Significance analysis of the regional differences on icing time of water onto fire protective clothing

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Abstract. The object of this work was to determine the icing temperature in icing experiment. Firstly, a questionnaire investigation was carried out on 38 fire detachments in different regions. These Statistical percentage results were divided into northern east group and northern west group. Secondly, a significance analysis between these two results was made using Mann-Whitney U test. Then the icing temperature was determined in different regions. Thirdly, the icing experiment was made in the environment of -20°C in Daxing’an Mountain. The anti-icing effect of new fire protective clothing was verified in this icing.

1. Introduction

Water was a popular and effective extinguisher in different form materials including water column, water spray and water mist. When fireman used water to extinguish a fire, most of the water would put into the fire. However, some of the water may reflect back from the wall or stone and splash onto fireman’s protective clothing’s surface. In extreme cold environment, this water on protective clothing would turn into ice sharply [1]. This ice would not only increase fireman’s weight load, but also harden the clothing’s joint parts and reduce fireman’s flexibility. Therefore, the water’s icing phenomenon should be studied systematically to solve these problems.

![Figure 1](image1.png)

Figure 1. The ice on fireman’s protective clothing in Harbin under -29°C on January 22, 2017.

Icing speed was associated with many factors. The icing progress was so complex that the molecular dynamics simulation could only be realized in recent years. The main influence factors included environment temperature and water status. The other influence factors included air pressure, salt concentration of water. To establish an icing experiment, these two main parameters should be determined. To environment temperature, all the water would turn into ice in theory when the temperature below freezing point if the time was long enough. However, icing in short time should be focused on especially. This crust over phenomenon would reduce fireman working effectiveness rapidly. To another factor water status, the water mist or water spray could be adjusted by modifying hydraulic giant. Then all the water statuses could be all the same in icing experiments.
Therefore, the environment temperature should be determined to crusting over phenomenon. There were also other secondary factors including salt concentration, water’s temperature and atmospheric pressure [2]. Then the icing experiment would be carried out under this situation and the water would turn into ice sharply in five minutes.

**Figure 2.** The ice on fireman’s protective clothing in Urumchi under -20°C on February 18, 2016.

2. **Questionnaire investigation**

In China, there were many provinces with higher latitude including Xinjiang, Qinghai, Gansu, Inner Mongolia, Shanxi, Ningxia, Hebei, Heilongjiang, Jilin and Liaoning. The temperature was quite low in winter even less than -20°C. To learn more information, a questionnaire investigation was carried out in northern fire detachments of China [3]. The question was mainly on the environment’s temperature [4]. During fire rescue in cold winter, water on fireman’s protective clothing’s outer shell may freeze into ice and even crust over sharply. What was the general temperature when crusting over happened less than five minutes? The choices were divided by 5 degree including A, -5°C; B, -10°C; C, -15°C; D, -20°C ; E, -25°C; F, -30°C; G, below -35°C.

**Figure 3.** The isotherm of China in January

2.1 **Questionnaire investigation in northern east**

Three provinces from Northeast China including Heilongjiang, Jilin, Liaoning were chosen with higher latitude. For example, Harbin was the capital of Heilongjiang Province. It was located in latitude 44°22’, whose average altitude was 127.95 m. The number of Jilin Province’s respondents was 431 coming from 8 fire detachments including Siping fire detachment, Jilin fire detachment, Yanbian fire detachment, Changchun fire detachment, Tonghua fire detachment, Baicheng fire detachment, Baishan and Liaoyuan fire detachment. The number of Heilongjiang Province’s respondents was 103 coming from 7 fire detachments including Mudanjiang fire detachment, Yichun fire detachment, Harbin fire detachment, Daqing fire detachment, Heihe fire detachment, Qiqihar and Daxing’an Mountain fire detachment. The number of Liaoning Province’s respondents was 142 coming from 9 fire detachments including Tieling fire detachment, Fushun fire detachment, Chaoyang fire detachment, Yingkou fire detachment, Fuxin fire detachment, Panjin fire detachment, Liaoyang fire detachment, Anshan and Jinzhou fire detachment.
Table 1. Statistical percentage results in Jilin Province

| Number | A%  | B%  | C%  | D%  | E%  | F%  | G%  |
|--------|-----|-----|-----|-----|-----|-----|-----|
| Siping | 39  | 0.00| 2.56| 15.38| 51.28| 25.64| 5.13| 0.00|
| Jilin   | 83  | 4.82| 6.02| 19.28| 39.76| 20.48| 9.64| 0.00|
| Yanbian | 50  | 4.00| 12.00| 28.00| 42.00| 12.00| 0.00| 2.00|
| Changchun | 123 | 3.25| 13.01| 22.76| 35.77| 25.20| 0.00| 0.00|
| Tonghua | 40  | 0.00| 2.50| 15.00| 42.50| 37.50| 0.00| 2.50|
| Baicheng | 34  | 0.00| 2.94| 11.76| 35.29| 44.12| 5.88| 0.00|
| Baishan | 39  | 2.56| 2.56| 2.56| 61.54| 25.64| 5.13| 0.00|
| Liaoyuan | 23  | 0.00| 17.39| 13.04| 39.13| 21.74| 8.70| 0.00|

