รายงานการวิจัยฉบับสมบูรณ์

เครื่องรับขยะเพื่อการรีไซเคิลอัตโนมัติเพื่อการจัดการขยะชุมชนในประเทศไทย

Reverse Vending Machine for Municipal Waste Management in Thailand

ดร. รณชัย ติยะรัตนาชัย

ดร. อิสระ อนันตวราศิลป์

ดร. ชัยวัฒน์ หนูทอง

งานวิจัยนี้ได้รับทุนสนับสนุนงานวิจัย

จากงบประมาณเงินรายได้ประจำปีงบประมาณ พ.ศ. 2556

วิทยาลัยนานาชาติ

สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

ชื่อโครงการ (ภาษาไทย)

เครื่องรับขยะเพื่อการรีไซเคิลอัตโนมัติเพื่อการจัดการขยะชุมชนในประเทศไทย

ชื่อโครงการ (ภาษาอังกฤษ)

Reverse Vending Machine for Municipal Waste Management in Thailand

แหล่งเงิน งบประมาณรายได้ วิทยาลัยนานาชาติ

ประจำปีงบประมาณ 2556 จำนวนเงินที่ได้รับการสนับสนุน 150,000 บาท

ระยะเวลาทำการวิจัย 14 เดือน ตั้งแต่ 1 มกราคม 2556 ถึง 28 กุมภาพันธ์ 2557

ชื่อ-สกุล หัวหน้าโครงการ และผู้ร่วมโครงการวิจัย พร้อมระบุ หน่วยงานต้นสังกัดและอีเมลล์

หัวหน้าโครงการ:

นาย รณชัย ติยะรัตนาชัย วิทยาลัยนานาชาติ rtiyarattanachai@gmail.com

ผู้ร่วมโครงการวิจัย:

นาย อิสระ อนันตวราศิลป์ isara.a@gmail.com

นาย ชัยวัฒน์ หนูทอง chaiwat.kmitl@gmail.com

คำสำคัญ (Keywords) recycle, municipal solid waste, green logistics, and sustainability

บทคัดย่อ

ปัจจุบันพลาสติกโพลีเอทีลีน (PET) เป็นวัสดุที่ใช้ในการทำบรรจุภัณฑ์ที่ได้รับความนิยมสูงสุด ขวดบรรจุภัณฑ์จำนวนมากถูกทิ้งกลายเป็นขยะหลังการใช้งานซึ่งอาจก่อให้เกิดปัญหาสิ่งแวดล้อมตามมา ในหลายประเทศเช่นประเทศเยอรมนีและสหรัฐอเมริกา เครื่องรับขยะเพื่อการรีไซเคิลอัตโนมัติ (RVM) ได้ถูกใช้อย่างแพร่หลายในการรับซื้อขวด PET คืนจากผู้บริโภค เครื่อง RVM นี้ช่วยเพิ่มปริมาณและคุณภาพของขยะเพื่อการรีไซเคิล ซึ่งในกรณีนี้รวมถึงขวด PET ด้วย อย่างไรก็ตามเครื่อง RVM นี้ยังค่อนข้างใหม่สำหรับประเทศไทยและยังไม่ได้มีการใช้อย่างแพร่หลาย ดังนั้นจึงจำเป็นต้องมีการศึกษาเกี่ยวกับการยอมรับการใช้เครื่อง RVM ในประเทศไทยตลอดจนผลกระทบของเครื่องที่มีต่อปริมาณและคุณภาพของขยะที่ได้รับการรีไซเคิลผ่านเครื่อง RVM นี้

ข้อมูลเกี่ยวกับปริมาณและคุณภาพของขวด PET ที่ได้รับการรีไซเคิลผ่านเครื่อง RVM ถูกเก็บจากพื้นที่ศึกษาบริเวณอาคารเฉลิมพระเกียรติ 55 พรรษาฯ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง โดยมีการแบ่งช่วงเวลาการศึกษาเป็นช่วงก่อนและหลังการติดตั้งเครื่อง RVM ในบริเวณพื้นที่ศึกษา

