Kanazawa Izumigaoka High School 06

Reproducing the Mpemba Effect Using Mineral Water

WATANABE Ryosuke, KASAMA Eishin, SHIOZAKI Kazuma, IKEMURA Shoya, OKUMURA Koki

Abstract

The Mpemba effect is a phenomenon where hot water freezes faster than cold water. This effect has been researched for a long time, however, no one has proved that the effect exists. Most of the previous experiments on the effect are conducted using purified water. To test the hypothesis that solutes cause the Mpemba Effect, we did experiments using aqueous solutions. We observed hot water freezing before cold water 24 times in 30 attempts under the conditions below.

1. Our Goal

Our goal is to find the conditions where the Mpemba Effect occurs consistently.

2. Hypothesis

Our hypothesis is that solutes in the water cause the Mpemba Effect.

The Mpemba Effect seems random and the effect is difficult to reproduce. Most other researchers concluded from experiments using pure water that the Mpemba Effect does not exist. We did similar experiments using pure water, but we rarely observed the effect. We thought that the reason why other researchers were not able to reproduce the effect was because they did not purify the water sufficiently, thus, we anticipated that solutes in water are a major cause of the Mpemba Effect.

3. Experiment Procedure

Instruments

Beakers, a thermometer, a transfer pipet, a freezer

We put two beakers into the freezer with an inside temperature of -10℃ to -20℃. The amount of the water in the respective beakers was 30ml. The water temperature of one was approximately 15℃. The other is about 60℃. We measured the temperature of the center of the water every second by using thermocouples. We regarded the water as frozen when it had completely turned to ice. There was no difference of the conditions except the initial temperature between the two samples.

Fig.1. Beakers and thermocouples

Fig.2. Frozen two specimens

The definition of The Mpemba Effect

When the hot water froze faster than the cold water, we regarded this as the Mpemba Effect. For example, in Fig.3. we can tell the Mpemba Effect is occurring. In addition we also regarded it as the effect when we observed that the hot water stayed at 0℃ for less time than the cold water. For example, in Fig.4. the temperatures of both specimens fall below 0℃ at the same time. However, the plateau of the hot water at 0℃ is shorter than that of the cold water.

Since the conditions were exactly the same except for the initial temperatures, we can say there could be some chemical or physical differences between two samples, so we can define those two types of results above as the Mpemba Effect.

Fig.3.

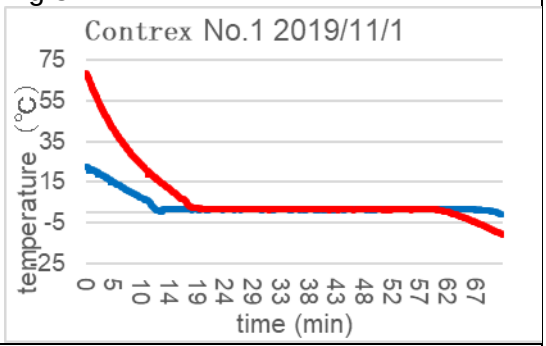
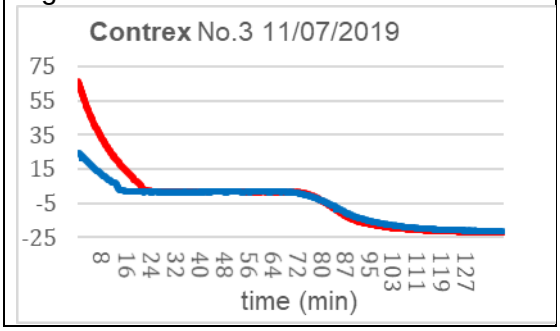


Fig.4.



4. Experiments and Results

4-1

Water used in experiments

1. Two types of mineral water

1 Evian: Hardness 1468mg/L (Ca: 80 mg/L, Mg: 26 mg/L)

2 Contrex: Hardness 304 mg/L (Ca: 468 mg/L, Mg: 74 mg/L, K: 2.8 mg/L)

Fig.5. Evian (left) and Contrex (right)