Table 2. Statistical percentage results in Heilongjiang Province

| Number | A%  | B%  | C%  | D%  | E%  | F%  | G%  |
|--------|-----|-----|-----|-----|-----|-----|-----|
| Mudanjiang | 18  | 0.00| 5.56| 38.89| 16.67| 38.89| 0.00| 0.00|
| Yichun   | 10  | 0.00| 0.00| 0.00| 80.00| 20.00| 0.00| 0.00|
| Harbin   | 20  | 0.00| 5.00| 25.00| 35.00| 5.00| 25.00| 5.00|
| Daqing   | 14  | 0.00| 0.00| 7.14| 50.00| 42.86| 0.00| 0.00|
| Heihe    | 10  | 0.00| 10.00| 10.00| 0.00| 40.00| 20.00| 20.00|
| Qiandong | 15  | 0.00| 6.67| 40.00| 40.00| 13.33| 0.00| 0.00|
| Daxing’an | 16  | 6.25| 12.50| 25.00| 6.25| 6.25| 18.75| 25.00|

Table 3. Statistical percentage results in Liaoning Province

| Number | A%  | B%  | C%  | D%  | E%  | F%  | G%  |
|--------|-----|-----|-----|-----|-----|-----|-----|
| Tieling | 26  | 0.00| 26.92| 23.08| 26.92| 19.23| 3.85| 0.00|
| Fushun  | 10  | 0.00| 0.00| 20.00| 30.00| 50.00| 0.00| 0.00|
| Chaoyang | 17  | 0.00| 23.53| 5.88| 41.18| 29.41| 0.00| 0.00|
| Yingkou | 11  | 0.00| 18.18| 36.36| 9.09| 0.00| 36.36| 0.00|
| Fuxin   | 11  | 0.00| 0.00| 90.91| 9.09| 0.00| 0.00| 0.00|
| Panjin   | 20  | 10.00| 15.00| 15.00| 45.00| 15.00| 0.00| 0.00|
| Liaoyang | 15  | 0.00| 20.00| 26.67| 26.67| 26.67| 0.00| 0.00|
| Anshan  | 19  | 0.00| 0.00| 36.94| 31.58| 26.32| 5.26| 0.00|
| Jinzhou | 13  | 0.00| 53.85| 15.38| 23.08| 7.69| 0.00| 0.00|

2.2 Questionnaire investigation in northern west

Three provinces were chosen including Qinghai, Gansu and Ningxia with both higher latitude and higher altitude. For example, Xining was the capital of Ningxia Hui autonomous region. It was located in latitude 46°04', whose average altitude was 2275 m. The number of Qinghai Province’s respondents was 234 coming from 6 fire detachments including Xining fire detachment, Haidong fire detachment, Haiman fire detachment, Huangnan fire detachment, Yushu and Haibei fire detachment. The number of Gansu Province’s respondents was 129 coming from 3 fire detachments including Lanzhou fire detachment, Tianshui and Baiyin fire detachment. The number of Ningxia Hui Autonomous Region’s respondents was 170 coming from 5 fire detachments including Yinchuan fire detachment, Shizuishan fire detachment, Guyuan fire detachment, Wuzhong and Zhongwei fire detachment.
Table 4. Statistical percentage results in Qinghai Province

| Number | A%   | B%   | C%   | D%   | E%   | F%   | G%   |
|--------|------|------|------|------|------|------|------|
| Xining | 107  | 1.87 | 13.08| 53.27| 25.23| 5.61 | 0.93 | 0.00 |
| Haidong| 51   | 7.84 | 15.69| 23.53| 47.06| 5.88 | 0.00 | 0.00 |
| Hainan | 16   | 0.00 | 6.25 | 56.25| 25.00| 12.50| 0.00 | 0.00 |
| Huangnan| 10  | 20.00| 20.00| 10.00| 50.00| 0.00 | 0.00 | 0.00 |
| Yushu  | 20   | 0.00 | 0.00 | 10.00| 70.00| 20.00| 0.00 | 0.00 |
| Haibei | 30   | 0.00 | 0.00 | 30.00| 36.67| 30.00| 3.33 | 0.00 |

