Dams and Reservoirs under Changing Challenges – Schleiss & Boes (Eds)
© 2011 Taylor & Francis Group, London, ISBN 978-0-415-68267-1

An experimental study on turbid water coagulation method using natural coagulant

H. Umino & N. Hakoishi
Public Works Research Institute, Tsukuba, Ibaraki, Japan

ABSTRACT: Long term persistent turbidity is a major problem in the water reservoirs of Japan. Coagulation, especially under conditions where all of the water is turbid, is expected to be an effective countermeasure. We examined the use of natural coagulants or soil colloids, which can be deposited in the reservoirs, with the objective of clarifying their coagulation performance and developing an effective coagulation method for turbid water. The experiments conducted in this study provided three important findings. The first is that effective removal of turbid water can be achieved by coagulation treatment that consists of distributing the coagulant and circulating the mixture of turbid water with coagulant. The second is that the pH of the allophane solution water should be adjusted to be acidic if the distribution procedure is omitted. The third is that the allophane has limited coagulation performance, which can be estimated by measuring the zeta potential.

1 INTRODUCTION

We demonstrated through several experiments that the turbid components of reservoir water could be coagulated by natural materials. Long term persistent turbidity is a major water quality problem in Japan's reservoirs. Selective intake facilities and fences for controlling turbid water flow have been employed as countermeasures against this problem. However, the effects of conventional countermeasures are limited, and if all of the water in a reservoir turns turbid, as can occur after large flood inflows or large-scale water circulation, the only solution is to wait for the particulate matter to settle.

Coagulation is expected to be an effective countermeasure in such circumstances where all of the water is turbid. Treatment of deposited sediments, however, can present a serious problem when artificial coagulants are used. Here, we examine the use of natural coagulants or soil colloids, which can be deposited in the reservoir.

2 LONG TERM PERSISTENCE OF TURBID WATER IN A RESERVOIR

Long term persistence of turbid water in a reservoir can occur after large-scale inflows. In September 2007 in Japan, especially in the Kanto Region, persistent turbidity had developed in several reservoirs. We selected the Kawaji Dam reservoir for our observations. The location of the dam is shown in Figure 1.

The monitoring data of turbidity at the Kawaji Dam reservoir is shown in Figure 2. In Kawaji Dam, turbidity was automatically and daily monitored for every 1 meter deep. The observation device was a production of the Tsurumi Seiki Co., Ltd. The measurement of turbidity was based on formazin and the scattered/transmitted light method was adopted. For example, the device indicates 100 degree for the 100 mg/L formazin solution. The large scale inflow was happened on 7th of September 2007. Before the incident, the turbidity was less than 5 degree in surface layer and less than 10 degree in middle layer. After the incident,

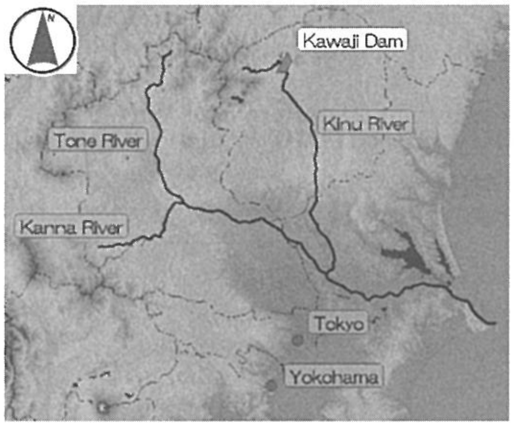

Figure 1. Location of Kawaji Dam.

