Brief overview of effervescent atomizer application

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Abstract. Effervescent atomizer is a kind of atomizer which uses bubbles as power of atomizing, and realizes atomization process through bubble formation, movement, deformation, as well as exit blasting. Compared with conventional pressure atomizer and pneumatic atomizer, it has the advantages of high efficiency, economy and environmental protection, thus attracting attention from all walks of life. Applications of effervescent atomizer in gas turbine combustor, internal-combustion engine, furnace and boiler and other fields were briefly viewed through classification and summary of large quantities of literature at home and abroad. Technical difficulties and development prospects of effervescent atomizer in the application research process were briefly analysed, and related research results were given, which providing reference for design and application of effervescent atomizer.

1. Introduction
Small, sophisticated, and various types of nozzles are widely used in sprinkling, atomization, fuel injection, sandblasting, spraying and other equipment. Atomization performance of atomizers directly affects the equipment usability. The improvement of atomization performance can greatly improve the system efficiency and lower the cost. It also provides more economical, more effective and more applicable scheme measures for the control and treatment of exhaust pollution.

At present, the most commonly used atomization technology mainly includes pressure atomization and pneumatic atomization. Pressure atomization mainly relies on its own liquid pressure as power to achieve atomization. Its advantages lie in the simple structure and low operating cost, and the drawback is about the narrow regulation range, leading to the droplet size increasing rapidly with the decrease of injection pressure, and the penetration ability of liquid fog is also greatly reduced. Pneumatic atomization is superior to pressure atomization in performance, but the severe shortcoming is the poor economy results from high gas consumption. Existing defects above encourages scholars from all walks of life to continuously seek new atomization technology [1, 2].

Effervescent atomization is a more efficient, economical and suitable atomization technology developed on the basis of traditional atomization. Its operating principle (as shown in Fig. 1 and Fig. 2) is injecting the gas phase into the liquid phase in an appropriate way, and forms a stable two-phase flow of bubbles in the atomizer mixing chamber; the bubbles accelerate, deform and expand in the two-phase flow process, and extrude the liquid into filaments at the exit of atomizer. Finally, the bubbles expansion until rupture in a very short distance away from the atomizer exit, resulting from the increase of internal and external pressure difference, which leads to the further breaking of liquid filament, forming smaller particle group [3-5].
Effervescent atomization technology has been the focus of attention in various fields since it was put forward in 1980s [6]. Compared with conventional atomization technology, effervescent atomizer has unique advantages, such as achieving good atomization performance under low pressure, less viscous influence on atomization performance, and less gas consumption. As a result, scholars from every walk of life have carried out lots of researches to apply effervescent atomizer to engineering practice. Therefore, atomizer design and experimental research have been carried out in many fields, including gas turbine [7-12], internal combustion engine [13-16], boiler [17-24], and industrial process applications. Furthermore, some products have been applied.

2. Gas turbine combustors
Fuel injection process plays an important role in the performance of gas turbine combustors especially in regard to pollution emissions. In recent years, standards of pollutant emission for both aviation and industrial gas turbines have become increasingly severe. People have to carry out research to continuously improve fuel injection performance to improve combustion efficiency. In addition, there is an increasing demand for fuel atomizers with multi-fuel capability. Finally, gas turbine fuel atomizers must provide good atomization performance in full flow range and have low susceptibility to blockage by contaminants and carbon buildup on the atomizer face.

Compared with traditional gas turbine atomizers, effervescent atomizers have more advantages in meeting the above requirements. That is, high performance spray, low emission pollution; the physical properties of fuel have little influence on atomization performance, and strong adaptability to fuel. In addition, the adjustable range is large (liquid flow rates and gas liquid ratios (GLRs)), and it can maintain good atomization performance within the regulation range. Compared to the conventional nozzles, larger nozzle diameter can be designed under the same flow rate, thus greatly reducing clogging problems. Besides, the fuel consumption is significantly reduced and the combustion efficiency is greatly improved.

Colantonio [7], Lefebvre [9], Li [10], Chin [11], etc. [12] have all carried out research on the effervescent atomizer application in gas turbine combustors. Colantonio developed an environmentally friendly combustion chamber with low nitrogen oxides by using effervescent atomization; Lefebvre analyzed problems existing in conventional atomizers of gas turbine combustors, proposed the application prospect of effervescent atomizer, and carried out relevant experiments; Li carried out comparative tests for three different types of effervescent atomizer, and analyzed that multi-nozzle effervescent atomizer were particularly suitable for gas turbine combustors. This is because when applied to gas turbine combustor, fuel circumferential uniform distribution can be achieved by a small number of atomizers; Chin introduced the design method of effervescent atomizer applied to gas turbine combustor in detail, and carried out test verification according to the design results.
3. Internal combustion engines (IC engines)

Pollutant emissions and combustion efficiency are also of prime concern for internal combustion engines. The pollutants emitted by internal combustion engines mainly include nitrogen oxides, unburned hydrocarbons, carbon monoxide, and particulate matter. The quantity of pollutants produced is governed by the combustion process control inside the internal combustion engine.

