Study on dry-basis separation test for urban residential waste

Changjiang Yang\textsuperscript{a,*}, Mengdi Yang\textsuperscript{b}, Qian Yu\textsuperscript{c}

\textsuperscript{a}Friends of Nature, Chaoyang District, Beijing, 100011, China
\textsuperscript{b}Zhejiang University, Zhejiang, 310058, China
\textsuperscript{c}National Academy of Education Administration, Beijing, 102617, China

Abstract

Since its implementation in 2000, China’s urban domestic waste separation pilot program has achieved little success. The root cause lies in the lack of moisture control for crude waste from the source. If wet-basis waste is placed in bags, collected by waste bins/cans and transferred by vehicles, waste is difficult to be separated for collection, transport and disposal, and a large amount of materials lose the value of recycling. High moisture and rapid reproduction of microbes leads to serious pollution, collection and transfer of daily waste upon generation and soaring transport cost. Unsorted waste also greatly increases the difficulty in collection, transport and disposal. The study on dry-basis separation test helps achieve the separation and temporary storage of domestic waste through moisture control, facilitating the low-frequency placement, collection and transport of domestic waste. Based on the test, a new concept of low-frequency direct transport and separation of domestic waste on a dry basis is raised, and corresponding key technical equipment to be developed is specified.

Keywords: urban resident; domestic waste; dry-basis separation

1. Issues

With more than 30 years of reform and opening-up and rapid industrialization and urbanization, China has witnessed surging annual urban domestic waste generation, which gradually becomes the crisis of surrounding waste faced by cities. To address the increasingly critical waste crisis, China introduced a waste separation pilot program in 8 cities (including Beijing) in 2000, which has achieved little success [1]. Since 2009, another round of waste separation pilot program has been implemented in many cities,

* Corresponding author.

Email addresses: ycj9418@sina.com
which achieves little effect and a dim prospect [2]. Mixed placement, transfer and disposal of waste on a wet basis is ubiquitous, and waste separation is almost defunct.

In fact, the wet-basis separation in these pilot cities makes it impossible for waste to be effectively separated for placement, collection and transport. It is urgent to explore a new separation technology system. Aimed at the problems of wet-basis separation, this study involves a one-year dry-basis separation test for urban residential waste, and explores the separation, temporary storage, placement, transfer and centralized separation and transport of domestic waste on a dry basis through moisture control from the source, with a view towards exploring a technological path that benefits both the control of environmental pollution caused by domestic waste and the resource recycling of domestic waste.

2. Test Time, Equipment and Method

2.1. Test time

The test was started on February 1, 2010 and completed on January 30, 2011. The test time is one year in total.

2.2. Test equipment and articles

Hot-air drying type household food waste disposer (hereinafter referred to as disposer), SF-400 electronic scale, log book, seal bag.

2.3. Test method

(1) Dewater food waste and toilet paper. Weigh on the electronic scale wet-basis food waste generated every day and take notes; after dewatering the food waste with the disposer, weigh dry basis and take notes; collect dry-basis food waste in the seal bag, and label the generation date, wet-basis weight and dry-basis weight thereon. Toilet paper was collected about every 10 days and dewatered, and the method is same as the food waste.

(2) Plastic bags were collected monthly, and the data record was updated accordingly. Glass, waste electronics, used clothes, bulky furniture and housekeeping waste were weighed subject to their generation dates, and the data record was updated accordingly.

2.4. Actual time for sample collection

The actual time for sample collection is 338 days, as waste samples were unavailable in 27 days within the annual test period.

3. Test Results and Analysis

3.1. Total annual domestic waste generation and physical components

3.1.1. Total generation and per capita waste generation per day

The domestic waste generated in the test year was 295.9kg in total, including 129.50kg of high-value marketable waste and 166.29kg of low-value unmarketable waste. Calculated as per the actual sample collection time of 338 days, waste generated by a three-member family is 0.875kg per day, and the per capita waste generation is 0.39kg/d, which is near the per capital waste generation of Beijing residents in
2008 (0.273kg/d) [3] (See Table 1). The high-value marketable waste (129.5kg) and low-value unmarketable waste (166.29kg) accounted for 43.80% and 56.2% of the total annual waste (295.89kg) respectively.

