Pilot-scale Upflow Pelletizer for THM Precursor and Turbidity Removal from Raw Water for Water Supply Production

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Abstract

In order to reduce trihalomethane (THM) formation in drinking water treatment, the presence of THM precursors in raw water must be minimized. This pilot-scale study was carried out using raw water from Pra-Pa canal to assess the effectiveness of upflow pelletization process in THM precursors removal. The experiments were conducted with different dosages of coagulant (Polyaluminium chloride) and coagulant aid (nonionic polymer). Process effectiveness was evaluated in terms of effluent turbidity, THM precursors removal and characteristics of pellet formation. Two parameters were used as indicators for THM precursors: total organic carbon (TOC) and ultraviolet absorbance at 260 nm (UV260). From this research, PACl and nonionic polymer dosages of 5 and 0.2 mg/L, respectively were suggested to be used in the system operation since removal efficiencies up to 48.6% for TOC, 78.9% for UV260 and 98.0 % for turbidity could be achieved. The diameter and settling velocity of pellets formed in this study were 0.19-0.33 mm and 19.66-53.96 m/h, respectively.

1.Introduction

The use of chlorine as a disinfectant in potable water had a long and successful history of making water sufficiently free of pathogenic organisms that minimized the probability of waterborne diseases among the consuming public. In developing countries, it is still a choice because of its effectiveness, relative ease of application and low cost. Lately, some experimental results have indicated that the use of chlorine during water treatment can produce trihalomethanes (THMs). This has caused a lot of alarms and concerns among health authorities and general public. Chloroform, one of the THM species, has been shown to be toxic affecting the liver and kidney functions and carcinogenic. This concern has led to psychologically reluctant acceptance by the public on the use of chlorine in water treatment. THMs, mainly chloroform, bromodichloromethane, di-bromochloro methane and bromoform occur as results of reactions between chlorine and natural organic matter (NOM) such as decomposing plants and animal materials in water. There are a few possible ways to reduce THMs. Among them, removal of THM precursors before formation of THMs and the removal of THMs themselves during water treatment are the main processes (Kavanaugh, 1978). This study focuses on the removal of THM precursors, a preventive approach, in water treatment. Precursors of THMs are macromolecules known as humic acid, fulvic acid, hymatomelanic acid and algal material. In most of surface water, concentrations of the mentioned precursors highly present ranging from 1 to 20 mg/L as TOC (Total Organic Carbon), which made them important precursors (Kavanaugh,1978). Therefore, the evaluation of THM precursors in raw water can lead to prevention of THMs formation. A pelletizer is a reactor in which destabilized colloids are forced to be in contact with one another through a proper degree of agitation, resulting in small but very dense pellets. The upflow pelletization process was successfully used to remove turbidity from synthetic raw water (Tambo and Matsui 1989; Panswad and Channarong, 1998). The process

