Design and application of analytical system for vertical foam’s structure

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Abstract. The purpose of this paper was to observe and analysis the vertical foam’s structure. Firstly, the horizontal foam’s structure characterization using binocular stereo microscope and particle analyzer was introduced. Secondly, the foam receiver and monocular stereo microscope with universal support were designed to observe vertical foam. Then the analytical system was composed of particle analyzer and microscope. Thirdly, this analytical system was applied to analysis fire fighting foam’s vertical structure. Further study should focus on foams’ structure evolution under heat radiation condition.

1. Introduction

Foams were formed by trapping pockets of gas in a liquid or solid. Fire fighting foam could be used to extinguish a fire by cooling the environment, coating the fuel and preventing combustible’s contact with oxygen. Foam’s fire control ability was relative with macroscopic parameters including foam’s type, expansion, drainage time and produce processing [1]. Foam’s fire control ability was relative with microscopic parameters including structure evolution and membrane thickness. The foam’s structure could be captured by camera device [2]. Based on horizontal foam structure’s study, the vertical foam’s analysis system would be established in this paper.

2. Binocular stereo microscope and particle analyzer

2.1. Binocular stereo microscope

Stereo microscope was an optical microscope variant designed for low magnification observation of a sample, typically using light reflected from the surface of an object rather than transmitted through it. To fire fighting foam with high transmittance, the light could both be used to reflect from foam’s surface and transmit through the foam. This SZ760T2LED stereo microscope’s maximum magnification could reach 110 X with the help of 2 X eyepiece. The working distance was 110 mm and pupillary distance was 54-76 mm. Then the horizontal foam’s structure evolution video could be obtained using camera device(2048*1536). The captured figures from the video could be analyzed using particle analyzer further more.

2.2. Particle analyzer for horizontal foam’s structure

Particle analyzer could be used to determine the size range, the average size and the distribution of the particles in a liquid sample [3]. The foam figure could be captured from the binocular stereo microscope’s video. Then the foam bubbles could be recognized and analyzed statistically. In addition, the relative parameters to foam bubble should not only include average foam bubble diameter, but also include diameters’ coefficient of variation [4].
Table 1. Foam bubble’s parameters in particle analyzer.

| Parameter Name     | Content                                                                 | Comments |
|--------------------|-------------------------------------------------------------------------|----------|
| Circumference      | The linear distance around the foam bubble’s boundary.                  | -        |
| Area               | The quantity that expressed the extent of a two-dimensional figure      | -        |
| Aspect ratio       | The ratio of short axis and long axis.                                   | <1       |
| Long axis          | The longest line segment that passed through the center of the circle or polygon foam bubble. | -        |
| Short axis         | The shortest line segment that passed through the center of the circle or polygon foam bubble. | -        |
| Diameter of foam   | Any straight line segment that passed through the center of the circle or polygon foam bubble. | To foam with non-circle shape, the diameter was an average diameter of equivalent circle. |
| The coefficient of variation | The ratio of the standard deviation to the mean of foam bubble’s average diameter. | The standardized measure of dispersion of a frequency distribution. |
| Foam number per unit area | The foam bubbles’ number per unit area on the foam figure. | This number was changing with foam’s evolving. |

Based on above study results, the analytical system for foam’s structure should be composed of binocular stereo microscope and particle analyzer. The special foam receiver with vertical observation window should be designed.

3. Analytical system for vertical foam’s structure

3.1. Foam receiver with vertical observation window

Considering this receiver might be used under heat radiation, the vertical transparent glass should be selected. Then, quartz glasses were introduced. The foam receiver’s height could be suitable and the added cushioning was put into the drainage receiver for buffering.

![Figure 1: Foam receiver (1: vertical transparent glass; 2: slope; 3: spiral joint; 4: support; 5: base; 6: drainage receiver with added cushioning.)](image)

There were six parts in foam receiver including four sides’ vertical transparent glass, four slopes, one spiral joint for drainage receiver, four supports, one base and one drainage receiver with cushioning. The physical parameters of quartz glasses were shown. The other parts including slope, base and support were produced using stainless steel.
Table 2. The physical parameters of quartz glasses.

| Parameter Name                     | Content                                                   |
|------------------------------------|-----------------------------------------------------------|
| Heat resistant                     | Softening point could reach 1730 °C.                     |
| Corrosion resistant                | Higher acid resistant than ceramics and stainless steel.  |
| Thermal Protective Performance     | The quartz glass in 1100 °C could be immersed into cold water immediately without any damage. |
| Light transmission                 | Visible light’s light transmittance could reach 93%.     |
| Electrical insulation              | High electrical insulation even in high temperature environment. |