2. Two types of saline water

3 Concentration 1.0×10^{4} mg/L (1% of solution concentration)

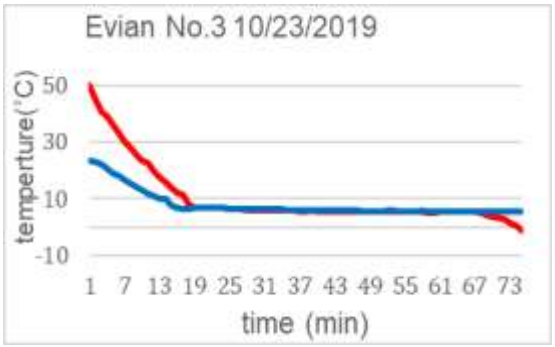
4 Concentration 25mg/L

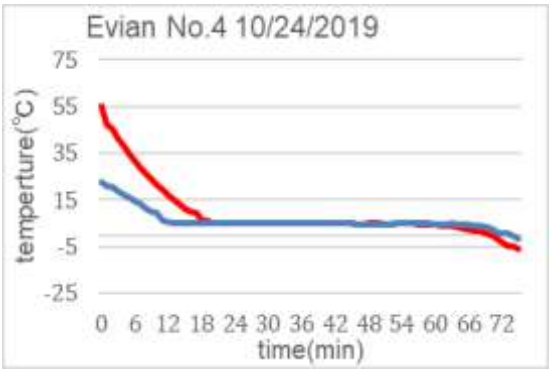
By setting the molar concentration to 4.4×10^{-4} mol/L, the concentration of the saline is almost the same as that of Contrex.

Fig.5. Number of Attempts and Successes

	No.1	No.2	No.3	No.4
Attempts	5	5	5	5
Successes	4	5	3	4

Fig.6. Results of 4-1





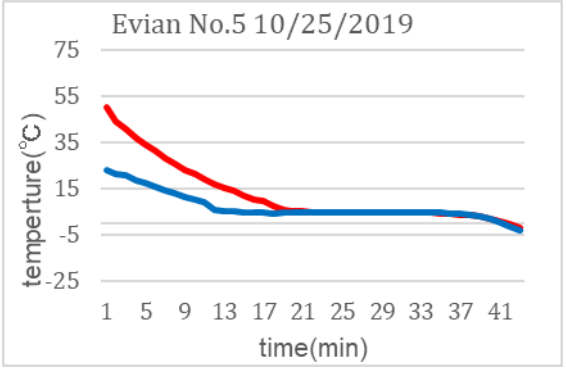
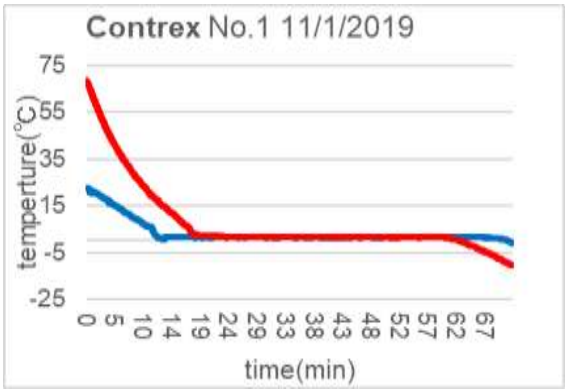
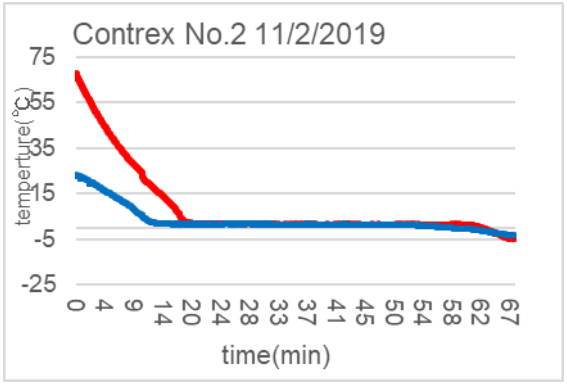
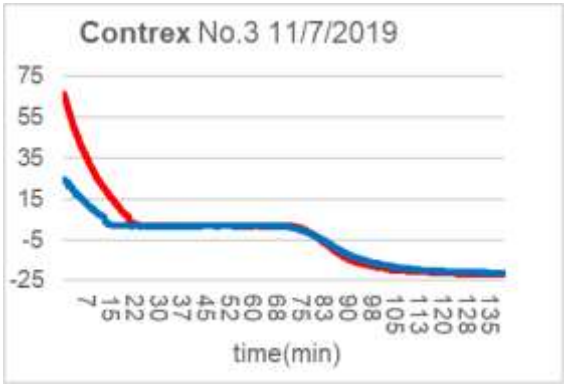
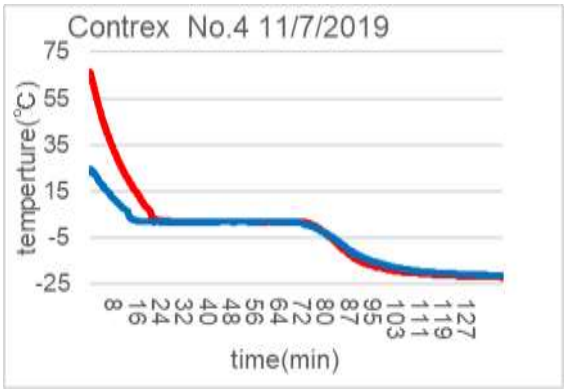


