  Journal of Water, Sanitation and Hygiene for Development | 07.1 | 2017

Practical Paper

Control of urine odor in different sanitation practices and its implication on water saving

Shervin Hashemi and Mooyoung Han

ABSTRACT

To avoid odor in sanitation systems, urine is usually diluted with water (flushed), which leads to high water consumption. The smell may remain in sanitation systems if the systems are not well managed, or if the urine is flushed with insufficient amounts of water. In this study, using the standard threshold odor number (TON) measurement as an indicator of urine odor, the effects of the pH and temperature of the diluting water regarding the amount of water:urine dilution ratio were studied. The effects of temperature and pH of the diluting water on TON when the dilution ratio was constant were investigated. Results show that lowering the pH and temperature of the diluting water can reduce the minimum dilution ratio needed to achieve TON = 0. At constant dilution ratio, reducing pH seemed to be more efficient, sustainable, and economical in comparison to adjusting the temperature of the diluting water. It was found that, based on the specific pH and temperature of the diluting water, there is a minimum dilution ratio required to avoid urine odor. Therefore, in sanitation systems, the amount of flushing should be adjusted based on the characteristics of the flushing water as well as on the amount of urination.

Key words | dilution ratio, sanitation, sustainability, threshold odor number, urine odor

Shervin Hashemi
Mooyoung Han (corresponding author)
Department of Civil and Environmental Engineering,
Seoul National University,
Seoul,
Republic of Korea
E-mail: *myhan@snu.ac.kr*

INTRODUCTION

Urination is a natural process and the most frequent form of excretion in human beings (Hashemi *et al.* 2015a). The urinary bladder of an adult person may hold as much as about 500 mL of urine, with the desire to urinate usually arising when the bladder contains about 150 mL. Then, as urine volume increases to 300 mL or more, the sensation of fullness becomes increasingly uncomfortable (Shier *et al.* 2007; Hashemi *et al.* 2015a, 2015b). Therefore, a healthy adult may urinate about 150 to 500 mL of urine four to eight times a day depending on the amount of fluids ingested (Fleisher *et al.* 2006).

One of the most important issues in sanitation management has to do with urine odor. Many kinds of toilets use water to dilute and flush down urine to avoid this odor (Larsen *et al.* 2001). The amount of water and the dilution ratio resulting from this may vary according to the type of sanitary system and the amount of flushing water, as shown in Table 1 (Hashemi *et al.* 2015a, 2015b). Nevertheless, the dilution of urine using flushing in sanitary systems leads to much water being consumed and produces significant amounts of wastewater.

In the case of fresh urine, food and drugs have a substantial impact on its smell, as such compounds can be excreted without being fully broken down (Gates & La Riviere-Hedrick 2006). However, the major challenge when it comes to odor in sanitation is related to urine that remains on the sanitary ware or urine that cannot be drained successfully (Zhang *et al.* 2013). In these cases, the odor is caused primarily from the ammonia released by the enzyme urease (Zhang *et al.* 2013; Hashemi 2015; Hashemi *et al.* 2016).

During storage of pure (undiluted) urine, the urea present is transformed into ammonia via a process that uses the enzyme urease (Udert *et al.* 2006). The produced

doi: 10.2166/washdev.2017.094

Table 1 | Types of sanitation practices for urination and related water consumption

Sanitation practice		Water consumption (L per flush)	Dilution ratio for 500 mL urine
Open urination		0	0
Waterless sanitation systems		0	0
Men's urinals (including water saving types)		0.5–4	1–8
Water saving toilets		4–8	8–16
Flushing toilets		9–15	18–30

ammonia reacts with water, and equilibrium of ammonium ions and hydroxide is reached, which increases the pH of the urine. Because the pKa of this equilibrium is 9.22, at a $pH > 9.22$, the major compound formed is ammonia, which dissolves in water by forming hydrogen bonds with water molecules as well as producing ammonium (Udert *et al.* 2006; Hashemi *et al.* 2016). Due to evaporation and the fact that oxygen has a higher electronegativity than nitrogen, the hydrogen bonds between ammonia and water molecules easily break, causing ammonia to be released as a gas, generating a strong odor of urine (Hashemi *et al.* 2016).

