Journal of Applied Research in Water and Wastewater 10(2018) 417-420

Journal of
Applied Research in Water and Wastewater

Journal homepage: www.arww.razi.ac.ir

Original paper

Applicability of ozonized water treatment for controlling fat, oil, and grease deposition onto a drainpipe

Naoyuki Kishimoto*, Mari Hatanaka, Yuichi Kinoshita

Faculty of Science and Technology, Ryukoku University, Setaoe-cho, Shiga, Japan.

ARTICLE INFO

Article history:
Received 16 July 2018
Accepted 20 Aguest 2018

Keywords:
Drainpipe
Blockage
FOG deposition
Grey water
Lipid
Ozone

ABSTRACT

The fat, oil, and grease (FOG) deposition onto pipes is a serious problem in wastewater management, especially in restaurants that have a limited space and no expert for water treatment. In this research effects of ozonized water treatment on controlling FOG deposition were discussed using lard as a model FOG deposit. Since ozonized water can be produced from tap water with an electrolysis ozonized water generator, ozonized water treatment has a potential to be a compact and easily operable process. A series of batch tests with 24-hours contact time revealed that ozonized water successfully prevented liquid lard from solidifying and enhanced the elution of solid lard. Both functions were proportionally intensified with the increase in ozone consumption. An intermittent ozonized-water flushing with 200-seconds contact time using a model drainpipe, whose inner wall was covered with solid lard, was also effective in removing lard from the drainpipe with the linear relationship between the lard elution and the ozone consumption. The observed ratio of the cumulative mass of eluted lard to the cumulative ozone consumption was 1.15±0.04 mgC/mgO_3. Thus, the intermittent flushing of drainpipe with ozonized water was inferred to be an effective option for controlling FOG deposition.

1. Introduction

Pure lard (Marinfood, Toyonaka, Japan) was used as a model FOG for all experiments, which contains 47% of saturated fatty acids against total fatty acids (Wada 1971). Since FOG deposits in drainpipes usually contains a high percentage of saturated fatty acids due to oxidation by oxygen in the air and water (Williams et al. 2012), the lard was thought to be more suitable for a model FOG deposits than vegetable oils like olive and sesame oils that usually contain a smaller amount of saturated fatty acids (MEXT 2016). The elemental molar ratio of carbon to nitrogen of the lard used was determined to be 5.0 using an automatic high sensitive NC analyzer (SUMIGRAPH NCH-22F, Sumika Chemical Analysis Service, Osaka, Japan).

Ozonized water for a series of batch tests was produced by aerating ultrapure water with ozonized gas generated from an analytical grade pure oxygen using a dielectric barrier discharge-type ozonizer (ED-OG-R3, EcoDesign, Hiki, Japan). For FOG deposit removal tests using a model drainpipe, ozonized water was produced from a tap water using an electrolysis ozonized water generator (DeoShower POS-100, Ebara Jitsugyo, Tokyo, Japan).

2. Materials and methods

2.1. Material

Pure lard (Marinfood, Toyonaka, Japan) was used as a model FOG for all experiments, which contains 47% of saturated fatty acids against total fatty acids (Wada 1971). Since FOG deposits in drainpipes usually contains a high percentage of saturated fatty acids due to oxidation by oxygen in the air and water (Williams et al. 2012), the lard was thought to be more suitable for a model FOG deposits than vegetable oils like olive and sesame oils that usually contain a smaller amount of saturated fatty acids (MEXT 2016). The elemental molar ratio of carbon to nitrogen of the lard used was determined to be 5.0 using an automatic high sensitive NC analyzer (SUMIGRAPH NCH-22F, Sumika Chemical Analysis Service, Osaka, Japan).

Ozonized water for a series of batch tests was produced by aerating ultrapure water with ozonized gas generated from an analytical grade pure oxygen using a dielectric barrier discharge-type ozonizer (ED-OG-R3, EcoDesign, Hiki, Japan). For FOG deposit removal tests using a model drainpipe, ozonized water was produced from a tap water using an electrolysis ozonized water generator (DeoShower POS-100, Ebara Jitsugyo, Tokyo, Japan).

