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Original Paper

A Type of "Bubble" Water-saving Faucet

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Abstract

At present, many places are seriously short of freshwater resources. Thus, saving water is the universal responsibility of contemporary citizens. Now faucet products such as ordinary washing nozzle, kitchen nozzle, face-washer nozzle, bathtub nozzle and washing machine nozzle are widely used in urban and rural households. Most have poor water-saving abilities, and much water is wasted through daily washing. Our bubble-type water-saving device is a brand-new water-saving device with a simple structure and low cost. It uses the Bernoulli principle and the bubble atomizing principle to inhale air naturally in water flow to atomize water flow. It can help achieve more than 50% water-saving efficiency in daily washing behavior.

Keywords

Faucet, Water saving, Bernoulli principle, Principle of bubble atomizing

1. Background and Significance

China is a country that lacks water resources. With a vast population base, the per capita water resource is only 2300 cubic meters, which is only one-fourth of the world's average. Saving water is particularly important and brings substantial social benefits. Diligence and frugality are the traditional virtues of the Chinese nation, and water-saving devices with good cost performance meet the actual needs of the public.

Market analysis and research show that there is no similar bubble-type water-saving faucet in the market at present. Bubble-type water-saving faucets can be installed in the existing ordinary washing nozzle, facial washer nozzle, and kitchen nozzle of every household. Moreover, this invention can also be applied in the sewage scouring and cleaning scenes in vegetable and fruit cleaning, automatic car washing, industrial production, and other fields.

2. Product Introduction

2.1 Product Appearance

A bubble water-saving device appearance is a cylinder with a diameter of 2 cm and a 6-8 cm length. It can be used in every household and added to the existing ordinary washing water nozzle, wash basin faucets, and kitchen water nozzle. Thus, those regular nozzles can be changed into a new type of bubble water-saving faucet and grade No. 1 water use efficiency (Requirement: the water flow is no greater than 6000 ml per minute). this invention will achieve more than 50% of water-saving efficiency.

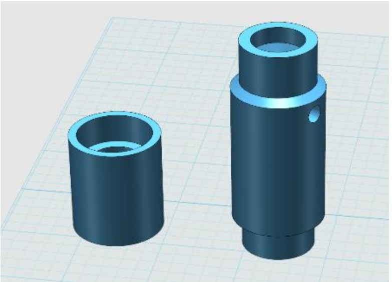


Figure 1. Overall Appearance

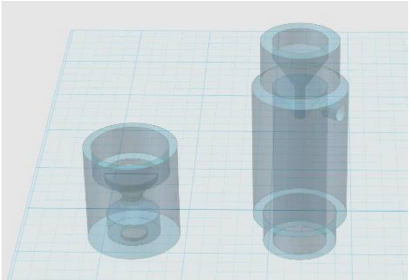


Figure 2. Internal Structure

The bubble-type water-saving device makes use of the Bernoulli principle to absorb air naturally in the water flow and form a gas-liquid two-phase flow at the outlet of the faucet, enhancing the impulsion of water flow and its ability to dissolve stains so that the time and consumption amount of daily washing activities can be effectively reduced.

In daily household water-consuming activities, such as washing hands and vegetables, water flow's primary function is to dissolve and wash away stains. The water flowing out of the ordinary faucet is columnar and concentrated, which has a small contact area with the object to be cleaned and takes a long time to dissolve stains. When stains are gradually dissolved, 90% of the water is wasted, resulting in a tremendous waste of water resources. After the bubble-type water-saving device is installed, the water flow can be atomized, and the water mist can fully contact the object to be cleaned, which shortens the time of stain dissolution and reduces the time of washing.

After the bubble-type water-saving device is installed, a gas-liquid two-phase flow is formed at the outlet, and the impact force of the gas-liquid mixture greatly increases. In actual use, the faucet only needs to be opened half as usual, and the impact force is still the same as that of the ordinary faucet when it is fully opened. Thus, it can further reduce water consumption and achieve a better water-saving rate.

To sum up, the comprehensive water-saving efficiency of bubble-type water-saving devices is more than 50%, and the social and economic benefits are very significant as well.

