Powder Technology 327 (2018) 303–309

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Experimental investigations of a new surfactant adding device used for mine dust control

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ARTICLE INFO

Article history:
Received 14 August 2017
Received in revised form 24 November 2017
Accepted 28 December 2017
Available online 03 January 2018

Keywords:
Adding method
Water mist
Dust
Mines

ABSTRACT

To guarantee the stable and quantitative adding of surfactant into the pressure pipe and not be affected by the inlet and outlet pressure changing, the method utilizing jet pump cavitation characteristics to add surfactant was proposed. Keeping pressure ratio lower than the critical pressure ratio, the adding quantity could remain unchanged. In order to improve the stabilities, reduce the pressure loss and improve the critical pressure ratio of the jet cavitation adding method, a new two-stage cavitation jet adding method and device were proposed, and the performance was investigated experimentally under different working flows and outlet pressures, and compared to the cavitation jet pump in this paper. The results showed that the negative pressure remained unchanged within a certain range of outlet pressure, then decreased gradually with the increase of outlet pressure for the new device, which was similar with the traditional one. Furthermore, the critical pressure ratio of the new device was larger than the traditional one, which indicated that the pressure loss for the new device was smaller and it was more stable as the adding amount of surfactant was constant. In addition, the critical pressure ratio could increase by reducing the additive proportion of surfactant. Based on the above contributions and field investigation, it is believed that the study will play an important role for automatic quantitative control.

1. Introduction

Mine dust is one of the major hazards in underground coal mines, which can cause pneumoconiosis and explosion accidents, threating workers' health and safety. Relevant data shows that pneumoconiosis is the most popular and serious occupational disease in mines. Compared with the production accidents, pneumoconiosis is more universal in the world's major coal-producing countries [1,2]. Coal dust explosion is the most serious disasters in coal mines. Compared with the gas explosion, the extent and scope of the coal dust explosion is larger and more destructive. In the world history of coal mining, the deadliest coal-mining accidents are almost caused by coal dust or gas coal dust explosions [3].

Long-term filed practice proves that at the beginning of the dust produced before spreading, using foam or water spraying can effectively avoid dust ejecting into the air, fundamentally eliminating dust [4–6]. But for the processes, such as cutting, crushing and blasting, the great amount of produced dust with a high speed cannot be suppressed well. There are always some dust escaping into the air [7,8]. Because of the simple system, flexible layout, convenient use and low cost of water mist technology, it is the most commonly used technical measure in mines to capture the escaped dust through the colliding, intercepting and wetting effect [9,10]. As the most coal dust is hydrophobic and the surface tension of water is high, water mist is limited in the ability to capture dust. To solve the problem, the method of adding surfactants into the water to reduce the surface tension of water, improving water atomization quality and wetting ability is usually adopted [11].

The conventional method for adding surfactants into the pressure water pipe usually requires an electrical metered pump [12]. As the risks associated with the use of electrical equipment in underground coal mines, as well as the complexity of such systems, their use is mainly restricted to a confined zone close to the working face. With the development of technology, the jet device is widely used to add liquid automatically for overcoming the problems caused by the electrical metered pump [13–15]. According to the related studies about the jet device, the agent adding amount is closely related to the suction negative pressure that is affected by the outlet pressure [16]. The agent adding amount changes when the outlet pressure varies. In the working process of atomizing nozzle, the exit of nozzle may contact with the caving coal sometimes or there are fragments blocking the nozzle exit, leading the outlet pressure varies. In addition, for some air atomizing nozzles, the compressed air flow is not stable in the coal mines. The jet device cannot realize a stable addition of surfactant when the air pressure changes. To solve this problem, the method using jet cavitation to add surfactant is proposed. For jet cavitation, the domestic and foreign scholars have been researching on its mechanisms and applications. The American Institute of Aeronautics and Astronautics found that the flow rate of jet device was not affected by outlet pressure fluctuation in the condition of cavitation, which

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https://doi.org/10.1016/j.powtec.2017.12.080
0032-5910/

successfully eliminated the effect of dynamic atmospheric pressure on the fuel flow rate and realized the precise control of fuel [17,18]. Since then, many scholars applied cavitation jet pump into the automatic control of liquid flow rate and designed various types of flow controllers [19–21]. But all the researches didn't mention liquid absorption in the cavitation condition. When jet cavitation occurs, the negative pressure of the suction chamber decreases to the saturated vapor pressure, which is a certain value at a constant temperature [22,23]. On account of the constant atmosphere pressure and suction chamber's pressure, the absorption amount should also be constant theoretically [24]. In China, through the experimental study on the liquid absorption of the jet pump, Wang and Lu have found that the absorption amount was invariant when the negative pressure of the suction chamber reached −0.09 MPa [25,26]. Taking advantage of the liquid jet pump's character that its flow ratio doesn't change in cavitation, the automatically and quantificationally adding-material equipment has been developed and been tested in practice in Chinese coal mines [27].