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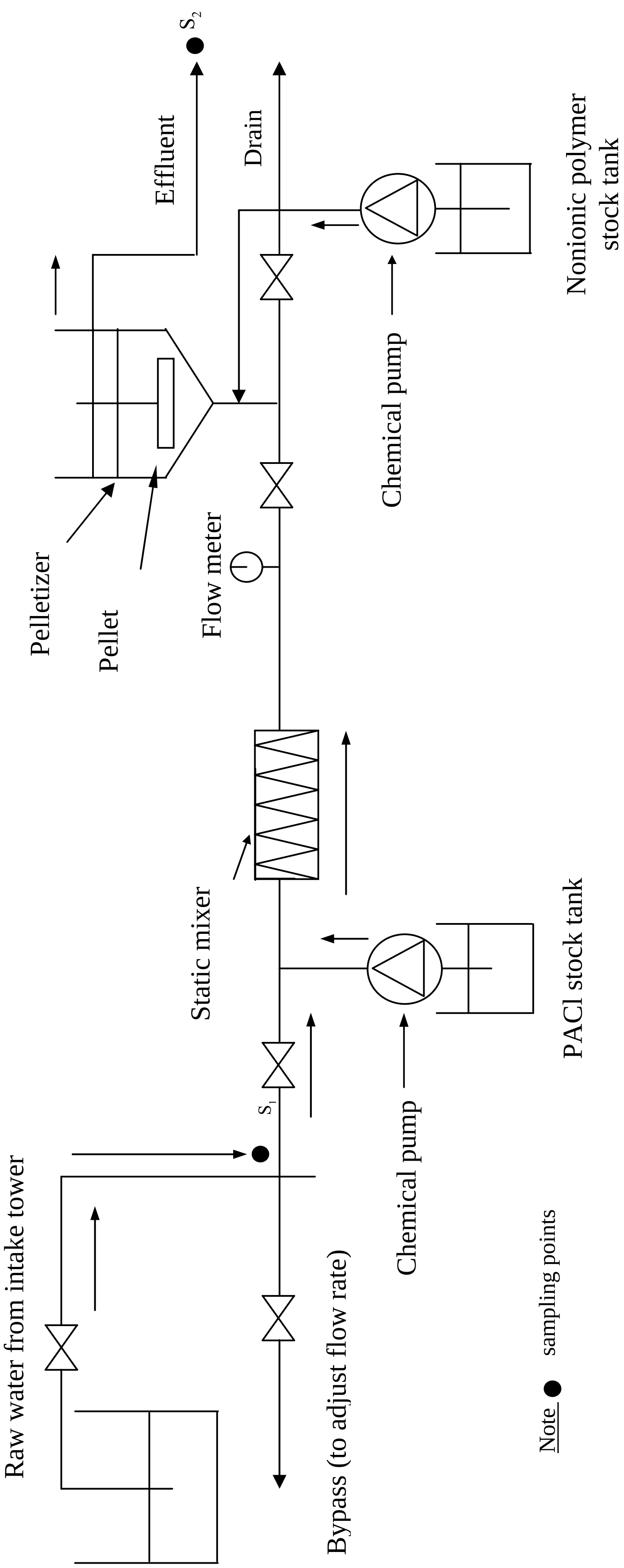

Figure 1 Process setup for the experiment.

was also satisfactorily applied in clarification for biological wastewater treatment processes precursors. In this study, the main objectives are to study the possibility and efficiency of upflow pelletization process to remove THM precursors for water supply production. In this reserch, the system was tested with raw water from Bangkhen Water Treatment Plant and run until a steady state condition was achieved. Polyaluminum chloride (PACl) and nonionic polymer were employed as coagulant and coagulant aid, respectively. The dosage of PACl was previously investigated for turbidity removal in the range from 1 to 5 mg/l, and at least 3 mg/l was recommended for application of pelletizer in water supply production (Chonpatathip, 2002). In addition, pH, turbidity, Total organic carbon (TOC) and UV (Tambo and Matsui 1993,1994). However, no studies used this system to remove THM absorbance at 260 nm (UV260) are analyzed as criteria to determine process performance in terms of THM precursor removal.

2. Experimental methods

2.1 Source of raw water

The natural water source used in this study was diverted from the Bangkhen Water Treatment Plant and then pumped to the pilot plant of Pelletizer, located inside Bangkhen Water Treatment. This location allows working with Pra-Pa canal, which is the main water source for the Bangkok Metropolitan areas. The characteristics of raw water used is shown in Table 1.

Table 1 Characteristics of raw water

Parameter	Range of values
Temparature (C°)	22-25
pH	7-8.5
Turbidity (NTU)	20-200
Alkalinity (mg $CaCO_3$/L)	80-100
TOC (mg/L)	1-10
UVabsorbance at 260 nm	0.143-0.293

2.2 Chemicals and instruments

2.2.1 Chemicals and Reagents

Chemicals used in this study are all analytical grade: KHP (OI Analytical), $Na_2S_2O_4$ (OI Analytical), Kaolin clay (PT. Kaolindo, Indonesia), Polyaluminium chloride (Goshu Kasei Co., Ltd) and nonionic polymer (Kurita C-133, Kurita-GK Chemical Co., Ltd). Polyaluminium chloride was used as a coagulant to neutralize charges of colloidal suspension and nonionic polymer was used as a coagulant aid to generate strength of floc in the system.

