Removal of Phosphorus from Domestic Wastewater in Actual On-site Treatment Systems using Phosphorus Removal Pellets

YOKO FUJIMURA*, MUNESATO SUGAWARA, MUNEHIRO KONDO, YUHEI INAMORI, RYUHEI INAMORI, YOSHIMASA AMANO, and MOTOI MACHIDA

1Graduate School of Engineering, Chiba University/1-33, Yayoi-cho, Inage-ku, Chiba 263-8522, Japan
2Fukushima Prefecture Johkasou Association Fukushima Branch /1-16-35, Noda-cho, Fukushima 960-8055, Japan
3Business management division, Nikka Maintenance Co., Ltd. /2-5-12, Higashi-kanda, Chiyoda-ku, Tokyo, 101-0031, Japan
4Foundation for Advancement of International Science/3-24-16, Kasuga, Tsukuba 305-0821, Japan
5Safety and Health Organization, Chiba University/1-33, Yayoi-cho, Inage-ku, Chiba 263-8522, Japan

Abstract

In the present study, the effect of phosphorus removal pellets containing alum as a main component on the phosphorus removal efficiency in various on-site treatment systems for domestic wastewater was evaluated. When 400 g/week or 800 g/week of phosphorus removal pellets were put into the aeration tank and the raw water tank of three types of Johkasou (Tandoku-shori Johkasou, conventional Johkasou and nitrogen removal type Johkasou), total phosphorus (T-P) and phosphate phosphorus (PO4-P) in the effluent water were decreased after one week. In addition, there was no adverse effect of phosphorus removal pellets on the removal of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total nitrogen (T-N) in the effluent water. Depending on the conditions of the Johkasou, the T-P concentration tended to be higher when the suspended solids (SS) concentrations were increased. When the phosphorus removal pellet was applied to the aeration tank and the raw water tank of the Tandoku-shori Johkasou and the conventional Johkasou, the ratio of T-P concentration in each effluent water after addition of pellets to that before the pellets addition (T-P ratio) ranged from 0.3 to 0.6. In contrast, the phosphorus removal effect was low in the nitrogen removal type Johkasou, despite that pellets were put into the aeration tank, whereas when the pellets were put into the raw water tank, the T-P ratio was around 0.6.

Keywords: Domestic wastewater, on-site treatment system, Johkasou, Phosphorus removal pellet

INTRODUCTION

In Japan, a large number of individual houses have been using on-site treatment system for domestic wastewater in the areas unprovided with a public sewerage system1-4). They are called Johkasou which plays an important role to reduce water pollution caused by domestic wastewater. Johkasou consists of a pretreatment process (anaerobic filter tank) followed by an aerobic process (contact aeration tank). Johkasou treating both black water (night soil) and gray water (domestic wastewater) is sometimes called Gappei-shori Johkasou. Currently in Japan the Gappei-shori Johkasou is just called Johkasou. The Tandoku-shori Johkasou treats only black water and drains with high
concentrations of nutrients. Having considered environmental loadings, the installation of the Tandoku-shori Johkasou is prohibited by law for the present, although they are still remained a lot in Japan\(^3\). Tandoku-shori Johkasou is not strictly included in “Johkasou”. Usually the smallest type of the Johkasou (Gappei-shori Johkasou) possesses treatment capacity of 5–10 population equivalents (p.e.). It contains an aerobic process, which is distinctly different from septic tanks, and biochemical oxygen demand (BOD) of the effluent after treatments of these systems is expected to be less than 20 mg/L in most of the cases\(^1\). Johkasou is one of the methods to effectively treat domestic wastewater before it flows into the drainage of the residential area. However, the effluent from Johkasou has still been reported as one of the source of pollutions in coastal areas such as lakes and bays\(^5,6\).

Recently, Johkasou having the functions to remove both nitrogen and phosphorus removal has been developed\(^7,8\). The Johkasou that can remove nitrogen or phosphorus is called “advanced treatment type”. The nitrogen removal type Johkasou is widely used in Japan\(^9\), whereas the phosphorus removal type one is not widespread because it needs high construction cost including the apparatus in which iron plates are electrolyzed in the aeration tank to flocculate and remove phosphorus. Because of consumption of the iron plates, it also needs the regular replacement of the plates.

