Organoleptic Characterization and Concentration Profiles of Odorous Compounds in Raw Influent versus Secondary-Treated Municipal Wastewater

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Abstract

Municipal wastewater contains a complex mixture of volatile and semi-volatile odorous compounds spanning reduced sulfur species, nitrogen-containing heterocycles and amines, halogenated solvents, monoaromatic hydrocarbons, and volatile fatty acids. This paper synthesizes quantitative concentration data for 19 key odorants in raw influent and secondary-treated effluent of municipal wastewater treatment plants (WWTPs) with organoleptic impact profiles generated by the MAMAY Organoleptic Digitizer 1.0. Concentration data are drawn primarily from Hwang et al. (1995) together with literature-derived removal efficiencies for compounds lacking paired secondary-effluent measurements; sensory impact is quantified in the proprietary unit val®. Total odor impact declined from 2271 val® in the raw influent to 976 val® in the secondary-treated effluent (≈57 % reduction). Reduced-sulfur compounds (hydrogen sulfide, methanethiol, dimethyl sulfide, dimethyl disulfide) were substantially attenuated, shifting the dominant sensory notes from "rotten eggs / sulfurous / vegetable" toward "fishy / chloroform / animalic / sweet." Nitrogenous odorants, particularly indole, skatole and the low-molecular-weight amines, together with residual chloroform and monoaromatics, exhibited far lower removal and continued to dominate residual odor. These findings reconfirm that secondary biological treatment preferentially removes reduced-sulfur species while leaving a persistent mixed nitrogenous / halogenated / aromatic odor signature, with implications for effluent reuse, odor-control process selection, and the design of tertiary polishing steps.

Keywords: *wastewater odor; hydrogen sulfide; methanethiol; indole; skatole; trimethylamine; chloroform; BTEX; volatile fatty acids; organoleptic digitizer; secondary treatment; val®*

1. Introduction

Odors emanating from wastewater collection and treatment systems have been a persistent public nuisance for decades. The principal inorganic odorants are hydrogen sulfide and ammonia, while the majority of organic malodors arise from the anaerobic decomposition of nitrogen- and sulfur-containing organic matter (Dague, 1972). These compounds include mercaptans, organic sulfides, indoles, skatole, and low-molecular-weight amines. In addition, municipal sewage routinely contains halogenated volatile organic compounds (VOCs) such as chloroform and dichloromethane, monoaromatic hydrocarbons (toluene and the xylene isomers), and short-chain volatile fatty acids (acetic, propionic and butyric acids) that can contribute both odor and, in some cases, taste.

Although a large literature exists on the characterization of odorous off-gases from WWTP unit processes, comparatively few studies have quantified the dissolved-phase concentrations of these compounds across the treatment train. The landmark work of Hwang et al. (1995) remains one of the most comprehensive surveys of sulfur- and nitrogen-containing odorants: the authors measured hydrogen sulfide, carbon disulfide, methyl mercaptan (methanethiol), dimethyl sulfide, dimethyl disulfide, trimethylamine, dimethylamine, n-propylamine, indole and 3-methylindole (skatole) at successive points in a large municipal plant in Tokyo that employed conventional activated-sludge treatment followed by pilot-scale aerated biofilters.

A central finding of that study was that more than 95 % of the sulfur-containing odorants present in primary effluent were eliminated in the aeration tank (by a combination of biodegradation and air stripping), whereas substantial residual concentrations of nitrogenous compounds persisted after secondary treatment. Parallel full-scale VOC-fate studies have shown that halogenated solvents are among the least efficiently removed VOC subclasses, while BTEX compounds undergo moderate stripping and biodegradation. Volatile fatty acids, by contrast, are rapidly consumed as readily biodegradable COD.

Recent advances in computational organoleptic modeling now allow the conversion of multi-compound concentration profiles into quantitative sensory-impact scores. The MAMAY Organoleptic Digitizer 1.0 implements such a model, expressing the contribution of each compound (or mixture) to a panel of odor and taste descriptors in the proprietary unit val®. In the present work we feed the Digitizer with the best-available concentration estimates for a suite of 19 odorants spanning all of the chemical classes listed above and compare the resulting sensory fingerprints of raw influent versus secondary-treated municipal wastewater. The goal is to provide an integrated chemical–sensory picture of the odor transformation that occurs during conventional secondary treatment.