ผลการศึกษาพบว่าปริมาณขวด PET ที่ได้รับการทิ้งเพื่อการรีไซเคิลหลังมีการติดตั้งเครื่อง RVM เพิ่มขึ้นประมาณ 20.88% เมื่อเทียบกับช่วงก่อนที่จะมีการติดตั้งถังขยะแยกประเภทขยะเพื่อการรีไซเคิล และเพิ่มขึ้น 26.41% เมื่อเทียบกับช่วงที่มีการติดตั้งถังขยะแยกประเภทแล้วแต่ยังไม่มีการติดตั้ง RVM ในแง่คุณภาพของขยะ ขวด PET ที่ได้รับผ่านเครื่อง RVM มีความเหมือนที่ดี โดยมีวัสดุอื่นเช่น เศษกระดาษ แก้ว หรือพลาสติกประเภทอื่นน้อยมาก ผลการศึกษาพบว่าเครื่อง RVM นี้มีแนวโน้มว่าจะได้รับการยอมรับที่ดีในประเทศไทย และเครื่อง RVM นี้น่าจะช่วยเพิ่มปริมาณและคุณภาพของขยะที่ได้รับการรีไซเคิลได้

ABSTRACT

Currently polyethylene terephthalate (PET) is the most favorable drinking packaging material worldwide. Most used PET bottles become waste after their usage, which had caused a lot of environmental problems. In developed countries such as Germany and the United States, reverse vending machines (RVM) had been widely used to accept recyclable wastes including PET bottles from consumers. Such machines help increase quantity and quality of the recycled PET bottles. However, RVM is still relatively new in Thailand. Therefore, this study has been conducted to investigate acceptance of the machine by consumers along with its impact on quantity and quality of PET bottles to be recycled.

Data regarding quality and quantity of recycled PET bottles was collected from the 55th Anniversary Chalermprakiat Building, King Mongkut's Institute of Technology Ladkrabang (KMITL) for pre- and post- installation periods of RVM for PET bottles. With the installation of RVM, the amount of recyclable PET bottles in the building had been increased approximately by 20.88% from pre-installation of separate bins for recyclable wastes and 26.41% from pre-installation of RVM and separate bins for recyclable wastes. In terms of quality, PET bottles accepted by the machine were well homogenous with minimal contents of other kinds of materials (e.g. paper, glass, and other types of plastics). According to the results, RVM tends to be well accepted by Thai consumers and could be used to increase quantity and quality of recyclable wastes in Thailand.

กิตติกรรมประกาศ

ผู้จัดทำขอขอบพระคุณวิทยาลัยนานาชาติสถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง ที่ได้สนับสนุนเงินทุนในการทำวิจัยนี้ ขอขอบคุณ คุณอังกูร บุรินทรชาติ และบริษัท บุญรอดบริวเวอรี่ จำกัด ที่ได้อนุเคราะห์เครื่อง P'PET ซึ่งเป็นหนึ่งในเครื่อง RVM ที่ได้รับการพัฒนาโดยคนไทย และมีความทันสมัยที่สุดในประเทศไทยในเวลานี้ ทางคณะผู้วิจัยขอขอบคุณ อิศณา คงสวัสดิ์วรกุล นักศึกษาปริญญาโทหลักสูตรโลจิสติกส์และการจัดการห่วงโซ่อุปทาน ในการช่วยทำการศึกษานี้ คณะผู้วิจัยขอขอบคุณเจ้าหน้าที่วิทยาลัยนานาชาติที่ช่วยอำนวยความสะดวกให้กับการทำวิจัยนี้ด้วยเช่นกัน

TABLE OF CONTENTS

LIST OF TABLES

Table

Page

LIST OF FIGURES

Figure

Page

CHAPTER 1
INTRODUCTION

This chapter describes background of information about the study focusing on Polyethylene Terephthalate (PET) and reverse vending machine (RVM). It also defines the scope and objectives of the study.

1.1 Background

Recycling yield two (2) major positive impacts, which are preserving the environment and generative economic values. Recycling process has been around for thousands of years. In the past, metal items such as pots and swords were melted to reproduce new items like statues, coins, and other household items (Harrison, 2013).

Plastics have been widely used all over the world in many applications. Therefore, it is one of the most significant components of a waste stream. Recycling of durable goods, such as automotive parts and carpets are being explored. Environmental recyclability and compatibility are being considered during the designing of new parts. Products life cycle management and analyses are also being studied as tools for decision making (Subramanian, 2000).

PET plastic is the world most favorable beverage packaging material due to its excellent properties. PET is well-known for its unbreakability and low weight compared to glass bottles with the same capacity (Welle, 2011). PET bottles become waste after usage, which has led to many environmental problems (Kim et al., 2010).

