

1 **VFA AND AMMONIA FROM RESIDENTIAL FOOD WASTE AS INDICATORS OF**
2 **ODOR POTENTIAL**

3 N. Qamaruz-Zaman* and M. W. Milke**

4 * School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong
5 Tebal, Pulau Pinang, Malaysia

6 ** Department of Civil and Natural Resources Engineering, University of Canterbury, Private
7 Bag 4800, Christchurch 8140, New Zealand

8 *Corresponding author. Tel.: +604 599 6287; Fax: +604 594 1009.

9 **Email address:** cenastaein@eng.usm.my

10

11

12

13

14

15

16

17

1 **Abstract**

2 Research was conducted to determine suitable chemical parameters as indicators of odor from
3 decomposing food wastes. Prepared food scraps were stored in 18 L plastic buckets (2 kg wet
4 weight each) at 20°C and 8°C to reproduce high and low temperature conditions. After 1, 3, 7,
5 10 and 14 days of storage, the odor from the buckets were marked to an intensity scale of 0 (no
6 odor) to 5 (intense) and the corresponding leachate analysed for volatile fatty acids, ammonia
7 and total organic carbon. A linear relationship between odor intensity and the measured
8 parameter indicates a suitable odor indicator. Odor intensified with longer storage period and
9 warmer surroundings. The study found ammonia and isovaleric acid to be promising odor
10 indicators. For this food waste mixture, offensive odours were emitted if the ammonia and
11 isovaleric acid contents exceeded 360 mg/l and 940 mg/l, respectively.

12 **Keywords:** isovaleric acid, OFMSW, odor management, kitchen waste, odor indicator
13 parameters.

14

15

16

17

1 **1. Introduction**

2
3 The separate collection and transportation of food residues from residential waste saves landfill
4 capacity, but presents with it the issue of malodor (Qamaruz-Zaman and Milke, 2008). The
5 coexistence of waste treatment facilities (e.g. composting or anaerobic digestion plant) with
6 people, particularly in urban areas, can hardly be avoided due to the consideration of
7 transportation costs and available land. This leads to odor concerns at waste treatment facilities,
8 and their close management. Similarly, there is a need for an understanding regarding the degree
9 of odor from food waste stored in household bins in order to ensure a successful organic waste
10 diversion program.

11
12 Food residues generated from domestic kitchens include fruit, vegetables (including peelings),
13 meat and bones, bread, fish bones, pasta, shellfish, rice, eggshells, coffee grounds, dairy products
14 and table scraps (Steuteville and Karen, 1996; Gies, 1996; Shin et. al., 2000; Farrell, 2001; Viana
15 and Schulz, 2003). These materials when decomposed may emit odor of varying intensities (Kim
16 et al., 2009), likely to be influenced by the storage conditions, as well as by the combination of
17 materials in the waste. For example, a high amount of meat may produce an objectionable odor
18 that could worsen with the presence of liquid, for example gravy or stew leftovers.

19
20 The managers of organic diversion programs are faced with a number of choices in terms of
21 materials for residents, collection equipment, and advice to residents. Bad odors from source-
22 separated food wastes can lead to reluctance of residents to participate. Therefore, waste
23 managers often need quick ways of evaluating whether changes to a program would increase or
24 decrease odor problems, and also need ways to evaluate if problems are due to specific wastes or
25 due to the segregation practices employed in individual residences. Sensitive analytical chemistry
26 methods can be used to quantify the concentrations of individual odorous gases (Sironi et al.,

1 2007), and olfactometry methods can use a panel of individuals to assess odor subjectively (EN
2 13725, 2003). Many efforts have been made to associate human sensing of odor with the
3 concentration levels of odorants measured by advanced analytical instruments (e.g., the
4 combination of gas chromatography with mass spectrometry) (Nagata, 2003; Kim, 2010; Kim,
5 2011).