2.2. Batch test for preventing FOG deposition

Fig. 1 illustrates the experimental procedure. An adequate portion of lard was heated for 30 minutes at 100ºC in a drying oven (NDO-520, Yamato Scientific, Tokyo, Japan), which simulated a cooking. Ozonized water was prepared as aforementioned and poured into a series of brown glass vials at a final volume of 100 mL. Then, a drop of the melted lard was put into each vial. A drop of lard contained the mass of 14.0±1.3 mg (average ± sample standard deviation). The vials were sealed tightly and were shaken gently by hand. After shaking, the vials were covered with aluminum foil and were stored for 24 hours at a room temperature. As a control, ultrapure water instead of ozonized water was also tested by the same procedure. The water before adding lard and after 24 hours was sampled and applied to dissolved ozone and

*Corresponding author Email: naoyuki@rins.ryukoku.ac.jp

Please cite this article as: N. Kishimoto, M. Hatanaka, Y. Kinoshita, Applicability of ozonized water treatment for controlling fat, oil, and grease deposition onto a drainpipe, Journal of Applied Research in Water and Wastewater, 5 (2), 2018, 417-420.

dissolved organic carbon (DOC) determinations. The mass of dissolved lard and ozone consumption were calculated as follows:

$$\Delta M_{DOC} = (C_{DOC,S} - C_{DOC,B})\ V \quad (1)$$

$$\Delta M_{O3} = (C_{O3,in} - C_{O3,S})\ V \quad (2)$$

where ΔM_{DOC} is the mass of dissolved lard [mg-C], $C_{DOC,S}$ is the DOC concentration of sample after treatment [mg-C/L], $C_{DOC,B}$ is the DOC concentration of sample of the control experiment [mg-C/L], ΔM_{O3} is the ozone consumption [mg-O_3], $C_{O3,S}$ is the dissolved ozone concentration of sample after treatment [mg-O_3/L], $C_{O3,in}$ is the initial dissolved ozone concentration [mg-O_3/L], and V is the water volume in a vial [L].

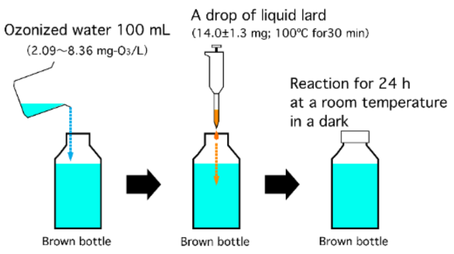

Fig. 1. Experimental procedure of batch test for preventing FOG deposition.

2.3. Batch test for removing FOG deposit

Fig. 2 illustrates the experimental procedure. The melted lard was prepared following the same way described in section 2.2. Then, 20 mL of the melted lard was poured into a series of brown glass vials to cover the bottom and was solidified by standing for 24 hours at a room temperature. The surface area of solid lard was 12.2 cm^2. Next, 60 mL of the ozonized water was poured into each vial. The vials were, then, sealed tightly, covered with aluminum foil, and stored for 24 hours at a room temperature. As a control, ultrapure water instead of ozonized water was also tested by the same procedure. The water before and after contacted with the solid lard was sampled and applied to dissolved ozone and DOC determinations. The mass of dissolved lard, ΔM_{DOC}, and the ozone consumption, ΔM_{O3}, were calculated from equations (1) and (2).

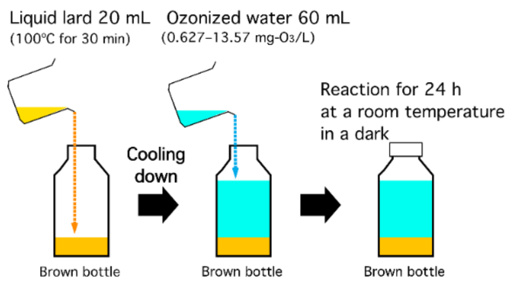

Fig. 2. Experimental procedure of batch test forremoving FOG deposit.

2.4. FOG deposit removal from a model drainpipe

The experimental setup for this experiment is shown in Fig. 3. The melted lard was prepared following the same way described in section 2.2. Then, the melted lard was fed into an acrylic resin pipe with 25-mm in diameter and 500-mm in length. After the excess lard was discharged from the pipe, it was manually rotated till the lard was solidified and covered the inner wall of the pipe. The lard-deposited pipe was stood on a table and further matured for 24 hours at a room temperature. This pipe was used as a model of FOG deposited drainpipe. To simulate an intermittent washing of a drainpipe with ozonized water, the aforementioned ozonized water produced from a tap water (dissolved ozone conc.: 0.235±0.016 mg-O_3/L) was fed into the model drainpipe with a peristaltic pump (RP-1000, EYELA, Tokyo, Japan) for 8 times. The fed volume of ozonized water was 2.0 L/feed at a flow rate of 10 mL/s and a feeding time of 200 seconds. All ozonized water fed into the model drainpipe was collected every batch operation, and its dissolved ozone and DOC concentrations were determined. As a control, the tap water instead of ozonized water was also tested by the same procedure. The mass of dissolved lard, ΔM_{DOC}, and the ozone consumption, ΔM_{O3}, for each batch operation were calculated from equations (1) and (2), where the fed water volume V_F (= 2.0 L) substituted for V. The cumulative mass of dissolved lard and the cumulative ozone consumption was calculated by the sum of ΔM_{DOC} and ΔM_{O3}, respectively.