The conventional Johkasou system possesses an anaerobic tank and a contact aeration tank, while the nitrogen removal type Johkasou has to be additionally equipped with an apparatus that circulates treated water from the bottom of the contact aeration tank to the anaerobic tank. In the previous paper, we evaluated the nitrogen removal performance for the nitrogen removal type Johkasou\(^10\). The ability to remove nitrogen and BOD in the nitrogen removal type Johkasou was higher than that in the conventional Johkasou, whereas total phosphorus (T–P) was not effectively controlled because the nitrogen removal type Johkasou did not have any function to remove phosphorus.

In coastal residential areas a system of phosphorus removal by using Johkasou is required. However, as mentioned above, the phosphorous removal type Johkasou are costly, so they are rarely installed. The coagulation methods using iron ion or aluminum ion are the effective methods for removing phosphorus from the wastewater\(^13,14\).

In this study, effects of phosphorus removal pellets for the reduction of phosphorus in the wastewater were examined in the current operating Johkasou. The pellet was newly developed by Sugawara et al.\(^17\) and was produced by Nikka Maintenance Co., Ltd., Japan. Main component of the pellet is potassium aluminum sulfate. Potassium aluminum sulfate called “alum” has been used as a coagulant. The pellet is safer to the human body and easier to be handled by molding into tablets than the conventional liquid coagulants. The phosphorus removal pellets can lower phosphorus concentration in the effluent water by simply putting them in the existing Johkasou without remodeling of the Johkasou. In the previous report, pellets were put into a bench scale nitrogen removal type Johkasou and the phosphorus removal effect was confirmed\(^17\). In this study, the pellets were put into three Tandoku-shori Johkasou, two conventional Johkasou and four nitrogen removal type Johkasou, and the effect of phosphorus removal in the current Johkasou was practically investigated. This paper reports the demonstration of high performance of phosphorus removal by the phosphorus removal pellets in various type Johkasou.

**METHODS**

**Phosphorus removal pellet** The pellet is cylindrical and 200 g in weight, and the diameter and height of the pellet are 6.0 cm and 4.5 cm, respectively. The main component is potassium aluminum sulfate (alum) and the pellet was formed by adding a small amount of auxiliary materials. Potassium aluminum sulfate has been used as a coagulant for last several decades and it is relatively safe material to human body. When powdered aluminum potassium sulfate is added in water, it dissolves promptly and flows out of the reaction tank in the Johkasou.
However, the pellet slowly but completely dissolves and the efficacy will be maintained for a longer period. Phosphorus removal pellets may release the aluminum ion, which flocculates with phosphate by contacting with the wastewater. Removing these precipitates as sludge, phosphorus can be consequently removed from the water.

When the pellets were placed in the contact aeration tank, they were put into a net bag and fixed in the tank. In case of the raw water tank of the Tandoku-shori Johkasou, pellets were directly put into the tank without the net bag. As for the conventional type Johkasou and the nitrogen removal type Johkasou, in cooperation of the users, the pellets were dosed in the washing water tank of the toilet, and the dissolved components from the pellet were discharged little by little by flushing into the raw water tank (Fig. 1).

The on-site experiments were conducted for totally 6 weeks for each Johkasou. In the beginning of experiments, one pellet (200 g) was dosed into the contact aeration tank, and left for 3 or 4 days. The pellet dissolves completely within around 3 days after the dosage into water. And then, another pellet (200 g) was put into the same tank, and left for 3 or 4 days. As a result, 400 g of pellets per week were put into the tank. These operations were repeated for 2 weeks. Then, 2 pellets (400 g) were additionally put into the same tank, and contacted with effluent for 3 or 4 days, and 2 pellets (400 g) were additionally put into the same tank and left for 3 or 4 days. As a result, 800 g of pellets per week were put into the tank. The pellets were put into the aeration tank for 3 weeks in total. Thereafter, the pellets were put into the raw water tank of the Tandoku-shori Johkasou, and the washing water tank of the toilet in the house where the conventional Johkasou or the nitrogen removing type Johkasou was installed. The amount of pellets and the application period were the same as the case when the pellets were placed in the aeration tanks. As a result, the experiment lasted 6 weeks.