Therefore, by studying the governing factors of urine odor, it might be possible to adjust the characteristics of the diluting water as well as the water:urine dilution ratio to overcome the odor of urine, which may lead to ideas for reducing water consumption for the different urine excretion practices presented in Table 1. Therefore, the objectives of this study are to:

1. determine the effect of the pH and temperature of the diluting water with regards to the minimum dilution ratio required to overcome urine odor;
2. remove odor more efficiently by adjusting the pH and temperature of the flushing water in sanitation systems that employ a constant amount of flushing water; and
3. suggest a method for reducing water consumption in actual sanitation practices.

MATERIALS AND METHODS

Raw materials

Pure urine samples were collected from men's waterless urinals, installed in Building 35 of Seoul National University, into new and clean 10 L plastic containers. The whole system was thoroughly cleaned prior to the study. The urine came from men who were 25–35 years old. The urine samples were stored in an air-conditioned room at 22 °C for 20 days. The pH and initial ammonia concentrations of the samples were measured daily for 20 days after collection following USEPA standards (USEPA 1983) using an Aquaprobe model AP-2000 (Aquaread Ltd.) and a UV/Visible spectrometer (model HS-3300 made by Humas Co.), respectively. No significant changes were detected in these measured characteristics after 17 days, thus the sample was deemed stable. After stabilization, the total dissolved solids (TDS) and temperature of the sample were measured by the Aquaread Aquaprobe apparatus mentioned above.

To dilute the urine samples, tap water from the Seoul metropolitan water supply system was used. The pH, ammonia concentration, TDS, and temperature of the tap water samples were measured immediately after sampling using methods similar to those applied to the urine samples. Table 2 presents the initial characteristics of the raw materials.

Sampling procedure

To investigate the effect of the pH and temperature of the diluting water on the odor of pure and diluted urine, 396 water samples with different pH values and temperatures were prepared using 100 mL glass samplers.

The pH of the diluting water samples was adjusted to range from 5 to 10 at 0.5 intervals using 99.5% citric acid and 1 M sodium hydroxide solution (made by Daejung Co).

To adjust the temperature of the diluting water samples, they were inserted into a Cole-Parmer Standard Benchtop Chilling/Heating Block (model EW-44175-00), at temperatures ranging from 5 °C to 30 °C, in 5 °C intervals.

By assuming 500 mL as the possible amount of urination and considering the water consumption of different types of toilets (Table 1), dilution ratios of 0, 0.5, 1, 4, 8, and 26 units of water to 1 unit of urine were used. For the case of a water:urine dilution ratio of 0:1, which represents waterless practices, the pH and temperature were adjusted for the pure urine samples directly.

Characterizing odor of samples using threshold odor number

Immediately after preparation, the samples underwent threshold odor number (TON) measurement following USEPA-approved Standard Method 2150 B (APHA 2012). Twenty people participated as smell testers to execute the TON measurement. The testers consisted of four individuals each, from Africa, the Americas, Asia, Europe, and Oceana. Each set of four testers included two males and two females, who were aged 25 to 32 years, were healthy, and had no nasal problems or difficulty regarding their sense of smell. All study participants provided informed consent, and an appropriate ethics review board approved the study design.

Table 2 | Initial characteristics of the raw material samples

Samples	pH	Ammonia concentration (mg/L)	TDS (mg/L)	Temperature (°C)
Urine	9.8 ± 0.2	6,152	7,683	20 ± 3
Tap water	7.4 ± 0.2	Not detected (<0.001 mg/L)	118	15 ± 2

RESULTS AND DISCUSSION

Effect of the pH of diluting water and dilution ratio on urine odor at various temperatures

Figure 1 presents the effect of dilution ratio and pH of the diluting water on TON of urine when the temperature of the diluting water was 15 °C. Similar results were observed for diluting water at other temperatures. In the case of water with pH < 7, no smell was detected at any dilution ratio. Similarly, for the dilution ratio of 26 units water to 1 unit urine, no smell was detected at any pH.