Qualities of waste materials refer to its purity or, in other term, homogeneousness. Recycling process usually consists of seven (7) steps but not limit to: 1) identification, separation and classification of plastics types; 2) grinding process follow by washing with or without cleaning agents; followed by 3) drying process; 4) silos, 5) agglutination; 6) extrusion; and 7) granulation (Santos et al., 2005).

Reverse vending machine (RVM) is one of the solutions, which could help to improve waste quality. It is a stand-alone machine with unmanned recycling process equipped. RVM is used for recycling beverage containers especially for containers, which are subject of "bottle bills" (Schulze, 1992). Bottle bill program helped recycle more than 16.5 billion beverage containers per year in California. RVMs collect, sort, and compact beverage containers along with recycling staffed to provide Californians with convenience way to recycle which has lead CA's bottle bill program a success (CAW, 2012).

In Thailand, a state-of-the-art RVM, called P'PET, has recently been developed. The machine also has user accounting system, which allows users to store money, which is generated from recycling, in their accounts. User may cash out the money or make a donation whenever they want (Matichon, 2011).

1.2 Problem Statement

Rapid urbanization and industrialization have resulted in changing of human livelihoods. More wealth has led to more wastes that will eventually cause environmental problems, for example, solid waste, air, and water pollution. Nowadays, solid wastes created by human became one of the most serious problems to the environment.

Developing countries are lacking of efficient waste management, which should entail, proper disposal methods. Many municipalities have implemented various approaches to manage wastes. Once of which is the integrated waste management. It is a promising waste management approach, which allows local people participate in waste separation starting from household level. Recycling helps in saving energy and provides cheaper base materials for industries. Recycling also helps to reduce wastes to be disposed in landfill. As a result, landfills can be used for a longer time (Foppes, 2000).

There are evidences indicating that poorly-sorted recycled plastics can lead to poor quality of raw materials that produced from the recycled plastics (Brachet et al., 2008). RVM does not only increase the amount of plastics to be recycled, but also helps solve this problem (CAW, 2012 and Becher et al., 1995). However, such machine is still relatively new in Thailand. Therefore, there is a need for study to investigate the impact of the existence of RVM in Thailand on the quantity and quality of recycled plastics.

1.3 Objective of the Study

The objective of the study is to investigate the impacts of RVM on the quantity and quality of recycled plastics, if any. The results of the study will be used to support decision making for enhancement of recycling industry and reverse logistics in Thailand.

1.4 Scope of the Study

The study area covered the 55^{th} Anniversary Chalermprakiat Building, KMITL. Data regarding quality and quantity of recycled PET bottles have been collected pre- and post-installation of P'PET, one of the most advanced RVM selected for the study.

CHAPTER 2
LITERATURE REVIEW

In this chapter, PET and its recycling processes are discussed. The information could be used as a guideline for developing countries such as Thailand to improve its waste management practices. The chapter also provides a summary of related studies, which has led to the development of this study.

2.1 Polyethylene Terephthalate (PET)

Polyethylene terephthalate or "PET" is one of the most familiar types of plastic packaging. PET quickly gained acceptance among consumers due to its lightweight and durability. There are many designs of PET bottles as presented as Figure 2.1 (Napcor, 2013). Process in producing PET bottles is done by stretch, blow, and molding.

Figure 2.1: PET Bottles (Zhwjiang Lebao Plastics Equipment Factory)

PET has been known for more than 60 years, under the name of "polyester". Milestones listed below shows the development of polyester fibers in the year of 1941 to modern PET bottles.

- 1941: First production of polyester fibers
- 1950s: Textile fibers production (brand names: "Dralon", "Trevira")
- 1950-60s Expansive use in textile industry
- 1970s: First packaging containers production
- End of 1980s: First production of refillable beverage containers (Vest, 2003)

PET is form by combining two monomers, which are modified ethylene glycol and purified terephthalic acid as presented as Figure 2.2. PET was first discovered and patented in England in the 1941 (Napcor, 2013).

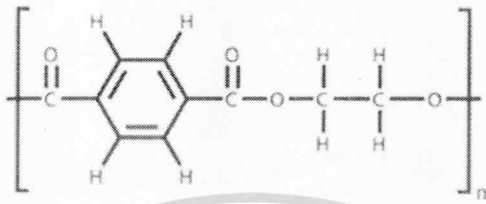

Figure 2.2: Polyethylene Terephthalate (Napcor, 2013)

2.1.1 PET Bottle Manufacturing Process

Bottles manufacturing process from PET primary granules are listed below:

a) Use standard type of injection molding machine to inject molding of preforms.

