# An examination of efficient turbid water coagulation method using natural coagulant

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## ABSTRACT

Long term persistent turbidity is a major problem in reservoirs of Japan and other countries. We are examining the practical methods using natural coagulants, such as allophane (clay), which can be deposited in the reservoirs, to prove experimentally the effectiveness of allophanes coagulation performance, and to develop a useful and environmental friendly coagulation method for turbid water. The experiments conducted in this study provided two important findings. The first is that, through the laboratory experiments, we proved that the new practical dispersers, which are a cavitation mixer and a high pressure water sprayer, can be used effectively to disperse allophane. And we confirmed the usage of these dispersers raises the zeta potential of allophane. This effect is presumed to promote coagulation. The second is that the coagulation effect at the depth of more than 10 m was confirmed through the field experiment, where the new dispersers were used. As mentioned above, we can propose more practical, useful, and environmental friendly treatment method for turbid water using allophane at dam reservoirs.

## 1. INTRODUCTION

In Japan and other countries, persistent turbidity caused by flood and underwater construction is a major water quality problem in reservoirs (Figure 1) (Lee et al. 2013 & Umino et al. 2011). Accordingly, selective intake facilities and fence controlling turbid water flow have been employed to counteract this problem as conservative treatments. However, the effects of these conventional countermeasures are limited, and if the water in a reservoir turns turbid, which can occur after large flood inflows or large-scale water circulation, the only solution is to wait for the water to turn still. So coagulation, especially under conditions where the water in a reservoir is turbid, is expected to be an effective countermeasure in such circumstances. However, the treatment of deposited sediments can present a serious problem when artificial coagulants are used.

Due to the above-mentioned reasons, we are examining the use of natural coagulants, which can be deposited in the reservoir. We demonstrated through several experiments that the turbid components of reservoir water could be coagulated by natural materials, and that allophane can be used for the treatment of turbid water. Allophane is a natural soil colloid. Moreover, based on our previous research, we found that the dispersion of coagulant and circulation were indispensable for effective coagulation (Umino et al. 2008). And we examined the possibility of chemical dispersion of the coagulant while adjusting the pH of the colloid suspension to reduce the dispersion load. We showed that the pH of the allophane suspension should be changed to acidic pH, if the dispersion procedure was omitted. However, considering practical applications, chemical dispersion contains a risk of affecting water environment in the reservoir, if the mixture of allophane and acetic acid solution is sprayed. And it was considered that the allophane had limited coagulation performance, which could be estimated by measuring the zeta potential. It is important to develop the effective coagulation method that could transmit the effects of coagulation from the surface to the deep layers of the reservoir (Umino et al. 2011).

Therefore, in this study, for practical use, we examined more useful and environmental friendly treatment method using natural coagulants (allophane). The purpose of the research was to develop an effective coagulation method for turbid water by the new dispersers instead of the conventional ones, which can perform a physical action, and to get the data on their coagulation performance.

**Figure 1. Underwater construction using the fence to prevent turbid water diffusion**

## 2. SELECTION OF COAGULANT

Allophane, a natural soil colloid, was used in this experiment (Figure 2).Among natural soil colloids, kaolin, allophane and imogolite have large specific surface and they can be used as coagulant. In this study, we selected allophane as a coagulant because of its good coagulation properties; moreover, it is easy to obtain. Allophane is present at high levels in weathered volcanic ash and volcanic soils. Volcanic soils are common in the Hokkaido, Tohoku, and Kyusyu regions, where there are many volcanos, thus, allophane particles are easy to obtain. Moreover, coagulation with allophane is thought to have minimal environmental impact on reservoirs and downstream rivers. Allophane is used in several industries. It is a porous material suitable for application as a drying or adsorption agent. Allophane is a colloidal particle and its dispersion and coagulation properties varies depending on the pH. The dispersed allophane particles are surrounded by positive electric charge, and it is easy for them to adsorb soil particles as they ordinarily have the negative electric charge. Considering its absorbing properties, we suggested that it would be possible to coagulate negatively charged soil particles present in turbid water.