Table 1. Total annual domestic waste generation and physical components*

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
<th>Wet weight (kg)</th>
<th>Dry weight (kg)</th>
<th>Moisture content (kg)</th>
<th>Moisture ratio (%)</th>
<th>Dry weight ratio (%)</th>
<th>Total weight (kg)</th>
<th>Total weight ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High value</td>
<td>Newspapers and books</td>
<td>65</td>
<td>65</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>129.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bulky furniture</td>
<td>64.6</td>
<td>64.6</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low value</td>
<td>Food waste</td>
<td>116.97</td>
<td>27.34</td>
<td>89.63</td>
<td>76.63</td>
<td>23.37</td>
<td>70.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waste plastics</td>
<td>20.36</td>
<td>20.36</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>12.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toilet paper</td>
<td>8.75</td>
<td>7.09</td>
<td>1.66</td>
<td>18.93</td>
<td>81.07</td>
<td>7.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glass ceramics</td>
<td>5.99</td>
<td>5.99</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>3.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Used clothes</td>
<td>5.32</td>
<td>5.32</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>3.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Housekeeping waste</td>
<td>3.60</td>
<td>3.60</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>2.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electronics</td>
<td>2.05</td>
<td>2.05</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>1.24</td>
<td></td>
</tr>
</tbody>
</table>

| Total    | 295.9                       | 204.6           | 91.29           | 31.55                 | 68.45              | 295.89              | 100%                |                        |

3.1.2. Physical components of domestic waste

According to Table 1, domestic waste collected in the test year falls into nine categories: food waste, paper, bulky furniture, waste plastics, toilet paper, glass ceramics, used clothes, housekeeping waste and waste electronics (in the sequence of generation). Among the nine categories, food waste (116.97kg) is the largest, and waste electronics (2.05kg) is the smallest. 7 types of low-value unmarketable waste samples (166.29kg in total) were collected in the test, 71.18% of which were food waste (116.97kg). This figure is near the ratio of food waste to domestic waste of Beijing residents (69.32%) [4].

---

* Newspapers and books include 40kg of books, 19kg of newspapers and 6kg of cartons.
Waste plastics include 7kg of waste knitted packing bags, 3.9kg of waste plastic packages and 0.946kg of plastics bags.
Toilet paper (12kg) includes 3.25kg of paper scraps. Wet-basis toilet paper is weighed at 8.75kg (243g x 3 x 12), and dry-basis toilet paper is weighed at 7.09kg (197g x 3 x 12).
3.2. Waste moisture and food waste nutrients

3.2.1. Waste moisture

Water content of food waste and toilet paper was measured according to the practical situation of samples. Food waste (116.97kg) contained 89.63kg of moisture, and the moisture content ratio was 76.63%. Toilet paper (8.75kg) contained 1.66kg of moisture, and the moisture content ratio was 18.93%. The moisture content ratio of low-value unmarketable waste was 58.51%, which is higher than the average moisture content ratio of domestic waste in Beijing (50.19%) [5]. Relevant studies indicate that
the moisture of municipal residential food waste (50-60%) is the main source of moisture in other components [6], making it difficult for other waste to be separated. Therefore, to control the pollution to other components during collection and transport, it is important to remove the moisture of food waste and toilet paper from the source.

3.2.2. Food waste disintegrating into odor gases

Wet-basis food waste is disintegrated into many kinds of odor gases. Ammonia (smell of urine), hydrogen sulfide (smell of rotten egg), methyl mercaptan (smell of rotten cabbage), methyl sulfide (smell of rotten vegetable), dimethyl sulfide (smell of rotten vegetable) and trimethylamine (smell of stinky fish) are key sources of the odor gases [7]. The mix of odor gases will generate combined stink, which is the trickiest problem in the placement, collection, transport and disposal of waste on a wet basis. A way to radically avoid the generation of stink is to terminate microbiological degradation by removing moisture from the source.

3.2.3. Food waste moisture forming waste leachate

Food waste moisture is the main source of domestic waste leachate. The daily leachate generation-to-disposal ratios at domestic waste landfills, incineration plants and composting plants are 30%, 20% and 10% respectively [8]. In 2005, 155 million tons of urban domestic waste was transferred, and 26.17 million tons of leachate was generated. There is about 90 million tons of leachate for 300 million tons of rural domestic waste per year. The total municipal and rural leachate generation is about 116 million tons, amounting to about 11.6 billion tons of municipal sewage and with huge potential pollution risk.