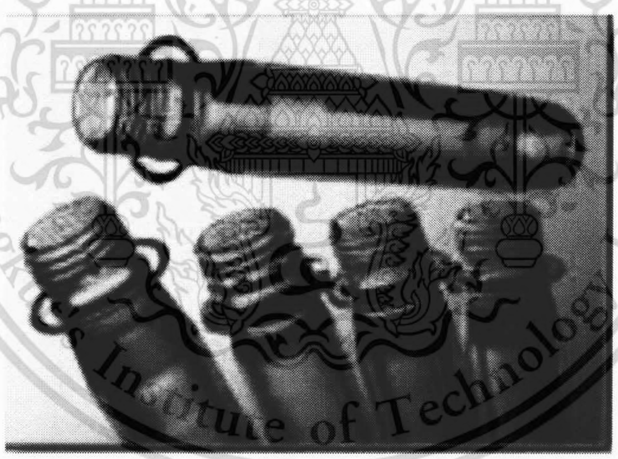

Figure 2.3: Injection Molded Preforms of PET Bottles (Vest, 2003)

b) Blow and stretch bottles from preforms

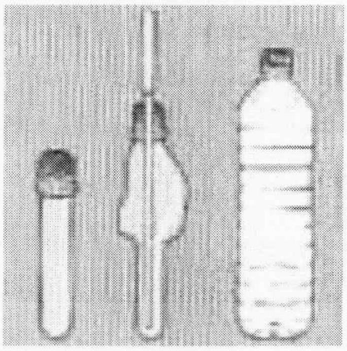

Figure 2.4: Blow Stretch Forming of PET-bottles (Vest, 2003)

After blow stretch forming of PET-bottles process, the preforms are heated in an infrared oven to soften the temperature and move to stretch forming mold process. Air is compressed through preforms' nozzle and presses the soft material to the walls of mold. Bottles are released from mold once the temperatures cool down (Vest, 2003).

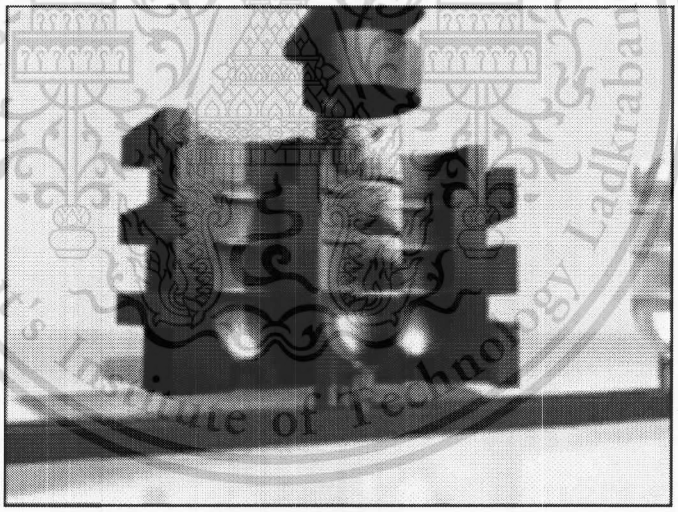

Figure 2.5: Stretch Forming Mold for PET Bottles (Vest, 2003)

2.1.2 PET Resin Identification Code

Resin identification code was established by the Society of Plastics Industry (SPI) in 1987. PET plastics are coded with number "1" of resin identification code inside the universal recycling symbol. The identification codes are usually located on the bottom of the container (Wikipedia, 2013).

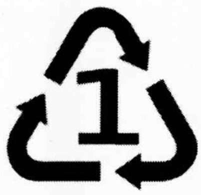

Figure 2.6: PET/PETE Resin Identification Code (Wikipedia, 2013)

2.1.3 PET Bottle Components

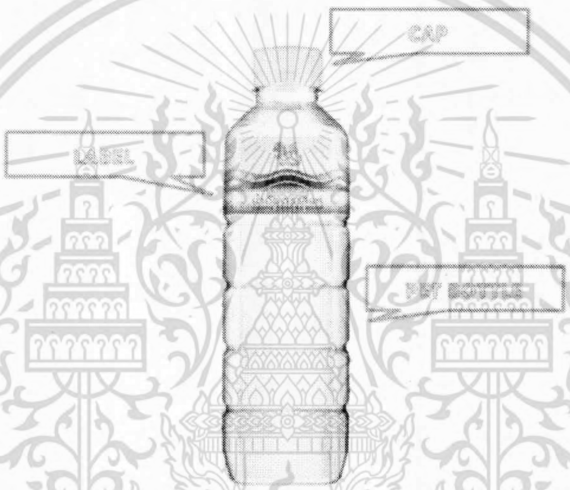

Figure 2.7: PET Drinking Bottle Component (Singha, 2013)