Outline of the examined Johkasous and experimental procedure

The phosphorus removal pellets were put into the contact aeration tank and the raw water tank of three types of Johkasous, namely Tandoku-shori Johkasou, conventional Johkasou and nitrogen removal type Johkasou (Fig. 1). Then, the effluent water (in the sedimentation tank just before disinfection) from each Johkasou was analyzed. Various Johkasous as shown in Table 1 were investigated in cooperation with Johkasou users in Sakura.
City (Chiba Prefecture, Japan) in 2010. The research area of this study was the watershed of Lake Inba-numa where removal of nutrients from domestic wastewater is required.

Three Tandoku-shori Johkasous, two conventional Johkasous and four nitrogen removal type Johkasous smaller than 10 p.e. in Sakura City were surveyed (Table 1). The Johkasous were investigated 7 times during the 3 weeks. The raw water and the effluent water (before disinfection) were collected every 3 or 4 days and the pellets were put into the tanks. These 3-weeks experiments were repeated twice, changing the position of the pellets after approximately 3 weeks interval. The first water samples of the two experiments were taken as “control” (Table 2) without pellet dosage.

### Sample collection and water analysis

The raw water and the effluent water in each facility were collected, then temperature, transparency and pH (HPH-110 pH meter, DKK Co., Ltd.) of water were measured at each site. Samples were immediately transferred to laboratory and stored at below 10°C until use. BOD and chemical oxygen demand (COD) using KMnO₄ at 100°C were quantified according to titration methods. The effluent for the measurement of suspended solids (SS) was filtrated by glass fiber filter (GS-25, ADVANTEC TOYO Co., Ltd.), then the filter was warmed at 110°C for 2 hours. After that, the sample was allowed to be cooled in desiccator and weighed. Total nitrogen (T-N) was measured by the alkaline potassium persulfate digestion and ultraviolet spectrophotometric method. The T-P and phosphate phosphorus (PO₄-P) concentrations were obtained based on molybdenum blue method. Each measurement was conducted in accordance with Japan Industrial Standard (JIS) K 0102 (1998).29

### RESULTS AND DISCUSSION

#### Change of water qualities in Johkasous

Figs. 2–4 show the changes of (a) T-P and PO₄-P, and (b) BOD, COD and T-N concentrations in the surveyed Tandoku-shori Johkasous, conventional Johkasous and nitrogen removal type Johkasous during the period when the pellets were placed in the contact aeration tank, and the results in the case of raw water tank and the toilet were depicted in Figs. 5–7. Samples were collected from September to December and the temperature of the effluent water was between 15°C and 32°C excluding Tandoku-shori Johkasou (T-3) in which 6 samples were collected at 15°C or less in winter.

Since the Tandoku-shori Johkasou treats only black water, a wide range of water qualities can be observed (Fig. 2). T-P and PO₄-P in the effluent water decreased within 1 week after the pellets were placed in the aeration tank. In the graphs of T-1 and T-2, PO₄-P tended to decrease compared with T-P. Since the pellets were dosed in the aeration tank, the phosphorus concentration in the raw water tank was not affected by the pellets. Furthermore, BOD, COD and T-N in the effluent water were not also affected by the addition of the pellets. The effluent T-P and PO₄-P of T-1 and the effluent PO₄-P of T-2 tended to decrease when the pellet was increased from 400 g to 800 g per week (since day 18), whereas the T-P and PO₄-P of T-3 did not change significantly.