**Figure 2. Allophane used in the experiment**

## 3. LABORATORY EXPERIMENTS

In the previous paper, we confirmed the effective coagulants can be achieved by coagulation treatment that involves dispersion of the allophane using ultrasonic wave disperser or acidic treatment (Umino et al. 2011). Figure 3 shows the summary of purpose and condition of laboratory sedimentation experiments. In this study, authors conducted the laboratory sedimentation experiments in order to develop more practical and environmental method of dispersion of coagulant (allophane) to be implemented at real dam reservoirs instead of the conventional approach. Specifically, we carried out the dispersion of coagulant (allophane) by physical action using new dispersers, which are "a high-pressure water sprayer" and “a cavitation mixer”, because it was assumed that the new dispersers would produce effect similar to the one of the conventional disperser. In addition, to compare the effect of coagulants, we carried out one more experiment, where the conventional disperser, called ultrasonic wave disperser, was used.

Meanwhile, in our previous study, we measured the zeta potential and found that the allophane had positive potential and artificial turbid water had negative potential. Zeta potential provides a measure of the overall surface charge of all the particles and colloids in a water sample. Most particles and colloids are found in natural water at normal pH conditions (pH 6 to 9) are negatively charged possessing a zeta potential in the range -14 to -30 mV (Jefferson et al.2004 & Holmes et al. 2015). Zeta potential is an effective tool for coagulation control because changes in zeta potential indicate changes in the repulsive force between colloids (Nasser 2011). It is thought that the particles of turbid water could be coagulated through electric adsorption. The coagulation ability could be estimated by measuring the zeta potential of sediment composed of allophane and turbid particles (Umino et al. 2011, 2014). Thus, we conducted the measurement of allophane particle zeta potential.

Purpose :Development of new disperser instead of ultrasonic wave disperser

Turbid water :Produced by using Kawaji dam sediment
Coagulaut :Purified allophane(except impurities)
Disperser :Ultrasonic wave disperser/ High-pressure Water Sprayer/ Cavitation mixer
Dispersion method :Dispersion after adding allophane to turbid water

**Figure 3. The summary of purpose and condition of laboratory experiments**

### 3.1 Sedimentation experiment

#### 3.1.1 Experiment method (Production of turbid water and specification of new dispersers)

Turbid water and sediment were sampled from the Kawaji Dam reservoir which had a long term persistent turbidity problem after a flood. As part of the preparations for the laboratory experiments, turbidity was adjusted to the prearranged degree by adding pure water. In addition, turbid water was artificially produced by using sediment collected from the bottom of the reservoir. The procedure for the production was as follows:

1. Sediment was stirred into pure water and large particles were filtered off (mesh size of the filter: 7μm) and the filtrate was extracted. Ultrasonic wave dispersion (600W, 20 kHz) was applied during filtering to accelerate dispersion.

2. Filtrate was poured into a bucket and left undisturbed for 24h.

3. The top clear layer of filtrate was collected and the turbidity and temperature were arranged.

All of the above procedures were conducted in an air-conditioned laboratory.

We studied rational dispersion technique with the purpose to develop the effective and practical method of coagulant (allophane) dispersion to be applied at dam reservoirs, with less impact on the environment, but at the same time highly practical. We chose two new dispersers instead of the ultrasonic wave disperser. One is a commercial high-pressure water sprayer, which is used to remove the dirt by highly pressurized water stream, and it can jet 6L/min at max 7MPa (Figure 4). Another is a cavitation mixer, which is used to make cement mortar and, when a pump is employed, it can jet 40 L/min at 0.3MPa (Figure 5).

### 3.1.2 Sedimentation experiment (Procedure)

Table 1 shows the cases of laboratory experiment. We implemented experiments to confirm the effects of coagulant performed by a cavitation mixer, a high-pressure water sprayer, and the ultrasonic wave disperser. We used artificial turbid water, as mentioned above, in the experiment. For the conditions of coagulation treatment, the quantity of coagulant was decided by the results of the past experiment. In particular, if the amount of purified allophane (mg/L) is over 2 times of turbidity value (NTU(nephelometric turbidity unit)), sufficient coagulant effects can be produced.(Umino et al. 2008) The change in turbidity was observed after the coagulation treatments. The experiment procedure was as follows:

1. Artificial turbid water was prepared using sediment from Kawaji Dam reservoir. The initial target turbidity was set at 450nephelometric turbidity unit (NTU) for a cavitation mixer's experiment (cases 1-3) and 50 NTU for a high-pressure water sprayer's experiment (cases 4-6).