Detection indicates that leachate at waste landfills contains 77 main organic pollutants, including 1 confirmed suspected carcinogen and 5 promoting carcinogens and co-carcinogens, posing great threats to the health of soil, surface water, underground water and human [9]. In 2002, landfill underground water pollution exceeding standard as a result of waste leachate accounted for 88.6%, according to CNEMC’s investigation into waste facilities in 47 major cities nationwide [10]. It is almost impossible to control the leakage pollution at landfills. Removing moisture from waste at the source and converting it to gaseous circulating water can completely address the pollution of domestic waste leachate.

3.2.4. Food waste separation

According to the test, vegetable and fruit peel, hard food waste and deteriorated food waste account for 98.49%, 8.72% and 1.75% of the total food waste respectively. Deteriorated food waste and cooked food waste, of which the saline matter accounts for 4.5%, are unsuitable for composting, and thus should be otherwise disposed of. Oil content was not detected. Based on test observation, food waste should fall into three categories, e.g. raw food waste (vegetable and fruit peel), hard food waste (kernel, shell and bones) and cooked food waste (deteriorated food waste and food waste containing saline matter and oil). However, this observation needs to be validated by a scale test.

3.2.5. Food waste nutrients

27.34% of dry-basis food waste was obtained through dry-basis separation. Rich in nutrient, food waste is a first-class raw material to produce organic fertilizer. Detection shows that nutrition constituent of dry-basis food waste collected in the test is superior to that specified in Control Standards for Urban Wastes for Agricultural Use (GB8172-87). Particularly, the organic matter content of food waste is about 6 times higher than the allowable value in the Standards (See Table 2).

Table 2. Nutrients of food waste
### Table 1. Test result of organic matter content

<table>
<thead>
<tr>
<th>Item</th>
<th>GB8172-87</th>
<th>Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter</td>
<td>10%</td>
<td>61.89%</td>
</tr>
<tr>
<td>Total nitrogen (on N basis)</td>
<td>0.5%</td>
<td>2.31%</td>
</tr>
<tr>
<td>Total phosphorus (on P basis)</td>
<td>0.3%</td>
<td>0.37%</td>
</tr>
<tr>
<td>Total nitrogen (on K basis)</td>
<td>1.0%</td>
<td>1.18%</td>
</tr>
</tbody>
</table>

3.3. Waste plastics, toilet paper, glass ceramics, used clothes, housekeeping waste and waste electronics

Through dry-basis separation, single-composition, clean raw materials are obtained, creating a precondition for resource recycling.

#### 3.3.1. Waste plastics

Waste plastics collected in the test accounted for 12.24% of low-value unmarketable waste, which is near the plastics ratio of waste in the 8 urban districts of Beijing (13.11%) [11]. The Outline of Technical Policies for Comprehensive Use of Resources in China requires the promotion of the technology to utilize waste plastics and wood materials to produce wood-plastic composites and products thereof. Clean waste plastics may become a major raw material to produce wood-plastic composites.

#### 3.3.2. Toilet paper

Toilet paper waste collected in the test includes toilet paper, napkins and sanitary napkins, which contain moisture and pathogenic microorganisms and need to be subject to moisture and odor removal before being independently separated for temporary storage. Toilet paper, having cellulose as its main component, comes from an official, stable source and is a raw material for producing fuel ethanol.

#### 3.3.3. Glass ceramics

18 unmarketable glass ceramic samples (5.99kg in total) were collected in the test, accounting for 3.60% of the low-value unmarketable waste (166.29kg). Large presence of fragments and impurities in glass ceramics is the main reason for the increasing shrink of waste composting in China. Incineration of glass ceramics has negative effects on grates. Suzhou has refined domestic waste separation by adding glass collection bins at waste placement outlets for independently recycling glass, so as to facilitate resource recycling [12].

#### 3.3.4. Used clothes

15 used clothes samples were collected in the test. Used clothes in dry-basis separation are neat and clean, and thus facilitate resource reuse. The priority of the scientific and technological progress tasks of the textile industry during the 12th Five-Year Plan period is to develop technology to recycle waste textiles and develop technologies to recycle pure chemical fiber waste textiles and natural fiber waste textiles. Used clothes have a huge resource recycle potential.

#### 3.3.5. Housekeeping waste

Among the 9 categories in the test, only housekeeping waste is non-recyclable, and needs to be directly disposed of. Mix of housekeeping waste with other waste will cause pollution, depriving other recyclable waste of the value of being recycled. Therefore, housekeeping waste should be separated independently.
3.3.6. Waste electronics

Electronics and lamps samples (68 in quantity and 2.05kg in weight) collected in the test, including batteries, energy saving lamps, filament lamps, mobile phones, chargers and remote controllers, are lighter than other samples collected in the annual test. Despite its long-time storage free from odor pollution, electronic waste causes serious pollution during landfill or incineration, and thus should be independently separated and collected.