2.2 Product Parameters

Water efficiency: Level 1

Water flow in 60 seconds: ≤6000ml

Applicable water pressure: 0.1-0.35mpa

2.3 Analysis of Product Selling Points

The biggest selling point is the high efficiency of more than 50% saving rate in saving water and the economic, social, and ecological benefits that result from saving water. Compared with other water-saving faucets, the production technology of this product is excellent and the processing method is simple, so the cost is greatly reduced compared with other similar products, which is conducive to the promotion and in-depth application of the product.

2.4 Product Patents

The original demonstration device of this product has obtained a national invention patent (ZL 201810204490.5) and a utility model patent (ZL 201820340731.4). This product is based on the technical principle of the above patents for industrial design and production and will try to obtain a new patent after further improvement in the industrial design after the declaration of a new paten

3. The Purpose and Basic Ideas of the Design Project

3.1 Objective

To design a kind of bubble-type water-saving device that is easy to make, easy to popularize, and low cost, and can be installed on ordinary faucets. Its typical application scenarios are ordinary washing faucets, kitchen faucets, and facial cleanser faucets in urban families and various public places. It also can be applied in the sewage flushing and cleaning scenes in vegetable and fruit cleaning, automatic car washing, industrial production, and other fields.

3.2 Basic Idea

Try to make a narrow tube in the water pipe, and try to draw air in the narrow tube. When the faucet is opened, high-speed water flow is generated in the narrow tube. Using the Bernoulli principle of "fast flow with low pressure", the air outside the water pipe is sucked into the high-speed water flow, forming bubble flow in the mixing cavity of the pipe downstream of the narrow tube, and then forming atomized water flow at the outlet of the water pipe.

4. Research Process of the Project

4.1 Stage I: Proof of Original Principle (2015-2020)

4.1.1 Put forward Questions and Ideas

In daily household water use, such as washing hands and vegetables, the main function of water flow is to dissolve and wash away stains. The water flowing out of the ordinary faucet is columnar and concentrated, which has a small contact area with the object to be cleaned and takes a long time to dissolve stains. During the time when stains are gradually dissolved, 90% of the water is wasted, resulting in a great waste of water resources. If the water is atomized, and appropriately expands the water mist out of the cone angle, the water mist can be fully in contact with the object to be cleaned, shortening the stain dissolution time.

The atomization of water must be controlled within a reasonable range. If the atomization is too high, the outlet pressure may be reduced, and the impact force of water mist may be reduced. Although the time of stain dissolution is shortened, it takes longer to wash away the stain, and in fact, it is difficult to obtain the effect of water saving.

The cone Angle of water mist outflow must also be controlled within a reasonable range. If the cone Angle is too large, the faucet in your home becomes a large-scale fire sprinkler and field irrigation, and cannot be used.

4.1.2 Conceptual Design

According to the result of literature research, the writer decided to design a bubble atomizing device mainly composed of a plastic hose, disposable syringe, clip, etc.

Standard atmospheric pressure is about 0.1 MPa. When the water in the water pipe at home is still, the water pressure is between 0.14 and 0.35 MPa, depending on the floor you live in. When water is flowing rapidly in a water pipe, the pressure applied to the pipe wall is reduced by Bernoulli's principle that "The faster the flow, the lower the pressure". If the flow rate of water exceeds a certain degree, so that the pressure exerted by water on the pipe wall is less than 0.1mpa. At the same time, if the pipe wall at this time has a hole connected with the air, it will not spray water out of the hole but will suck in air from the hole. To speed up the flow of water, a narrow tube effect (which is similar to the Venturi tube) can be used in addition to opening larger.

4.1.3 Preliminary Design

Use a regular plastic hose and connect it to the usual faucet, making it straight down. The means of connection can use a special turning joint. However, from the consideration of saving cost, we can use the hose whose inner diameter is equal to the outside diameter of the faucet completely, and cover it directly on the faucet, tighten it with iron wire. In somewhere appropriate, insert the syringe needle from the side diagonally at the bottom of the hose. Clamp the hose at the position of the needle to form a narrow tube (or form a narrow tube by winding and tightening the wire step by step) to speed up the flow of water. The syringe is fixed with transparent tape and a hose. When there is no need to use water-saving mode, as long as the piston push rod is inserted back into the syringe, it will naturally return to the ordinary water-outlet mode.