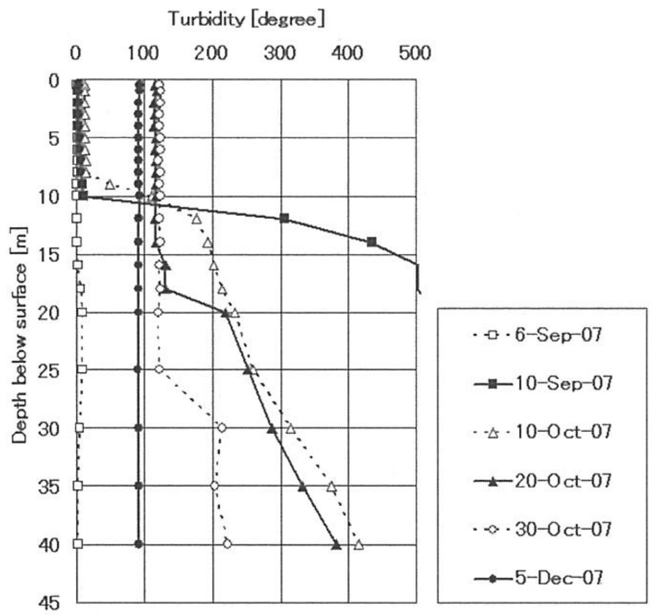

Figure 2. Change in degree of turbidity (Kawaji Dam Reservoir/formazin based).

the surface layer turned clear, on the other hand, extremely turbid water still remained in the middle layer and bottom layer.

It is regarded that the circulation of all the layers in the reservoir started between the 10th and 20th of October 2007. Prior to that time, the degree of turbidity was low in the surface layer, and turbidity was not a problem as long as the surface intake remained effective. In October, the temperature declined and the surface of the reservoir cooled. This cooling of the surface layer caused full circulation, because the water density of the surface layer and the other layers became almost the same. At the time of observation in December, turbidity had persisted for more than one and a half months since this mixing of the water layers. Waiting for dilution brought by clear water inflow was the only strategy to be taken at that time. Considered the artificial coagulation treatment, the target degree after coagulation should be set at 5 to 10 degree corresponding with the turbidity of the day before incident.

3 PREPARATION FOR EXPERIMENTS

3.1 *Selection of coagulant*

Allophane, a natural soil colloid, was used in this experiment (Fig. 3). Among natural soil colloids, kaolin, allophane and imogolite have large specific surface and they could be used as

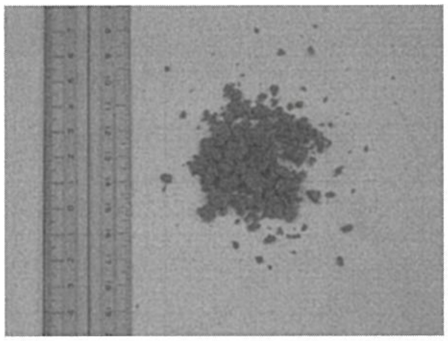

Figure 3. Allophane used in the experiment.

coagulant. In this study, we selected allophane as a coagulant because of its high performance in coagulation; moreover, it was easily obtained. Allophane is present at high levels in weathered volcanic ash and volcanic soils. Volcanic soils are widely distributed in the Hokkaido, Tohoku, and Kyushu regions of Japan and are easily obtained. Moreover, coagulation with allophane is considered to minimize the 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 colloidal particle and has a character of distribution and coagulation according with the pH condition. The distributed allophane particles are surrounded by plus electric charge and it is easy to adsorb soil particles because soil particles ordinarily have the minus electric charge. In view of its absorbing characteristics, we considered that it would be capable of coagulating particulate matter in water.

3.2 *Production of turbid water*

Turbid water and sediment were sampled from the Kawaji Dam reservoir. As part of the preparations for the laboratory experiment, 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 production was as follows:

1. Sediment was stirred into pure water and large particles were filtered off (mesh size of the filter: 7 μm) and the filtrate was extracted. Supersonic distribution was applied during filtering to accelerate distribution.
2. Filtrate was poured into a bucket and left undisturbed for 24 h.
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.

3.3 *Preliminary experiment*

We conducted a preliminary experiment to determine the quantity of coagulant that would be suitable for the turbidity of samples. It was reported that 90 to 180 mg-dry/L had been enough for the turbidity of 55 to 85 NTU (nephelometric turbidity unit) in Kawaji Dam reservoir (Umino et al. 2008). Referred the former paper, the concentration of coagulant was set 90 mg-dry/L in Case 3.1, 150 mg-dry/L in Case 3.2 and 180 mg-dry/L in Case 3.3 for the sample of 50 NTU. As the coagulation treatment, both supersonic distribution of coagulant and circulation of the mixture of turbid water and coagulant were adopted.