Water qualities of the conventional Johkasous tended to be higher than those of the Tandoku-shori Johkasous (Fig. 3). T-P and PO₄-P in the effluent water decreased in 1 week. The phosphorus concentration in the raw water tank also declined after applying the pellet, because the activated sludge generated in the aeration was regularly sent to the raw water tank together with the pellet components. Although BOD and COD

### Table 1 Types of Johkasou investigated in this study.

| Type of Johkasou | Equipment No. | Number of users for design | Actual number of users |
|------------------|---------------|----------------------------|------------------------|
| Tandoku-shori Johkasou | T-1 | 5 | 3 |
|                  | T-2 | 7 | 5 |
|                  | T-3 | 10 | 3 |
| Conventional Johkasou | C-1 | 7 | 3 |
|                  | C-2 | 5 | 3 |
| Nitrogen removal type Johkasou | N-1 | 5 | 4 |
|                  | N-2 | 10 | 7 |
|                  | N-3 | 7 | 3 |
|                  | N-4 | 7 | 4 |
in the effluent water were not affected by the pellets, T-N tended to increase with increasing the amount of pellet from 400 g to 800 g per week (since day 18). In the previous study, it was reported that denitrification was inhibited in lower solution pH caused by alum. In this survey, the effluent pH exhibited small fluctuation (pH: 6.7–7.5), implying that the increase in the T-N concentration was not attributed to the effluent pH, although the reason of the increase was unclear. It was also indicated that the phosphorus concentration was not largely influenced by the increase in the pellets dosage from 400 g per week to 800 g per week.

When the pellet was added into the nitrogen removal type Johkasous, the improvement in water qualities was observed compared to those of the Tandoku-shori Johkasous, although the values were greatly fluctuated (Fig. 4). The concentrations of T-P and PO₄-P in the effluent water were similar to those in the raw water tank, because the treated water in the nitrogen removal type Johkasous was always circulated via the raw water tank. The phosphorus concentration in the effluent water in the nitrogen removal type Johkasous was not remarkably reduced by the addition of pellet compared to other Johkasous. When the pellet amount increased from 400 to 800 g per week, the phosphorus concentration slightly decreased. It is assumed that the size of nitrogen removal type Johkasou was larger than that of the conventional Johkasou and the pellet component was dispersed throughout the tanks as the water circulated constantly, so

![Fig. 2 Changes of water quality in the Tandoku-shori Johkasous (T-1, T-2, T-3) when the pellets were placed in the aeration tank. (a) Changes of T-P and PO₄-P in the raw water and the effluent water. (b) Changes of BOD, COD and T-N in the effluent water. Symbol of (a): ● T-P in raw water, ○ PO₄-P in raw water, ▲ T-P in effluent water, △ PO₄-P in effluent water Symbol of (b): ◇ BOD in effluent water, ◆ COD in effluent water, □ T-N in effluent water](image-url)

![Fig. 3 Changes of water quality in the conventional Johkasous (C-1, C-2) when the pellets were placed in the aeration tank. (a) Changes of T-P and PO₄-P in the raw water and the effluent water. (b) Changes of BOD, COD and T-N in the effluent water. Symbol of (a): ● T-P in raw water, ○ PO₄-P in raw water, ▲ T-P in effluent water, △ PO₄-P in effluent water Symbol of (b): ◇ BOD in effluent water, ◆ COD in effluent water, □ T-N in effluent water](image-url)
the concentration of the pellet component was not high enough for phosphorus aggregation in case of 400 g per week. BOD and COD in the effluent water were hardly affected by the pellet addition, while T-N tended to increase after increasing the pellet dosage from 400 to 800 g per week as well as the conventional Johkasou.

Even though the pellets were directly dosed in the raw water tank in the Tandoku-shori Johkasous (Fig. 5), the concentration of each water quality in the raw water was sometimes raised greatly. The differences in T-P and PO₄-P between the raw water and the effluent water when the pellets were directly dosed in the raw water tank were smaller compared to the case when the pellet was placed in the aeration tank. T-P and PO₄-P in the raw water and in the effluent water decreased within about 1 week except for T-3. Since the pellets were put into the raw water tank,
Removal of Phosphorus from Domestic Wastewater in Actual On-site Treatment Systems using Phosphorus Removal Pellets

both phosphorus concentrations of the raw water and the effluent water were declined. As for BOD, COD and T-N in the effluent water, they were not affected by the dosage of pellet and the influence of the increased amounts of pellets from 400 to 800 g per week could be negligible as well.

