Fire hazard analysis of alcohol aqueous solution and Chinese liquor based on flash point

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Abstract. In this paper, a series of experiments were conducted to study the flash point of alcohol aqueous solution and Chinese liquor. The fire hazard of the experimental results was analysed based on the standard GB50160-2008 of China. The result shows open-cup method doesn’t suit to alcohol aqueous solution. On the other hand, the closed-cup method shows good applicability. There is a non-linear relationship between closed-cup flash point and alcohol volume concentration. And the prediction equation established in this paper shows good fitting to the flash point and fire hazard classification of Chinese liquor.

1. Introduction
China has a long history of liquor culture since Du Kang has made it four thousand years ago [1]. Chinese liquor can be divided into different flavor: Maotai type, Luzhou type, fragrance type, rice type and others. The decisive effect on the flavor style is not to account for 99% of the alcohol and water, but those of the trace materials, their different proportions and levels lead to different flavor style and different tastes. At the same time, fires caused by Chinese liquor happened very frequently. As for the fire hazard of Chinese liquor, it may be different with alcohol aqueous solution. The flash point is one of the major physical properties used to determine the fire hazard of fuels, and the lower the flash point, the greater the fire risk [2]. GB50694-2011 [3] has given an empirical equation to predict the flash point of Chinese liquor, but in the actual use of the empirical equation, it is found that the prediction is not accurate, especially when the alcohol volume concentration is low. To rebuild the prediction model, and reveal the relationship between Chinese liquor and alcohol aqueous solution in flash point and fire hazard, a series of flash point experiments were conducted in this paper.

2. Experimental approaches

2.1. Experimental Apparatus and Verification

Figure 1. The automatic open-cup and closed-cup flash point tester.
Figure 1 shows the automatic open-cup and closed-cup flash point tester [4] (SCKB3000, Zibo Shengkang Dianqi CO., LTD, China), which can perform the standard test methods of GB/T3536-2008 [5] and GB/T261-2008 [6]. Before the experiments, some standard substances closed-cup flash point are tested and compared with the Open Chemistry Database as listed in table 1 to verify the tester, and it can be seen that the test values of n-tetradecane, phthalate and n-hexadecane meet the requirements.

| Test mode       | Closed-cup test | Open-cup |
|-----------------|-----------------|----------|
| Test substance  | n-Tetradecane   | n-Hexadecane | n-Hexadecane | Phthalate |
| Standard values | 372             | 408      | 373           | 491      |
| Test values     | 371.5           | 407.7    | 372.6         | 491.7    |

2.2 Specimen
The specimens of the study were of the alcohol aqueous solutions with alcohol volume concentration (AVC) of 5%, 10%, 20%, 30%, 35%, 40%, 50%, 60%, 70% and 100%. In addition, alcohol has a very low boiling point of 13°C compared with the environment temperature. So all the specimens were cooled to 5°C using a fridge before the test. Every test at the same condition was repeated several times to ensure reproducible results within permitted error ranges.

3. Results and discussion

3.1 Open-cup flash point

![Figure 2. The open-cup flash point curves of alcohol aqueous solution.](image1)

![Figure 3. The closed-cup flash point curves of alcohol aqueous solution.](image2)

Figure 2 shows the open-cup flash point experimental result, and it can be found that the flash point value of alcohol aqueous solution drops with AVC increases in general. But there are two inflection point when AVC is 5% and 30%. In theory, when the alcohol volume concentration is lower, the lower the alcohol content in the vapour under the same heating conditions. The difference between theory and experimental result is because alcohol has a low boiling point of 13°C, alcohol in the solution has been volatile before reaching the open-cup flash point. For liquid fuels with a large vapourability, open-cup method shouldn’t be recommended, closed-cup method is the right choice. Despite this, we use binomial fitting method for the experimental data, the fitting curve is approximately straight. In fact, the AVC of Chinese liquor is almost all between 10% and 70%, so only need to fit the data in this interval, shown as Figure 2, to predict the open-cup flash point of Chinese liquor and alcohol aqueous solution.