Fig.7. Results of 4-2









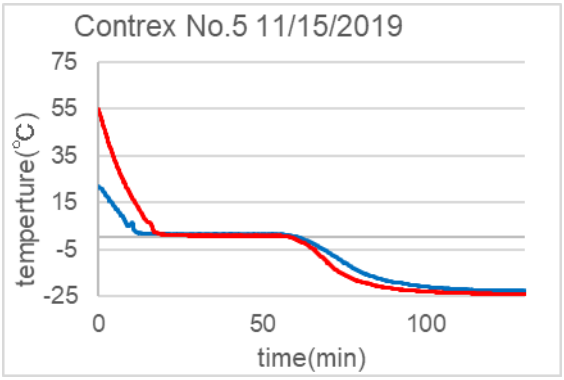
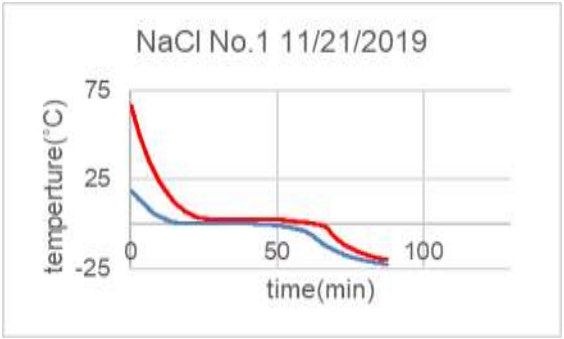
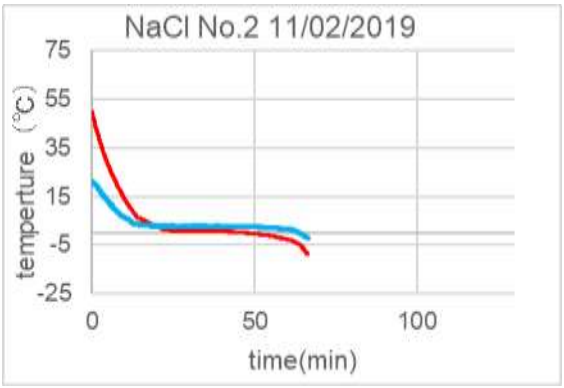
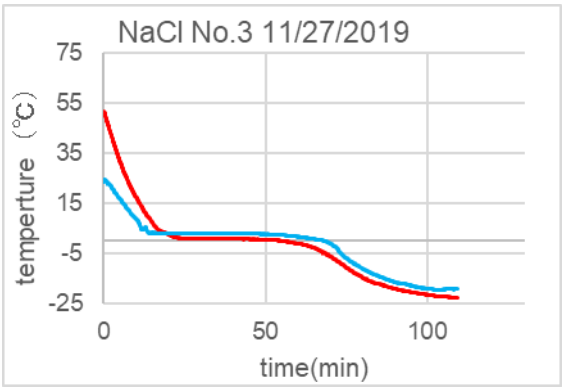
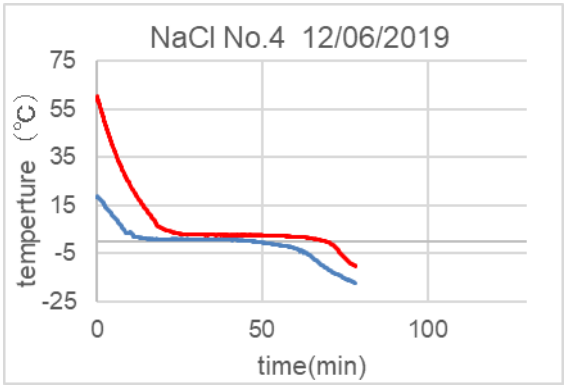