3.4. Sample frequency, low-frequency placement, low-frequency collection and transport and centralized separation and transport

3.4.1. Sample occurrence frequency

Waste samples collected in the test fall into the following 9 categories: toilet paper (2,390 times), newspapers (830 times), plastic bags (718), food waste (338 times), housekeeping waste (104 times), electronics and lamps (62 pieces), glass ceramics (18 pieces), used clothes (18 pieces) and bulky furniture (2 pieces). The 5 categories with high frequency (twice or above per week) include toilet paper, newspapers, plastic bags, food waste and housekeeping waste (in the sequence of frequency). The 4 categories with low frequency (twice or less per week) include waste electronics, glass ceramics, textiles and bulky furniture (in the sequence of frequency) (See Table 3).

Table 3. Occurrence Frequency by Sample†

<table>
<thead>
<tr>
<th>High-frequency samples</th>
<th>Toilet paper</th>
<th>3,384 times (equivalent to 65 times/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newspapers</td>
<td>830 times (equivalent to 16 times/week)</td>
<td></td>
</tr>
<tr>
<td>Plastic bags</td>
<td>718 pieces (equivalent to 14 times/week)</td>
<td></td>
</tr>
<tr>
<td>Food waste</td>
<td>338 times (equivalent to 6.5 times/week)</td>
<td></td>
</tr>
<tr>
<td>Housekeeping waste</td>
<td>104 times (equivalent to 2 times/week)</td>
<td></td>
</tr>
<tr>
<td>Low-frequency samples</td>
<td>Waste electronics</td>
<td>62 pieces/item (equivalent to 1.2 times/week)</td>
</tr>
<tr>
<td>Glass ceramics</td>
<td>18 pieces (equivalent to 0.35 time/week)</td>
<td></td>
</tr>
<tr>
<td>Textiles</td>
<td>18 pieces (equivalent to 0.35 time/week)</td>
<td></td>
</tr>
<tr>
<td>Bulky furniture</td>
<td>2 (equivalent to 0.039 time/week)</td>
<td></td>
</tr>
</tbody>
</table>

3.4.2. Low-frequency placement and transfer

According to the survey on the catering industry of Shenyang conducted by Zhao Weiwei and Yan Yongqiang, a routine microbe inspection conducted by the Shenyang Center for Disease Control and Prevention indicates that [13] food waste stored for 12 hours under room temperature in August contains mold, saccharomyces and pathogenic bacillus cereus, the total bacterial count is 4.1x105, and coliform is equal to or larger than 24,000MPN/100g. Microbial activity reaches peak when the moisture content

† Toilet paper: 3,384 times (Toilet paper: 3 x 2 x 365=2,190 times; napkins: 3 x 1 x 365=1,090 times; hygienic products for women: 52 x 2 = 104; Total: 3,384).
Newsapers: 830 times (on the basis of Beijing Youth Daily 1 x 365, Reference News 1 x 365 and over 100 books sold).
Food waste samples were unavailable in 27 days of the entire year. Actual food waste sample: 338 days. Food waste frequency: 338/52 = 6.5 times/week.
Plastic bags were calculated subject to the actually collected soft plastic bags.
Food waste was calculated subject to the actual number of occurrence days (365-27 = 338).
Housekeeping waste was calculated twice a week (104 times in total).
Electronics and lamps, ceramic and glass, textiles and bulky furniture were calculated subject to actually collected samples.
The moisture content ratio of domestic waste was 58.51%, which means the microbial activity could reach peak. During reaction, microbes in the domestic waste could form a variety of odor gases simultaneously. With the possibility of rapidly breeding a large amount of harmful bacteria and generating odor gases, domestic waste must be transported as soon as possible.

In most cases, the time for transferring domestic waste from household placement to transfer stations exceeds 12 hours, and food waste in mixed waste loses the possibility of being recycled. In this test, food waste collected in mixed waste can be stored for a relatively long time (1-2 weeks) after moisture removal. The World Bank called for the collection of domestic waste of Chinese residents not to be in excess of twice per week [15]. Dry-basis separation makes it possible to reduce placement frequency and transport frequency.

### 3.4.3. Low-frequency transport cost

The daily cleaning and transport fees account for 60-80% of the overall cost of the entire waste disposal system, imposing a heavy financial burden. In the past few years, to transport more than 15,000 tons of waste from town to suburban landfills or stacking plates, Beijing’s sanitation authority needed to dispatch more than 500 waste transport vehicles in 6 trips each day. The annual transport cost was RMB 438 million [16].