2.2.2 Instruments

Many instruments were used, i.e., UV-Spectrophotometer (Model U-2000, Hitachi, Japan); pH meter (Accumet®pH Meter 910, USA.); Turbidity meter (HACH 2100N, USA.); TOC analyzer (Model 1010, O.I. Corp., College Station, TX), Gas Chromatrograph equipped with an electron capture detector (Model GC-14A, Shimadzu.); Particle size analyzer (Masterizer X Version.2.15, Malvern Instruments Ltd.);Refrigerator (Gold Spot, Korea); Oven (Memmert GmbH, Model 700, Schwabach, Germany); Suction (Hitachi, Japan).

2.3. Experimental set-up

The experimental apparatus used in this study consists mainly of static mixer for rapid mixing and a pelletization reactor. The reactor has a height of 3 m. and internal diameter of

3.5 m. A scheme of the pilot plant is shown in Figure 1.

2.4. Experimental Procedure for pelletizer

A sufficient pellet mass was first developed in the reactor by a start-up process which was achieved by introducing a feed water of 150,000 mg/L kaolin to the system along with coagulant and coagulant-aid doses according to particular experiment. An ample mass of pellet could be obtained within approximately 1-3 hours, after which the process was fed with real surface water from Bangkhen Water Treatment Plant.Both the 150,000 mg/L kaolin synthetic water and the real surface water were pumped into the static mixer unit while the PACl was introduced. The destabilized water was then mixed with the polymer before entering the bottom part of the pelletization reactor and flowing upwards through the height of the reactor, in which an agitator provided a sufficient degree of mixing for a good pelletization. The treated water then flows through the outlet and finally drains to a nearby gutter. With the continuous running, the total volume of pellets in the reactor increased. When it reached the full bed height of 150 cm. from the bottom of the reactor, excess pellet-flocs would continuously withdrawn to keep constant height of pellet bed.

Study on effects of coagulant and coagulant aid dosages on the process performance

The study of the effects of coagulant and coagulant aid dosages was performed by varying PACl dosages of 3, 4 and 5 mg/L and nonionic polymer dosages of 0.1, 0.2 and 0.3 mg/L. The operating condition of the system is shown in Table 2.

2.5 Sampling procedure

Water samples were taken from two locations in the pilot system (point S_1 and S_2 in Figure 1). For each pilot run, raw and treated waters were taken at 12 h. intervals for analysis of pH, turbidity, TOC and UV260. The pellet samples were taken at 0, 30, 60, 90, 120 and 150 cm pellet height at 12 h. intervals for analysis of suspended solid (SS), size, and setting velocity.

Table 2 Operational set up for determination of the effects of number of paddles and upflow velocity

Fixed variables:	
Paddle speed	2 rpm
Number of the paddles	6
Pellet blanket height	150 cm (max)
Run time	48 h for each experiment
Independent variables:	
Upflow velocity	10 m/h
Chemical dose	PACl
	with nonionic polymer

2.6. Analytical methods

2.6.1 TOC

The samples were filtered through a pre-washed 0.45 μm membrane filter paper to remove suspended particles prior to measurement of TOC by a total organic carbon analyzer with the method of sodium persulfate oxidation (Standard Methods 5310-D, 1995). The analyzer was regularly calibrated with 1000 ppm potassium hydrogen phthalate (KHP) as recommended by the manufacturer.

2.6.2 UV260

Ultraviolet Absorbance (UVA) was measured at a single wavelength of 260 nm, using UV-Visible spectrophotometer with a 1 cm quartz cell. The instrument was calibrated to zero absorbance using a filtered, distilled, and deionized water sample. The samples were first filtered through a pre-washed 0.45 μm membrane filter paper to remove suspended particles, which can interfere with this measurement.

2.6.3 Turbidity

Turbidity was measured with a Hach 2100A turbidimeter using latex solution standards which turbidity measurements with accuracy of 0.01 NTU could be obtained. Treated-water sample was gently mixed prior to measurement. The water turbidity was expressed in Nephelometric Turbidity Unit (NTU).

2.6.4 Pellet Size

The particle size of pellet samples was determined by using a Masterizer X Version. 2.15 particle size analyzer, (Malvern Instruments Ltd.). The lenses used in this experiment were 0.2 and 2000 μm. The sample was placed in a sample cell across a laser beam. This instrument measured the average particle size and standard size distribution. Consequently, the specific surface area was calculated from the particle diameter with the assumption of being a spherical particle.