2. Materials and Methods

2.1 Concentration Data

Dissolved-phase concentrations of the principal sulfur and nitrogen odorants were taken from Hwang et al. (1995) for the raw influent of a large Tokyo municipal WWTP (capacity 720 000 $m^3\ d^{-1}$). Because that study reported secondary-effluent concentrations only for a limited subset of compounds (most sulfur species fell below or near the detection limit after aeration), secondary-effluent values for the remaining compounds were estimated by applying literature-derived removal efficiencies appropriate to each chemical class:

- Reduced sulfur compounds (H_2S, CS_2, methanethiol, DMS, DMDS): 90–98 % removal, reflecting the combined effects of stripping and biodegradation documented in full-scale activated-sludge plants.
- Low-molecular-weight amines (dimethylamine, trimethylamine, n-propylamine): ≈70 % removal, consistent with their lower volatility and more limited biodegradability relative to the sulfur species.
- Indole and skatole: 9–15 % removal, reflecting the well-documented persistence of these N-heterocycles through secondary treatment.
- Halogenated VOCs (chloroform, dichloromethane): ≈15 % removal (low end of the 2–56 % full-scale range reported for chlorinated solvents).
- Monoaromatics (toluene, o-/m-/p-xylene): ≈45 % removal (upper-middle of the same full-scale VOC range).
- Volatile fatty acids (acetic, propionic, butyric): order-of-magnitude estimates of ~95 % removal based on typical activated-sludge consumption of VFAs as readily biodegradable COD.

All dissolved-phase concentrations were converted to the volumetric unit required by the Digitizer and are reported in $\mu g\ m^{-3}$. The conversion was performed using 1 $\mu g\ L^{-1}$ = 1 $mg\ m^{-3}$ = 1,000 $\mu g\ m^{-3}$. The original liquid-phase concentrations were converted accordingly before being entered into the Digitizer. The complete set of 19 compounds is listed in Table 1.

2.2 Organoleptic Digitizer

Concentration vectors for the two matrices (raw influent and secondary-treated effluent) were submitted to MAMAY's Organoleptic Digitizer 1.0. The system returns a ranked list of odor and taste descriptors together with their quantitative impact in the unit val®, as well as a total odor-impact score. Reports were generated on August 2026 for a 1-unit sample volume.

3. Results

3.1 Compound Concentration Profiles

Table 1 presents the full set of 19 compounds used as Digitizer input. The dramatic attenuation of the reduced-sulfur suite is immediately apparent: hydrogen sulfide falls from 23 900 $\mu g\ m^{-3}$ to 400 $\mu g\ m^{-3}$ (98 %), methanethiol from 148 000 to 7 400 $\mu g\ m^{-3}$ (95 %), and dimethyl disulfide from 52 900 to 5 300 $\mu g\ m^{-3}$ (90 %). In contrast, indole and skatole decline only modestly (15 % and 9 %, respectively). The three amines retain roughly 30 % of their influent levels. Chloroform and methylene chloride show only ~15 % removal, toluene and the xylenes ~45 %, while the three volatile fatty acids are reduced by approximately 95 %.

Table 1. Concentrations of all 19 key odorous compounds used as Digitizer input ($\mu g\ m^{-3}$).

Compound	CAS No.	Class	Raw Influent	Secondary	Removal
Hydrogen sulfide	7783-06-4	Reduced S	23 900	400	98 %
Carbon disulfide	75-15-0	Reduced S	800	40	95 %
Methanethiol	74-93-1	Reduced S	148 000	7 400	95 %
Dimethyl sulfide	75-18-3	Reduced S	10 600	500	95 %
Dimethyl disulfide	624-92-0	Reduced S	52 900	5 300	90 %
Dimethylamine	124-40-3	Amine	210 000	63 000	70 %
Trimethylamine	75-50-3	Amine	78 000	23 000	70 %
n-Propylamine	107-10-8	Amine	33 000	10 000	70 %
Indole	120-72-9	N-heterocycle	570 000	485 000	15 %
Skatole (3-methylindole)	83-34-1	N-heterocycle	700 000	640 000	9 %
Trichloromethane (chloroform)	67-66-3	Halogenated	220 000	187 000	15 %
Methylene chloride	75-09-2	Halogenated	180 000	153 000	15 %
Toluene	108-88-3	Monoaromatic	80 000	44 000	45 %
o-Xylene	95-47-6	Monoaromatic	30 000	16 500	45 %