6
7 Simple and cost-effective chemical indicators that quantify the intensity of odor emission could
8 provide an alternative to more sophisticated and expensive methods. *E. Coli* is used as an
9 indicator or surrogate of pathological organisms in water because *E. Coli* is commonly present
10 when pathogens are present, and *E. coli* is easier to measure than pathogens are. For odor, the
11 measurement of concentrations of one or more key compounds, which reflect the degradation of
12 the main waste constituents, can be used as indicators in an analogous way to *E. coli* as a
13 surrogate or indicator to monitor odor development and/or the determination of odor intensity. It
14 has been suggested by Spoelstra (1980) that for good indicators: (i) the components must be
15 products of protein (or possibly carbohydrate) degradation, (ii) the formation of the components
16 must reflect kinetics of degradation, (iii) the components must respond in a representative way to
17 environmental changes e.g. aeration, methane formation, and (iv) the concentrations must be
18 suitably large for easy measurements; trace components are not suitable. The selection of
19 indicators also depends on speed of analysis and the availability of equipment (Williams,
20 1984). With odor indicators, results can be obtained where no odor panel is available and
21 retrospective analysis of appropriate data can indicate the effectiveness of treatments that were
22 designed for other purposes (Williams, 1984).

23
24 A wide variety of odorants are constantly being released from the environment including
25 acetaldehyde, isovaleric acid, dimethyl sulfide, butyraldehyde, butyric acid, valeric acid and
26 ammonia from lake sediments (Susaya et al., 2011). Ammonia is commonly high in fishery

1 wastes (Seo et al., 2011), and has also been reported in stormwater catch basin waste (Kabir et
2 al., 2010).

3
4 Residential food waste because of its wet nature, high organic content, and mixture of chemical
5 substances, quickly produces odors as it begins to decompose. Volatile fatty acids (VFAs) and
6 ammonia can be expected to result from the decomposition of organic matter containing
7 carbohydrates and protein. Ammonia is produced from either aerobic or anaerobic decomposition
8 of proteins and amino acids (Pagans et al., 2007). VFAs are a product of fermentative or
9 anaerobic degradation of a wide variety of complex organic compounds (Nielsen et al., 2007).
10 Carbohydrates are degraded to a limited number of VFAs (mainly acetic, propionic and butyric
11 acids), while proteins are broken down to straight chain fatty acids, and fats and oils are broken
12 down to long chain fatty acids. The longer chained acids can be hydrolyzed or biodegraded to
13 lower molecular weight acids such as acetic, propionic and isovaleric (Lyberatos and Skiadas,
14 1999).

15
16 This research was conducted to investigate the use of odor indicators to quantify odor emission
17 from food waste kept at two different temperature conditions. Three indicators-- total organic
18 carbon (TOC), volatile fatty acids (VFAs) and ammonia (NH₃)-- are analysed to demonstrate
19 their suitability in odor quantification. The TOC would indicate the amount of organics present in
20 the sample whereas the latter two are chosen based on the assumption that food waste
21 decomposition can occur, via an aerobic or anaerobic pathway, releasing VFA or NH₃.

22

23 **2. Methodology**

24 *2.1 Experimental Procedure*

1 To minimise the effect of feedstock variation on odor production, a standard food waste mixture
2 as shown in Table 1 was used throughout the study. The food waste model is based on a previous
3 study (Qamaruz-Zaman and Milke, 2008) and consisted of vegetables (34% wet weight basis),
4 fruit (19%), meat (12%) and small amounts of coffee grounds, filters, teabags, rice, leftover
5 spaghetti, eggshells and bread. The waste (2 kg wet weight) was discarded into 18 L plastic
6 buckets and stored, lidded, for 14 days in temperature controlled rooms of 20°C and 8°C.

7
8 A total of five buckets were kept at each temperature conditions. After 1, 3, 7, 10 and 14 days of
9 storage, one bucket from each group was evaluated. Because the buckets were emptied during
10 evaluation, fewer replicates remained in storage as time progressed. The evaluation of buckets
11 followed the following procedure; first, buckets were weighed, then scored for their subjective
12 odor intensity, followed by leachate analysis and finally pictures of the decomposed wastes were
13 taken.