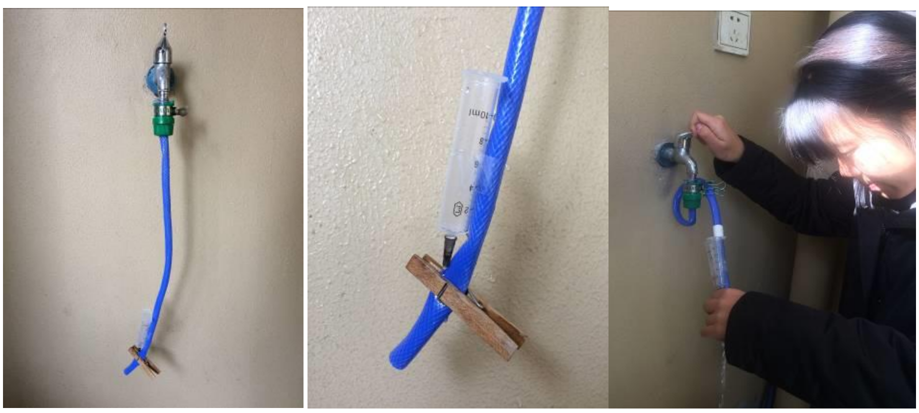
4.1.4 Experiment and Improvement Process

(1) First round of experiments (2015-2016)

The principal proof experiment was carried out 4 times from the first to the second year of the author's junior high school. The experiment place was on the 1st, 3rd, and 6th floor of ordinary residential buildings and the 13th floor of high-rise residential buildings with secondary water supply. A plastic hose with an inner diameter of 12mm was used, a 10ml syringe was used, and needles of No.7, No.9, No.12, and No.16 were used respectively (the inner diameter of the needles ranged from 0.5mm to 1.2mm). The clamps were used, including pincer pliers, ordinary bamboo-wood clothes clips, metal fish-tail clips of different specifications, and metal bill clips.

Experimental process:

A. Connect the hose to the outlet of the ordinary faucet to ensure that the joint does not seep water; B. Insert the syringe diagonally in the direction of water flow at the appropriate position of the hose, and remove the piston of the plastic syringe; C. Open the faucet and adjust the water flow; D. Repeat the experiment on different floors with different clips.



Findings:

A. When the hose is level with the ground, open the faucet, and water overflow at the needle of the syringe. However, after the clamp is placed outside the hose at the point of the needle, the water does not overflow and instead, it begins to breathe in air. The syringe makes A "squeak" sound, and the color of the water flow at the outlet of the hose gradually turns from transparent to white. A large number of bubbles are mixed in the water flow.

B. When the hose is perpendicular to the ground, open the faucet and the water does not overflow. As the faucet opens wider, the needle directly begins to breathe in air and makes a slight "squeak" sound. Keep the faucet opening unchanged, after the clamp on the outside of the hose at the point of the needle, the suction tone of the syringe becomes significantly higher, the volume becomes significantly larger, and the outlet water flow becomes significantly white, and the mixing bubbles become more. Try to continue squeezing the clamp with a vice, and the syringe suction sound will be higher and louder, the outlet flow will be whiter, and the mixing bubbles will be more.

C. The water outlet pressure of the 1st, 3rd, and 6th floors of the primary water supply and the 13th floor of the high-rise residential buildings with secondary water supply is slightly different: the 13th floor > the 1st floor > the 3rd floor > the 6th floor. However, in the experiments on all floors, the phenomenon of air suction occurred. On the floors with high basic water pressure, the phenomenon of air suction occurred when the faucet was only half opened.