Lawler et al. [13] conducted experiments with jet flames stabilized on effervescent atomizers. Toluene was the liquid sprayed and methane was the atomizing gas. The results show that pollutants (including unburned hydrocarbons and carbon monoxide) were seen to drop by 80% or more with an increase in GLR from 5 to 15%. The study suggests that the use of effervescent atomization for IC engine fuel injection could possibly lead to drastic decreases in pollutant emissions. In addition, this technique provides good atomization when operating at injection pressures that are several times lower than those of conventional fuel nozzles. This would reduce parasitic losses and raise engine efficiency.

Wade et al. [14,15] established that a high-pressure effervescent atomizer can produce sub-10 μm sprays under injection pressure less than 35MPa. Satapathy and Sovani improved on Wade et al.'s design. Satapathy developed an atomizer that produced sub-5 μm sprays when operating at injection pressures less than 28 MPa and GLRs less than 0.02 (as shown in Fig. 3). Sovani achieved the sub-10 μm sprays under the injection pressure of 13MPa. Wade and Satapathy's experiments were carried out in high-density environment to simulate the actual environment of the late compression stroke in modern diesel engines combustor. These results demonstrate that effervescent atomizer can produce sprays comparable to, or finer than, those produced by modern conventional Diesel atomizers, even though injection pressures may be up to five times lower.

4. Furnaces and boilers

Thermal power plants consume a large amount of fuel oil for boiler ignition and combustion stabilization every year [17]. As high-grade hydrocarbon fuels become scarce, power plants urgently need to develop new fuel-saving boiler ignition combustion technology. A new type of energy-saving nozzle that can handle less refined fuels has to be designed to replace the original pressure-swirl atomizers [18].

Effervescent atomizers are characterized by their ability to solve problems above well. Wu Daohong, Liu Liansheng, Zhou Jinhua and Ane [19-22] have conducted lots of researches and experiments on application of small effervescent atomization oil gun. The results show that compared with traditional mechanical atomization oil gun, the former is more energy-saving, and fuel saving can reach about 16%
under the same working conditions. Structure of effervescent atomizer designed by Zhou Jinhua [21] is mainly composed of main body, oil pipeline, gas inlet pipe, mixer, cap and sealing head, which is shown in Fig. 4.

![Figure 3. Relationship between SMD and GLR by Satapathy](image)

![Figure 4. Schematic diagram of effervescent atomizer designed by ZHOU J H](image)

Sankar et al. [18] developed a swirl effervescent atomizer for application to industrial and residential boilers. Loebker and Empie [23] designed an effervescent atomizer for spraying a pulping industry by-product into a heat recovery boiler. The atomizer designed aimed to meet the optimum droplet size requirement of the boiler (2-3mm mass median diameter). Qualitative and quantitative results were obtained from spray images by using a high shutter speed camera. The qualitative results describe the liquid breakup process while the quantitative results give the relationship between the average droplet diameter and GLR and viscosity. In addition, both inside-out and outside-in geometries were tested, and the latter geometry showed smaller mean drop size. The atomizer, namely, outside-in geometries, sprayed drop sizes less than 5 mm under injection pressures less than 207 kPa and GLRs lower than 5%. Jedelsk [24] has designed many kinds of multi-nozzle effervescent atomizer, and with the aid of laser phase Doppler velocimeter (PDA) and high-speed cameras, comparative experiments were carried out. The results show that the spray shape of the multi-nozzle atomizer (as shown in Fig. 5) is basically similar to that of the single nozzle. In addition, atomizer sprayed unsteadily under the condition of low air pressure and GLR, which can be avoided by reasonable design and adjusting working parameters.
5. Water mist fire suppression

Water mist fire suppression system because of its environmental protection and energy saving has broad market prospects and economy benefits. Therefore, carrying out the research and development of water mist fire suppression system is of great important practical significance [25].

Effervescent atomizers have broad application prospects in water mist fire suppression system considering its advantages. They can produce sub-100 μm spray under low pressure, avoiding the cost and safety problems caused by high pressure; Its low gas consumption reduces the operating cost; besides, the orifice is larger, enabling them to handle less refined liquids without clogging, and easy to manufacture; finally, the atomization performance is relatively insensitive to variations in liquid physical properties, so atomizers can applicable for high viscosity solution due to the addition of fire suppression additives. Using halogen fire suppression gas or inert fire suppression gas for assist atomization, fire suppression effect can be greatly improved in many cases [26] because of the better gas dispersion. As a result, a number of scholars have devoted themselves to the research for water mist technology based on effervescent atomization, and carried out many theoretical and experimental studies.