The pellet was placed in the washing water tank of the toilet connected to conventional Johkasous (Fig. 6). The phosphorus concentrations, especially PO$_4$-P, in the raw water and in the effluent water decreased after 1 week from the beginning of the survey. Since the pellet components flowed into the raw water tank, both phosphorus concentrations of the raw water and the effluent water were declined, whereas the addition of the pellets into the tank did not affect BOD and COD concentrations. T-N tended to increase during the survey, but the effluent pH (around 7.1 - 7.6) was not decreased as observed for the case of placing the pellets in the contact aeration tank. The difference in the amounts of pellet dosage on the phosphorus concentrations could not be observed.

By the addition of the pellets into the washing water tank of the toilet connected to nitrogen removal type Johkasous, T-P and

![Fig. 6](image-url) Changes of water quality in the conventional Johkasous (C-1, C-2) when the pellets were put into the toilet and flowed into the raw water tank. (a) Changes of T-P and PO$_4$-P in the raw water and the effluent water. (b) Changes of BOD, COD and T-N in the effluent water.

Symbol of (a): ● T-P in raw water, ○ PO$_4$-P in raw water, ▲ T-P in effluent water, △ PO$_4$-P in effluent water
Symbol of (b): ◆ BOD in effluent water, ◇ COD in effluent water, □ T-N in effluent water

![Fig. 7](image-url) Changes of water quality in the nitrogen removal type Johkasous (N-1, N-2, N-3, N-4) when the pellets were put into the toilet and flowed into the raw water tank from the toilet. (a) Changes of T-P and PO$_4$-P in the raw water and the effluent water. (b) Changes of BOD, COD and T-N in the effluent water.

Symbol of (a): ● T-P in raw water, ○ PO$_4$-P in raw water, ▲ T-P in effluent water, △ PO$_4$-P in effluent water
Symbol of (b): ◆ BOD in effluent water, ◇ COD in effluent water, □ T-N in effluent water
PO$_4$-P in the raw water and in the effluent water were decreased in 1 week (Fig. 7), although such trend was not obtained for N-3. In the nitrogen removal type Johkasou, when the pellets were added into the washing water tank of the toilet, the effect of pellets on phosphorous removal was larger than that in case of adding the pellets in the aeration tank. It was inferred that the pellet component could be easily contacted with phosphorus during the pellet component concentration was enough. BOD, COD and T-N in the effluent water were not affected by the addition of the pellet, and the effect of increasing pellets from 400 to 800 g per week was not very large.

**Relationship between SS and T-P in the effluent water** In a small Johkasou, the SS concentrations of the effluent water often increase due to the change in the amount of inflow water. Since SS contain phosphorus, the leak of SS from Johkasou implies that phosphorus also flows out. Fig. 8 displays the relationship between SS and T-P in the effluent water of (a) Tandoku-shori Johkasou when the pellets were put into the aeration tank and the raw water tank, and (b) conventional Johkasou and nitrogen removal type Johkasou when the pellets were placed in the aeration tank and the wash tank of the toilet. In the Tandoku-shori Johkasou, when the SS concentration of the effluent water became 100 mg/L or more, the T-P concentration was generally 10 mg/L or more (solid lines in Fig. 8(a)), while the T-P concentration exceeded 2.0 mg/L when the SS concentration showed over 30 mg/L (solid lines in Fig. 8(b)) in the effluent water of the conventional and nitrogen removal type Johkasou. However, when the concentration of PO$_4$-P was high in the conventional Johkasou and nitrogen removal type Johkasou, the T-P concentration was often high even if the SS concentration was 30 mg/L or less.

It is implied that SS concentrations exhibited the high correlation with T-P concentrations in the condition that T-P in the effluent water was extremely higher than PO$_4$-P.