2. A bucket was prepared and 20 liters of the artificial turbid water was poured into the bucket (cases 1-3). A bucket was prepared and 40 liters of the artificial turbid water was poured into the bucket (cases 4-6).

3. A sample of 1 liter of this artificial turbid water was removed from bucket to a beaker, and a predetermined quantity of coagulant was added to the beaker. The concentration of coagulant was set at 900 mg-dry/L in case 2 and case 3 for the sample of 450 NTU, and 180 mg-dry/L in case 5 and case 6 for the sample of 50 NTU. The mixture of water and coagulant in all cases was almost pH7.


**Figure 5. A high-pressure water sprayer**

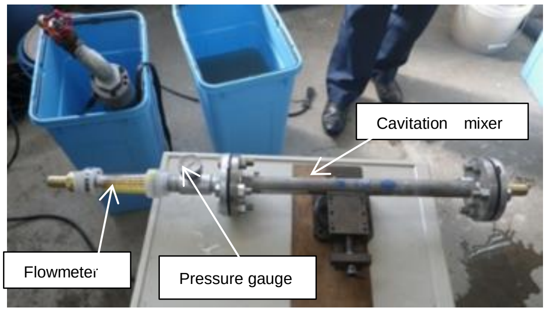



**Figure 4. A cavitation mixer**

**Table 1. The cases of laboratory experiment**

| case No. | | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Disperser | None | CM | UWD | None | HPWS | UWD |
| Turbidity of artificial turbid water (NTU) | 450 | | | 50 | | |
| Purified Allophane(mg/L) | 0 | 900 | | 0 | 180 | |
| pH | almost neutral | | | 6.6 | 6.6 | 7.1 |
| Dispersion method | None | Dispersion after mixing allophane and turbid water | | None | Dispersion after mixing allophane and turbid water | |
| Circulating time / rpm | 180 sec/150 rpm | | | | | |

Note: **CM**: a cavitation mixer, **HPWS**: a high-pressure water sprayer, **UWD**: ultrasonic wave disperser

4. Then the mixture of coagulant and artificial turbid water were dispersed by a cavitation mixer (case 2) or a high-pressure water sprayer (case 5). And the mixture of coagulant and artificial turbid water were dispersed by ultrasonic wave disperser (1,200W, 28kHz) for 20 seconds (case 3, case 5). We called this method “Dispersion after mixing allophane with turbid water”. Artificial turbid water prepared by circulation only was used in case 1 and case 4.

5. In all the cases, the samples of allophane and turbid water mixture were circulated for the period of 180 seconds at a rotational speed of 150 rpm.

6. The mixture of artificial turbid water and coagulant was left undisturbed and the change in turbidity was observed at 1 point in the beaker under 4 cm below the surface.

### 3.1.3 Result

The results of the experiment are shown in Figure 6.The turbidity in case 1 achieved 147 NTU at 360 min. The turbidity in case 2 (where a cavitation mixer was used) achieved 51 NTU at 360 min after the coagulation treatment. The turbidity in case 3 (where ultrasonic wave disperser was used) achieved 0 NTU at 360 min after the coagulation treatment. The turbidity in case 4 achieved 44 NTU at 360 min. The turbidity in case 5 (where a high-pressure water sprayer was used) achieved about 4 NTU at 360 min after the coagulation treatment. And case 6 (where an ultrasonic wave disperser was used) achieved about 2 NTU at 360 min after the coagulation treatment. As the result, we confirmed that a cavitation mixer and a high-pressure water sprayer had potential as more useful devices, if used at an actual reservoir for dispersion of coagulant (allophane) instead of ultrasonic wave disperser(the conventional device).