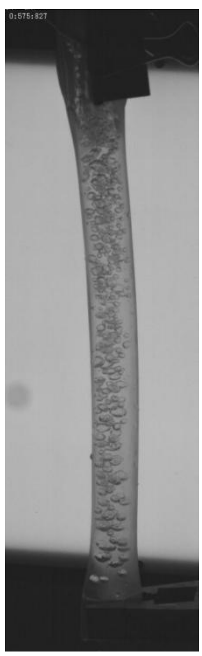
Through the first round of experiments, the preliminary design scheme has been proved to be successful and feasible.

(2) Second Round of experiments (2018)

The second round of experiments began in February 2018 during the winter vacation of senior high school.

Experiment 1: The effect of the mixing chamber's length-diameter ratio on the atomization of water flow

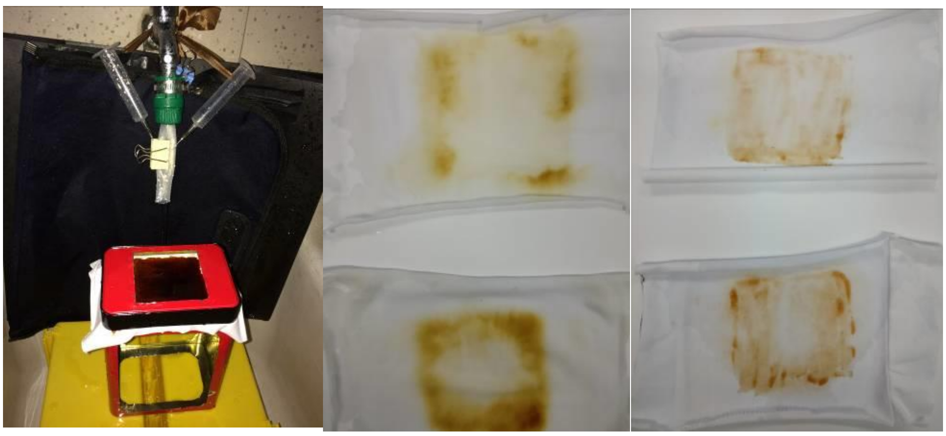
Below the clamping section of the hose is the gas-water mixing chamber, and a 12cm hose (length-diameter ratio of 10) is reserved below the clamping area to start the experiment. The morphological changes of gas-liquid two-phase flow in the mixing chamber were observed. It was found that in the 6-7cm section below the clamping section, the water was white with many tiny bubbles mixed, but in the section below, the white appeared to weaken. High-speed cameras at 500 frames per second found that this was because the tiny bubbles regrouped into larger ones as they descended, weakening the atomization effect. In the continuation of the experiment, the hose below the clamping section was gradually cut short until the remaining 6 cm (l/D ratio 5), and the relatively optimal gas-liquid two-phase flow was obtained at the outlet position.



Conclusion: The best length-diameter ratio of the gas-water mixing chamber is 5.