Results show that at a constant temperature for diluting water with an adjusted pH, there is a minimum dilution ratio for which TON is zero. In addition, for certain sanitation practices, e.g., using 0.5 units of water with pH = 8.5 to dilute 1 unit of urine as presented in Figure 1, when the

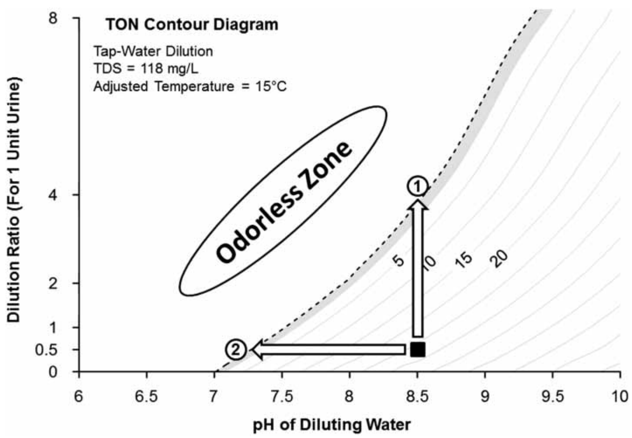

Figure 1 | Effect of the pH of diluting water and dilution ratio on TON of urine when the temperature of the diluting water was 15 °C. The odorless zone is attainable by increasing the dilution ratio (arrow 1) and/or reducing the pH of the diluting water (arrow 2).

temperature of diluting water is constant, there are two ways to overcome the smell: one is to increase the dilution ratio up to 4 units of water for 1 unit of urine (arrow 1); the other is to lower the pH of the diluting water to approximately 7.2 (arrow 2).

For overcoming the urine odor in the condition presented in Figure 1, by increasing water consumption, an eight times higher dilution ratio is required (from half a unit of water to four units of water for one unit of urine). This practice is not suitable, as it increases water consumption. However, by using water with a pH lower than 7, it is possible to keep urine free of odor. In the case of waterless practices, the pH reduction can be made by spraying weak acids directly inside the sanitary ware.

Effect of the temperature of diluting water and dilution ratio on urine odor at various pH levels

Figure 2 presents the effect of dilution ratio and the temperature of the diluting water on TON of urine when the pH of the diluting water was 8.5. Similar results were observed for diluting water with a pH > 7.

Analogous to the case of constant diluting water temperature, results show that when the pH of diluting water is constant, at a certain temperature, there is a minimum dilution ratio at which the urine odor is removed. Furthermore, for certain sanitation practices, e.g., 0.5 units of water at 15 °C for 1 unit of urine as presented in Figure 1, when the pH of water is constant, there are two ways to overcome the smell: one is to increase the dilution ratio (arrow 1) and the other is to reduce the temperature of the diluting water (arrow 2).

When diluting with high temperature water, overcoming the smell is more difficult and requires higher water consumption. Therefore, flushing or diluting with hot water may not be suitable. These results also explain why stronger urine odors are detected in sanitation systems during summer than in the winter.

Lowering water temperature is effective in reducing urine smell. However, it cannot eliminate it. As such, slightly increasing the dilution ratio can be more efficient in removing the odor of urine. However, because increasing water consumption is undesirable, utilizing water with pH > 7 may not be useful.

Effect of the pH and temperature of diluting water with constant water dilution on avoiding urine odor

Figure 3 presents the effect of the pH and temperature of diluting water on TON of urine when the dilution ratio was 4 units of water for 1 unit of urine. Similar results were observed for other dilution ratios less than 26 units water to 1 unit urine.

Again, the results show that for certain sanitation practices, e.g., using water with a temperature of 15 °C and pH of 9, when the dilution ratio is constant, there are two ways to overcome the smell: one is to decrease the temperature (arrow 1) and the other is to reduce the pH of the diluting water (arrow 2).