15 *2.2 Odour evaluation*

16 Two individuals were used to evaluate odor. Because the waste decomposition occurred in the
17 bucket, the odor volatilized within the headspace of the container. As such, odor assessment was
18 done directly on the bucket without gas sampling. The smell was marked according to the odour
19 intensity scale depicted in Table 2.3. A mark was assigned to the characteristic smell of that
20 bucket, based upon a range between 0 (no odour) to 5 (intense odor).

21
22 During the odour testing, one assessor conducted a preliminary scaled assessment of each bucket.
23 This judgement was then confirmed by the second assessor. In roughly half of these human odor
24 evaluations, the two assessments did not match. To resolve this, both evaluators performed odour
25 testing together on the buckets that caused the confusion, side by side. This was repeated until all

1 buckets were scored to the satisfaction of both evaluators. The time taken for each bucket to be
2 smelt was less than a minute per bucket, after which the lid was put back on.

3

4 *2.3 Leachate Analysis*

5 The concentration of odor indicators was measured only in the liquid phase. There was a lack of
6 leachate being produced from the decomposing wastes which then resulted in the adoption of a
7 leachate extraction technique (Qamaruz-Zaman and Milke, 2007) to enable enough liquid
8 samples for analysis. The idea behind the liquid extraction procedure was to wash the outsides of
9 the wastes. This is based on the concept that odour is associated with the waste's outer layer
10 rather than its inner portion, where the smell remains enclosed and is less volatile. The buckets
11 were at times aerobic and at times anaerobic, much like food waste stored in households would
12 be. Because of this, the compounds extracted can be expected to be similar to those extracted in
13 many household food waste storage conditions.

14

15 First, the bucket contents were emptied into a muslin bag which were then completely soaked
16 with tap water for 30 minutes. The volume of tap water used was determined from the weight of
17 the bucket contents, with 1 ml of tap water addition per g of waste. The waste-contained muslin
18 bags were hung for another 30 minutes to recover liquid. The simulated leachate then underwent
19 filtration to 0.45 μ m Milipore filter without any polymer addition or centrifugation, prior to
20 analysis.

21

22 **Liquid samples were analysed for ammonia (NH₃-N) on a Hach Spectrophotometer and**
23 **total organic carbon (TOC) on a Teledyne Tekmar (USA) Apollo 9000 Analyzer. Volatile**
24 **fatty acid (VFA) were determined on a HP6980 Gas Chromatograph, with, only acetic,**

1 **propionic, butyric and isovaleric acids being reported and summed as total VFA (TVFA).**
2 **Other VFA were not considered because they were found to be at much lower**
3 **concentrations and so less suitable as odor indicator parameters. The quality of the gas**
4 **chromatograph results were maintained through re-validation of an acetic acid standard**
5 **solution at the start and completion of five sample injections. Table 3 describe the basic**
6 **quality assurance parameters for all the above target components including the minimum**
7 **detection limit and the uncertainty of measurements. pH of the extracted leachate was**
8 **taken using an EDT RE357 Microprocessor pH meter, which was calibrated daily.**

9 **Results and discussion**

10 *3.1 Waste Decomposition*

11 As illustrated by Figure 1, the waste was more decomposed in 20°C storage than when stored at
12 8°C. About 10% of the initial weight was lost in the decomposition process, where weight loss
13 was higher for the warmer condition.

14

15 *3.2 Odor Indicator Concentrations*

16 In general, odor intensity increased linearly with increasing storage time for food wastes stored
17 at ambient (20°C) and lower temperature (8°C) conditions (refer Figure 2). Odor from the higher
18 temperature was always more intense than at lower temperature. For wastes stored at the higher
19 temperature, a very intense odor (scale of 5) was evident after 7 days, compared to storing at the
20 lower temperature which emitted only a light odor (scale of 2). An offensive odor (scale of 5)
21 never occurred with the latter. The findings follows that of Zhou et al. (2003) who observed
22 more intense odor from a landfill in China during the summer months compared to winter,
23 Their study recorded traces of volatile organic compounds (VOCs) being 1-2 order of magnitude
24 higher during summer. This behaviour of rise in odor emissions in parallel to temperature are
25 likely true until a temperature setpoint of 60°C (Zhang et al., 2009). Beyond this point, odor

1 emissions decreased despite the rise in temperature. It was thought that the odor-causing -
2 microorganism have stopped growing or started to die off at 60°C.