Fig.8. Results of 4-3









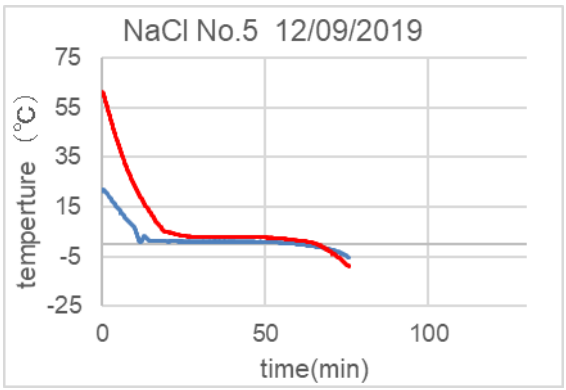
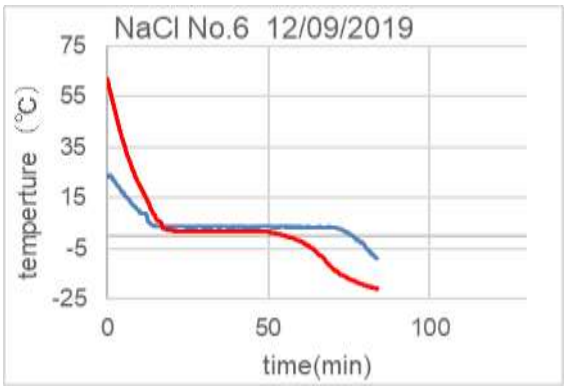
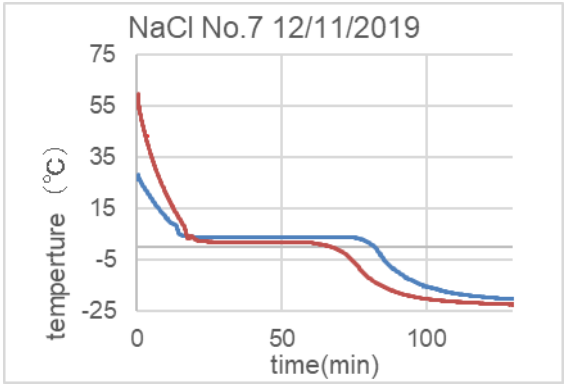
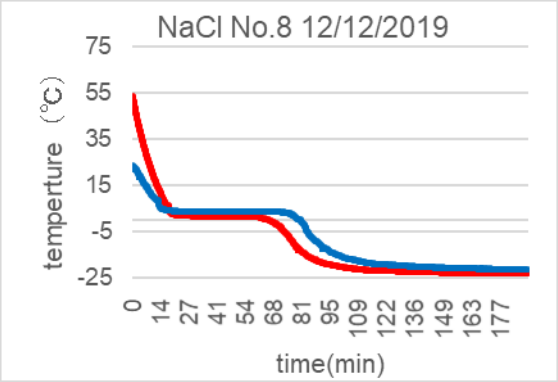
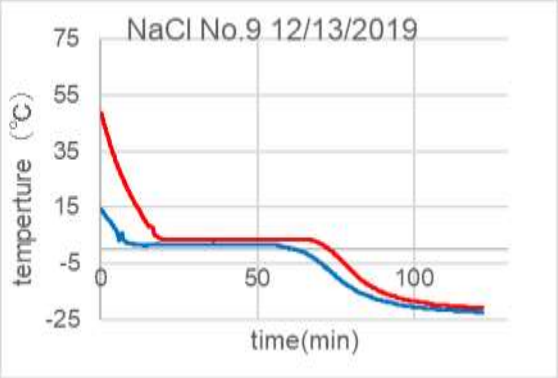


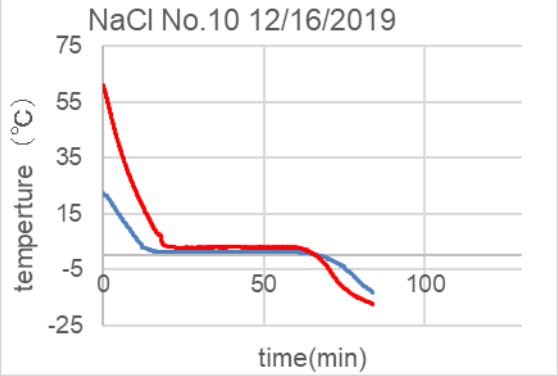
Fig.9. Results of 4-4











4 - 2

We decided to focus on using Contrex due to the high success rate from 4-1.