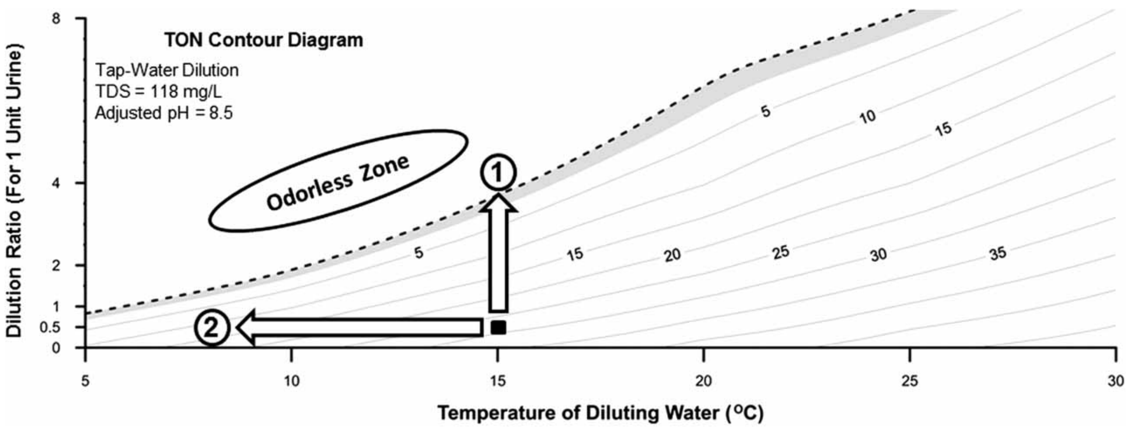

Figure 2 | Effect of the temperature of diluting water and dilution ratio on TON of urine when the pH of the water was 8.5. The odorless zone is attainable by increasing the dilution ratio (arrow 1) and/or reducing the temperature of the diluting water (arrow 2).

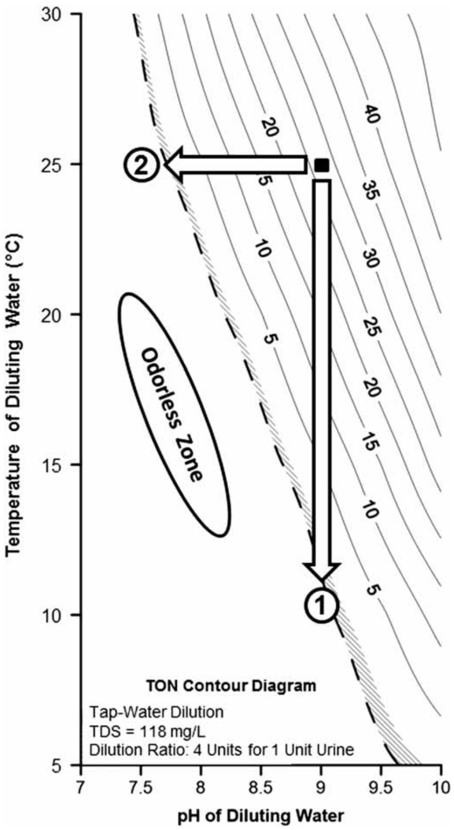

Figure 3 | Effect of the pH and temperature of diluting water on TON of urine when the dilution ratio was fixed at 4 units of water to 1 unit of urine. The odorless zone is attainable by reducing the temperature (arrow 1) and/or pH (arrow 2) of the diluting water.

In this practice, during high-temperature seasons, the temperature of the water must be lowered by approximately 15° (from 25 °C to about 10 °C). In this case, as an example, for 1 L of water, the required energy is calculated as approximately 0.0175 kWh (Paufler & Guggenheim 1985).

Therefore, by assuming 100 flushes per day for a men's public urinal, which consumes 4 L of water per flush, the annual cost of energy is calculated as about US $241 per year based on 2015 energy prices in the United States (Statista 2016). Concerning the annual costs for only one set of men's public urinals and the reduction in water temperature to avoid urine odor, this practice may not be economical.