3
4 From the initial ammonia content of 100 mg/l, ammonia increased to 1370 mg/l for the higher
5 temperature after 14 days storage, while it tripled to 360 mg/l at low temperature.
6 Correspondingly, the odor intensity for the elevated temperature was very intense (scale of 5)
7 whereas it was only moderate (scale of 3) for the lower temperature.

8
9 With volatile fatty acids, an inverse relationship was observed between acetic acid and odor
10 whereby the former decreased at rising odor intensity. Where the difference between odor
11 intensity was large, the drop in acetic acid was small, implying the weakness of acetic acid to
12 indicate food waste odor intensity. Similarly, neither butyric and propionic acid were found
13 suitable as food waste odor indicators. No correlation was found with TVFA, which was
14 influenced by the non-correlative response of the major individual acids, namely, propionic,
15 acetic and butyric acids (Table 4).

16
17 Isovaleric acid was the only VFA measured that shows potential as a food waste odor indicator.
18 When the presence of odor was minimal or even none, no isovaleric acid was present in the
19 leachate. Likewise, the highest concentration of 1240 mg/l, recorded at the higher temperature
20 after twelve days, saw an odor intensity of 5. Isovaleric acid increased with time and was always
21 higher at the elevated temperature.

22
23 Unlike ammonia and isovaleric acid, no relationship was observed between odor intensity and
24 the measured total organic carbon (TOC). Despite the rise in odor intensity level for both
25 temperature conditions, the same pattern was not observed with the TOC measurements. The
26 TOC content fluctuated without any regard to a particular storage period, temperature, or odor

1 intensity.

2

3 It was thought that pH could have influenced the formation of odor. The increasing pH from 5.3
4 to 6.9 and 6.5 after 14 days for high and low temperatures respectively, saw a subsequent rise in
5 ammonia from 100 mg/l to 1370 mg/l (20°C) to 360 mg/l (8°C). According to Nakasaki et al.
6 (2000), the increase in pH value is a result of both the production of NH₃ associated with protein
7 degradation and the decomposition of the organic acids. The pH results show significant
8 variability with a relatively small change over time. We conclude that pH appears to be a
9 relatively poor choice for an odor indicator.

10

11 *3.3 Identification of Indicator Threshold Value*

12 Table 5 shows indicator concentrations and the corresponding odor intensities. Odor was not
13 detected when ammonia and isovaleric acid were below 170 mg/l and 530 mg/l, respectively.
14 However, odor was very strong when the ammonia concentration rose to between 841 – 1400
15 mg/l and isovaleric acid between 1060 – 1240 mg/l.

16

17 Ammonia and isovaleric acid have been identified among odor compounds released during the
18 composting process. The former has a pungent and sharp odor characteristic and can be smelt by
19 the general population at 39,600 µg/m³, while the latter is more of a rancid cheese characteristic
20 with a 52.8 µg/m³ odor threshold (Epstein, 2011). Increases in ammonia are likely to be
21 reflective of organic nitrogen reduction to a more suitable nitrogen form for bacterial
22 incorporation (Powers et al., 1999). This is important as these bacteria work to degrade protein in
23 food wastes, hence fulfilling the criteria proposed by Spoelstra (1980) that odor indicators should
24 be products of protein degradation.

25 Isovaleric acid stood out as a promising odor indicator, even though it was the VFA at the lowest

1 concentration of the four acids reported. Similarly, an experiment by Zhu et. al. (1997) found that
2 some products reduced swine manure odor threshold without significantly reducing the total
3 amount of VFAs, signifying a poor correlation. These five commercial additives; MPC, Bio-
4 Safe, Shac, X-Stink and CPPD were based on chemical, enzymatic and bacterial interactions to
5 reduce odor release from swine manure. Their study suggested that the products may have
6 reduced the concentrations of long chain and branching fatty acids, and since these acids did not
7 necessarily exist in high concentrations, they were unlikely to have made a significant difference
8 on the total VFA. This supports our findings with isovaleric acid.