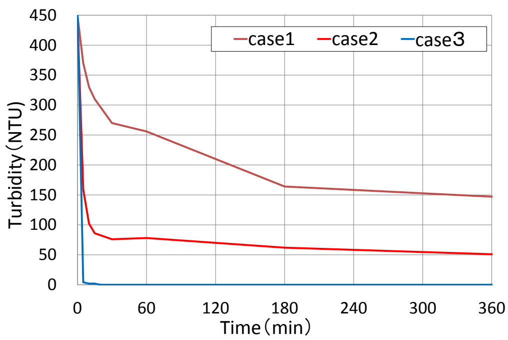



**Figure 7. A Change in turbidity of Cavitation mixer cases**

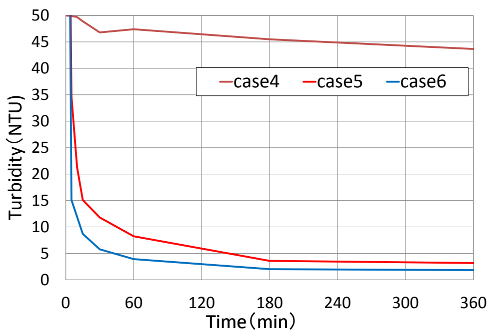



**Figure 6. A Change in turbidity of high-pressure water sprayer**

### 3.2 Measurement of zeta potential

#### 3.2.1 Experiment method and Procedure

We conducted the measurement of zeta potential of particles within artificial turbid water of allophane using “ELSZ-1000Z”, a device produced by OTSUKA ELECTRONICS Co. LTD, affiliated with National Institute for Materials Science. In addition, we also measured these dispersed materials with a high-pressure water sprayer and a cavitation mixer in order to confirm the dispersion effect. Table 2 shows the condition of the experiment. The procedure was as follows:

**Table 2. The samples of laboratory experiment (Measurement of zeta potential)**

| sample No. | allophane | Concentration (mg/L) | Dispersed processing |
|---|---|---|---|
| sample1 | Purified (except impurities) | 20000 | none |
| sample2 | | 10000 | |
| sample3 | | 500 | |
| sample4 | | 20000 | HPWS |
| sample5 | | 500 | |
| sample6 | Non-processed(original) | 20000 | none |
| sample7 | | 10000 | |
| sample8 | | 500 | |
| sample9 | | 20000 | CM |
| sample10 | | 500 | |

Note: CM: a cavitation mixer HPWS: a high-pressure water sprayer

1. Artificial turbid water was prepared using purified allophane and non-processed allophane with clear water. The concentration was set at 500-20000 mg/L (pH6-8).

2. A part of these turbid water was dispersed with a high-pressure water sprayer and a cavitation mixer (Only one cycle was performed).

3. These turbid water samples were set at ELSZ-1000Z.

#### 3.2.2 Result

Figure 7 shows the result of the measurement. Same as in the past results, the allophane has positive potential. Based on the new results, we discovered that almost all of the zeta potential of dispersed materials (sample 4,5,9,10) were bigger than non-dispersed ones (samples 1-3, samples 6-8). This phenomena proves that the coagulant dispersion with a high-pressure water sprayer and a cavitation mixer is an effective method to increase the zeta potential.

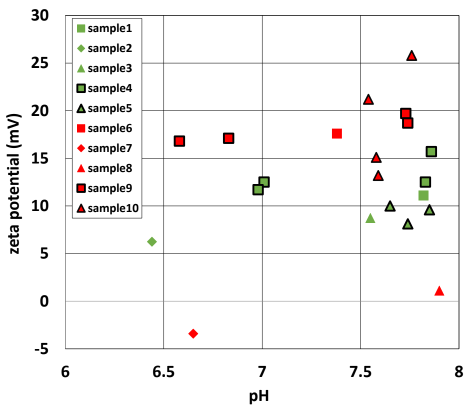



**Figure 8. The correlation of zeta potential and pH of allophane particles**

## 4. FIELD SEDIMENTATION EXPERIMENT

In our previous study, it was confirmed that the effects of allophane coagulation could be spread to the depth of 2 to 4 meters below the reservoir surface, when the surface layer was coagulated in the laboratory experiment. And we showed that it was possible to develop an effective coagulation method that would ensure the spread of coagulation effects from the surface to the deep layers of the reservoir (Umino et al. 2011). Following the above laboratory experiment results, we conducted the field experiment at Amagase Dam reservoir in order to confirm vertical spreading effects of coagulation and develop the practical and environmental method to be applied at real dam reservoirs. For practical use, our purpose was to confirm the new disperser's function and vertical effect of coagulation. Having performed two experiments: one with a cavitation mixer and the other with a high pressure sprayer, our goal was to measure the difference of effect of dispersion methods, quantity of allophane, and cycle frequency. In addition, having considered the cost, we used the non-processed allophane in a cavitation mixer's experiment.