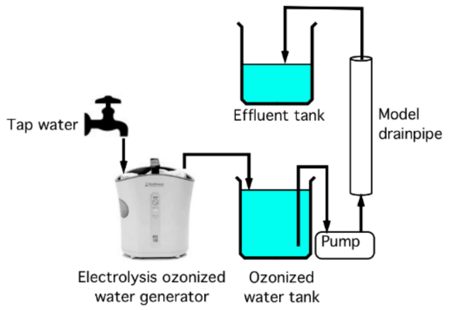

Fig. 3. Experimental setup for FOG deposit removal from a model drainpipe.

2.5. Chemical Analyses

The dissolved ozone determination followed the indigo method (Bader and Hoigné 1982). The DOC concentration was determined with a total organic carbon analyzer (TOC-V_{CSN}, Shimadzu, Kyoto, Japan) after filtrating a water sample with a glass fiber filter (Whatman GF/B, GE Healthcare Japan, Hino, Japan).

3. Results and discussion

3.1. Effect of ozone on preventing FOG deposition

Fig 4 shows the relationship between ΔM_{DOC} and ΔM_{O3} at a series of batch tests for preventing FOG deposition, in which the initial concentration of dissolved ozone was changed in the range of 2.09–8.36 mg/L. Fig 4 clearly demonstrates that ΔM_{DOC} was proportional to ΔM_{O3}. Accordingly, ozone was effective in preventing FOG deposition, and a higher ozone dose was inferred to enhance the preventing effect on FOG deposition. The slope of regression line in Fig. 4 was 0.342±0.012 mgC/mgO_3 (slope ± standard error) that means the efficiency of ozone on preventing FOG deposition, namely lard dissolution per ozone consumption.

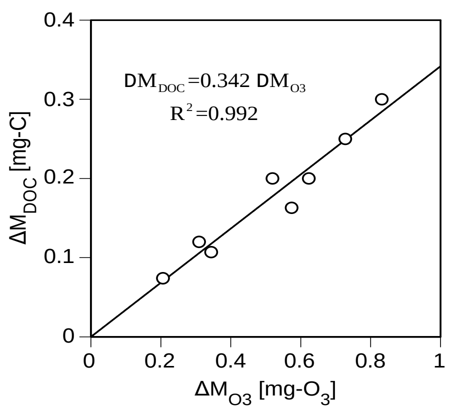

Fig. 4. Relationship between mass of dissolved lard (ΔM_{DOC}) and ozone consumption (ΔM_{O3}) at a series of batch tests for preventing FOG deposition.

Please cite this article as: N. Kishimoto, M. Hatanaka, Y. Kinoshita, Applicability of ozonized water treatment for controlling fat, oil, and grease deposition onto a drainpipe, Journal of Applied Research in Water and Wastewater, 5 (2), 2018, 417-420.

3.2. Effect of ozone on removing FOG deposit

Although the initial concentration of dissolved ozone was in the range of 0.627–13.57 mg/L for batch tests for removing FOG deposit, dissolved ozone concentration after 24-hours contact time was less than 0.040 mg/L at the all tests. Thus, almost all ozone was consumed during the test. The obtained relationship between ΔM_{DOC} and ΔM_{O3} at a series of batch tests for removing FOG deposit is shown in Fig. 5. The FOG deposits were eluted into the ozonized water in proportion to the increase in ozone consumption, which suggests that partial oxidation by ozone enhanced the elution of deposits.

The slope of regression line in Fig. 5 was 0.116±0.004 mgC/mgO$_3$ that was smaller than the slope in Fig. 4. The difference in slopes in Figs. 4 and 5 might indicate that the reactivity of ozone with liquid lard is higher than that with solid one.