9

10 **4. Conclusions**

11 This research has shown that ammonia and isovaleric acid have the potential as odor indicators
12 for stored food wastes. It was not the intention to try to identify the compounds directly
13 responsible for the odor volatilized from the waste and measure those concentrations. Rather, the
14 intention was to utilise readily measurable, and common odor compounds, which are common
15 end products of anaerobic and aerobic decomposition of organic wastes, and also relatively
16 independent of the mix of food wastes. It is acknowledged that specific food wastes could lead
17 to specific odor problems with odorous, trace gaseous compounds. An attempt was made in this
18 study to counteract this effect by using a mix of food wastes, yet, there is still the potential that
19 specific foods could be odorous and not be picked up with either ammonia or isovaleric acid.
20 The leaching of ammonia and isovaleric acid found in this study could vary significantly if other
21 food waste mixtures are used. The threshold values presented have not been tested with other
22 food waste mixtures.

23

24 It is not advised that treatment regimes be designed to specifically target at reducing the
25 concentrations of these indicators, as it cannot be guaranteed that by diminishing the ammonia

1 and isovaleric acid in the leachate, food waste would have less odor. Instead, the unacceptable
2 limits of concentrations of leachate indicator compounds, would be useful as a guide for waste
3 managers of when the food waste odor is likely to become a nuisance.

4
5 No previous research has been reported on the use of odor indicators for residential food waste.
6 Further study is needed on a variety of aspects including the sensitivity of the results to variations
7 in food waste composition and the sensitivity to human odor assessment methods.

8

9 **References**

- 10 Blackford, C., Greer, G., & Young, J. (1998). Guidelines for community odor assessment. Dept.
11 of Resource Management/Lincoln Environmental, Lincoln University, Lincoln, NZ.
- 12 EN 13725 (2003). Air Quality – Determination of Odour Concentration by Dynamic
13 Olfactometry. Comité Européen de Normalisation, Brussels, Belgium, pp. 1–70.
- 14 Epstein, E. (2011). Industrial composting: Environmental engineering and facilities management.
15 CRC Press, 2011.
- 16 Farrell, M. (2001). Evaluating residential organics collection pilot. *BioCycle*, 42(3), 34
- 17 Gies, G. (1996). Residential organics diversion strategies. *BioCycle*, 37(4), 90.
- 18 Kabir, E., Kim, K-H., Ahn, J-W., Hong, O-F, and C, Y-S. (2010). Offensive odorants released
19 from stormwater catch basins (SCB) in an urban area. *Chemosphere*, 81, 327-338.
- 20 Kim, K-H, Pal, R., Ahn, J-W, and Kim, Y-H (2009). Food decay and offensive odorants: A
21 comparative analysis among three types of food. *Waste Management*, 29(4), 1265-1273.
- 22 Kim, K-H. (2010). Experimental demonstration of masking phenomena between competing
23 odorants via an air dilution sensory test. *Sensors*, 10(8), 7287-7302
- 24 Kim, K-H. (2011). The averaging effect of odorant mixing as determined by air dilution sensory