The results are shown in Figure 4. Hack 2100P Turbidity Meter was used for the observation of formazin based turbidity. The target degree of turbidity was set at less than 5 NTU at 30 min after the coagulation treatment, which corresponded to the ordinary turbidity of surface layer in Kawaji Dam reservoir. We found that the degree of turbidity declined with time. Thirty minutes after coagulation treatment, the turbidity was 5.3 NTU in Case 3.1, 4.5 NTU in Case 3.2 and 5.8 NTU in Case 3.3. There was little difference between the three cases.

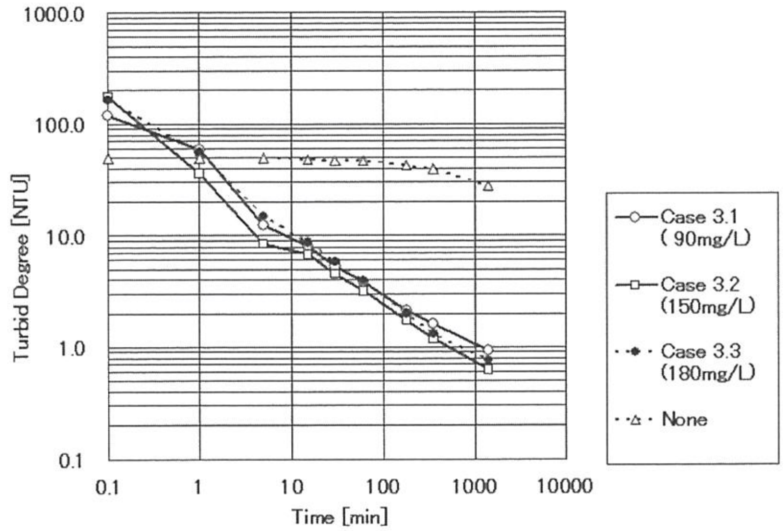

Figure 4. Change in degree of turbidity (preliminary experiment).

In contrast, there was hardly any change in turbidity in the case without coagulation treatment (Case 3.4). The appropriate concentration of coagulant for water with an initial turbidity of 50 NTU was considered to be 90 mg-dry/L, so we adopted this rate for the main experiment.

4 STANDARD COAGULATION TREATMENT IN WATER TANK

In an earlier paper, we reported that allophane was useful for the treatment of turbid water. Moreover, we reported that the distribution of coagulant and circulation were indispensable for effective coagulation (Umino et al. 2008). Here, we have expanded on the earlier study, changing from settling cylinders to water tanks, in order to demonstrate that the former reported procedures are effective at any size of experiment.

4.1 *Procedure*

We used artificial turbid water in the experiment. For the conditions of coagulation treatment, the quantity of coagulant was decided by the results of the preliminary experiment and the duration of distribution was arranged for two cases. The change in turbidity after the coagulation treatments was observed. The experimental procedure was as follows:

1. Artificial turbid water was created using sediment from the Kawaji Dam reservoir. The target initial degree of turbidity was set at 50 NTU.
2. A water tank was prepared and the artificial turbid water was poured into the tank to a volume of 500 liters.
3. A sample of 50 liters of turbid water was removed from the water tank to a bucket, and a predetermined quantity of coagulant was added to the bucket. The concentration of coagulant was 90 mg-dry/L.
4. The mixture of sampled water and coagulant was returned to the water tank, and then the coagulant and artificial turbid water were distributed by supersonic wave distributor (1,200 W, 28 kHz) for 12 min (Case 4.1) or 24 min (Case 4.2) while circulation was underway.
5. The mixture of artificial turbid water and coagulant was left undisturbed and the change in degree of turbidity was observed at 6 points in the water tank.

4.2 *Results*

The results of the experiment are shown in Figure 5. The target degree of turbidity was set at less than 5 NTU at 1440 min after the coagulation treatment, corresponding to the ordinary