Supposing that the waste is collected and transported on a two-day basis, a three-day basis, a four-day basis, a five-day basis, a six-day basis and a weekly basis respectively and the annual transport cost is about RMB 438 million, the annual waste transport costs for Beijing would be RMB 219 million, RMB 146 million, RMB 109.5 million, RMB 87.6 million, RMB 73 million and RMB 63 million respectively. Savings from weekly transport would be RMB 375 million.

(RMB 438 million, RMB 219 million, RMB 246 million, RMB 109.5 million, RMB 87.6 million, RMB 73 million and RMB 63 million)

![Weekly transport cost by frequency](image)

**Fig. 3.** Weekly transport cost by frequency

### 3.4.4. Centralized separation and transport

Drying food waste and toilet paper for temporary storage lays a new foundation for separation and transport. Li Zhenshan divides the components of domestic waste into usual components and unusual
components. In this test, the components of domestic waste are divided into high-frequency components and low-frequency ones.

According to the idea of centralized separation and transport, high-frequency toilet paper, plastic bags, food waste and housekeeping waste are considered to be cleaned and transported on a weekly basis, and the collection and transport period for low-frequency electronics, glass ceramics, textiles and bulky furniture is considered to be longer. For waste to be separated for transport, vehicles for centralized separation and transport need to be developed.

4. Conclusions

4.1. Removing moisture from food waste and toilet paper is the precondition for dry-basis separation.

Moisture removal can suppress the degradation of microbes in food waste and toilet paper, avoiding pollution to other components. Removing moisture from waste at the source and converting it to gaseous circulating water can fundamentally address the pollution of odor gases and leachate from domestic waste.

4.2. Dry-basis separation can collect clean waste raw materials at the source, laying a foundation for resource recycling.

Dry-basis separation focuses on pollution control for food waste, toilet paper and housekeeping waste. Dry-basis separation can collect clean food waste, toilet paper, plastic bags, waste electronics, glass ceramics and used clothes at the source, facilitating resource recycling.

4.3. Dry-basis separation can greatly reduce the quantity of waste to be landfilled or incinerated, increasing resource utilization rate.

Among the 9 categories in the test, only housekeeping waste is non-recyclable, and thus needs to be directly disposed of. Dry-basis separation ensures that existing landfills in Beijing can continue to be in service for 39 years.

4.4. Dry-basis separation lays foundation for low-frequency placement and collection and centralized separation and transfer.

On the premise of water control, high-frequency waste such as toilet paper, plastic bags, food waste and housekeeping waste can be placed, collected and transferred on a weekly basis, and the collection and transport period for waste electronics, glass ceramics, textiles and bulky furniture is considered to be longer (monthly or quarterly). Such idea needs further validation.

5. Outlook

5.1. Developing new rapid intelligent food waste moisture removal equipment

Problems with the hot-air drying type household food waste disposer during the test, such as long moisture removal time and difficulty in removing moisture from meat, need to be solved.

5.2. Developing new equipment for collecting plastics, food waste and toilet paper
In the test, plastics, and in particular soft plastics, are large in quantity and hard plastics bottles occupy a relatively large space, bringing inconvenience for collection. Food waste suitable for composting, food waste containing salt and oil, and hard food waste such as bones need to be collected separately. Equipment is required to address the challenges in moisture, odor and collection of toilet paper.

5.3. Developing centralized separation and collection equipment for communities

Impurities and moisture of food waste, cleanliness and impurities of waste plastics, and moisture of toilet paper need to be monitored. To facilitate transport, separation and collection stations need to compress packing paper and plastics.

5.4. Developing centralized separation and transport vehicles

Food waste, waste plastics, toilet paper and housekeeping waste, which are placed on a weekly basis, are separated for collection and centralized transport. For better transport, special transport vehicles need to have separated spaces for low-frequency waste including glass ceramics, used clothes and waste electronics.

5.5. Multi-sample study for dry-basis separation

In the test, only one family provided its domestic waste for analysis. The sample quantity is far from enough. Under the circumstance that the feasibility is 95% and the mean relative error is set at 0.05, at least 550 samples need to be collected to the requirements of statistical survey. More studies are required for dry-basis separation.

References

[16] Li Zhenshan et al., Research on the system for separate collection, transportation and disposal of urban domestic waste in Beijing, 2008, pp. 16.