3.3. FOG deposit removal from a model drainpipe

As is shown in Figs. 4 and 5, ozone was effective in dissolving lard independently of its phase. Therefore, ozonation was inferred to be a promising process to control FOG deposits as Fujimoto et al. (2003) pointed out. However, it is difficult to install an ozonizer and peripheral equipment into a restaurant because of the limited space for installation and the lack of human resources for operation. Accordingly, a maintenance-free and easily operable system is desired.

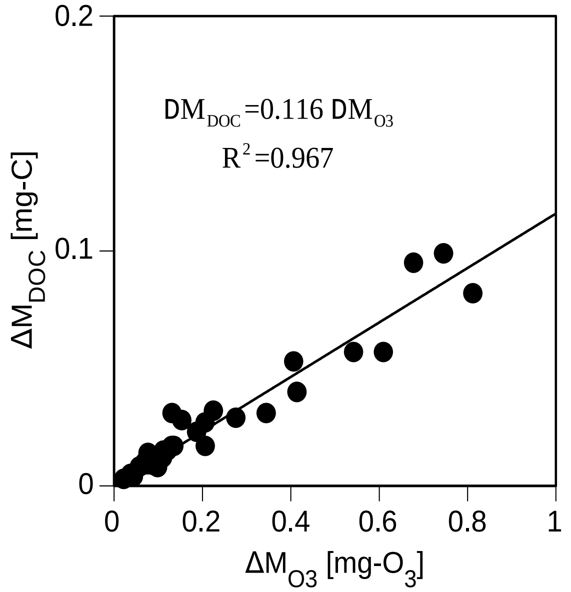

Fig. 5. Relationship between mass of dissolved lard (ΔM_{DOC}) and ozone consumption (ΔM_{O3}) at a series of batch tests for removing FOG deposit.

Recently, small-sized electrolysis systems for ozonized water production from tap water have been developed and practically used (Nishiki et al. 2011). Although dissolved ozone concentration in ozonized water produced with such a system is not high, it requires a tap water supply alone for ozonized water production and does not require any expert for operation. These properties should be discussed carefully when an electrolysis ozonized water generator is applied to a FOG deposition control. Here, intermittent flushing of drainpipes by ozonized water was introduced for preventing FOG deposition and dissolving fresh FOG deposits on the inner wall of the pipe.

Fig. 6 shows the relationship between cumulative ΔM_{DOC} and cumulative ΔM_{O3} at FOG deposit removal tests from a model drainpipe by intermittent flushing using ozonized water produced with the electrolysis ozonized water generator.

The cumulative ΔM_{DOC} was proportional to the cumulative ΔM_{O3}. However, the slope of regression line in Fig. 6 was 1.15±0.04 mgC/mgO$_3$ that was much higher than the slope in Fig. 5. The contact time of ozonized water with the FOG deposits was 200 seconds in the FOG deposit removal test using the model drainpipe, whereas it was 24 hours in the batch test for removing FOG deposit. Therefore, ozone might be further consumed through slow reactions with dissolved FOG in the bulk solution at the batch test for removing FOG deposit, which lowered the $\Delta M_{DOC}/\Delta M_{O3}$. Unsaturated fatty acids occupy 53% of total fatty acids in lard; 44% of monoenoic fatty acids (41% in oleic acid [18:1(Δ^9)] and 3% in palmitoleic acid [16:1(Δ^9)]) and 9% of polyenoic fatty acids (7% in linoleic acid [18:2($\Delta^{9,12}$)] and 2% in arachidonic acid [20:4($\Delta^{5,8,11,14}$)]) (Wada 1971).

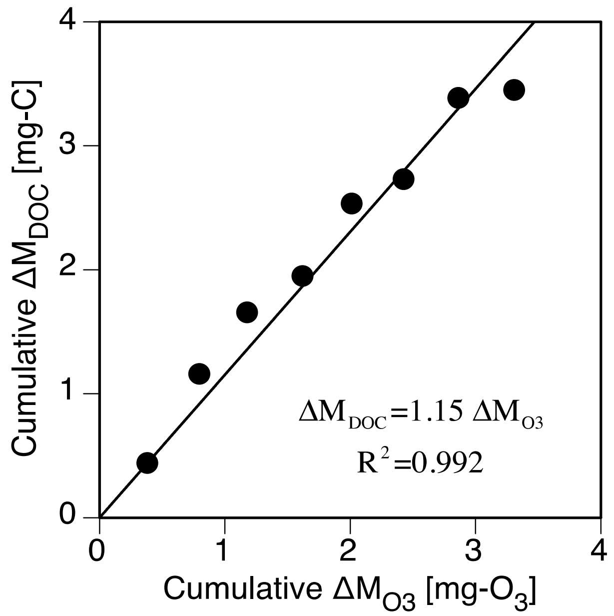

Fig. 6. Relationship between the cumulative mass of dissolved lard (ΔM_{DOC}) and the cumulative ozone consumption (ΔM_{O3}) at the FOG deposit removal test using a model drainpipe.

