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Optimization of cavitation venturi tube design for pico and nano bubbles generation

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ABSTRACT

Hydrodynamic cavitaion venturi tube technique is used for pico and nano bubble generations in coal column flotation. In order to determine the optimal design of hydrodynamic cavitation venture tube for pico and nano bubble generation, a four-factor three-level Central Composite Design of Experimental was conducted for investigating four important design parameters of cavitation venturi tube governing the median size and the volume of pico and nano bubbles. The test results showed that maximum volume of pico and nano bubbles, 65–75%, and minimum mean pico and nano bubble size, 150–240 nm, were achieved at the medium ratio of the diameter of outlet of the venturi-tube and diameter of throat (3–4), medium outlet angle (11–13°), high inlet angle (26–27°) and high ratio of the length of the throat and the diameter of throat (2.3–3). Study the effects of the producing pico and nano bubbles on fine coal flotation was performed in a 5 cm diameter 260 cm height flotation column. The optimal percentage of pico and nano bubbles was about 70%, which produced maximum combustible material recovery of 86% with clean coal ash content of 11.7%.

1. Introduction

Nano bubbles have been studied for years in various fields of science and technology because of their wide range of potential applications based on the technique used for bubble generations. They have been used for cleaning and defouling solid surface, ultra-sound imaging, bioengineering, dewatering of organic solids from industrial wastes, removal of salts, etc. [1]. Pico-nano bubbles generated by hydrodynamic cavitation venturi tube were found to be able to improve coarse particles and fine particles flotation performances, as well as reducing reagents consumption [2,3]. The bridging of tiny bubbles between hydrophobic surfaces enhances coarse and fine particle flotation [4,5].

The generation of pico-nanobubble is a very complex physico-chemical process [6,7]. Many design variables influence the pico and nanobubble generation, thus, it is necessary to make some effort to investigate their influences on the flotation process [8]. The role of different designs of hydrodynamic cavitation venturi tube, as well as the effect of frother dosages [9,10], on pico and nano bubble generation remains to be explored. In order to determine the optimal design of cavitation venture tube, and eventually better understand the mechanisms of pico and nano bubble enhanced froth flotation of coal particles, the pico and nano bubble size distribution was studied. The tests of pico-nano bubble generation were performed with a specially designed cavitation venturi tube at varying values of four major design parameters including, the ratio of the diameter of inlet of the venturi-tube and the diameter of throat (Din/Dt), the ratio of the length of the throat and the diameter of throat (Lt/Dt), inlet and outlet angles. The effect of different frother dosages on pico-nanobubble generation was investigated, and the study of the effects of pico-nanobubbles on the flotation performance were also presented and discussed in this publication.

2. Experimental

2.1. Materials

Bituminous coal sample from Pittsburgh No. 8 seam is acquired from Green County, Pennsylvania, USA for this study. The sieving results are given in Table 1, which is distributed over a wide size range as indicated by 22.03% particles being larger than 355 μm and 28.16% particles being finer than 45 μm. The feed ash content is 30.64%.

2.2. Cavitation venturi tube

The schematic diagram of the cavitation venturi tube is given in Fig. 1. The venture tube is specifically designed for generating pico and nano bubbles.

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Table 1
Particle size and ash distributions for Pittsburgh No. 8 seam coal.

Size range (μm)	Individual		Cumulative	
	Wt (%)	Ash (%)	Wt (%)	Ash (%)
−710 + 600	10.21	18.97	100.00	30.64
−600 + 355	11.82	18.94	89.79	31.97
−355 + 250	6.22	19.62	77.97	33.94
−250 + 150	9.16	19.92	71.75	35.18
−150 + 75	19.48	19.02	62.59	37.42
−75 + 45	14.95	26.03	43.11	45.73
−45	28.16	56.19	28.16	56.19

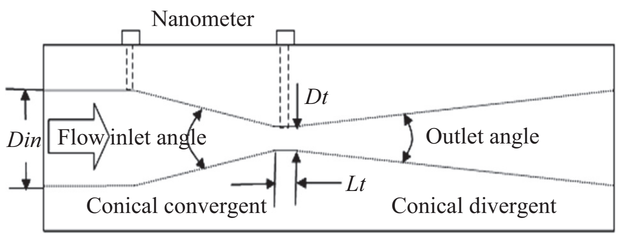

Fig. 1. Schematic diagram of cavitation venturi tube.

2.3. Pico bubbles, nano bubbles and micro bubbles measurement system

Pico-nano bubbles (<0.5 μm) and nano bubbles (0.5–1 μm) generating and measurement systems were designed and set up as shown in Fig. 2. The column is made of plexiglass tubing having 5.0 cm ID and 67.3 cm height. The lower section of the column has 15.2 cm ID and 18.4 cm height. The larger diameter of the lower section of the column is designed to stabilize the flow in the system. The specifically designed venturi tube and static mixer are used to generate pico and nano bubbles, and micro bubbles, respectively. The solids-bubbles recirculating stream flow through the static mixer at 12 L/min, which splits by a two-way connector into valve 4 to the venturi tube, or valve 5 to the column. All tests are measured 10 min after the bubble being generated. In order to eliminate the effect of bubbles rising during measurement, the silica particles, pico-nano bubbles and nano bubbles, and frother solution are recirculating slowly through valve 1 without flowing through the venturi tube. The bubbles are then transported by a peristaltic pump in and out of the measuring flow cell placed in the Malvern Mastersizer 2000 laser particle size analyzer.