**Effect of pellets on phosphorus removal in the Johkasou** Table 2 shows the effect of the pellets on phosphorus removal in this study. In Table 2, the average value of T-P (n = 2) in the effluent water of each Johkasou before the addition of pellet was obtained as a control. The ratio of T-P in each effluent water to that in the control (hereinafter, described as “T-P ratio”) was calculated and represented in parentheses. The description of “400 g/week pellets” indicates the average value of three T-P measurements from the 7th day to the 15th day and “800 g/week pellets” means the average value of two T-P

![Fig. 8](image-url) Relationship between the effluent SS and T-P in (a) the Tandoku-shori Johkasou and (b) the conventional Johkasou and the nitrogen removal type Johkasou. Solid line: SS and T-P concentrations of (a) 100 mg/L and 10 mg/L, and (b) 30 mg/L and 2.0 mg/L, respectively.
measurements of the effluent water from the 17th day to the 21st day after the addition of pellets. In the calculation of the average value, the abnormal value caused by the malfunction of the Johkasou (SS > 200 mg/L in the Tandoku-shori Johkasou; SS > 80 mg/L in the conventional and the nitrogen removal type Johkasous) was excluded.

In the Tandoku-shori Johkasou, the T-P ratio of the effluent water to the control ranged approximately from 0.4 to 0.6, whereas lower values (0.3 to 0.4) were obtained in the conventional Johkasou. In the pellet-added Tandoku-shori Johkasou and the conventional Johkasou, the difference in the T-P ratio between the aeration tank and the raw water tank varied depending on each Johkasou. There was small difference in T-P between 400 g/week and 800 g/week, which was caused by the fact that the water quality fluctuation of the actual Johkasous was large. On the other hand, poor phosphorus removal effect was observed in the nitrogen removal type Johkasou, when the pellets were placed in the aeration tank. However, when they were put into the raw water tank, the T-P ratio exhibited ca. 0.5 to 0.7. This could be caused by the fact that the capacity of the nitrogen removal type Johkasou investigated in this paper was ranging from 3.0 to 5.5 m³ that was larger than the conventional Johkasou (about 2.0 m³), and when the pellet was placed in the aeration tank the component concentration of the pellet was not high enough for obtaining satisfactory aggregation.

### Table 2 T-P concentrations in the effluent water and the ratio of T-P concentration between the presence and absence of the pellet (The absence treatment is the control).

| Equipment No. | Control* | 400 g/week** | 800 g/week*** | 400 g/week** | 800 g/week*** |
|---------------|----------|--------------|---------------|--------------|---------------|
|               |          | pellets in aeration tank | pellets in aeration tank | pellets in raw water tank | pellets in raw water tank |
| T-1           | mg/L     | 23.4         | 11.5†         | 5.35         | 10.8†         | 13.4 |
|               | (ratio)  | (1.00)       | (0.49)        | (0.23)       | (0.46)        | (0.57) |
| T-2           | mg/L     | 32.1         | 20.7          | 19.7†        | 24.6†         | 18.2 |
|               | (ratio)  | (1.00)       | (0.65)        | (0.61)       | (0.77)        | (0.57) |
| T-3           | mg/L     | 11.7         | 3.74          | 3.80         | 7.77          | 8.52 |
|               | (ratio)  | (1.00)       | (0.32)        | (0.32)       | (0.66)        | (0.73) |
| T-avg.        | mg/L     | 22.4         | 12.0          | 9.62         | 14.4          | 13.4 |
|               | (ratio)  | (1.00)       | (0.54)        | (0.43)       | (0.64)        | (0.60) |
| C-1           | mg/L     | 4.08         | 0.89          | 1.25         | 1.08          | 1.12 |
|               | (ratio)  | (1.00)       | (0.22)        | (0.31)       | (0.26)        | (0.27) |
| C-2           | mg/L     | 3.85         | 1.22          | 0.95         | 2.06          | 1.49 |
|               | (ratio)  | (1.00)       | (0.32)        | (0.25)       | (0.53)        | (0.39) |
| C-avg.        | mg/L     | 3.97         | 1.05          | 1.10         | 1.57          | 1.30 |
|               | (ratio)  | (1.00)       | (0.27)        | (0.28)       | (0.40)        | (0.33) |
| N-1           | mg/L     | 4.65         | 4.07          | 1.94         | 2.31          | 1.82 |
|               | (ratio)  | (1.00)       | (0.88)        | (0.42)       | (0.50)        | (0.39) |
| N-2           | mg/L     | 4.06         | 3.02          | 2.23         | 2.31          | 1.95 |
|               | (ratio)  | (1.00)       | (0.74)        | (0.55)       | (0.57)        | (0.48) |
| N-3           | mg/L     | 1.91         | 2.52†         | 1.98         | 2.09          | 1.89 |
|               | (ratio)  | (1.00)       | (1.32)        | (1.04)       | (1.10)        | (0.99) |
| N-4           | mg/L     | 5.03         | 3.94          | 3.22         | 3.39          | 2.44 |
|               | (ratio)  | (1.00)       | (0.78)        | (0.64)       | (0.67)        | (0.48) |
| N-avg.        | mg/L     | 3.91         | 3.39          | 2.34         | 2.52          | 2.02 |
|               | (ratio)  | (1.00)       | (0.87)        | (0.60)       | (0.65)        | (0.52) |