Huang Xin [25] designed two types of effervescent atomizers, namely, inside-out and outside-in gas injection geometries, and carried out theoretical with experimental studies for both flow and spray characteristics by setting up the test rig. The droplet size and velocity distribution, cone angle and flux density of water mist produced by effervescent atomizer were measured under different conditions by a LDV/PDA (Laser Doppler Velocimetry /phase Doppler Anemometry) system and other methods. The results show that the liquid mass flow rate mainly depends on GLR and injection pressure, and decreases sharply at first and then slows down with the increase of GLR. The injection gas orifice area has a great influence on the flow characteristics, and larger area orifice is suitable for higher GLR.

Xu Fang [28] developed a new effervescent atomizer, and studied the flow characteristics and spray characteristics through experiment. Similar to Huang Xin’s experimental system, two sets of water and gas supply pipelines were used. The basic conclusions were consistent with results from Huang Xin. Besides, flow characteristics of dual supply and its influencing factors were further verified.

Zhang Xiaojing [25] carried out the numerical simulation research on outlet field and fire suppression performance of water mist effervescent atomizer with the aid of Fluent commercial software. Variation of water mist velocity field and temperature filed after injecting the water mist was mainly studied. The results show that the maximum average velocity is near the axis, velocity changes remarkably in radical direction from -20 to 20mm (as shown in Fig. 6). Average velocity increases firstly and then decreased in axial direction. When the water mist is injected, the temperature of fire field decreases in all direction, the smaller the drops, the stronger the suppression. In addition, the smaller the D10 (the particle size whose distribution fraction reaching 10%), the more obvious the cooling effect, and the wider the action range. Therefore, strengthening the atomization performance is surely conductive to enhancing fire suppression effect for water mist fire suppression system.
6. Others

In recent years, applications of effervescent atomizer have been extended to garbage incineration, industrial spraying, pharmaceutical industry and food drying industries with the continuous development and progress of effervescent atomization technology.

Effervescent atomizer is relative insensitivity to liquid viscosity, which is especially important when spraying waste products, whose rheological properties are often unknown and cannot be adequately controlled. Besides, performance is relatively insensitive to the atomizer discharge orifice size, so larger orifices can be designed to reduce clogging substantially. Furthermore, comparing to a conventional atomizer, the liquid flow velocity in the orifice of effervescent atomizer is much lower, which greatly reduces the erosion problems created by solids suspended in the waste. Finally, lower velocities in the orifice lead to lower drop velocities. As a result, the burnout lengths are shorter and the incinerator can be made more compact.

Spraying Systems Inc. [30] developed high transfer efficiency spraying technology by using effervescent atomization. Petersen [31] applied this technology to pharmaceutical industry, and using effervescent atomizer to spray some polymer aqueous solutions. Stähle [32,33] and Wittner [34] brought effervescent atomization technology to the drying process of industrial food, and Stähle used effervescent atomizer to spray and dry starch paste suspension. Besides, atomization performance of effervescent atomizer and air core liquid ring atomizer at low gas consumption was compared and analyzed. Stähle also studied the influence of liquid viscosity on the internal morphology and spray particle size of atomizer, and Wittner carried out studies on the effects of liquid viscosity, gas pressure and GLR on the effervescent atomizer performance.

7. Conclusion

Effervescent atomization technology is widely used in various fields of industrial process because of its advantages. However, there is still no unified conclusion on the study of atomization mechanism. Although many important research results have been achieved in the aspects of gas-liquid inside the atomizer and the jet atomization outside the atomizer, there are still many problems to be explored and studied from the current research [2, 35].

1). Issues about gas-liquid two-phase mixing in the mixing chamber of effervescent atomizer. Previous studies have shown that the gas-liquid two-phase mixing in the mixing chamber has a great influence of the jet atomization effect. Current studies mainly focus on the influence of gas-liquid
morphology in the mixing chamber on the jet atomization, and lack of research on the bubble formation and movement in the mixing chamber.

2) Issues about gas-liquid two-phase flow in the orifice region of effervescent atomizer. The flow field changes dramatically, and the gas-liquid two-phase flow changes significantly in the orifice region. The existing research mainly obtains the images of gas-liquid flow pattern through visualization experiment, and the theoretical analysis is immature, especially for the morphology and evolution of different gas-liquid flow pattern inside the orifice, as well as the stretching, rupture and expansion behavior of bubbles inside the orifice need to be further studied.

3) Issues about jet mechanism and jet instability of effervescent atomizer. Exiting studies on jet mechanism and instability are mainly based on jet image, jet pressure and other information. However, other important information which reflects the mechanism and instability of jet atomization is lacking, which needs to be further excavated to obtain quantitative characterization methods.

4) Issues about prediction of atomization performance index. Developing a theoretical model for evaluating the performance of effervescent atomizer can greatly reduce the development period and cost, yet the existing theoretical model is not accurate enough, as well as limited in application, and needs to be further improved.

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