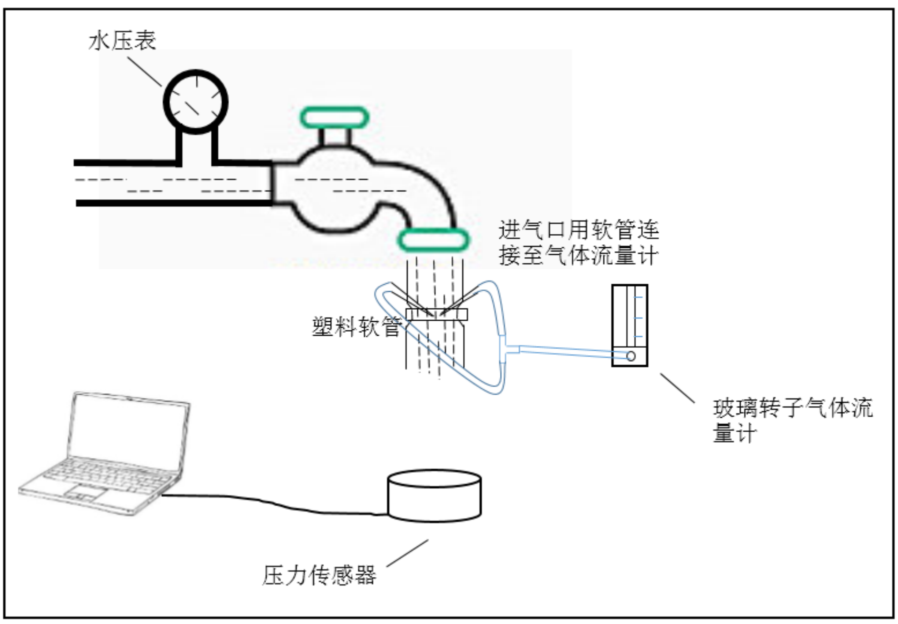
Experiment 2: Cleanliness experiment

Soak soy sauce and tomato juice with a white cotton cloth to become polluted cloth, cut out the test stand with an iron tea tube, tighten the polluted cloth on the test stand, put it 4 cm below the hose outlet, and wash the test for 10 seconds with air suction and without air suction. It was found that when the air was sucked, the polluted cloth was cleaner after being washed for 10 seconds than ordinary water without air. The following pictures show the simple operating table and the comparison experiments of the washing ability respectively.



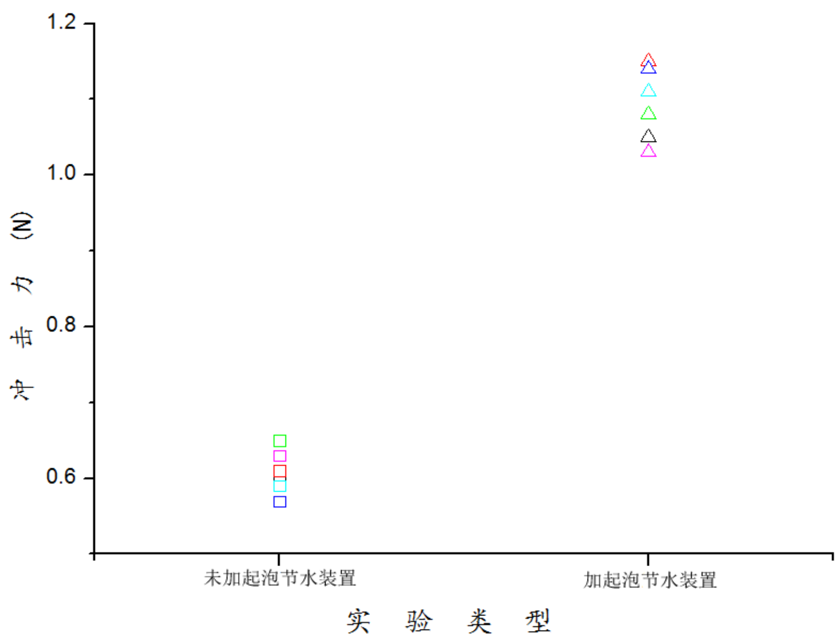
Conclusion: the washing ability of gas-liquid two-phase flow is better than that of ordinary water flow. As a result, it takes less time to wash out the same pollutants and use the flow of air to get better water efficiency.

Experiment 3: Quantitative data experiment of water-saving efficiency



Experimental device diagram

The experiment was carried out under the pressure of 0.2mpa. In the experiment, the force sensor was used to test the impact force data of water flow with and without the bubble water-saving device, as shown in the figure below:



After the device was installed, the average impact force of water flow increased from 0.61N to 1.09N, and the impact force of water flow increased by about 78.7%.

At the same time, we tested the air intake and water output, as shown in the table below. After the bubble water-saving device was installed, the gas-liquid ratio ALR was about 0.1, and the water output was reduced by 22.7% on average, achieving the purpose of water-saving.

Whether to add bubble water saving device	**Air intake (L/min)**	**Water yield (L/min)**
no	0	12.6-13.8
is	0.96-1.2	9.6-10.8

Due to the increase of water impact force after the bubble water-saving device is installed, in actual use, the tap only needs to be opened half to obtain the same impact force as that when the bubble water-saving device is not installed and the tap is fully open, to further reduce water output and achieve a better water-saving rate.

