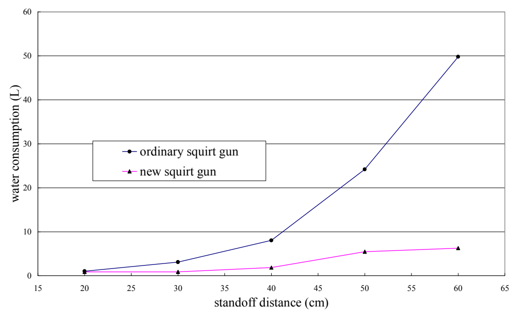

Fig. 6. Comparison of water consumption of the new squirt gun with that of ordinary squirt gun for cleaning.

Table 1. Test results of ordinary squirt gun for cleaning.

Standoff distance (cm)	Driving pressure (MPa)	Time interval (s)	Area eroded (mm^2)	Water consumed (L)	Water consumed unit area (mL/mm^2)
20	8. 5	9.37	202.4	1.03	5.09
30	8. 5	28.30	178.5	3.11	17.44
40	8. 4	73.19	176.6	8.05	45.59
50	8. 4	219.93	343.5	24.19	70.44
60	8. 4	452.66	358.8	49.79	138.77

Table 2. Test results of the new squirt gun for cleaning.

Standoff distance (cm)	Driving pressure (MPa)	Time interval (s)	Area eroded (mm^2)	Water consumed (L)	Water consumed unit area (mL/mm^2)
20	8.5	8.09	155.2	0.89	5.73
30	8.5	8.06	188.6	0.89	4.70
40	8.4	16.94	159.9	1.86	11.66
50	8.4	49.62	249.3	5.46	21.90
60	8.4	57.1	215.6	6.28	29.13

squirt gun from Table 1 and Table 2, which indicates that former possesses stronger ability of decontamination.

6. Conclusions

According to the theory of jet pump and cavitating water jet, the authors put forward a new type of squirt gun which possesses marked features as followed: cavitating water jet out of the new squirt gun can enhance ability of decontamination and even tests indicate that the new squirt gun can save on water up to 70% compared with ordinary squirt gun when the standoff distance is more than 50 cm; the amount of air entrained can be controlled in light of requirements; the fluids entrained into suction chamber may be a certain gas and also may be other fluid such as detergent. Otherwise, this new squirt gun has advantages of simple structure, convenient manufacture, smaller investment, better benefits and easy popularization over traditional squirt gun.

Nomenclature

h : Pressure ratio, which is the ratio of pressure of jet pump at outlet to the working water pressure, $h = \Delta p_c / \Delta p_0$;
q : Volumetric flowrate ratio, which is the ratio of volumetric flowrate of entrained fluid to that of the driving fluid, $q = Q_s / Q_0$;
m : The area ratio, which is the ratio of the sectional area of the throat pipe to that of the outlet of nozzle, $m = f_3 / f_1$;
m_y : The optimal area ratio;
D_0 : Diameter of nozzle;
D_3 : Diameter of throat pipe;
ρ_s : Ddensity of entrained fluid;
ρ_0 : Density of the driving fluid;
g : Gravitational acceleration;
α : Function of throat entry;
φ_1 , φ_2 : Velocity coefficients of the nozzle, throat pipe respectively;
μ_1 : Slip coefficent of velocity between particles and liquid in the exit of nozzle;
z : Potential energy of corresponding cross section;
v : Average velocity of corresponding cross section;
L_c : Distance between outlet of first stage nozzle and inlet of throat pipe;
L_k : The length of the throat pipe (second stage nozzle);
ε : Shrinkage factor of water jet at the outlet of nozzle;
α_0 , α_3 : Correction coefficient of energy;

subscript

0 : Intake cross section of first stage nozzle;
S : Intake cross section of suction pipe;
3 : Cross section of throat pipe;

The detail of above definitions can be found in references.

References

[1] H. Q. Lu, *Theory and Application of Jet Technology,* (in Chinese), Publishing House of Wuhan University, Wuhan City, Hubei Province, China, (2005).