Compound	CAS No.	Class	Raw Influent	Secondary	Removal
m-Xylene	108-38-3	Monoaromatic	10 000	5 500	45 %
p-Xylene	106-42-3	Monoaromatic	20 000	11 000	45 %
Acetic acid	64-19-7	VFA	20 000	1 000	~95 %
Propionic acid	79-09-4	VFA	10 000	500	~95 %
Butyric acid	107-92-6	VFA	5 000	300	~95 %

Note: Color coding by chemical class. Secondary values for most compounds are literature-grounded estimates (see Methods). Skatole is the only compound with a genuinely paired influent/effluent measurement in the Hwang data set. VFA values are order-of-magnitude estimates.

3.2 Organoleptic Impact Profiles

The Digitizer output for the two matrices is summarized in Table 2 (top-ranked descriptors). Total odor impact fell from 2 271 val® (raw) to 976 val® (secondary), a reduction of approximately 57 %. The sensory hierarchy changes markedly. In the raw influent the strongest notes are “rotten eggs,” “fishy” and “vegetable/sulfurous.” After secondary treatment the hierarchy becomes “fishy,” “chloroform,” “animalic” and “sweet.” The near-disappearance of the classic reduced-sulfur descriptors and the relative persistence of fishy (amine-driven), chloroform (halogenated VOC), animalic/indolic (N-heterocycle) and residual aromatic notes constitute the dominant organoleptic signature of secondary effluent.

Table 2. Ranked organoleptic descriptors (val®) for raw influent and secondary-treated effluent.

Descriptor	Raw Impact	Secondary Impact	Change	Rank (Raw → Sec)
Rotten eggs	509.9	66.0	−87 %	1 → 6
Fishy	414.2	225.7	−45 %	2 → 1
Vegetable	205.1	46.4	−77 %	3 → 8
Sulfurous	199.7	31.2	−84 %	4 → 9
Pungent	155.0	67.6	−56 %	5 → 5
Chloroform	120.7	111.3	−8 %	6 → 2
Sweet	100.5	82.6	−18 %	7 → 4
Animalic	89.2	85.0	−5 %	8 → 3
Ammoniacal	87.0	47.7	−45 %	9 → 7
Indolic	25.7	24.6	−4 %	15 → 11
Total Odor Impact	2 271.1	976.5	−57 %	—

Source: MAMAY Organoleptic Digitizer 1.0 reports generated 10 August 2026 for the complete 19-compound input vectors.

Figure 1. Organoleptic profile (val®) for raw influent municipal waste water (10 top attributes)

Type All	Sensations 1..	Impact	Unit
Odor	Rotten eggs	509.92	val®
Odor	Fishy	414.23	val®
Odor	Vegetable	205.06	val®
Odor	Sulfurous	199.69	val®
Odor	Pungent	155.01	val®
Odor	Chloroform	120.69	val®
Odor	Sweet	100.55	val®
Odor	Animalic	89.18	val®
Odor	Ammoniacal	87.01	val®
Odor	Cabbage	65.71	val®

Total Odor Impact: 2271.06 val®

Odor Sensations Treemap

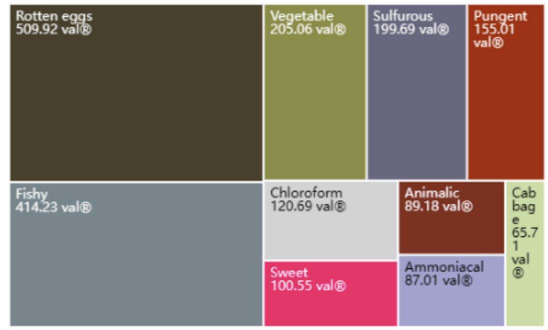


Figure 2. Organoleptic profile (val®) for secondary treated municipal wastewater (10 top attributes)