- 1 tests: a case study of reduced sulfur compounds. *Sensors*, 11, 1405-1417
- 2 Lyberatos, G. and Skiadas, I. V. (1999). Modelling of anaerobic digestion – a review. *Global*
3 *Nest: the International Journal*, 1(2), 63-76
- 4 Nagata, Y. (2003). Odor intensity and odor threshold value. *Journal of Japan Air Cleaning*
5 *Association*, 41(2), 17-25 Nakasaki, K., Ohtaki, A., and Takano, H. (2000). Biodegradable
6 plastics reduces ammonia emission during composting. *Polymer Degradation and*
7 *Stability*, 70, 185-188
- 8 Nielsen, H. B., Uellendahl, H., and Ahring, B. K. (2007). Regulation and optimization of the
9 biogas process: propionate as a key parameter. *Biomass and Bioenergy*, 31(11-12), 820-
10 830
- 11 Pagans, E., Font, X and Sanchez, A. (2007). Coupling composting and biofiltration for ammonia
12 and volatile organic compound removal. *Biosystems Engineering*, 97(4), 491-500
- 13 Powers, W. J., Van Horn, H. H., Wilkie, A. C., Wilcox, C. J., and Nordstedt, R. A. (1999).
14 Effects of anaerobic digestion and additives to effluent or cattle feed on odor and odorant
15 concentrations. *Journal of Animal Science*, 77(6), 1412-1421
- 16 Qamaruz-Zaman, N. and Milke, M. W. (2007). Leachate extraction for food waste odor
17 indicators. *Proceedings Sardinia 2007, Eleventh International Waste Management and*
18 *Landfill Symposium, S. Margherita di Pula, Cagliari, Italy; 1 – 5 October 2007*
- 19 Qamaruz-Zaman, N. and Milke, M. W. (2008). Laboratory comparison of odor control
20 techniques for separated residential food waste. *Communications in Waste Management*
21 *and Research*, 9(2), 18-24
- 22 Seo, S-G., Ma, Z-K., Jeon, J-M., Jung, S-C, and Lee, W-B. (2011). Measurements of key
23 offensive odorants in a fishery industrial complex in Korea. *Atmospheric Environment*,
24 45, 2929-2936.
- 25 Shin, H.S., Han, S.K., Song, Y.C. and Hwan, E. J. (2000). Biogasification of food residuals.
26 *Biocycle*, 41(8), 82-86.

- 1 Sironi, S., Capelli, L., Centola, P., Del Rosso, R., and II Grande, M. (2007). Continuous
2 monitoring of odors from a composting plant using electronic noses. *Waste Management*,
3 27(3), 389-397.
- 4 Spoelstra, S. F. (1980). Origin of objectionable odorous components in piggery wastes and the
5 possibility of applying indicator components for studying odor development. *Agriculture*
6 *and Environment*, 5, 241-260.
- 7 Steuteville, R., and May, K. (1996). Examining residential organics diversion. *BioCycle*, 37(6),
8 30.
- 9 Susaya, J., Kim, K-H., and Chang, Y-S. (2011). Characterization of major offensive odorants
10 released from lake sediment. *Atmospheric Environment*, 45, 1236-1241.
- 11 Viana, E., and Schulz, H. E. (2003). Collection, processing and characterization of food residues
12 from residential waste for use in broiler chicken feed. *Journal of Solid Waste Technology*
13 *and Management*, 29(1), 24-30.
- 14 Williams, A. G. (1984). Indicators of Piggery Slurry Odor Offensiveness. *Agricultural Wastes*,
15 10, 15-36.
- 16 Zhang, W., Lau, A. K., and Wen, Z. S. (2009). Preventive control of odor emissions through
17 manipulation of operational parameters during the active phase of composting. *Journal of*
18 *Environmental Science and Health, Part B: Pesticides, Food Contaminants, and*
19 *Agricultural Wastes*, 44(5), 496-505
- 20 Zhu, J., Bundy, D. S., Li, X., and Rashid, N. (1997). Controlling Odor and Volatile Substances in
21 Liquid Hog Manure by Amendment. *Journal of Environmental Quality*, 26(3), 740-743.
- 22 Zou, S. C., Lee, S. C., Chan, C. Y., Ho, K. F., Wang, X. M., Chan, L. Y., and Zhaag, Z. X.
23 (2003). Characterization of ambient vilatile organic compounds at a landfill site in
24 Guangzhou, South China. *Chemosphere*, 51, 1015-1022
- 25

1 Table 1. The food waste content (in wet weight percentages) used in the experiments

<u>Item</u>	<u>Percentage (%)</u>
Carrot skin	0.5
Apple skin	1.5
Apple seed	1.5
Pumpkin seed	2.0
Teabags	2.6
Bread	3.0
Pumpkin skin	3.5
Potato skin	4.0
Mixed vegetable (stir fry)	4.0
Chicken skin (raw)	4.0
Eggshells	4.0
Coffee ground and filter	4.5
Mashed potato	5.0
Spaghetti leftover	5.0
Boiled pumpkin	5.4
Broccoli stalk (raw)	6.6
Cooked rice	7.0
Orange peel	7.0
Chicken bone (raw)	8.0
Banana skin	8.5
Salad	<u>12.5</u>
	100.0