### 4.1 Field experiment location and facilities

The field experiments conducted at a part of channel intake in the dam upgrading project at Amagase Dam in Kyoto Prefecture. As the construction site had many facilities, we could conduct the test easily. Table 3 shows the experiment facility and depth position of Turbidimeter in each disperser. Figure 8 shows the experiment facilities with two kinds of dam upgrading project fields. One has consisted of turbid water net, with the following dimension: with width of 4m x 4m and depth of 15m for a cavitation mixer experiment. Another experiment had 3 turbid water tubes, with the following dimensions: tube diameter - φ500mm, tube depth - 15m for a high-pressure water sprayer experiment (Figure 8). Turbidimeter was installed at the depth of 10m in a high-pressure water sprayer experiment. Turbidimeter was installed at the depth of 7m in a cavitation mixer experiment (Figure 8). The depth depended on the cable length of turbidimeters.

**Table 3. The experimental facility and depth position of Turbidimeter in each disperser**

| Disperser | A cavitation mixer | A high-pressure water sprayer |
|---|---|---|
| Experiment facility | Turbid water net (4m×4m×15m) | 3 ×Turbid water tube (φ500mm ×15m) |
| Depth position of Turbidimeter | 7m | 10m |

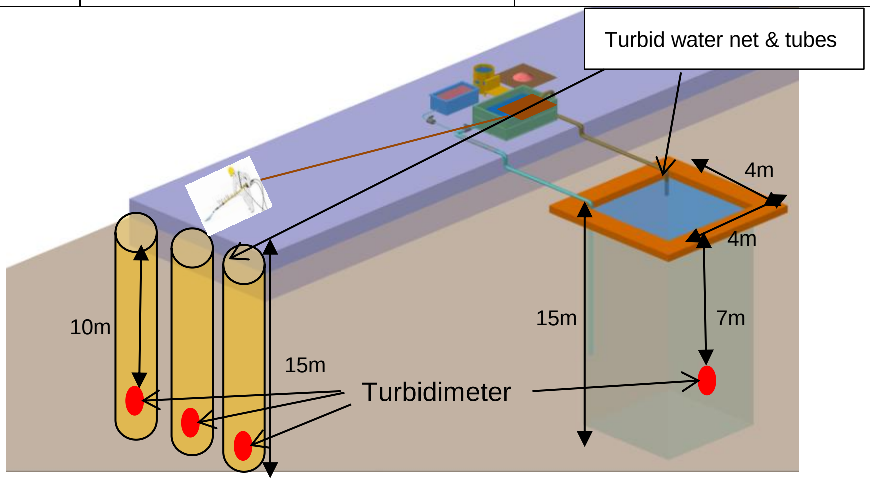



**Figure 9. The image of experimental facilities**

### 4.2 Experiment method

#### 4.2.1 Production of turbid water, using coagulant and dispersion method

Figure 9 is the summary of the field experiment's purpose and conditions. Table 4 shows the materials for turbid water and the coagulant per disperser in the field experiment. Turbid water was produced from the local sediment, which was excavated during field facility construction. As to coagulation formation, the non-processed allophane was used for it in a cavitation mixer experiment, as a cheap and easy-to-use method. On the other hand, the same purified allophane, which was used in the laboratory experiment, was also used for a high pressure water sprayer experiment. Non-processed allophane could not be used, because impurities were included and it might cause the clogging. Figure 10 shows the image of dispersion method “before mixing allophane and turbid water” and “after mixing allophane and turbid water” when applied at an actual reservoir. In our previous study, the dispersion method after mixing allophane and turbid water was more effective for coagulation than the dispersion method before mixing allophane and turbid water (Umino. 2014).