Type All	Sensations 1..	Impact	Unit
Odor	Fishy	225.67	val®
Odor	Chloroform	111.27	val®
Odor	Animalic	85.00	val®
Odor	Sweet	82.57	val®
Odor	Pungent	67.62	val®
Odor	Rotten eggs	65.97	val®
Odor	Ammoniacal	47.66	val®
Odor	Vegetable	46.41	val®
Odor	Sulfurous	31.16	val®
Odor	Floral	31.14	val®

Total Odor Impact: 976.49 val®

Odor Sensations Treemap

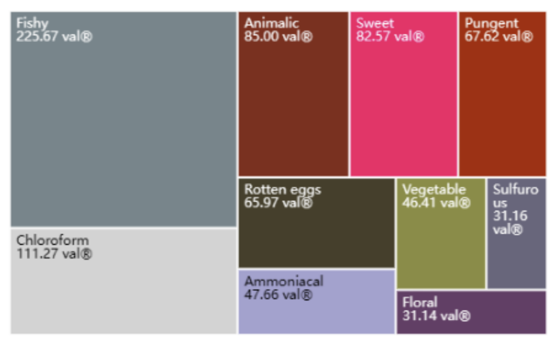
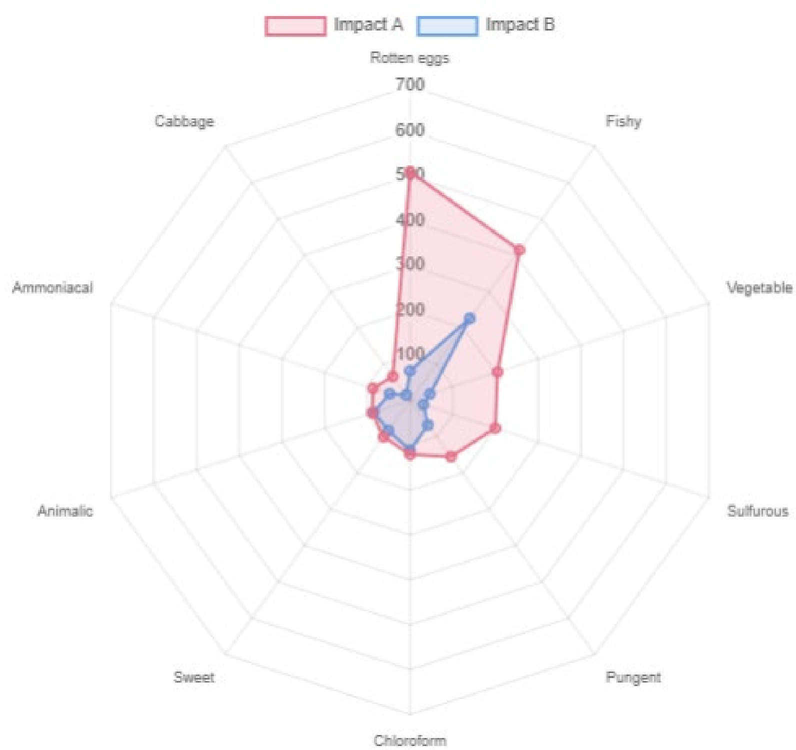


Figure 3. Organoleptic profile (val®) comparison for raw influent and secondary treated wastewater (10 top attributes)

Type	Sensations	1..	Impact A	Impact B	A vs B	Unit	A vs B %
Odor	Rotten eggs		509.92	65.97	443.95	val®	87%
Odor	Fishy		414.23	225.67	188.56	val®	46%
Odor	Vegetable		205.06	46.41	158.65	val®	77%
Odor	Sulfurous		199.69	31.16	168.53	val®	84%
Odor	Pungent		155.01	67.62	87.39	val®	56%
Odor	Chloroform		120.69	111.27	9.42	val®	8%
Odor	Sweet		100.55	82.57	17.98	val®	18%
Odor	Animalic		89.18	85.00	4.17	val®	5%
Odor	Ammoniacal		87.01	47.66	39.35	val®	45%
Odor	Cabbage		65.71	15.00	50.71	val®	77%