There are two (2) types of label:

1) Opaque

2) Transparent

Caps, labels, and bottles are made up of different types of plastics. Caps are made from high-density polyethylene (HDPE), Polypropylene (PP), or plastic that is less dense than water. Labels are made from premature ventricular contraction (PVC) and bottles are made of PET. Caps are not made from PET because PET can easily be deformed once squeeze and bend with fingers (Recycling NJ, 2013).

2.1.4 Recycled PET

In 1976, St. Jude Polymers Company established first recycling process of PET. The recycled PET (RPET) began with recycled into paint brush bristles and plastic strap. The important step was "repelletize" post-consumer PET plastics, which was first done by St. Jude in 1977. Many PET remanufacturing companies rely on plastic in pelletized form for their process, which increased the variety of products that can be made from RPET (Hurd, 2013).

However, major push in development of both demand and capacity of RPET occurred when Wellman, Inc., major plastic fiber manufacturer stepped into the business. In early 1978, Wellman began to recycle PET into fiber product that was suitable for carpet and fiberfill applications. Throughout 1980s and early 1990s, Wellman continued to increase its use of RPET and increased their production capacity and consequent the market demand for RPET. Wellman's major event was the development of vertical integration of RPET. The company incorporated it into its own product lines. Another development was the first textile fiber manufactured from 100% recycled PET in 1993, which was called "Eco Spun" and it is now a familiar fabric material particularly in sportswear. Since then, St. Jude and Wellman are joined by more than a dozen other companies, whose combined PET recycling process capacity produces over half billion pounds of RPET resin annually (Hurd, 2013).

Reliable and efficient pre-process and in-process sorting methods play an important role in throughput and cost of recycling process (Teichmann et al., 2013). Pre-process sorting may consist of either manual or automated sorting system for separation and identification of different plastics types and grades from mixed plastics and from other contamination such as paper and aluminum. In-process sorting is mainly done by electronics equipment and automated identification and separation system to sort plastics by color, type, and type of plastic materials. It also separates plastics from other impurities. There are no exact processes in recycling firms because these techniques are proprietary (Teichmann et al. 2013).

2.2 Recycling Process in Thailand

Recycling business has existed in Thailand for many decades. The business started from Chinese immigrant, who roamed the street using tricycle or pushcart in collecting used materials, which is known as "Saleng". Waste dealing business has generally considered as a low status and dirty work. However, recyclable waste dealer could play an important role of waste management in Thailand (Foppes, 2000).

2.2.1 Pre-Manufacturing Process

Wastes are collected by both residual and commercial. Once wastes are collected to a certain amount, the wastes will be sold to material recovery facilities (MRF) such as Wongpanit or private sector, saleng, or collected by refuse vehicle. As presented in Step 3 on Figure 2.9, re-separation may or may not occur due to different ranges of knowledge. Some people may not know that different colors of PET can be sold at different prices. Different kinds of PET are recycled into different kinds of products.

One of the reliable price lists of recycled materials in Thailand is the list offered by Wongpanit Company Limited. The list is updated daily as one of the example presented as Table 2.1.

Table 2.1: Plastic Price Lists (Wongpanit, 2013a)

Type of product	Price/kg (THB)
Transparent PET bottle	10.00
Color PET bottle	1.50
Mixed color plastic (non-PET)	8.5

* Price updated as of 4 June 2013

Historical PET prices had been observed for two (2) weeks as presented as Figure 2.8. Large quantities of recyclable materials are recommended to be sold during high-price period.