Ozone reacts with a *cis*-double bond in an unsaturated fatty acid by the Criegee mechanism that produces a Criegee ozonide or two aldehydes as shown in Fig. 7(a) (Pryor et al. 1995). Since the aldehydes produced by the Criegee mechanism are more hydrophilic than the original fatty acid, ozonized water treatment can enhance the solubility of FOG deposits. When oleic acid, which is a major fatty acid in lard, is ozonized, aldehydes with nine carbon atoms, namely nonanal and 9-oxononanoic acid, are produced. Accordingly, it is expected that $\Delta M_{DOC}/\Delta M_{O3}$ is over 2.25 mgC/mgO$_3$. However, the observed $\Delta M_{DOC}/\Delta M_{O3}$ of 1.15 mgC/mgO$_3$ was lower than the expected one. This can be explained by three ozone consumption mechanisms; the Criegee ozonide formation, reactions with unsaturated aldehydes produced by ozonation of polyenoic fatty acids, and reaction with hydrogen peroxide (H_2O_2) produced through the Criegee mechanism. In the third mechanism (O_3/H_2O_2 radical chain reactions) two hydroxyl radicals (OH) are produced from two O_3 molecules as shown in Fig. 7(b) (Glaze et al. 1987), which further oxidize and decompose the FOG deposits. However, since OH and O_3 are oxidants deriving one and two electrons from electron donors, respectively, total amount of oxidants is decreased by the O_3/H_2O_2 reactions.

Based on the ozonization mechanism shown in Fig. 7, ozonized water treatment will be effective in removing fresh FOG deposits, because the unsaturated fatty acids in FOG are transformed into saturated ones by aging in pipes (Williams et al. 2012). Therefore, the daily periodical flushing of drainpipes using ozonized water was inferred to be an effective and feasible countermeasure for FOG deposition. The electrolysis ozonized water generator using tap water is suitable for such onsite production of ozonized water.

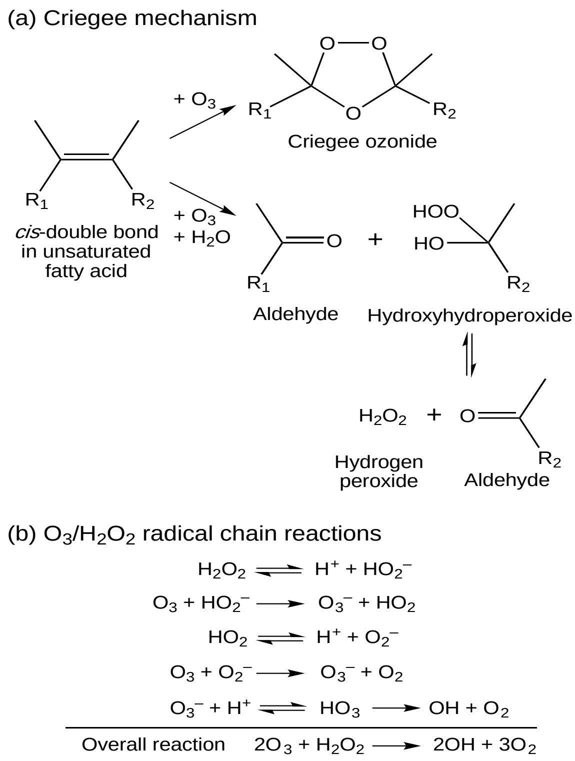

Fig. 7. Reaction of ozone with *cis*-double bond in unsaturated fatty acid and the following radical chain reactions of ozone with hydrogen peroxide produced through the Criegee mechanism.

4. Conclusions

The applicability of ozonized water flushing for controlling FOG deposition was discussed using lard as a model FOG deposit in this research. Two effects of ozonized water were expected for FOG deposition control, namely prevention of FOG deposition and removal of FOG deposits.

When liquid lard was contacted with ozonized water, dissolved ozone reacted with liquid lard and successfully prevented the solidification of lard. This effect was proportionally intensified with the increase in ozone consumption.