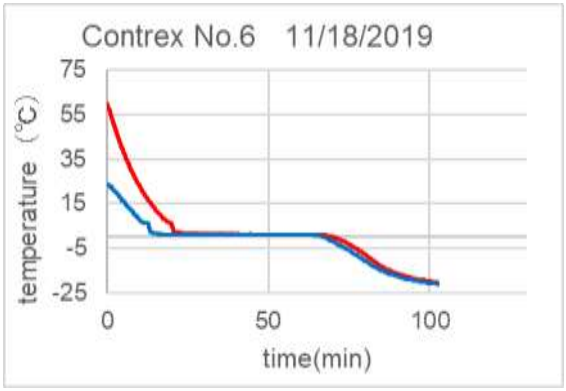
Water used in experiments

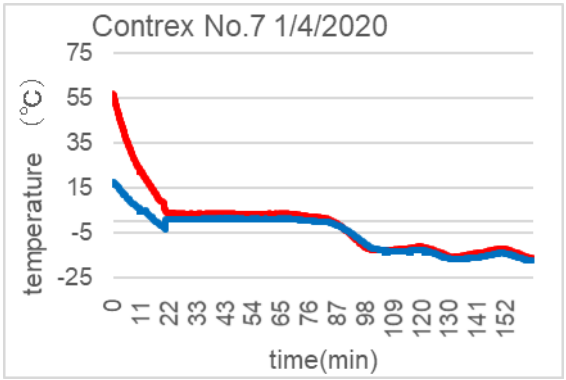
Contrex：Hardness 1468mg/L

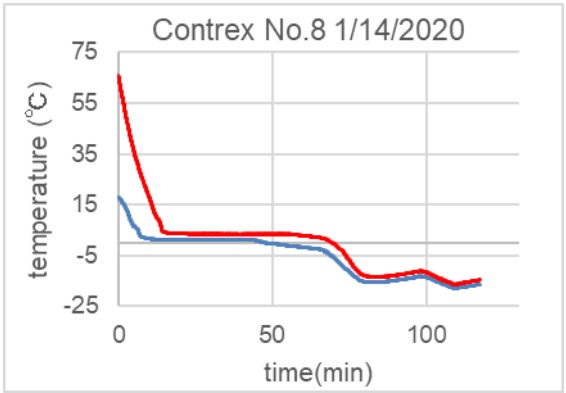
Fig.10. Number of Attempts and Successes (2)

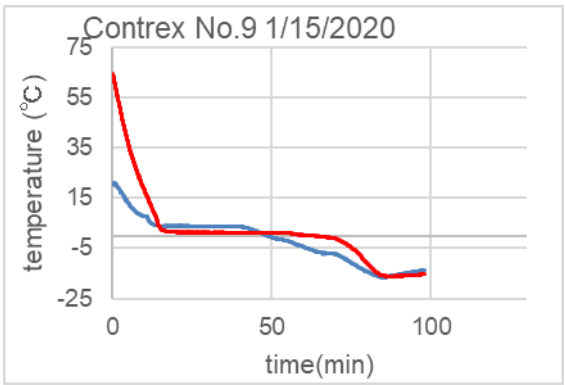
	Contrex
Trials	30
Successes	24

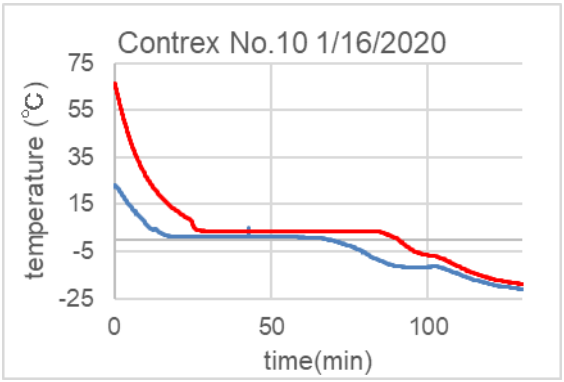
Fig.11. Results of 4-2







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temperature (℃)
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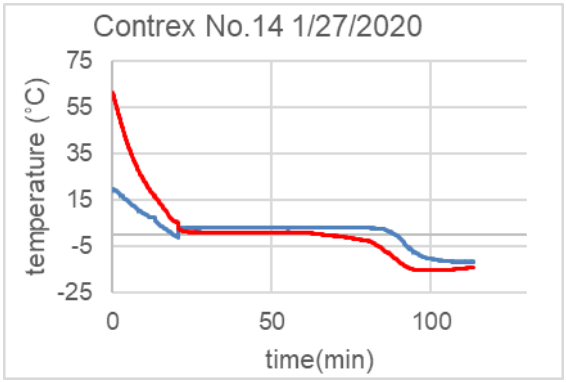
55
35
15
-5
-25
0
50
100
time(min)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temperature (°C)
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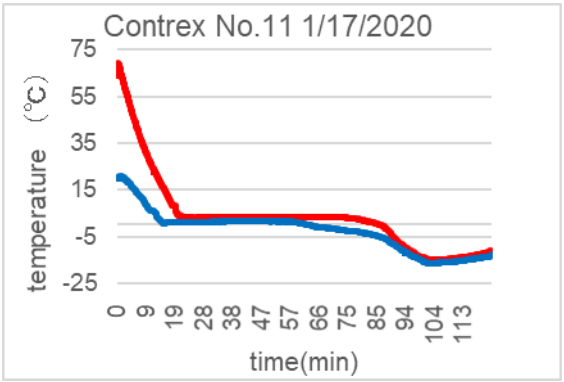
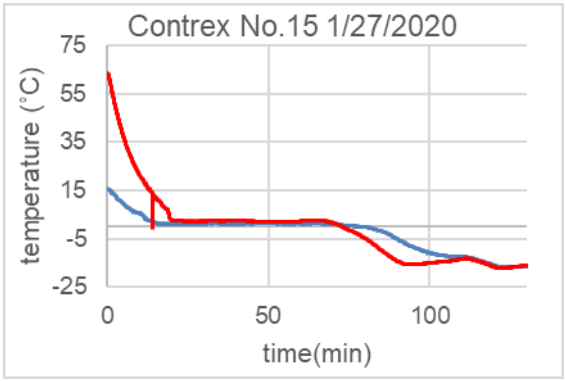
55
35
15
-5
-25
0
50
100
time(min)