2.6.5 Pellet Setting Velocity

Setting velocities of various pellet particles were measured by allowing the particles that were sampled through an undisturbed method to settle descent in a quiescent setting column.

3. Results and discussion

In this study, PACl and nonionic polymer were used as coagulant and coagulant aid. The experimental investigation was carried out by varying coagulant dosages from 3 to 5 mg/L and coagulant aid dosages from 0.1-0.3 mg/L since at least 3 mg/l of PACl should be used for water supply production (Chonpatathip, 2002).

3.1 Effects of coagulant and coagulant aid dosages on TOC, UV260, and turbidity removal

From Fig.2, The results of effects of PACl with 0.1 mg/L of nonionic polymer show that the removal of TOC, UV260, and turbidity slightly increased with increasing in PACl dosage. The maximum percentage removal of TOC, UV260 and turbidity was obtained at 5 mg/L of PACl. It is evident that the higher PACl dosage can promote a slightly better charge neutralization of the colloidal particles and also can permit better attachment of the particles into pellets. Therefore, higher PACl dosage could produce better quality water than lower PACl dosage. Figure 3 shows the effects of PACl with 0.2 mg/L of nonionic polymer on TOC, UV260 and turbidity removal. The results show that the removal of TOC, UV260, and turbidity decreased with increasing in PACl dosage. The maximum percentage removal of TOC, UV260, and turbidity was found to be achieved with 5 mg/L of PACl. It can be explained that higher amount of PACl dosage can promote charge neutralization of the colloidal particles, increase the inter-particle collision rate and also can permit better attachment of the particles into pellets. Therefore, higher PACl dosage could produce better quality of water than in the case of lower PACl dosage.

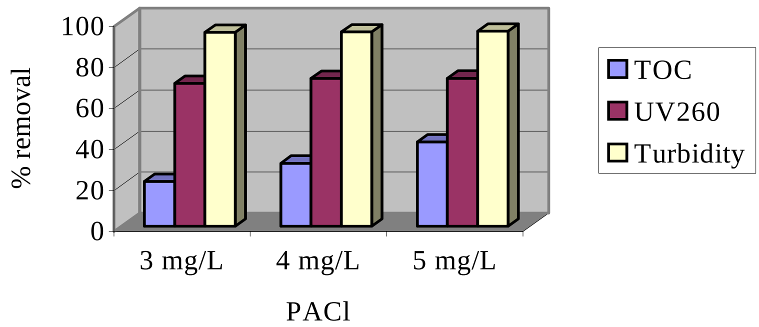

Figure 2 Percentage of TOC, UV260, and turbidity removal with 0.1 mg/L of nonionic polymer

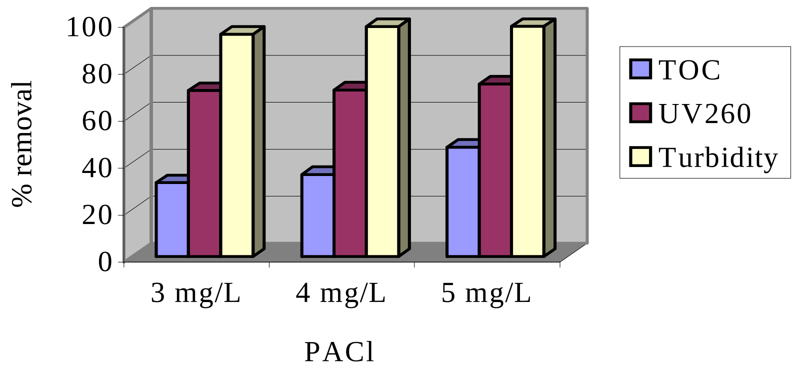

Figure 3 Percentage of TOC, UV260, and turbidity removal with 0.2 mg/L of nonionic polymer