The temperature of the diluting water in some men's urinals can be lowered by putting ice cubes inside the sanitary ware. Although this may be effective in reducing urine odor, it can increase the potential for urine scale formation and cause clogging in pipeline systems because it reduces the solubility of scale-forming compounds (Hashemi *et al.* 2015a).

However, by reducing the pH of the diluting water, it is possible to control the odor of the urine by utilizing weak natural acids such as acetic acid (vinegar) or citric acid (lemon juice), which seems to be a more sustainable and economical practice. The amount of acid to add can be calculated based on chemical stoichiometry.

Reducing water consumption in sanitation systems by controlling odor of urine

Based on the presented results, the amount of flushing water should consider both the characteristics of the flushing water and the amount of urination to overcome odor with the exact required amount of water. As the amount of flushing water is constant most of the time, the dilution ratio for most of the sanitation practices is higher than required to overcome the odor, which means that water is often being wasted, as presented in Figure 4.

Thus, by lowering the pH, the required dilution ratio to avoid urine odor can be lowered, which reduces water

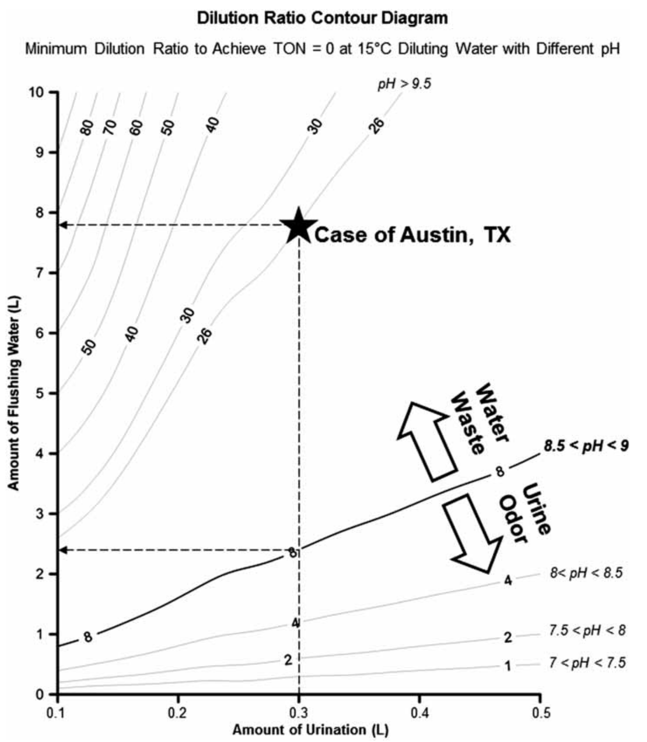

Figure 4 | Diagram of minimum dilution ratio for different pH ranges of diluting water in sanitation systems based on the actual amount of urination and flushing water.

consumption in sanitation systems. For example, the pH of tap water in Austin, TX, USA is reportedly about 9.6 (Austin Water 2016). Based on Figure 4, 26 units of water with such a high pH are required per 1 unit of urine to make the urine odorless. However, by adjusting the water to $8.5 < pH < 9$, the required water consumption when flushing 0.3 L urine may be reduced, from 7.8 L to 2.4 L.

CONCLUSIONS

In this study, the effects of the pH and temperature of the diluting water and dilution ratio on reducing the odor of urine were investigated. The results show that utilizing diluting water with a pH less than 7 is very efficient in avoiding odor. Reducing the temperature also has a positive effect; therefore, flushing with hot water is not recommended.

In sanitation systems where the amount of flushing water (indicated as dilution ratio) cannot be changed, lowering both temperature and pH of the flushing water can help in avoiding odor. However, not only is reducing the temperature uneconomical as it may incur expenses from energy consumption, but it may also cause other problems such as promoting the formation of urine scale. Instead, pH reduction using weak natural acids should be considered an easy, sustainable, and efficient management method for overcoming odor. In waterless sanitation practices, spraying these weak acids inside the sanitary wares can be useful for managing odor.