Table 5. Statistical percentage results in Gansu Province

| Number | A%   | B%   | C%   | D%   | E%   | F%   | G%   |
|--------|------|------|------|------|------|------|------|
| Lanzhou| 74   | 1.35 | 18.92| 56.76| 10.81| 6.76 | 4.05 | 1.35 |
| Tianshui| 20  | 0.00 | 25.00| 40.00| 25.00| 5.00 | 0.00 | 5.00 |
| Baiyin  | 35   | 2.86 | 25.71| 20.00| 48.57| 2.86 | 0.00 | 0.00 |

Table 6. Statistical percentage results in Ningxia Hui Autonomous Region or Ningxia Province

| Number | A%   | B%   | C%   | D%   | E%   | F%   | G%   |
|--------|------|------|------|------|------|------|------|
| Yinchuan| 40  | 0.00 | 35.00| 50.00| 5.00 | 10.00| 0.00 | 0.00 |
| Shizuishan| 15 | 33.33| 6.67 | 20.00| 20.00| 20.00| 0.00 | 0.00 |
| Guyuan  | 30   | 0.00 | 23.33| 56.67| 20.00| 0.00 | 0.00 | 0.00 |
| Wuzhong| 65   | 0.00 | 16.92| 44.62| 21.54| 12.31| 4.62 | 0.00 |
| Zhongwei| 20  | 15.00| 50.00| 30.00| 5.00 | 0.00 | 0.00 | 0.00 |

3. Significance analysis

3.1 Evaluation results in two groups
In northern east, 37.24% of firemen believed that the general temperature should be lower than -20°C when crusting over happened less than five minutes. But 41.65% of firemen from northern west believed that this general temperature should be lower than -15°C. Therefore these two different results should be studied by significance analysis.

Figure 4. Evaluation result of water’s temperature when crusting over in northern east.

Figure 5. Evaluation result of water’s temperature when crusting over in northern west.
3.2 Significance analysis
In statistics, the Mann-Whitney U test was a nonparametric test of the null hypothesis that two populations were the same against an alternative hypothesis [5]. This test could be used in large sample and this survey was taken by 1209 firemen. In three northeastern provinces, 14 firemen chose -5°C, 67 firemen chose -10°C, 141 firemen chose -15°C, 252 firemen chose -20°C, 161 firemen chose -25°C, 32 firemen chose -30°C, 9 firemen chose below -35°C. In three northwestern provinces, 18 firemen chose -5°C, 96 firemen chose -10°C, 222 firemen chose -15°C, 141 firemen chose -20°C, 46 firemen chose -25°C, 8 firemen chose -30°C, 2 firemen chose below -35°C.

| Cold Area       | N  | Mean rank | Sum or ranks |
|-----------------|----|-----------|--------------|
| Northern east   | 676| 515.33    | 348364.50    |
| Northern west   | 533| 718.75    | 383080.50    |
| Total           | 1209|           |              |

Table 7. Ranks of water’s crusting over temperature

| Water’s crusting over Temperature |
|-----------------------------------|
| Mann-Whitney U                    | 119538.500 |
| Wilcoxon W                        | 348364.500 |
| Z                                 | -10.423 |
| Asymp. Sig. (2-tailed)            | 1.9434787232177113E-25 |

The result of the Mann-Whitney U-test showed that Sig. < 0.05, so two populations in these two regions were significantly different from each other and two conclusions should be made respectively. This significant difference may be relative with atmospheric pressure caused by altitude as shown in Figure 6. It could be concluded that water’s crusting over temperature was -20°C in three northeastern provinces and water’s crusting over temperature was -15°C in three northwestern provinces. These data could be used to ensure environment temperature in anti-icing experiment.

Figure 6. Phase diagram of water and ice in different pressure and temperature.

4. Icing experiments
Then icing experiments were carried out in Daxing’an Mountain fire detachment [6]. The environment temperature was -21°C. The water spray status was shown in Figure 7, whose flow rate was 150 L/min. The wind speed was 1 meter per second. After 60 seconds, the added ice data were shown in Table 9 between different fire protective clothing. The weight included protective clothing and plastic model [7,8].
In summary, the icing temperature in northern east was determined and the icing experiment was carried out. Firstly, the icing temperature in northern east should be lower than -20 °C. Secondly, the new type of fire protective clothing could reduce more added ice compared with old traditional fire protective clothing in icing experiment. Thirdly, the icing time to new type of fire protective clothing was relatively longer than old traditional fire protective clothing. Therefore, this icing experiment with determined icing temperature could be used to evaluate icing performance. In the future, the anti-icing performance of new type fire protective clothing would be further studied [12,13].

5. Conclusion

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