3.2 Closed-cup flash point
Figure 3 shows the closed-cup flash point experimental result, and it can be found that with AVC decreases, the closed-cup flash point grows. When AVC is less than 40%, the flash point value growth rate is gradually getting bigger. When AVC is equal to 5%, the growth rate become biggest, and the difference between 5% and 10% is 44.6°C. The alcohol content of the vapour in the closed-cup is gradually thinner, and it needs more energy to ignite the vapour. It can be concluded as once AVC is lower than 10%, the closed-cup flash point will become a sharp increase as figure 3. Using binomial fitting method for the experimental data, but the fitted curve is less consistent with the data when AVC is between 5% and 10%. So we just fitted the data in the interval from 10% to 70% as shown in figure 3, and R² of the curve is nearly 0.998, which means it can well predict closed-cup flash point of Chinese liquor and alcohol aqueous solution, shown as equation (1).

\[ Y = 59.94315 - 1.17166 X + 0.00915 X^2 \]  

(1)

3.3 Fire hazard analysis

The flash point is one of the major physical properties used to determine the fire hazard of fuels, and the lower the flash point, the greater the fire risk. Measurement of the closed-cup flashpoint provides a method of classifying flammable liquids fire hazard [2]. Many countries have developed their standards to evaluate the liquid fire hazard. In China, GB50160-2008 [7] is used to guide the classification. In this standard class A is the highest fire hazard risk level when the closed-cup flash point is lower than 28°C. When flash point is between 28°C and 60°C, it’s class B. when the flash point is higher than 60°C, it’s class C. According to the study of Lu [8], the common Chinese liquor closed-cup flash point is listed as table 2.

| AVC (%) | Closed-cup test (°C) | AVC (%) | Closed-cup test (°C) |
|---------|---------------------|---------|---------------------|
| 38      | 29.1                | 52      | 24.5                |
| 45      | 26.5                | 54      | 23.7                |
| 50      | 24.9                | 57      | 23.2                |

In the standard GB50694-2011 [3], a linear regression equation is established as equation (2). Plotted the Chinese liquor data of table 2, the fitted results of equation (1) and equation (2) in figure 4. First of all, figure 4 also shows the well consistent of equation (1) with the experimental closed-cup flash point results. The flash point development of Chinese liquor with AVC is similar to that of alcohol aqueous solution, and the closed-cup flash point of Chinese liquor grows as AVC decreases. Compared with equation (1), the prediction of flash point of equation (2) is not accurate. To a certain extent, it can be said to be serious deviation. Unlike national standard, the result shows it is a non-linear relationship between Chinese liquor flash point and AVC. And this paper recommends the use of equation (1) to predict the flash point instead equation (2) in the standard GB50694-2011.

\[ Y = 36.6619 - 0.2430X \]  

(2)

Figure 4. The fire hazard of Chinese liquor and alcohol aqueous solution.
Comparing the two sets data of equation (1) and Chinese liquor, it can be found that there are still differences. The differences result means the trace materials in Chinese liquor have some effect on closed-cup flash point to a certain extent. Because the Chinese liquor used in reference [8] is Maotai type, so it can be inferred that the flash point of different flavour style Chinese liquor in the same AVC may has slight difference.

As to fire hazard classification, it can be seen the critical AVC between class A and class B is 39% based on the experimental result and equation (1). The critical AVC of class A and class B is 41 based on the common Chinese liquor closed-cup flash point data. The relative error between the two is less than 5%, which means good agreement. Therefore, once AVC is higher than 40%, its fire hazard will be the highest level class A, which means the highest fire protection measures should be provided. At the same time, the prediction result is 35.6% based on equation (2), which has no reference value compared with equation (1) and the common Chinese liquor flash point data.

4. Conclusions
In this paper, after a series of experimental study, the following conclusions can be got.
(1) Closed-cup method is more suitable to test flash point of alcohol aqueous solution and Chinese liquor, compared with open-cup method, because alcohol is volatile.
(2) There is a non-linear relationship between alcohol aqueous solution / Chinese liquor flash point and alcohol volume concentration. And the prediction equation shows good agreement with Chinese liquor closed-cup flash point data.
(3) It can be inferred that the flash point of different flavour style Chinese liquor in the same AVC may has slight difference.
(4) The critical alcohol volume concentration between fire hazard class A and class B is 40%. Once the alcohol volume concentration is higher than 40%, its fire hazard will be reached to the highest level class A, which means the highest fire protection measures should be matched to the alcoholic beverages factory.

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