Contrex No.11 1/17/2020
temperature (℃)
75
55
35
15
-5
-25
0
9
19
28
38
47
57
66
75
85
94
104
113
time(min)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temperature (°C)
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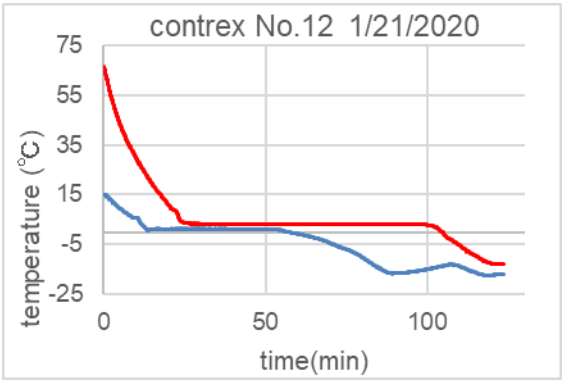
55
35
15
-5
-25
0
50
100
time(min)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temperature (℃)
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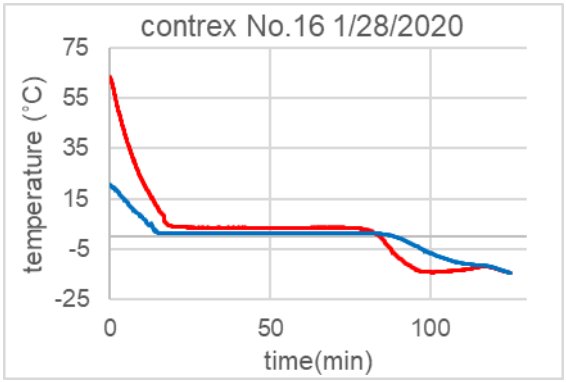
55
35
15
-5
-25
0
50
100
time(min)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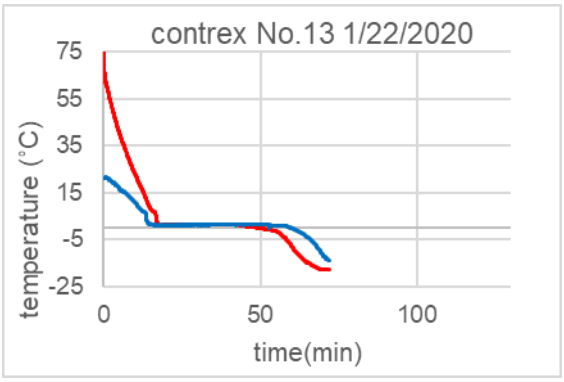
35
15
-5
-25
0
50
100
time(min)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temperature (°C)
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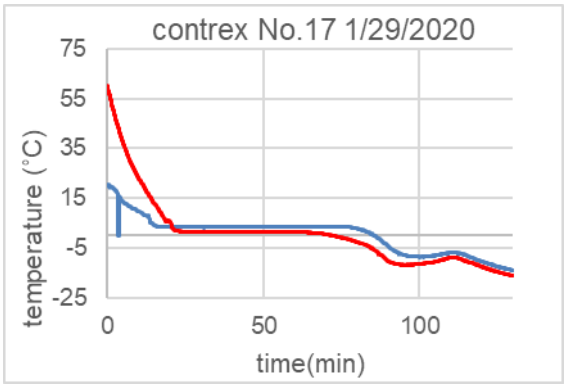
55
35
15
-5
-25
0
50
100
time(min)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temperature (°C)
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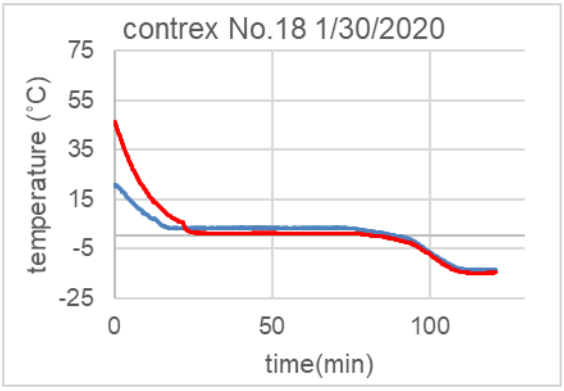
55
35
15
-5
-25
0
50
100
time(min)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temperature (°C)
75
55
35
15
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-25
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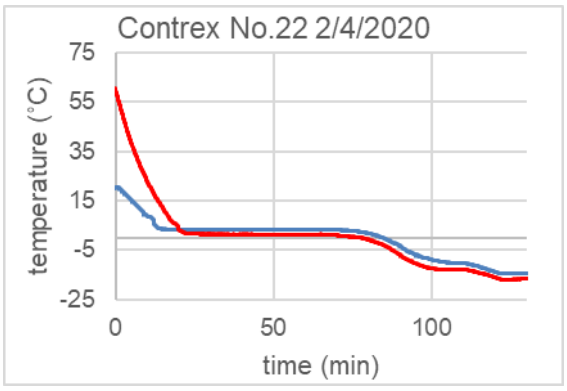
100
time(min)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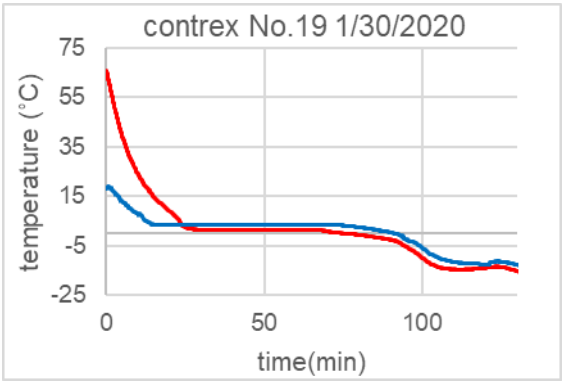
temperature (°C)
75
55