Although cavitation additions have these advantages, there are many negative effects when cavitation occurs, especially the low efficiencies and mechanical erosion, which causes the critical operating condition was not used in the application [28,29]. At present, the research of cavitation resistance materials has made great progress. Using cavitation resistant material such as hardened stainless steel can avoid mechanical erosion [30]. As the working environment is complicated in coal mines, the noise intensity of the working cavitation jet pump is allowed. According to the Kudirka's study, the flow ratio of jet pump was independent of the outlet pressure when it decreased to 0.1–0.2 [31]. Lu suggests that the critical pressure ratio should be below 0.4 to ensure the stable addition, which indicates great energy loss and narrow working range. Hence the most difficult problem is the low efficiencies and poor stabilities [32,33].

To solve the problem, in this study, a new design of a two-stage cavitation jet device was introduced, and a self-built experimental system was used to measure its properties and compare with the conventional jet device. After testing its good and stable work conditions, the field investigation was conducted to verify the new device is more suitable for mine dust control.

2. New design of two-stage cavitation jet device

Fig. 1 shows the principle of two-stage cavitation jet device and the curve shows the pressure changes in the device when it works normally. It consists of two single stage jet pumps with a common import, which are named primary and secondary jet pump respectively. They are parallel structures. The jet pump entrances A_1, A_2 are connected to the same water sources, secondary jet pump's export C_2 is connected to the primary jet pump's suction inlet B_1, the secondary pump's suction inlet B_2 is connected with surfactant through the pipettes. When the device works, the pressure water flows through the primary jet pump, the differential pressure between A_1 and C_1 makes the pressure water flow through the secondary jet pump and cavitation generated in the suction inlet B_2, sucking the surfactant into the secondary jet pump under the action of atmospheric pressure. Then the mixing liquid flows into the primary pump's suction inlet B_1 and completes the mixing with the water in the primary jet pump.

According to the Bernoulli's equation, the relationship between sections 1–1 and 2–2 of the primary jet pump can be written as:

$$\frac{P_1}{\rho}+\frac{v_1^2}{2}=\frac{P_2}{\rho}+\frac{v_2^2}{2} \tag{1}$$

where P_1 and P_2 are the inlet water pressure and jet nozzle exit pressure, Pa; v_1 and v_2 are the inlet velocity and nozzle exit velocity, m/s; ρ is the liquid density, kg/m^3; Since v_2 is much larger than v_1, v_1 is neglected. The inlet mass flow rate of primary jet pump m_1 can be expressed as:

$$m_1 = S_2\sqrt{2\rho(P_1-P_2)} \tag{2}$$

where S_2 is the jet nozzle exit area, m^2.

Similarly, for the secondary jet pump, the inlet mass flow rate m_2 can be expressed as:

$$m_2 = S_2'\sqrt{2\rho(P_1'-P_2')} \tag{3}$$

where P_1' and P_2' are the inlet water pressure and jet nozzle exit pressure, Pa; S_2' is the jet nozzle exit area, m^2; ρ is the liquid density, kg/m^3.

According to the basic principle of fluid mechanics,

$$\mathrm{m} = m_1 + m_2 \tag{4}$$

$$P = P_1 = P_1' \tag{5}$$

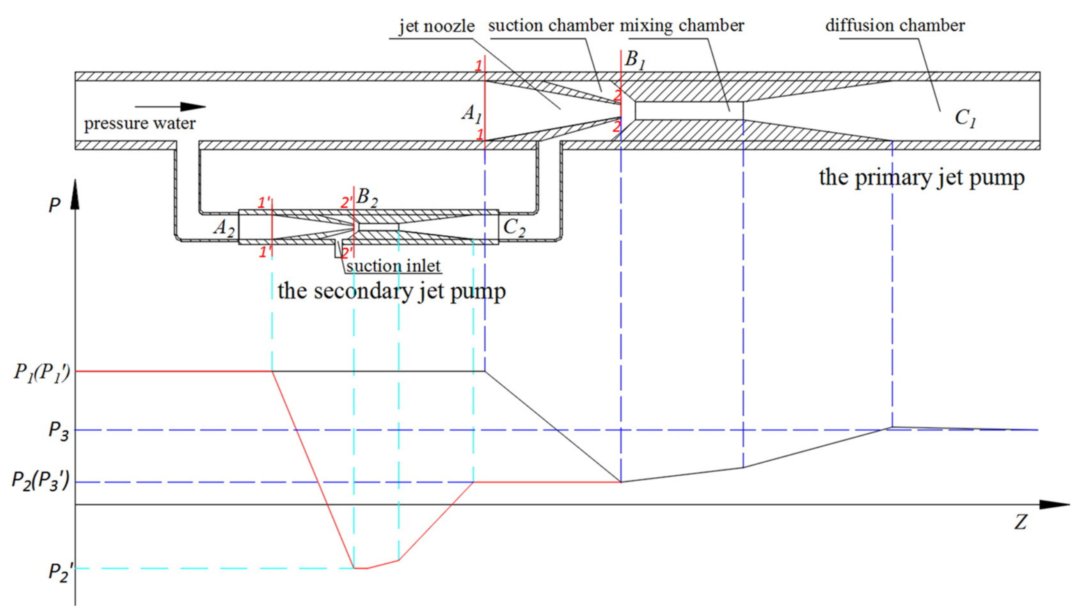

Fig. 1. Principle of two-stage cavitation jet device.