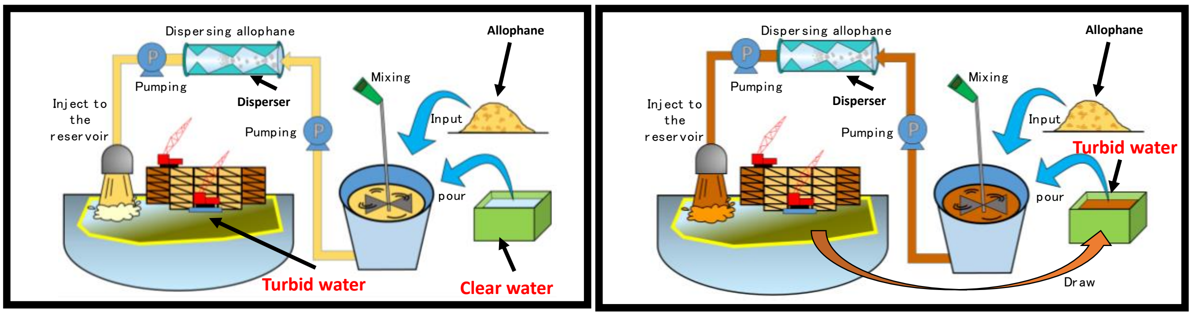
Purpose: Testing of new disperser's performance and measuring the coagulation effect and its spread to reservoir depth

Turbid water :Produced by injecting Amagase dam's sediment directly to experiment facilities
Coagulaut :Purified Allophane / Non processed allophane
Disperser :High-pressure Water Sprayer/Cavitation mixer
Dispersion method:Dispersion after adding allophane to turbid water/ Dispersion before adding allophane to turbid water

**Figure 10. The summary of field experiment’s purpose and conditions**

**Table 4. Materials used per disperser in the field experiment**

| Disperser | A cavitation mixer | A high-pressure water sprayer |
|---|---|---|
| Material for turbid water | Amagase dam’s sediment (original) | Amagase dam’s sediment (except coarse sand) |
| Coagulant | Non-processed allophane (original) | Purified allophane (except impurities) |




Before mixing allophane and turbid water method After mixing allophane and turbid water method

**Figure 11. The image of dispersion method before and after mixing allophane and turbid water**

### 4.2.2 Procedure

We performed experiments to confirm the vertical spread of coagulant dispersion to the depth of 2 m and lower. Table 5 shows the cases of field experiment. Cavitation mixer was used in cases 7-10 and high-pressure water sprayer was used in cases 11-14. case 7 and case 11 were the experiments, where turbid water only was used. Others were the experiments, where the new dispersers were used for coagulant dispersion. The change in turbidity after the coagulation treatments was measured at the depth of 7m and 10m below the surface with a turbidimeter. The experiment procedure was as follows:

1. To produce the target turbid water, the volume of local sediment, which was excavated at the construction site, was decided by the results of the preliminary experiment, the aim of which was to determine the target turbidity before the field experiment.

2. Turbid water was produced by mixing water and sediment obtained from reservoir. In these cases, the local sediment, with the exception of coarse sand, was used to reproduce the long term persistent turbidity during the high-pressure water sprayer's experiment.

3. After that, turbid water was circulated to achieve the initial target turbidity at 100-250 NTU in the facilities as evenly as possible. These targets were decided by laboratory experiment results and based on consideration of reservoir environment.

**Table 5. The cases of the field experiment**

<table>
<tr><th>case No.</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th></tr>
<tr><td>DATE</td><td colspan="8">2015/01/26 - 2015/02/02</td></tr>
<tr><td>Water temperature</td><td colspan="8">6.2℃ - 7.2℃</td></tr>
<tr><td>Disperser</td><td>none</td><td colspan="3">CM</td><td>none</td><td colspan="3">HPWS</td></tr>
<tr><td>Target turbidity (NTU)</td><td colspan="4">250</td><td colspan="3">100</td><td>200</td></tr>
<tr><td>Initial turbidity (NTU)</td><td>235</td><td>260</td><td>230</td><td>260</td><td>106</td><td>81</td><td>154</td><td>203</td></tr>
<tr><td>Concentration of allophane(mg/L)</td><td>0</td><td>600</td><td>300</td><td>250</td><td>0</td><td>200</td><td>400</td><td>400</td></tr>
<tr><td>pH</td><td colspan="8">7.3 – 7.7</td></tr>
<tr><td>Dispersion method</td><td>none</td><td colspan="3">DBA</td><td>none</td><td colspan="2">DBA</td><td>DAA</td></tr>
<tr><td>Circulation time</td><td>none</td><td colspan="2">2hours</td><td>none</td><td colspan="4">none</td></tr>
</table>