Total Odor Impact A: 2271.06 val® **Total Odor Impact B: 976.49 val®**



4. Discussion

The quantitative results obtained with the Organoleptic Digitizer are fully consistent with the chemical observations reported by Hwang et al. (1995) for the sulfur and nitrogen suites, and with broader VOC-fate literature for the halogenated and monoaromatic compounds. That study documented >95 % elimination of dissolved sulfur odorants across the aeration tank, while nitrogenous species, especially the indoles and the low-MW amines, showed only modest attenuation. The present sensory modeling translates those concentration changes into perceptual terms: the total odor load is roughly halved, yet the residual odor is no longer dominated by the highly offensive “rotten-egg / cabbage / sulfurous” family; instead, it is dominated by fishy (amine-driven), chloroform (persistent halogenated VOC), animalic/indolic (N-heterocycle) and residual aromatic notes.

Inclusion of the full set of 19 compounds clarifies the contribution of each chemical class. The five reduced-sulfur species account for the bulk of the high-impact “rotten eggs / sulfurous / vegetable” notes that disappear after secondary treatment. The three amines and two N-heterocycles (indole, skatole) drive the persistent fishy, animalic and indolic character. Chloroform, present at high absolute concentration and poorly removed, emerges as the second-ranked descriptor in secondary effluent. The monoaromatics (toluene + xylenes) and the three VFAs contribute lower-ranked but still detectable notes (sweet, oily, rancid, acidic) that survive or are only partially attenuated.

Two practical implications follow. First, conventional secondary treatment cannot be relied upon to produce an organoleptically neutral effluent suitable for unrestricted non-potable reuse or for discharge into low-dilution receiving waters where residual odor may still be noticeable. Second, odor-control strategies aimed at secondary effluent should target the persistent nitrogenous fraction and the poorly stripped halogenated VOCs (activated-carbon adsorption, advanced oxidation, or biological polishing specifically adapted to indoles, amines and chlorinated solvents) rather than relying solely on the air-stripping and sulfide-oxidation mechanisms that already operate efficiently inside the aeration tank.

It should be noted that many of the secondary-effluent concentrations used here are literature-grounded estimates rather than plant-paired measurements. The only fully paired value is that for skatole. Future work that applies the Digitizer to a complete, contemporaneous influent–effluent data set (for example the multi-plant survey of Islam, Hanaki & Matsuo, 1998) would further strengthen the chemical–sensory linkage. Likewise, the VFA concentrations remain order-of-magnitude estimates pending more precise speciation data.

Finally, the absolute magnitude of the val® scores is specific to the MAMAY model and its underlying odor-activity coefficients. While the rank order and relative changes are expected to be robust, direct numerical comparison with other sensory units (odor units, dilution-to-threshold, etc.) is not warranted without inter-method calibration.

5. Conclusions

1. Secondary biological treatment reduces total organoleptic impact of municipal wastewater by approximately 57 % (2 271 → 976 val®) when the full suite of 19 odorants is considered.
2. Reduced-sulfur compounds are preferentially removed; the dominant sensory notes shift from “rotten eggs / sulfurous / vegetable” to “fishy / chloroform / animalic.”
3. Nitrogenous odorants (indole, skatole, low-MW amines) together with residual chloroform and monoaromatics persist at high residual concentrations and largely determine the residual odor character of secondary effluent.
4. Volatile fatty acids are efficiently removed (~95 %) and contribute little to residual odor after secondary treatment.
5. These findings reconfirm the classic chemical observations of Hwang et al. (1995) for S- and N-compounds, extend them to halogenated and aromatic VOCs, and translate the concentration changes into quantitative sensory space, providing a rational basis for the selection of tertiary odor-polishing technologies.
6. The MAMAY Organoleptic Digitizer offers a practical tool for converting multi-compound concentration vectors into ranked sensory descriptors, thereby bridging the gap between analytical chemistry and human perception in wastewater odor management.

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Disclaimer

The organoleptic impact values reported herein are generated by MAMAY's proprietary Digitizer technology (val® is a registered trademark of MAMAY Technologies Ltd.). The technology is provided "as is," is currently in beta mode, and has not been independently verified against standardized sensory panels. Concentration data for secondary effluent are in part literature-derived estimates rather than direct measurements from a single plant. Users of this information do so at their own discretion and responsibility. MAMAY Technologies Ltd. makes no warranty regarding accuracy or fitness for any particular purpose.