*Average value of two data of T-P before pellet input. **Average value of three data of T-P from the 7th day to the 15th day after pellet input. ***Average value of two data of T-P from the 17th day to the 21st day after pellet input. †Calculated value excluding the abnormal value due to the malfunction of the Johkasou.
removal of T-P in the condition of 800 g/week tended to be higher than that of 400 g/week, which is also presumed to be caused by the large size of the tank. In the Johkasou N-3 where the T-P concentration in the control was as low as 2 mg/L or less, there was no effect of the pellet regardless of adding it into the tank. Since the tank size of the nitrogen removal type Johkasou was large and the phosphorus concentration of raw water was low, the coagulation effect would become low. It is important to adjust the amounts of pellet dosage according to the size of the Johkasou.

Since common users of the Johkasous have difficulty placing the pellets in the aeration tank, it is recommended that the users should add the pellets into the raw water tank from the toilet, specifically dosing it directly into the toilet, which is much easier than putting it into a washing water tank.

CONCLUSIONS

This study examined the effect of the phosphorus removal pellets containing alum as a main component on the phosphorus removal efficiency in various on-site treatment systems (Tandoku-shori Johkasou, conventional Johkasou and nitrogen removal type Johkasou) for domestic wastewater. The main conclusions can be summarized as follows.

1) In most cases the phosphorus concentrations in the effluent water decreased after 1 week when pellets were placed in the Johkasous.
2) The influence of pellets on BOD, COD and T-N concentrations in the effluent water in the Johkasou was not clearly observed.
3) In the Tandoku-shori Johkasou, when the SS concentration of the effluent water became 100 mg/L or more, the T-P concentration was generally 10 mg/L or more, while the T-P concentration exceeded 2 mg/L when the SS concentration showed over 30 mg/L in the effluent water of the conventional and nitrogen removal type Johkasou.
4) In the pellet-added Tandoku-shori Johkasou, the T-P ratio of the effluent water over the control was about 0.4 to 0.6, while ca. 0.3 to 0.4 was observed in the conventional Johkasou.
5) In the nitrogen removal type Johkasou, when the pellets were placed in the aeration tank, the phosphorus removal effect was low, whereas when they were put into the raw water tank, the T-P ratio exhibited ca. 0.5 to 0.7.
6) When the amount of pellet addition increased from 400 to 800 g per week, the phosphorus concentrations of the effluent water of Tandoku-shori Johkasou and conventional Johkasou did not decrease remarkably, while that of nitrogen removal type Johkasou tended to be decreased.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Hisako Ogura (former Chiba Prefectural Environmental Research Center) for her helpful advice for the study on phosphorus removal pellets. We are grateful to Dr. Katsumasa Hanno and Ms. Satoko Yokoyama (Chiba Prefectural Environmental Research Center) for supporting our research. Gratitude is also extended to Chiba Prefecture Water Quality Division and Sakura City Living Environment Section for their cooperation on this research. Finally, we would like to express our gratitude as well for the fact that this research was carried out in the project of the Committee for Lake Inba-numa Watershed Management.