2

3

1 Table 2. The odor intensity rating table (source: Table 2.2 (Blackford et. al., 1998))

Scale	1		3		5
Intensity level	Very light	Light	Moderate	Strong	Very strong
Description	- activates the sense of smell - characteristics may not be distinguishable	- activates the sense of smell - distinguishable and definite - not necessarily objectionable in short durations	- easily activates the sense of smell - very distinct and clearly distinguishable - may tend to be objectionable and/or irritating	- objectionable - cause a person to attempt to avoid it completely - could indicate a tendency to possibly produce physiological effects during prolonged exposure	- so strong it is overpowering and intolerable for any length of time - could tend to easily produce some physiological effects
Scale of 0: odor not detectable					

2
3
4
5
6
7
8

1

Table 3 The MDL and uncertainty of the VFAs, TOC and NH₃-N

Compound	Minimum detection limit (MDL) mg/l	Uncertainty (g/l)
Isovaleric acid	530	0.54 ± 0.07
Acetic acid	2124	
Propionic acid	2244	
Butyric acid	1751	6.5 ± 0.8
Total organic carbon	1000	1 ± 0.03
Ammonia	0.4	0.0115 ± 0.0004

2

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

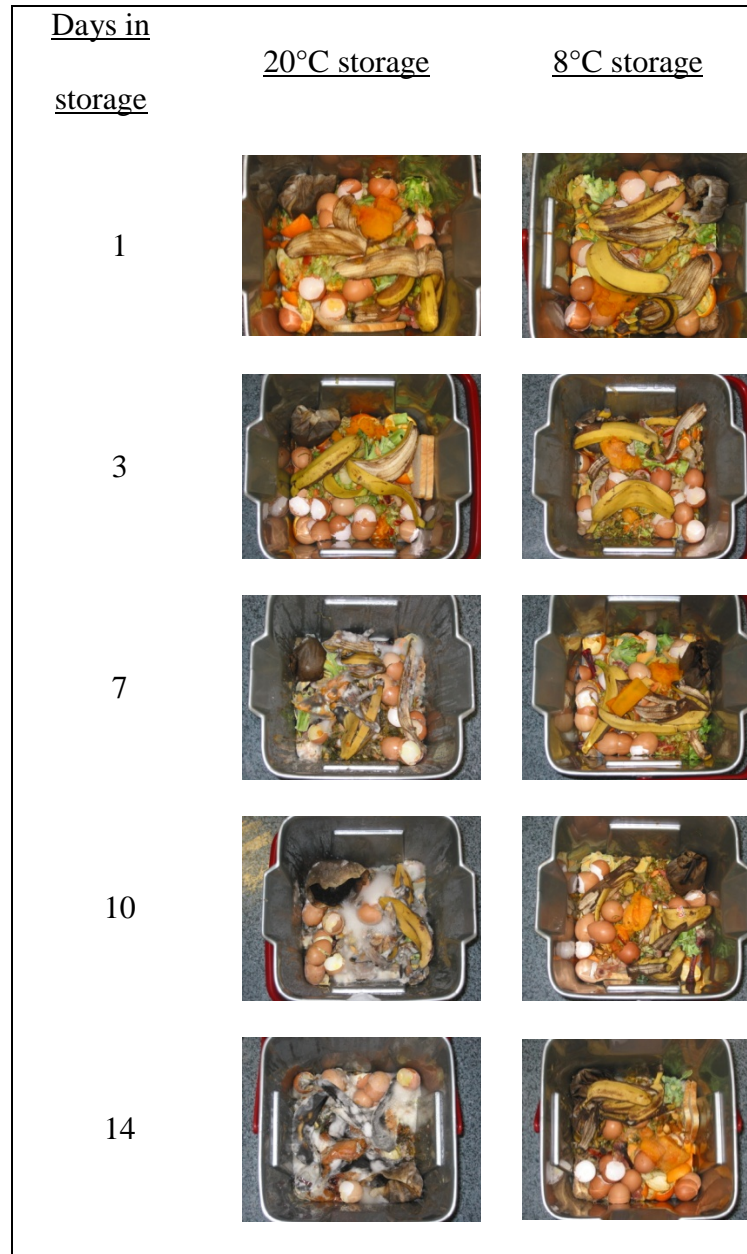
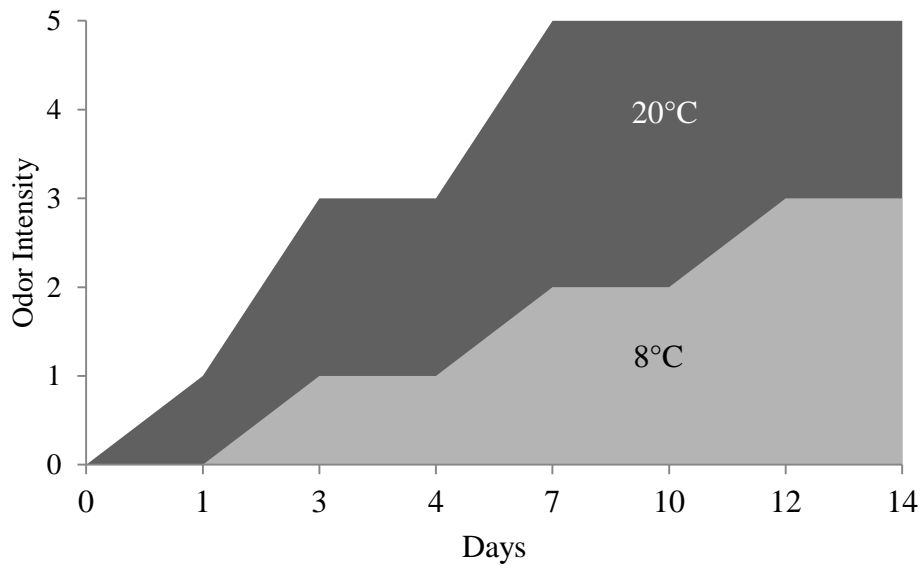