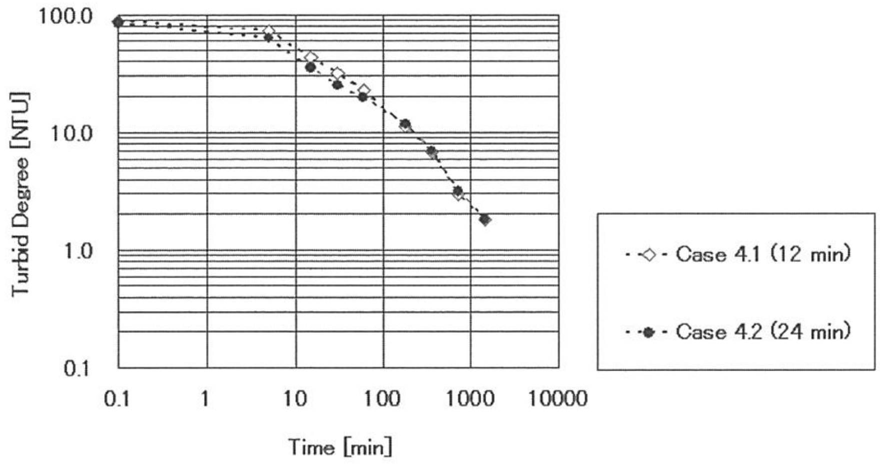

Figure 5. Change in degree of turbidity (water tank).

turbidity of surface layer in Kawaji Dam reservoir. The differences of turbidity among 6 points were little for each case so that the average of 6 points was plotted on the figure.

At 1440 min after coagulation treatment, the turbidity was 1.8 NTU in both cases and the target degree was achieved. Under these experimental conditions, 12 min of distribution was sufficient for coagulation treatment. We increased the size of the experiment from settling cylinders to a water tank, and have also confirmed that the distribution of coagulant and circulation of turbid water/coagulant mixture are effective as a coagulation treatment.

5 DISTRIBUTION OF COAGULANT UNDER ACID CONDITIONS

Allophane is a natural soil colloid, the distribution and coagulation characteristics of which vary with the pH of the colloid solution. In practical applications, it would be difficult to distribute the coagulant. We examined the possibility of chemically distributing the coagulant while adjusting the pH of the colloid solution to reduce the distribution load.

5.1 *Procedure*

We conducted an experiment to examine the distribution performance of allophane solution along with the pH conditions. Three samples of allophane solution were prepared as the coagulant and agitation was adopted as the coagulation treatment. After treatment, the changes in turbidity degree were observed to evaluate the efficiency of allophane solution. The experimental procedure was as follows:

1. Medium-sized beakers were prepared and 1 L of turbid water was poured into each one.
2. A 50-mL sample of turbid water was taken from each beaker and placed into a small beaker. Predetermined allophane solution was added. The pH of the allophane solution was adjusted to 4 (Case 5.1) and 5 (Case 5.2) by adding acetic acid solution. In addition, allophane solution without pH adjustment was also examined (Case 5.3). The concentration of coagulant was 150 mg-dry/L for each case.
3. The mixture of turbid water and allophane solution was returned to each medium-sized beaker and then agitated by stirring apparatus for 3 min to accelerate coagulation of the turbid particles.
4. The mixture of turbid water and allophane solution was left undisturbed and the change in degree of turbidity was observed at 4 cm below the surface.

5.2 *Results*

The experimental results are shown in Figure 6. The target degree of turbidity was set at less than 5 NTU at 30 min after the coagulation treatment.

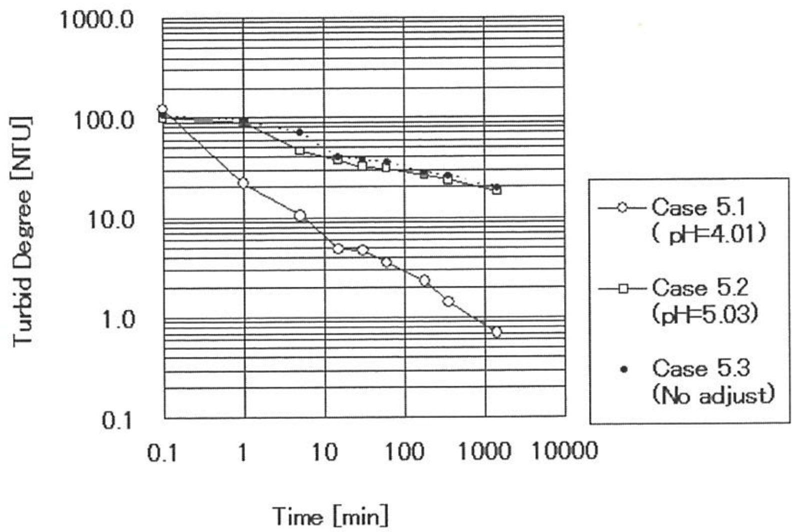

Figure 6. Change in degree of turbidity (pH adjustment).