Under the condition of installing a bubble water-saving device, the impact force of outflow water was adjusted to 0.61N by turning down the tap switch. At this time, water yield further decreases, as shown in the table below, with an average decrease of 38.6%, and water-saving efficiency becomes more obvious

Whether to install foaming water saving device	Water impact force (N)	Air intake (L/min)	Water yield (L/min)
no	0.61	0	12.6-13.8
is	0.61	0.80-0.96	7.8-8.4

Experimental conclusions: Stable gas-liquid two-phase flow can be formed after installing a bubble water-saving device, and the gas-liquid ratio is about 0.1. Under the premise of keeping the water impact force unchanged, the water output per unit time is reduced by 38.6%. The comprehensive water-saving efficiency can be further increased to more than 50% due to the higher cleaning degree of gas-liquid two-phase flow and shorter washing time.

4.2 Stage II: Further Transition Research Stage (2021-Present)

Although the research of the first stage has achieved successful results, there are still some regrets: the use of hose, syringe, and clip. Although it is simple, the operator needs to have a certain DIY ability. What's more, the device is not beautiful enough. It is easy to loose and damage after a long time of use, which is not conducive to promotion and application.

In view of this, the main goal of the second stage is to carry out the product design based on the technical principles of the first stage results. The design still adheres to the idea of low cost, as far as possible to simplify parts, reduce production difficulty, reduce production costs, and strive to adapt to the market common various faucets.

The technical core of the water-saving device of the first stage is that, according to the direction of water flow, three parts, namely, the inlet pipe at the head, the gas-water mixing cavity at the middle, and the tail, are respectively converged from top to bottom.

In accordance with this idea, researchers began to try the prototype design of the product during the winter vacation in late January 2021. We learned to use 3D One software, made samples with a 3D printer, and carried out experiments in the balcony laundry pool at home. After more than 10 sample modifications and more than 30 repeated experiments during the winter vacation, we experienced numerous experimental failures and finally obtained satisfactory experimental results, which laid a foundation for the industrial design of the product.

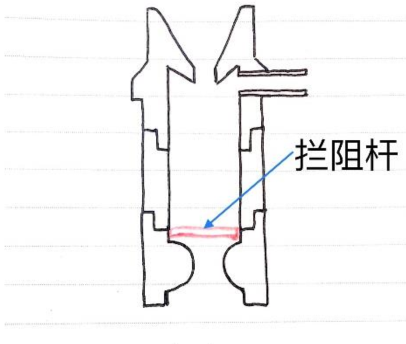


图5

The middle section with different lengths and the tail convergence section with different throat diameters were used to conduct water absorption experiments respectively. The experimental record table was made to record the data of each experiment. It is found that when the throat diameter of the first convergence segment is 3mm and the throat diameter of the tail convergence segment is 6mm, the suction effect is good. When the length of the middle air-water mixing chamber is between 43-83mm, the suction effect is good.

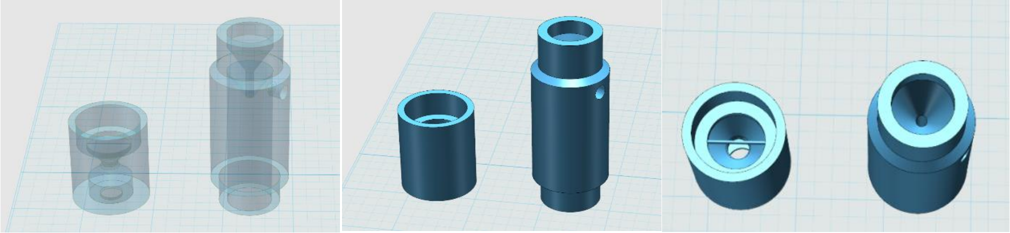
It is found that the water flow at the outlet of the water-saving device presents obvious gas-liquid two-phase flow. When the outlet is placed in a glass measuring cup filled with water, a large number of bubbles can be seen. It was found that the water consumption decreased significantly when the measuring cylinder was connected with water. Under the same condition that the faucet was fully turned on, the water flow in the previous 60 seconds was 8400ml, but after adding the water-saving device, the water flow in 60 seconds decreased to 5100ml. The impact force of water flow is significantly enhanced. With the addition of a water-saving device, the impact force of water flow can be equivalent to that when the tap is opened halfway, which further reduces the water consumption in actual use scenarios.