2.4. Pico-nano bubble column flotation

Fig. 3 shows the schematic diagram of 5.08 cm ID and 250 cm height open flotation column equipped with static mixer and venture tube for pico-nano bubbles generation. The slurry feed is fed into a feed tank, and appropriate amount of collector and frother are then added for precondition with a circulating loop and pump. The feed slurry is then fed into the upper portion of the flotation column. The fresh water, air and recirculating tailings are passing through the static mixer and cavitation venture tube connected in series before injected into the lower portion of the flotation column. The flotation column is also equipped with wash water device to flush down the entrained ultrafine mineral particles. A special designed tailings discharge section is also added to improve the mixing and contacting of bubbles and solids, by recirculating about one third of solids back to the flotation column. The static mixer is used to produce the micro-bubbles and more importantly to improve the mixing and contacting of bubbles and solids from the tailings re-circulating stream.

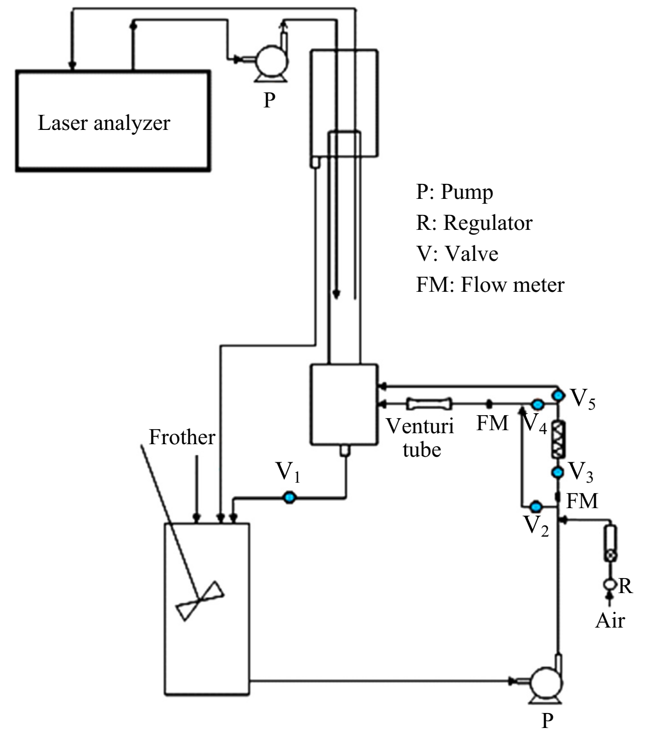

Fig. 2. Schematic diagram of the pico-nano bubbles and micro-bubbles measurement system.

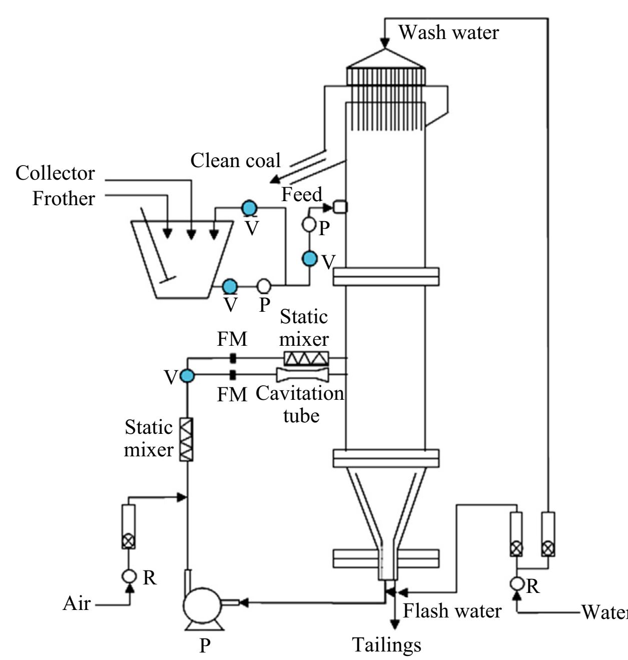

Fig. 3. Schematic diagram of flotation column equipped with static mixer and cavitation venture tube.

The combustible material recovery and pico-nano bubble percent are defined as follows.

$$Y_c\% = \frac{(A_t - A_f)}{(A_t - A_c)}\% \tag{1}$$

$$R_c\% = Y_c\% \frac{(100 - A_c)}{(100 - A_f)}\% \tag{2}$$