We found that the degree of turbidity declined with time. After 30 min, the turbidity was 4.7 NTU in Case 5.1, 31.9 NTU in Case 5.2 and 37.6 NTU in Case 5.3. The target degree was attained only in Case 5.1. By adjusting the pH condition of the allophane solution to be acidic, instead of applying supersonic distribution, effective performance of coagulation was achieved. From the results of the experiment, pH of the allophane solution should be adjusted to around 4 if the distribution procedure is omitted.

On the other hand, there is a risk of affecting the water environment in the reservoir by spraying the mixture of allophane and acetic acid solution. It is estimated that the pH condition of the reservoir water could become acidic. Possible effects on the reservoir environment are yet to be evaluated.

6 VERTICAL TRANSMISSION OF COAGULATION IN SETTLING CYLINDERS

As mentioned above, allophane proved useful for the treatment of turbid water; moreover, the distribution of coagulant and circulation were indispensable for effective coagulation. If we consider the practical application of the coagulation treatment, the vertical transmission of coagulation effects should be realized because the coagulation treatment would be executed at the surface layer of the reservoir water. Here, we determine the vertical transmission of coagulation effects by conducting a continuous experiment using settling cylinders.

6.1 *Procedure*

The purpose of the experiment was to clarify the transmission of coagulation effects from the surface to the bottom of the reservoir along the vertical axis. We conducted a continuous coagulation experiment using a settling cylinder 2.2 m in length. The shape of the settling cylinder is shown in Figure 7. The sample was artificial turbid water created using sediment. The change in turbidity after the coagulation treatment was observed. The procedure for the primary experiment, Case 6.1, was as follows:

1. Artificial turbid water was prepared with turbidity of 50 NTU.
2. A settling cylinder was prepared and the artificial turbid water was poured into the cylinder up to a depth of 2.0 m.
3. A sample of 25 liters of turbid water was removed from the settling cylinder to a bucket, and the coagulant was added. The concentration of coagulant was 90 mg-dry/L.
4. The mixture of sampled water and coagulant was returned to the settling cylinder, and then the coagulant and artificial turbid water were distributed by a supersonic wave distributor (600 W, 28 kHz) for 12 min while circulation was underway.

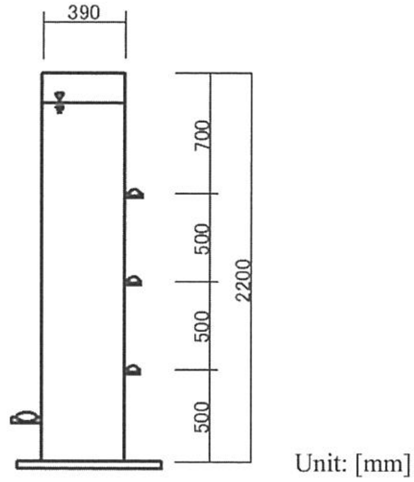

Figure 7. Shape of settling cylinder.

5. The mixture of artificial turbid water and coagulant was left undisturbed and the change in degree of turbidity was observed at 4 points in the settling cylinder.

After the completion of Case 6.1, sediment composed of allophane and turbid particles was collected from the bottom of the settling cylinder and placed in another settling cylinder, to which artificial turbid water was added for the preparation of Case 6.2. The purpose of this case was to evaluate the coagulation potential of sediment. The ratio of sediment and turbid water in volume was 1:9. for this case. Only circulation was conducted as the coagulation treatment in case 6.2, but it showed poor performance in coagulation, so that both distribution and circulation were conducted in Case 6.3. Both Case 6.2 and Case 6.3 simulated the coagulation conditions for the depth of 2 to 4 m below the surface

After the completion of Case 6.3, sediment was collected and placed in another settling cylinder. Then, Case 6.4 was started by adding turbid water. The coagulation treatment for Case 6.4 was the same as for Case 6.3. Case 6.4 simulated the coagulation conditions for the depth of 4 to 6 m below the surface. The treatment for each case is summarized in Table 1.