Results also yield that for a specific pH range or temperature of the diluting water, a minimum dilution ratio is needed to avoid odor. As the amount of urination is not taken into account in sanitary systems and the amount of flushing water is usually constant, excessive amounts of water often are being consumed, given the amount of urine in most current sanitation systems. Results from this study could lead to a redesign of systems for optimizing water usage based on the volume of urination. Smart systems using information technology could be utilized to measure the amount of urination each time and subsequently estimate the sufficient amount of water necessary for each flush, of course, considering the temperature and pH of the water. As seen in the case study of Austin, by reducing the pH of the diluting water, it is possible to have sustainable and water-saving sanitation management.

ACKNOWLEDGEMENTS

This research was supported by the Institute of Construction and Environmental Engineering at Seoul National University. The authors wish to express their gratitude for the support. Furthermore, this work is financially supported by the Korea Ministry of Environment (MOE) as Eco-Innovation project (413-111-008), Advanced Industrial Technology Development project (2014000150010) and Waste to Energy Recycling Human Resource Development project.

REFERENCES

APHA 2012 *Standard Methods for the Examination of Water and Wastewater*, 22nd edn. American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA.

Austin Water 2016 *Water Quality Report Summaries*. http://www.austintexas.gov/department/water-quality-reports-major-industrial-users/ (accessed 1 June 2016).

Fleisher, G. R., Ludwig, S. & Henretig, F. M. 2006 *Textbook of Pediatric Emergency Medicine*. Lippincott Williams & Wilkins, Riverwoods, IL, USA.

Gates, S. & La Riviere-Hedrick, M. 2006 *Gastronaut: Adventures in Food for the Romantic, the Foolhardy, and the Brave*. Houghton Mifflin Harcourt, Boston, MA, USA.

Hashemi, S. 2015 Fate of Nitrogen in Urine Separated Toilet System. *MSc Dissertation*, Department of Civil and Environmental Engineering, Seoul National University, Seoul, Republic of Korea.

Hashemi, S., Han, M. & Kim, T. 2015a Identification of urine scale problems in urinals and the solution using rainwater. *Journal of Water, Sanitation and Hygiene for Development* **5** (2), 322–329.

Hashemi, S., Han, M. & Kim, T. 2015b The effect of material and flushing water type on urine scale formation. *Water Science and Technology* **72** (11), 2027–2033.

Hashemi, S., Han, M. & Kim, T. 2016 Optimization of fertilization characteristics of urine by addition of Nitrosomonas europaea bio-seed. *Journal of the Science of Food and Agriculture* **96** (13), 4416–4422.

Larsen, T. A., Peters, I., Alder, A., Eggen, R., Maurer, M. & Muncke, J. 2001 Re-engineering the toilet for sustainable wastewater management. *Environmental Science & Technology* **35** (9), 192A–197A.

Paufler, P. & Guggenheim, E. A. 1985 *Thermodynamics. An Advanced Treatment for Chemists and Physicists*, 7th edn. North-Holland Physics Publication, Amsterdam, The Netherlands.

Shier, D., Butler, J. & Lewis, R. 2007 *Hole's Human Anatomy & Physiology*, 11th edn. McGraw-Hill, New York, USA.

Statista 2016 Global electricity prices by select countries in 2015 (in U.S. dollar cents per kilowatt hour). Available at: http://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/ (accessed 1 June 2016).

Udert, K. M., Larsen, T. A. & Gujer, W. 2006 Fate of major compounds in source-separated urine. *Water Science and Technology* **54** (11–12), 413–420.

USEPA 1983 *Methods for Chemical Analysis of Water and Wastes*, 2nd edn. United States Environmental Protection Agency, Washington, DC, USA.

Zhang, J., Giannis, A., Chang, V. W., Ng, B. J. & Wang, J. Y. 2013 Adaptation of urine source separation in tropical cities: process optimization and odor mitigation. *Journal of the Air & Waste Management Association* **63** (4), 472–481.

First received 23 June 2016; accepted in revised form 2 December 2016. Available online 14 February 2017