3.2. **Monocular stereo microscope**

Table 3. The parameters of binocular stereo microscope.

| Parameter Name                    | Content                          | Comments                                      |
|-----------------------------------|----------------------------------|-----------------------------------------------|
| Stereo microscope model           | DTX-1                            | -                                             |
| Maximum magnification             | 45 X                             | 90X(with the help of 2 X eyepiece)            |
| Numbers of object lens            | 1                                | -                                             |
| Numbers of universal support      | 1                                | Keep the stereo microscope at any angle       |
| Numbers of focusing device        | 1                                | To get clear figures.                         |

Then the monocular stereo microscope with universal support was introduced (2048*1536). The vertical analyzer system was built up composing of foam receiver and monocular microscope. The height of universal support was 400 mm.

Figure 2: foam receiver (left) and monocular microscope (right).

4. **Application of vertical analyzer system**

There were different types of fire fighting foam agent such as AFFF and P\textsuperscript{[5]}. AFFF meant aqueous film forming foam extinguishing agent, which could control fire by both foam babble and aqueous film. P meant protein agent, which came from animals’ hoof or hair. After generation, the vertical foam’s structure could be observed using vertical analyzer system\textsuperscript{[6]}.
Figure 3: Vertical AFFF foam structure (left) and vertical P foam structure (right).

The difference could also be compared intuitively as shown in Table 4. In these data, the coefficients of variation were quite variable. The lower coefficient of variation was, the more stable foam structure was. P was more stable than AFFF, which meant P had longer drainage time according to foam bubble’s parameters [7]. P’s stability was caused by the protein scaffold whose structure could keep the shape of foam bubble. Then P had a longer burnback time compared with AFFF or other fire fighting foam.

| Parameter Name     | AFFF       | P          |
|--------------------|------------|------------|
| Circumference      | 1892.89 μm | 1668.25 μm |
| Area               | 388519.34 μm² | 265961.96 μm² |
| Aspect ratio       | 0.97       | 0.96       |
| Long axis          | 597.38 μm  | 528.61 μm  |
| Short axis         | 571.10 μm  | 503.41 μm  |
| Diameter of foam   | 576.13 μm  | 508.78 μm  |
| The coefficient of variation | 0.7009 | 0.5556 |
| Foam number per unit area | 1.842 | 2.933 |

5. Conclusion
In this paper, the vertical analyzer system was built up composing of foam receiver and monocular microscope. This vertical analyzer system could be used to compare the vertical AFFF and P foam’s vertical structure parameters. In the further, more foams’ structure evolution under heat radiation would be studied systematically. This work would contribute to improve fire fighting foam’s mechanism research and foam’s extinguishing effect [8].

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References
[1] Chen T, Cheng H U, Bao Z, et al. Experimental study on extinguishing of pool fire with compressed air foam system in road tunnel[J]. Journal of Safety Science & Technology, 2017.
[2] Xia J J, Fu X C, Zhang X Z, et al. Design and Application of Endoscope with Aided Lens for Observation of Fire-Fighting Foam[J]. Applied Mechanics & Materials, 2013, 271-272:823-828.
[3] Moe M K, Huber S, Svenson J, et al. The structure of the fire fighting foam surfactant Forafac®:1157 and its biological and photolytic transformation products[J]. Chemosphere, 2012, 89(7):869-875.
[4] Xia J J, Fu X C, Bao Z M, et al. Design of a modified particle analyzer for the automatic identification of the globular foam’s boundary[C]/Electromechanical Control Technology and Transportation: Proceedings of the 2nd International Conference on Electromechanical Control Technology and Transportation (ICECTT 2017), January 14-15, 2017, Zhuhai, China. CRC Press, 2017: 329.

[5] Gao H, Zhang M, Xia J J, et al. Time and surfactant types dependent model of foams based on the Herschel–Bulkley model[J]. Colloids & Surfaces A Physicochemical & Engineering Aspects, 2016, 509:203-213.

[6] Sheng Y, Jiang N, Sun X, et al. Experimental Study on Effect of Foam Stabilizers on Aqueous Film-Forming Foam[J]. Fire Technology, 2018, 54(1): 211-228.

[7] Dong S, Lu X, Wang D, et al. Experimental investigation of the fire-fighting characteristics of aqueous foam in underground goaf[J]. Process Safety and Environmental Protection, 2017, 106: 239-245.

[8] Da Costa J, McCabe J. Fire Fighting Foaming Compositions: U.S. Patent Application 15/525,829[P]. 2017-12-28.