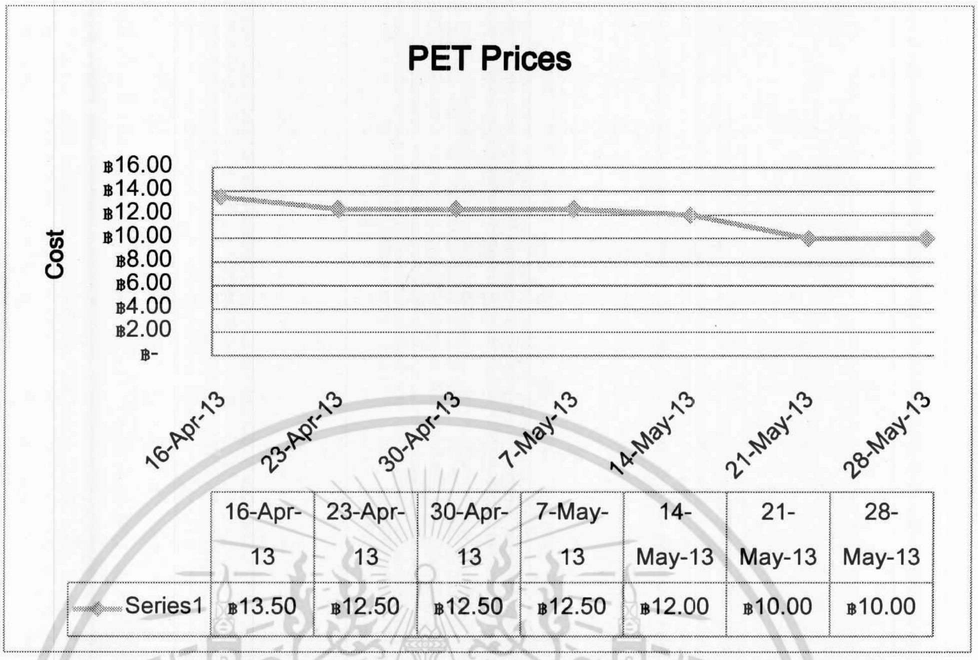

Figure 2.8: PET Statistical Price

After re-separation process, the sorted PET bottles will be crushed into bales for easy transportation. Once the bales of PET have been gathered into a certain amount, for example, full truck load, it will be sent to manufacturer for a further process.