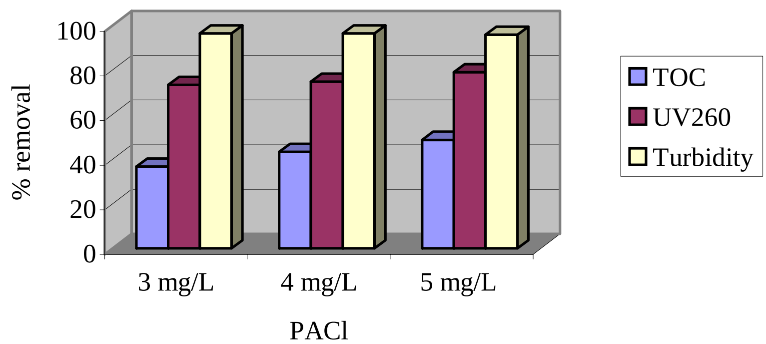

Figure 4 Percetage of TOC, UV260, and turbidity removal with 0.3 mg/L of nonionic polymer

Figure 4 shows the effects of PACl dosage on TOC, UV260, and turbidity removal. With 0.3 mg/L of nonionic polymer as the coagulant aid, the performance with regards to TOC and UV260 removal increased with an increasing in PACl dosage. The results indicate that the higher PACl dosage tend to promote better charge neutralization of organic material and to reduce the repulsive force between particles more than the lower PACl dosage. The results also show that percentage of UV260 removal is higher than TOC removal in all conditions. This observation is consistent with the previous studies suggesting that the humic substances be removed more efficiently by chemical coagulation than other NOM fractions. The maximum percentages of TOC and UV260 removal were observed with the Pelletizer with 5 mg/l of PACl and 0.3 mg/l of nonionic polymer. The results also indicate that at same PACl dosage, the percentage of TOC and UV260, and turbidity removal increased with increasing nonionic polymer dosage. The reason is that higher polymer dosage increased better interactions with oppositely charged surfaces and improved shear resistance as a result of the bridging action of the nonionic dosage. This led to the formation of more settleable pellet. Thus, good quality could be obtained. Although, the 0.3 mg/L of nonionic polymer could give the highest percentage of TOC and UV260 removal. However, it could be suggested that the nonionic polymer dosage should be used only 0.2 mg/L because the results between using 0.2 and 0.3 mg/L of nonionic polymer showed no significant difference. This could help minimize operation cost due to less amount of the polymer is used. From the present study, the highest efficiency of turbidity was also achieved with 5 mg/L of PACl and 0.2 mg/L of nonionic polymer. The addition of nonionic polymer in combination with PACl for turbidity removal is lower in terms of dosage of nonionic polymer than in the case of both TOC and UV260 removal because particulate matters were destabilized and entrapped in to pellet easier than case of organicmatters.

3.2 Effects of coagulant and coagulant aid dosages on characteristics of pellets

Figure 5 shows the effects of PACl and nonionic polymer dosages on size of pellets. The results indicate that increasing in PACl caused a slightly decrease in size of pellet. At high PACl dosage could produce smaller pellet size than using low PACl dosage. This was because high PACl dosage produced more water molecules from hydrolysis reaction. The water molecules were displacing in the floc. Thus, pellet-flocs generated much more void water and bulky. After that bulky floc was broken down to become smaller size. When using PACl with high nonionic polymer dosage, pellets became larger size resulted from improving of charge neutralization and improving of shear resistance as a result of the bridging action of nonionic polymer.