When solid lard was contacted with ozonized water for 24 hours, dissolved ozone reacted with solid lard and eluted it in proportion to ozone consumption. To simulate the situation of FOG deposit removal from a drainpipe, ozonized water produced from tap water by electrolysis was intermittently applied to flushing a model drainpipe whose inner wall was covered with lard deposits. As a result, the lard deposits were successfully eluted by ozonized water flushing with the contact time of 200 seconds. The eluted mass of lard deposits was proportional to the cumulative ozone consumption. The observed ratio of the cumulative mass of eluted lard to the cumulative ozone consumption was 1.15±0.04 mg-C/mg-O_3.

Since ozone reacts with *cis*-double bond in unsaturated fatty acid and fragments it, ozonized water treatment will be effective in removing fresh FOG deposits. Accordingly, the daily periodical flushing of drainpipes using ozonized water was inferred to be an effective and feasible countermeasure for FOG deposition onto drainpipes.

References

Bader H., Hoigné J., Determination of ozone in water by the indigo method: A submitted standard method, Ozone: Science & Engineering 4 (1982) 169–176.

Bratsch S.G., Standard electrode potentials and temperature coefficients in water at 298.15 K, Journal of Physical and Chemical Reference Data 18 (1989) 1–21.

Brooksbank A.M., Latchford J.W., Mudge S.M., Degradation and modification of fats, oils and grease by commercial microbial supplements, World Journal of Microbiology and Biotechnology 23 (2007) 977–985.

Fujimoto N., Ishibashi S., Taguchi K., Yamamoto H., Ogata S., Experimental study on the waste-liquid treatment by high ozone concentration for the kitchen at a restaurant industry, Environmental Science 16 (2003) 117–123.

Gary E., Sneddon J., Determination of the effect of enzymes in a grease trap, Microchemical Journal 61(1999) 53–57.

Glaze W.H., Kang J.-W., Chapin D.H., The chemistry of water treatment processes involving ozone, hydrogen peroxide and ultraviolet radiation, Ozone: Science & Engineering 9 (1987) 335–352.

He X., Iasmin M., Dean L.O., Lappi S.E., Ducoste J.J., Reyes F.L., Evidence for fat, oil, and grease (FOG) deposit formation mechanisms in sewer lines, Environmental Science & Technology 45 (2011) 4385–4391.

He X., de los Reyes III F.L., Leming M.L., Dean L.O., Lappi S.E., Ducoste J.J., Mechanisms of fat, oil and grease (FOG) deposit formation in sewer lines, Water Research 47 (2013) 4451–4459.

Keener K.M., Ducoste J.J., Holt L.M., Properties influencing fat, oil, and grease deposit formation, Water Environment Research 80 (2008) 2241–2246.

Kritchevsky D., Fats and Oils in Human Health,. in: C. C. Akoh, D. B. Min (Eds.), Food Lipids: Chemistry, Nutrition, and Biotechnology, Marcel Dekker, New York, pp. 543–558, (2002).

MEXT, Standard Tables of Food Composition in Japan -2015-, 17th Ed. MEXT (Ed.), Ministry of Education, Culture, Sports, Science and Technology, Tokyo, (2016).

Nishiki Y., Kitaori N., Nakamuro K., Performances of small-sized generator of ozone-dissolved water using boron-doped diamond electrodes, Ozone: Science & Engineering 33 (2011) 114–120.

Pryor W.A., Squadrito G.L., Friedman M., The cascade mechanism to explain ozone toxicity: The role of lipid ozonation products, Free Radical Biology and Medicine 19 (1995) 935–941.

Sugimori D., Microbial treatment of wastewater contaminated by lipids,. Bulletin of the Society of Sea Water Science, Japan 65 (2011) 272–279.

Tanaka M., Water Pollution and Pollutants Source, in: METI (Ed.), Technologies and Laws on Pollution Control: Water Quality, Maruzen, Tokyo, pp. 21–60, (1995).

Wada S., Cookery and fat,. Science of Cookery 4 (1971) 123–127.

Wakelin N.G., Forster C.F., An investigation into microbial removal of fats, oils and greases, Bioresource Technology 59 (1997) 37–43.

Williams J.B., Clarkson C., Mant C., Drinkwater A., May E., Fat, oil and grease deposits in sewers: Characterisation of deposits and formation mechanisms, Water Research 46 (2012) 6319–632.

Please cite this article as: N. Kishimoto, M. Hatanaka, Y. Kinoshita, Applicability of ozonized water treatment for controlling fat, oil, and grease deposition onto a drainpipe, Journal of Applied Research in Water and Wastewater, 5 (2), 2018, 417-420.