Contents lists available at ScienceDirect

Process Safety and Environmental Protection

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

Foaming agent self-suction properties of a jet-type foam preparation device used in mine dust suppression

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ARTICLE INFO

Article history:
Received 13 May 2015
Received in revised form 22 July 2015
Accepted 1 August 2015
Available online 8 August 2015

Keywords:
Dust suppression
Foam
Foaming agent
Outlet pressure
Self-suction
Vacuum degree

ABSTRACT

In this study, we introduce a jet-type foam preparation device for use in mine dust control, which can enhance the reliability and applicability of the foam production process compared with conventional foam generators. In order to elucidate the foaming agent self-suction properties of this novel foam generator, we used a self-built experimental setup to investigate the effects of the working pressure and outlet pressure on negative pressure (vacuum degree) during foaming agent suction, as well as the functional relationship between negative pressure and the foaming agent by adding parameters. We also studied the effects of the valve opening degree on the foaming agent flow rate and addition ratio. The results showed that the working pressure and outlet pressure affected the formation of negative pressure in a positive linear manner and a negative linear manner, respectively. Thus, the negative pressure increased linearly as the working pressure increased, whereas it decreased in a linear manner as the outlet pressure increased. There was also a quadratic relationship between the vacuum degree and foaming agent quantity with the piecewise characteristics of the growth process, where they increased slowly with a lower vacuum degree but increased rapidly with a higher vacuum degree. After creating a moderate negative pressure with the water jet, the foaming agent could be added automatically at a low flow rate with a low ratio via the regulating valve on the liquid suction hose. This study provides basic information that should facilitate the application of this novel foam preparation technique.

1. Introduction

Mine dust generally refers to the fine solid particles produced during the mining process, which is one of the most serious hazards found in mines because it can cause pneumoconiosis in miners and dust explosion accidents, thereby constituting a severe threat to the health and safety of miners (Wang, 2015; Fabiano et al., 2014; Chen et al., 2013; Cao et al., 2014). In recent years, the amount of total dust produced and the percentage of respirable dust have increased sharply due to growth in the levels of mechanization and mining intensity in mines. For example, the concentrations of respirable dust always exceed 300 mg/m^3 in the mine heading face driven by a roadheader (Jin et al., 2010). Thus, it is very importance to develop and implement efficient dust suppression technologies for mines.

Foam is a special type of two-phase gas–liquid medium, which has a large flow rate and surface area, as well as a high capacity for adhering to and wetting dust, thereby making it highly efficient for dust suppression, while it also requires much less water consumption compared with the

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http://dx.doi.org/10.1016/j.psep.2015.08.001
0957-5820/

conventional water spraying method (Seibel, 1976; Mukherjee and Singh, 1984; Laurito and Singh, 1987). Foam technology has been shown to be an effective method for enhancing the efficiency of mine dust capture (Wang et al., 2013; Ren et al., 2014; Xi et al., 2014). The foam preparation method can directly affect the effectiveness and cost of suppressing dust using foam. However, conventional foam generators are based on compressed air, which requires a compressed air pipeline and a device to add an additional foaming agent (Page and Volkwein, 1986; Ren et al., 2012; Wang et al., 2011), thereby increasing the complexity but reducing the reliability of foam preparation. Furthermore, compressed air pipelines are usually unavailable near many of the dust generating points in mines. Hence, the development and application of foam technology is restricted severely.

To address these problems and to adapt foam technology to the complex conditions found in underground mines, we previously proposed a jet-type foam generator with air and foaming agent self-suction (Wang et al., 2014a). This novel foam preparation device employs water pressure to power the system and it automatically draws air into the foaming agent, thereby eliminating the need for a compressed air pipeline and a device for adding a foaming agent. This method has been applied successfully at a fully mechanized coal face in Zhuxianzhuang Mine, where it achieved a dust suppression efficiency of >85% (Wang et al., 2014b). The jet-type foam generator is based on foaming agent suction, which is related directly to the effect and cost of foam preparation. However, no in-depth studies have investigated the foaming agent self-suction properties of this method, thereby hindering the efficient and low cost production of foam. Therefore, in this study, we conducted experimental investigations of the effect of the working pressure and the outlet pressure on the negative pressure during suction (vacuum degree), as well as the throat differential pressure of the jet-type foam generator. In addition, we analyzed the relationship between the vacuum degree and the foaming agent addition ratio. We also studied the effect of the valve opening degree on the performance of foaming agent addition.