Figure 1. The decomposition of food wastes at high and low temperature

1



2

3

Figure 2. Odor intensity of food waste stored at different temperatures

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

31

1
2
3 Table 4. The odor intensity and corresponding leachate characteristics at separate temperature
4 conditions during 14 days storage

Day	Temperature	O.I.*	pH	TOC (mg/l)	NH ₃ -N (mg/l)	Acetic (mg/l)	Prop ^a (mg/l)	Butyric (mg/l)	Iso- Valeric (mg/l)
1	High	1	5.9	3320	170	n/a	n/a	n/a	n/a
	Low	0	6.3	3580	100	2900	3600	4100	530
3	High	3	5.4	1180	300	3200	3800	3800	530
	Low	1	5.9	2430	190	3100	3500	2600	530
7	High	5	5.9	2240	830	3000	3400	2500	710
	Low	2	6.4	1490	230	3000	3600	3300	530
10	High	5	6.6	1070	1040	3100	3600	2700	1070
	Low	2	6.4	1790	260	3000	3400	2400	680
14	High	5	6.9	1250	1380	3100	3500	2700	1240
	Low	3	6.5	1800	360	2900	3500	2500	950

5 * O.I: odor intensity, ^a: Propionic
6
7
8
9
10
11
12
13
14

1

2 Table 5. Suggested threshold ammonia and isovaleric acid values for varying odor intensities

Odor intensity	Ammonia (mg/l)	Isovaleric Acid (mg/l)	Description of odor
0	100 - 170	≤ 530	No odor: <i>undetectable, unnoticeable</i>
1	170 - 240	530 – 670	Faint: <i>slight occasional wafts, undistinguishable odor</i>
2	240 - 300	670 – 700	Light: <i>slight and constant, distinguishable odor</i>
3	300 - 360	700 - 940	Moderate: <i>Distinguishable odor and sometimes irritating</i>
4	360 - 840	940 - 1060	Strong: <i>Unbearable odor but causes no physiological effects</i>
5	840 - 1400	1060 - 1240	Intense: <i>Intolerable odor for any length of time and can produce physiological effects</i>

3

4