REFERENCES

1) Nakajima, J., Fujimura, Y., Inamori, Y.: Performance evaluation of on-site treatment facilities for wastewater from households, hotels and restaurants, Water Sci. Technol., 39, 85-92 (1999)
2) Gaulke, L. S.: On-site wastewater treatment and reuses in Japan, Proc. ICE-Water Manage., 159, 103-109 (2006)
3) JECES: Johkasou database. Japan Education Center of Environmental Sanitation, Tokyo, Japan, http://www.jeces.or.jp/en/database/index.html (2009) (accessed on January 6, 2017).
4) Tsuzuki, Y.: Pollutant discharge and water quality in urbanisation. Springer Science & Business Media, 61-65, Cham Heidelberg New York London (2014)
5) Tanaka, T., Ogiwara, T., Kobayashi, Y.,
Kinoshita, E., Sugiyama, H.: Pollutant load discharged from johkasou system and its impact on water quality of river and lake, J. Jpn. Soc. Water Environ., 30, 219–225 (2007) (in Japanese)

Fajri, A. J., Yamada, T., Setiyawan, A. S., Li, F.: Evaluation of water and sediment quality in open channels that receive effluent from Johkasou facilities, J. Water Environ. Technol., 13, 207–219 (2015)

Imura, M., Sato, Y., Inamori, Y., Sudo, R.: Development of a high-efficiency household biofilm reactor, Water Sci. Technol., 31, 163–171 (1995)

Moriizumi, M., Fukumoto, A., Yamamoto, Y., Okumura, S.: Basic studies on the characteristics of phosphorus removal by the electrochemical elution of iron, J. Jpn. Soc. Water Environ., 22, 459–464 (1999) (in Japanese)

Takahashi, N., Sasaki, A., Shirakawa, Y., Nomura, M., Nishimura, O.: Comparison for removal of coliform group between BOD removal type Johkasou and nitrogen removal type Johkasou, Jpn. J. Water Treat. Biol., 53, 1–10 (2017) (in Japanese)

Fujimura, Y., Kiuchi, K., Amano, Y., Machida, M.: Performance evaluation of nitrogen removal type on-site treatment system for domestic wastewater, Jpn. J. Water Treat. Biol., 53, 111–118 (2017)

Omoike, A. I., Vanloon, G. W.: Removal of phosphorus and organic matter removal by alum during wastewater treatment, Water Res., 33, 3617–3627 (1999)

Inoue, M., Kim, J., Nishimura, O., Inamori, Y., Sudo, R.: Improvement of phosphorus removal by a Media-added batch activated sludge process combined with droplet method of thick iron solution under low water temperature condition process with intermittent aeration, J. Jpn. Soc. Water Environ., 22, 882–887 (1999) (in Japanese)

Yamamoto, Y., Inoue, M., Nishimura, O., Inamori, Y., Matsumura, M.: Evaluation of phosphorus removal process of on-site domestic wastewater treatment systems using dripping method of thick iron solution, Jpn. J. Water Treat. Biol., 38, 29–38 (2002)

Yamamoto, Y., Miura, Y., Inoue, M., Fujimoto, N., Inamori, Y., Matsumura, M.: Evaluation of anaerobic filter bed-biological filtration process physicochemical phosphorus removal methods, Jpn. J. Water Treat. Biol., 38, 47–55 (2002) (in Japanese)

Mishima, I., Nakajima, J.: Coagulants and phosphorus behavior in activated sludge process for phosphorus removal, J. Jpn. Soc. Water Environ., 26, 99–104 (2003) (in Japanese)

Arnaldos, M., Pagilla, K.: Effluent dissolved organic nitrogen and dissolved phosphorus removal by enhanced coagulation and microfiltration, Water Res., 44, 5306–5315 (2010)

Sugawara, M., Kondo, M., Yamazaki, H., Xu, K. Q., Inamori, R., Inamori, Y.: Evaluation of nutrient removal performance in a bench-scale Johkasou system using phosphorus removal pellet, J. Bioind. Sci., 1, 25–31 (2012)

Japanese Standards Association: Testing methods for industrial waste water, JIS K 0102 1998, Japanese Standards Association, Tokyo, Japan (1998) (in Japanese)

(Submitted 2018. 10. 2)
(Accepted 2019. 6. 17)