4.2.3 Experimental Summary of the Second Stage

According to GB25501-2010 “Water Efficiency Limit value and Water Efficiency Grade of Water nozzle”, GB18145-2014 “Ceramic Plate Sealing water nozzle” and QB/T1334-2013 “General Technical Conditions of water nozzle”, If the water flow rate of ordinary washing faucet, facial cleanser faucet and kitchen faucet exceeds 9000ml in 60 seconds, it is an unqualified product. If its 60-seconds water flow ≤ 9000mL, it belongs to grade 3 water efficiency qualified product, but does not belong to water-saving nozzle. When 60 seconds water flow ≤7500ml, it belongs to the class 2 water efficiency water-saving nozzle. 60 seconds water flow ≤6000ml, it belongs to grade 1 water efficiency water-saving nozzle.

At present, we have designed a stultified bubble water-saving device, and the water-saving effect is obvious. In the experiment on the ordinary faucet, which originally belongs to level 3 water efficiency (water flow of 60 seconds is 8400ml), the water efficiency immediately reaches level 1 (water flow of 60 seconds is 5100ml) after installing the bubble water-saving device.

After repeated experiments, the current bubble water-saving device is small in size, easy to install, simple in structure, has fewer parts, and components, and is easy to produce and process.



5. Investigation of Similar Studies by Others

After confirming the idea, researchers searched online and found no other similar research, patents, or products that realized bubble water saving in a simple and low-cost way.

At present, the commonly integrated bubbler on the tap in the home almost has no actual water-saving effect. When the faucet is immersed in a transparent measuring cup, it is found that there is no air in the water flow and no bubbles are generated. The total water yield did not change through the 10-second water connection experiment under the two states of removing the bubbler and installing the bubbler. It was also found that there was no obvious change in the atomization degree of outlet flow when the raw plastic belt was used to seal the air inlet on the side of the bubbler to avoid air suction. This shows that the bubbler mainly relies on a multi-layer rectifier network to pressure atomize water flow, and the actual air intake is very small.

Although the bubbler can make the water flow produce an atomization effect, the cost is the reduction of water flow impact force, which means cleaning items need longer water outlet time, and cannot really save water. What’s more, it is very easy to be blocked by solid impurities in tap water small particles.

An online search found that there are some related researches on water-saving faucets, and there are products with similar functions on the market. There are a small number of invention and utility model patents on bubble water-saving faucets (or special connectors). After searching patents, we found that the special connector (or bubble water-saving faucet) design which can be installed in the ordinary faucet, without exception is a set of complex designs, the number of parts and components is large and complex. They all need to separate mold manufacturing, which results in high product costs, and high price, not conducive to promotion.

Zhejiang University, Li Qizhang, Chen Puyang, Zheng Ruirui, Cheng Wei, Shi Yukun, Li Xinyu, Zhang Xiang, Wang Qin, and others invented “a kind of atomizing faucet and its gravity gas supply device” (Authorization notice NO. CN104790470B), its defect is the use of gravity gas supply, rely on the pedal mechanism with a small travel to inject gas into the water flow. Only 8-10 seconds of washing time can be provided for atomizing faucets.

Literature research shows that bubble atomization technology is mainly used in internal combustion engines, gas turbines, aircraft engines, heavy oil atomization, and other industrial fields, but there is a lack of extended research on household water saving.

6. Further Improvement

1. The current product design has completed functional experiments, but it is still in the laboratory stage of 3D printing and transparent acrylic customization. Next, it is necessary to further understand the actual production process of the nozzle and its spare parts industry, further evaluate the production cost and optimize the product design.

2. The current design can be applied to the water saving of ordinary washing nozzle, facial washer nozzle, kitchen nozzle, and other daily washing behaviors. Still, the increase of water pressure when using will

produce a certain degree of splashing phenomenon. In the next step, the design needs to be further optimized, or the main application scenarios are put in vegetable cleaning, automatic car washing, industrial production, and other sewage flushing and cleaning fields.

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