2. Basic principle of the jet-type foam generator

As described in the authors' previous work (Wang et al., 2014a), the jet-type foam generator mainly comprises a pressure water inlet, jet nozzle, air suction chamber, liquid (foaming agent) suction chamber, mixing chamber (throat), diffuser chamber, and foaming chamber. There is an air suction hole on the air suction chamber, a liquid suction hose with a needle valve on the liquid suction chamber, and a spiral stirrer in the foaming chamber.

The working process for this jet-type foam generator with air and foaming agent self-suction mainly involves four steps, in the following order: air-agent self-suction by jet negative pressure, jet breaking and mixing, preliminary diffusion pressurization to obtain bubbles, and rotational flow-reinforcing foam generation. The low flow rate of the water pressure is powered but the air and foaming agent are absorbed automatically via the negative pressure formed by the water jet based on its entrainment effect, and thus there is no need for a compressed air pipeline, pump, or other addition device. The rotational flow method using a spiral stirrer is employed to reduce the flow resistance and the energy loss from the foaming media, which can enhance the bubble production capacity and outlet pressure, as well as guaranteeing the formation of negative pressure for the air and foaming agent suction. This method converts the conventional foam preparation technology using compressed air and a device for adding extra foaming agent into a novel air and foaming agent self-suction type system, which can significantly simplify the foam preparation process, as well as enhancing its reliability and range of application.

3. Experimental

3.1. Experimental setup

Fig. 1 shows the self-built experimental system that we used to study the foaming agent self-suction properties of the jet-type foam preparation device. In this experimental setup, the water source was a clean water pool and a 3WP14-15/25 plunger pump was used to provide pressurized water as power for the jet-type foam generator. The flow rate of pressurized water could be regulated by a frequency converter on the plunger pump. Regulating valve I was electro-controlled to easily regulate the flow rate of the foaming agent, thereby allowing the intelligent adjustment of the valve opening degree with the PLC module and the upper computer, where the opening degree when fully open was recorded as 100% and that when fully closed was recorded as 0%. Regulating valve II was employed to change the outlet pressure, thereby allowing us to conduct foaming agent self-suction experiments with the jet-type foam preparation device under different outlet pressures.

In the experimental setup, the measurement instruments mainly comprised an electromagnetic flowmeter for measuring the working flow rate of water, a precise pressure gauge for measuring the working pressure, a micro-electromagnetic flowmeter for measuring the foaming agent flow, a vacuum pressure gauge for measuring the suction vacuum degree, a differential pressure transmitter for measuring the throat differential pressure, and a pressure transmitter for measuring the outlet pressure. The measurements obtained from the differential pressure transmitter were transmitted to the upper computer via the signal acquisition module. The accuracy of the above measurement instruments, respectively is 1%, 0.4 grade, 0.2%, 0.1 grade, 0.2% and 0.4 grade. The foaming agent used in the experiments was KJC-II, which was developed by the author.

3.2. Experimental design

(1) The experimental setup was assembled according to Fig. 1, where we ensured that each connection was firm and well sealed. We shut off the sluice valve on the air inlet and started the plunger pump. The output working condition of the pressurized water was regulated by the frequency converter, and we observed and measured the working flow q_0 and working pressure p_0 of the pressurized water.
(2) We performed foaming agent suction experiments using different working pressures according to the following steps. The opening degree of valve I was kept at 30% and regulating valve II was fully open. The working pressure p_0 and working flow q_0 were increased gradually by raising the pump's frequency by 1.0 Hz each time. Measurements were then obtained for the suction negative pressure (vacuum degree), foaming agent flow rate, and