6.2 *Results*

The results of the experiment are shown in Figure 8. The target degree of turbidity was set at less than 5 NTU at 1,440 min after the coagulation treatment. The degrees of turbidity in this figure are the means of the four observation points in the settling cylinder.

At 1,440 min after coagulation treatment, the turbidity was 4.0 NTU in Case 6.1, 35.8 NTU in Case 6.2, 4.7 NTU in Case 6.3 and 40.8 NTU in Case 6.4. Both Case 6.1 and Case 6.3 achieved the target degree. This means that the sediment from Case 6.1 had sufficient coagulation ability because Case 6.3 showed good performance. On the other hand, the sediment from Case 6.3 had little coagulation ability because Case 6.4 showed poor performance. Moreover, the result for Case 6.4 suggests that the effects of coagulation could not be transmitted further than 4 m below the surface of the reservoir.

We measured the zeta potential (Table 2) and found that the allophane had positive potential and the artificial turbid water had negative potential. It was regarded that the particles of turbid water could be coagulated through electrical adsorption. The coagulation ability could be estimated by measuring the zeta potential of sediment composed of allophane and turbid particles.

Finally, it was considered that the allophane has limited coagulation performance; moreover, the effects of coagulation could be transmitted only 2 to 4 m below the reservoir surface if the surface layer was coagulated. An effective coagulation method that can transmit the effects of coagulation from the surface to the deep layers of the reservoir needs to be developed.

Table 1. Specifications for coagulation treatment.

Case	Coagulant	Distribution	Circulation
Case 6.1	Allophane	12 min	12 min
Case 6.2	Sediment from Case 6.1	None	12 min
Case 6.3	Sediment from Case 6.1	12 min	12 min
Case 6.4	Sediment from Case 6.3	12 min	12 min

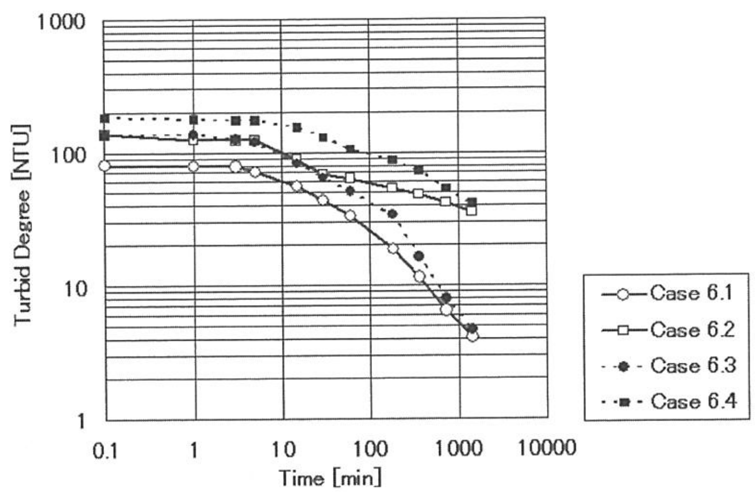

Figure 8. Change in degree of turbidity (continuous experiment).

Table 2. Zeta potential of allophane, turbid water and sediment.

Sample	Zeta potential [mV]
Wet allophane	2.0
Artificial turbid water	–23.3
Sediment (Case 6.1)	–11.4
Sediment (Case 6.3)	–20.5
Sediment (Case 6.4)	–19.7

7 CONCLUSIONS

We examined the use of natural coagulants or soil colloids, which can be deposited in the reservoirs, as an effective countermeasure for persistent turbidity under conditions where all the water in the reservoir is turbid. The experiments conducted in the study yielded three important findings. The first is that effective coagulation can be achieved by coagulation treatment that consists of distributing the coagulant and circulating the mixture of turbid water with coagulant. The second is that the pH of the allophane solution water should be adjusted to be acidic if the distribution procedure is omitted. The third is that the allophane has limited coagulation performance, which can be estimated by measuring the zeta potential.

REFERENCE

Umino, H. & Hakoishi, N. 2008. Turbid water treatment in a reservoir using natural coagulant, The 5th EADC International Symposium on Co-existence of Environment and Dams; Proc. Symp., Yokohama, October 2008. Yokohama: Japan.