35
15
-5
-25
0
50
100
time (min)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temperature (°C)
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55
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15
-5
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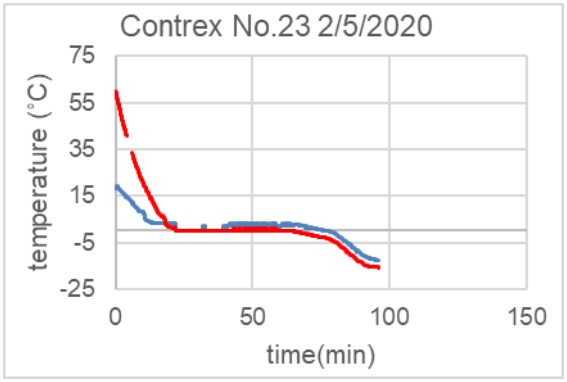
0
50
100
time(min)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-25
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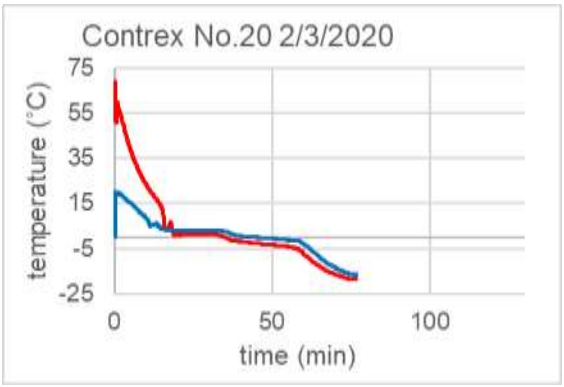
150
time(min)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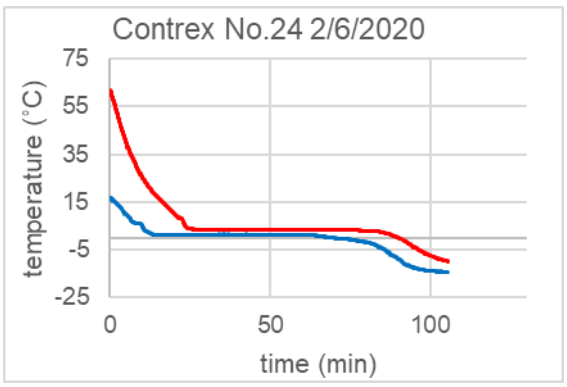
55
35
15
-5
-25
0
50
100
time (min)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temperature (°C)
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55
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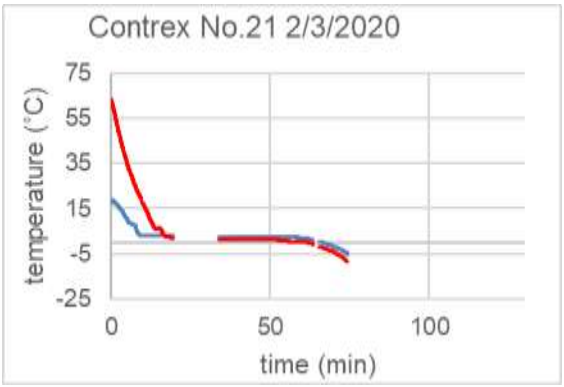
time (min)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temperature (°C)
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55
35
15
-5
-25
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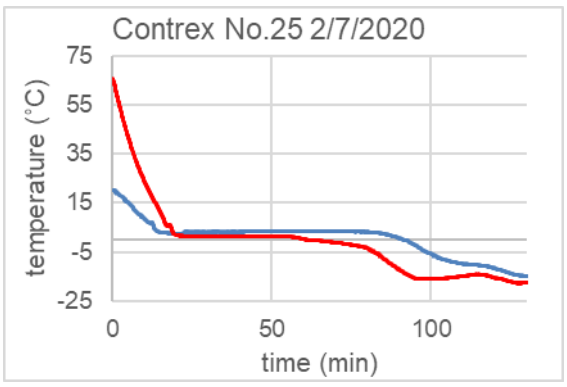
50
100
time (min)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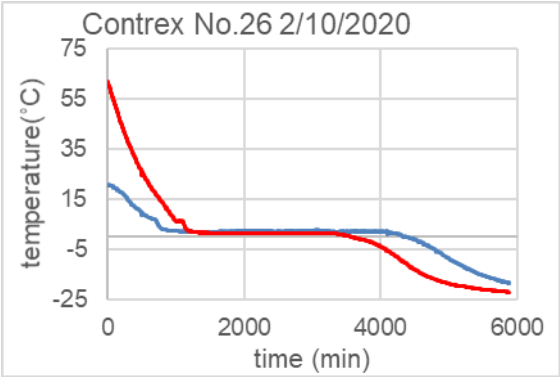
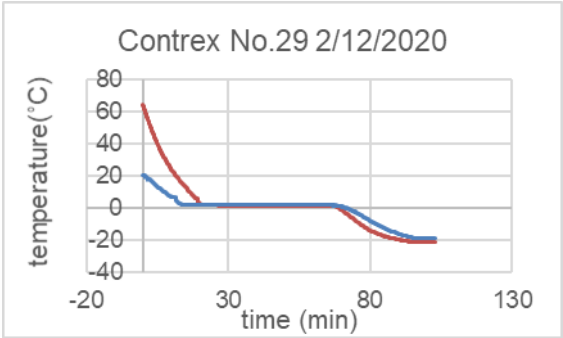
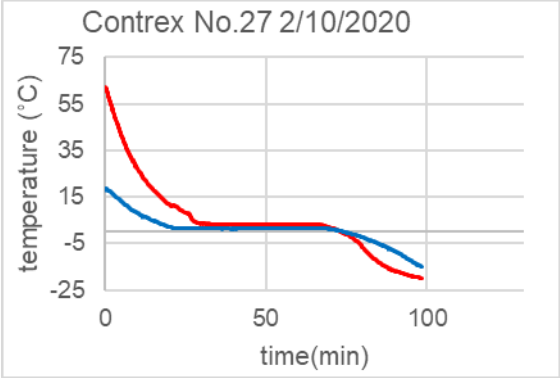
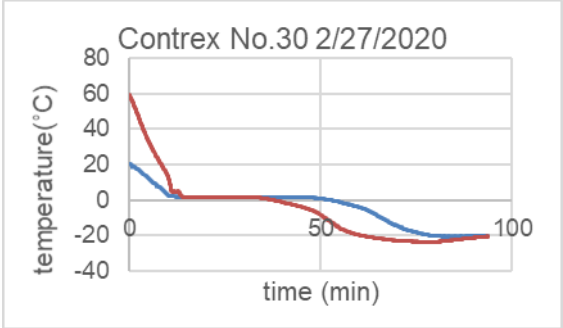
temperature (°C)
75
55
35
15
-5
-25
0
50
100
time (min)