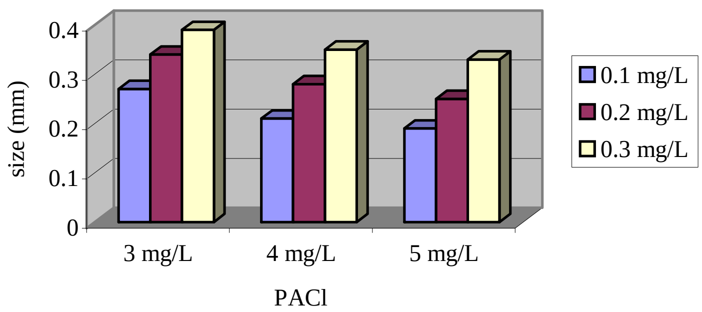

Figure 5 Effects of PACl and nonionic polymer dosages on size of pellets

With respect to pellet settleability, pellet size, density and permeability all affect settling velocity (Gregory 1993). Tambo and Watanabe (1979) showed that the density of pellet with a given diameter decreases with an increase in aluminum ion to particle. Thus, an increase in coagulant dosage may produce a decrease in the settling velocity of pellet, depending on the resulting pellet size. Similar results were obtained from this study. The results in Fig. 6 indicate that settling of pellet slightly decreased with increasing PACl dosage. It is therefore that higher PACl dosage, accompanied by a decrease in coagulation pH, altered floc size and density such that pellet settleability decrease. As a result of the nonionic polymer addition, both improving charge neutralization and interparticle bridging led to the formation more settleable pellet. Here, the pellet diameter obtained in the case with PACl 5 mg/l and nonionic polymer 0.2 mg/l was found to be in the range of 0.19-0.33mm. Thus, higher nonionic polymer dosage could producepellets with higher settlingability than using lower nonionic polymer dosage.

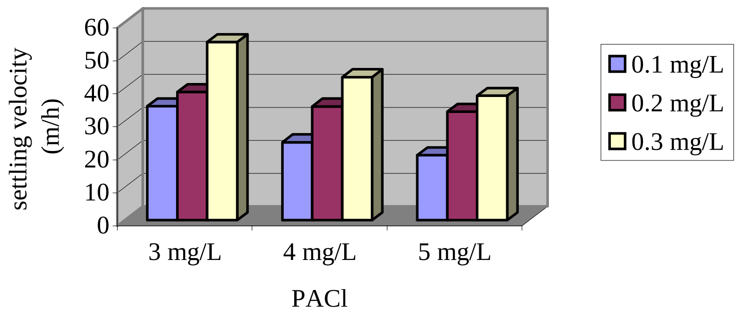

Figure 6 Effects of PACl and nonionic polymer dosages on settling velocity of pellets

4. Conclusions

Removal of THM precursors from surface water source by up-flow pelletization process was investigated at pilot scale. On the basis of the results of these investigations, the following conclusion are drawn:

1. The pelletizer could be applicable for THM precursor removal. The removal efficiency up to 43.2% THMFP, 48.6% TOC, 78.9% UV260, and 98.0% turbidity were obtained in this study.
2. The maximum removal of TOC and UV260 was obtained using 5 mg/L of PACl and 0.3 mg/L of nonionic polymer. At these concentrations, humic substances are likely to be removed by formation of insoluble aluminum-humate complex and adsorption to aluminum hydroxide precipitation.
3. Maximum of turbidity removal was obtained using 5 mg/L of PACl and 0.2 mg/L of nonionic polymer. At these concentrations, particles were removed predominantly by sweep-floc coagulation. A further increase in coagulant and coagulant aid had little effects on turbidity removal.
4. The addition of nonionic polymer as a coagulant aid improved both charge neutralization and interparticle bridging, leading to the formation of larger, stronger, and more settleable pellet.
5. The diameter and settling velocity of pellets taken from the pellet bed were in the range of 0.19-0.33 mm ,and 19.66-53.96 m/h, respectively.

5. References

Chonpatathip, W. 2002. Effect of Impeller Configuration on Turbidity Removal Efficiency by Pelletization Process. Master Thesis, Chulalongkorn University.

Gregory, R. 1993. The role of colloid interactions. Water Sci. Tech. 27(10): 1-17.

Kavanaugh, M.C. 1978. Modified Coagulation for Improved Removal of Trihalomethane Formation Potential. *J. AWWA*. 70(11): 613-620.

Panswad, T. and Channarong, B. 1998. Turbidity Removal by the upflow Pelletization Process for Low Turbidity Water. *J.Water SRT-Aqua*. 47(1):36-40.

Tambo,N. and Watanabe,Y. 1979. Physical aspect of flocculation process: Fundamental treatise. Wat.Res.13: 429-439.

Tambo, N. and Matsui, Y. 1989. Performance of Fluidized Pellet Bed Separator for High Concentration Suspensions Removal. *J. Water SRT-AQUA*. 38(38): 16-22.

Tambo, N. and Matsui, Y. 1993. The Mechanism of Pellet Flocculation in a Fluidized Bed Operation. *J. Water SRT-AQUA*. 42(2): 67-76.

Tambo, N. and Matsui, Y. 1994. Control of Coagulation Condition for Treatment of High-turbidity Water by Fluidized Pellet Bed Separation. *J. Water SRT-AQUA*. 42(4): 212-222.