Note: CM: a cavitation mixer , HPWS: a high-pressure water sprayer , DBA: Dispersion method before mixing allophane and turbid water, DAA: Dispersion method after mixing allophane and turbid water

4. For the conditions of coagulation treatment, the quantity of coagulant was determined by the results of the above laboratory experiment. The concentration of coagulant was set at 200-600 mg-dry/L. This quantity of coagulant mixed with regular clear water from the reservoir was added to the facilities from the surface with the new dispersers (cases 8-10, cases 12-13). The dispersion method was used in these cases before mixing allophane and turbid water. Dispersion method was adopted for the case 14 after mixing allophane and turbid water. The water-coagulant mixture pH was measured at 7 in all the cases.

5. case 8 and case 9: mixture of the turbid water and coagulant was circulated with the pump for 2 hours.

6. The mixture of artificial turbid water and coagulant was left undisturbed and the change in turbidity was registered at 1 point 7 m or 10 m (depending on the cases) below the surface by the turbidimeter.

### 4.3 Result

The results of the experiment are shown in figure 11 and 12. The turbidity in case 7 reached 16 NTU at 360 min. The turbidity in case 8 reached 2 NTU at 360 min after the coagulation treatment. The turbidity in case 9 reached 15 NTU at 360 min after the coagulation treatment. The turbidity in case 10 reached 14 NTU at 360 min after the coagulation treatment. At 360 min we confirmed the effect of coagulation treatment performed with a cavitation mixer compared to case 7. Next, the turbidity in case 11 reached 57.7 NTU at 960 min. The turbidity in case 12 reached about 53 NTU at 960 min after the coagulation treatment. The turbidity in case 13 reached about 44 NTU at 960 min after the coagulation treatment. The turbidity in case 14 reached 19 NTU at 960 min. At 960 min, we confirmed the effect of coagulation treatment performed with a high pressure water sprayer compared to case 11.

As the result, the application of a cavitation mixer method and a high-pressure water sprayer method was proven to be effective for coagulation performance at the depth of about 10 m through the field experiment. And with the increasing quantity of allopane, the effect of coagulation became stronger. As it was proved before, circulating the mixture of turbid water and coagulant is effective in case 8, and the method of dispersion after mixing allophane and turbid water is more effective. It is better than the method of dispersion before mixing allophane and turbid water.  However, if we consider to apply this method at the actual reservoir, the method of dispersion after mixing allophane and turbid water is less useful. In addition, the non-processed allophane, which is cheaper than the purified one, is more effective material for coagulation in a cavitation mixer's experiment.