5. Discussion

In pure water, the Mpemba Effect was not observed, but in water containing solutes (metal ions), the Mpemba phenomenon appeared in 80% of cases (24 out of 30 results of 4-2). From these results, we believe said that impurities caused the effect. In this experiment, we used only metal ions as solutes, so it is difficult to say for sure, but we conclude that the change in energy state due to the electrical coupling between ions and water molecules is the cause of the Mpemba Effect. It would be possible to explain the Mpemba Effect from a microscopic point of view, rather than from supercooling, evaporation from the water surface, convection, etc. However, no concrete theory has been made so far.

6. Future of the Research

We will conduct experiments using pure water under the same conditions as those experiments above to confirm that the solutes cause the Mpemba Effect. We will also experiment with non-ionic impurities to find out the causes of the effect. In addition, the results should be compared numerically, quantified, and a concrete theory should be created.

7. Acknowledgments

Japan Advanced Institute of Science and Technology

Assistant Professor Kazushi Oda

Professor Taku Mizukami

8. References

E.B. Mpemba and D.G. Osborne (1979) “Cool?” Phys. Educ.

D. Auerbach (1995) “Supercooling and the Mpemba effect - when hot-water freezes quicker than cold” Am J Phys.

Henry C.Burridge, Paul F. Linden (2016) “Questioning the Mpemba effect: hot water does not cool more quickly than cold” Scientific Reports