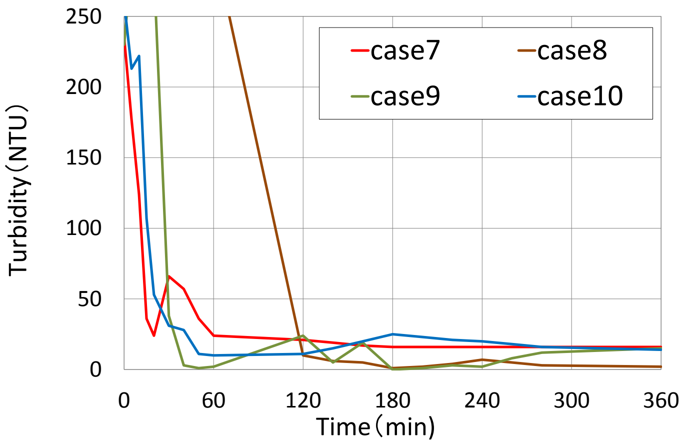



**Figure 12. Change in turbidity at 7m depth (a cavitation mixer)**

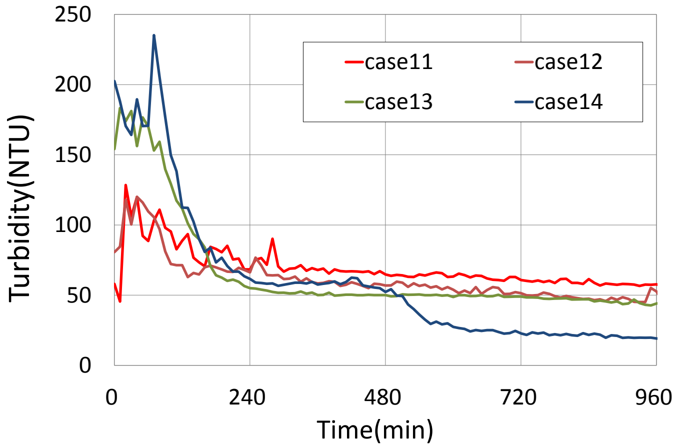



**Figure 13. Change in turbidity at 10m depth (a high pressure water sprayer)**

## 5. CONCLUSION

We are examining the practical methods using natural coagulants, such as allophane (clay), which can be deposited in the reservoirs, to prove experimentally the effectiveness of allophanes coagulation performance, and to develop a useful and environmental friendly coagulation method for turbid water. The experiments conducted in this study provided two important findings. The first is that, through the laboratory experiments, we proved that the new practical dispersers, which are a cavitation mixer and a high pressure water sprayer, can be used effectively to disperse allophane. And we confirmed the dispersion by these dispersers raises the zeta potential of allophane. This effect is presumed to promote coagulation. The second is that the coagulation effect at the depth of more than 10 m was confirmed through the field experiment of using new dispersers. As mentioned above, we can propose more practical, useful, and environmental friendly treatment method for turbid water using allophane at dam reservoirs. Some dams have the target turbidity of 10NTU in the reservoir. We expect that this technique will contribute to the more effective reservoir management.

## 6. ACKNOWLEDGEMENTS

We are deeply grateful to Biwako River Work Office of the Kinki Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), and Waterworks Office of Kyoto Prefecture for their cooperation with our field experiment research. And we are deeply grateful to National Institute for Materials Science for their cooperation with zeta potential measuring.

## 7. REFERENCES

Holmes M,Reeve P,Pestana C,Chow C,Newcombe C& West J(2015). *Zeta potential measurement for water treatment coagulation control.* Published as part of proceedings of Australia’s International Water Conference & Exhibition 2015,in Glendale, AZ, May 6-8, 2015

Jefferson B,Sharp E L, Goslan E ,Henderson R &Parsons(2004). *Application of charge measurement to water treatment processes.* Water Science and Technology: Water Supply, Vol.4 No 5-6 pp 49-56.

Lee G,Yum K, Ban Y,& Sohn B(2013).*The estimation of turbid-water occurrence possibility in basins for the environmental improvement of dam reservoirs.* Published as part of proceedings of the 5th EADC International Symposium on Co-existence of Environment and Dams in Yokohama, Japan, October 2008.

Nasser A (2011). *Select the Best Effect of Coagulate for Removal Nitrite and Nitrate in Row Water.* A project Submitted as a partial fulfillment of the requirements for the degree of (B.S.C) in civil Engineering, Republic of Iraq Ministry of Higher Education University of Technology Building and Construction Dept.

Umino H & Hakoishi N (2008). *Turbid water treatment in a reservoir using natural coagulant*. Published as part of proceedings of the 5th EADC International Symposium on Co-existence of Environment and Dams in Yokohama, Japan, October 2008.

Umino H & Hakoishi N (2011). *An experimental study on turbid water coagulation method using natural coagulant*. Published as part of proceedings of Dams and Reservoirs under changing Challenges"79th Annual Meeting of ICOLD 2011", pp.363-370, International Commission on Large Dams, in Lucerne, Switzerland, June 2011.

Umino H, Kobayashi M & Hakoishi N (2014). *Coagulation and dispersion characteristics of volcanic ash coagulants and their application to turbid water treatment in a reservoir*. JSCE collection of papers B1 (Water engineering), Vol.70, No.4, pp. I_1573- I_1578.(in Japanese)

Umino H(2014). *Study on reservoir turbid water treatment using inorganic coagulant derived from volcanic ash soil.* University of Tsukuba doctoral thesis.(in Japanese)