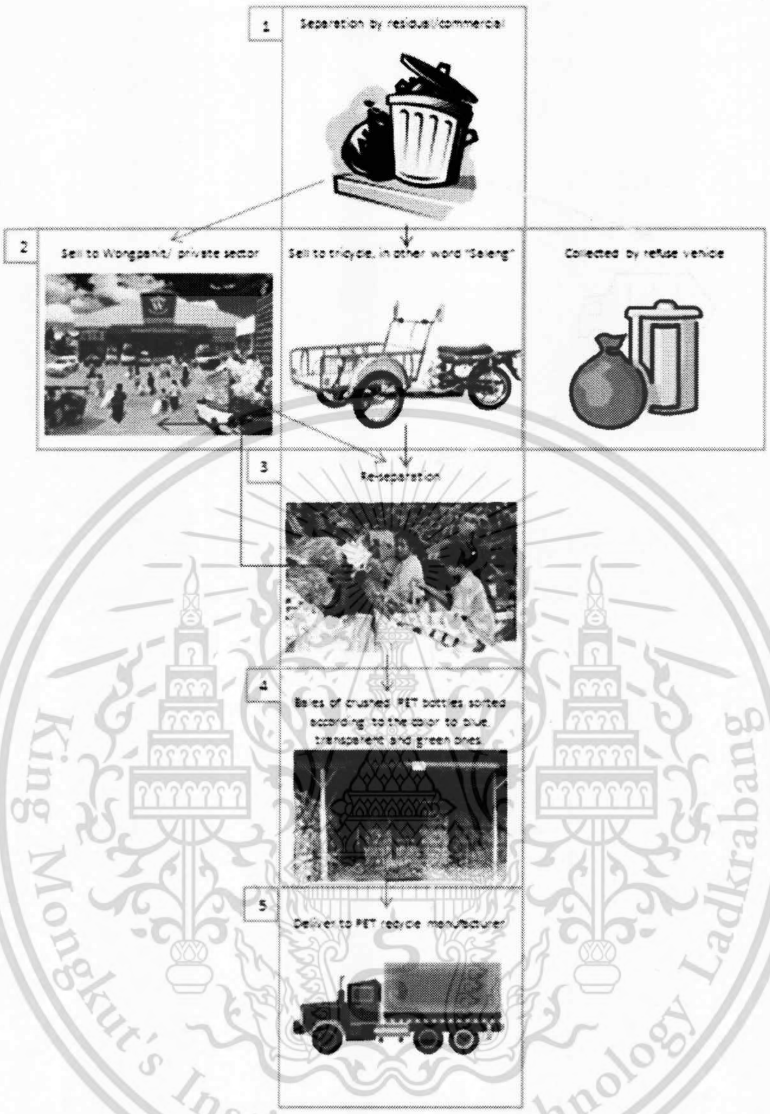

Figure 2.9: Pre-manufacturer Process

2.2.2 Manufacturing Process

After bales of PET arrived at the manufacturer, labels on PET bottle will be manually peeled off by hand and cutter. Then, PET bottles will be put into the machine to grind; PET outcome will be called as "PET flake". Once grinding process is done, the next process is to soak it in water. Soaking in water will help separate PET bottle from caps, straws, and other contaminants. Due to the fact that caps, straws, and some other contaminants have less density than water, they will float, while PET with greater density than water will sink as presented on Figure 2.10. After this step, the clean PET flakes are ready for the next step.

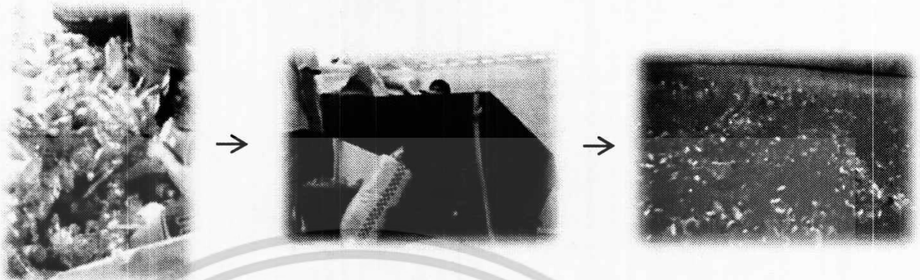

Figure 2.10: Process in Manufacturer (Rux69, 2012)

The next process is to dry PET flakes. The drying processes are to be done by shaking and drying machine. Once PET flakes are dried as presented on Figure 2.11, they will be packed into a sack and sell to manufacturers that produce goods from RPET.

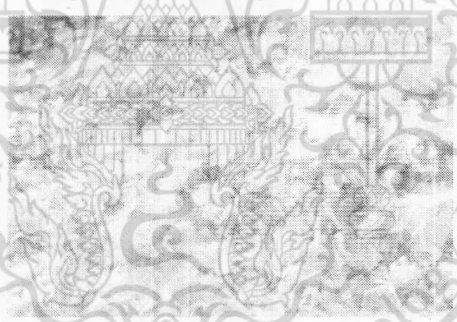

Figure 2.11: Clean PET Flake (Rux69, 2012)

PET flake can be reproduced into several kinds of product. It can be recycled back into PET bottles, as well as produced into new kinds of products such as pillow fabric (Wongcharoen, 2008).

2.3 Recycling of PET Bottles in the United States

PET is one of the most familiar types of plastic packaging found in American households. With its lightweight and unique designed, PET quickly gained acceptance among consumers. In 1997, it was estimated that 31% of PET were produced among all plastics bottles in the U.S. However, the production number of producing PETs had been continuously rising (Hurd, 2013).

With recent technology in PET recycling, it is now possible to close the recycling loop by recycling bottles and containers back into the original products, which are bottles and containers even in some of the food contact packaging (Hurd, 2013).

2.3.1 PET Bottles Recycling Collection Services in the United States

The United States (U.S.) is a developed country where as Thailand is a developing country. In discussing on recycling process in the U.S., could come up with an improvement of recycling process in Thailand. The quality of the recycled plastic resins depends greatly on the efficiency of sorting methods. Development of sorting method will in turn increase the reclaim volume and value of the recycled plastics (Teichmann et al., 2013).

2.3.1.1 Bottle Bills

First method is Returnable Container Legislation, or "Bottle Bills" created as statewide laws. The legislation was passed around many states in the country, which provide a redemption value. When consumer returned the containers for redemption value, it is then aggregate into large quantities of recyclable materials at beverage retailers and wholesalers to be collected by recyclers; while simultaneously provide economic incentive for consumer to return containers for recycling (Hurd, 2013).

Refer to Figure 2.12, distributor or bottler collects deposit from retailer when containers are delivered. Retailer collects deposit at purchase from consumer. Consumer deposit got refunded when container is returned to retailer. Deposit refunded to retailer when distributor or bottler received the returned containers (Sierra Club, 2013).

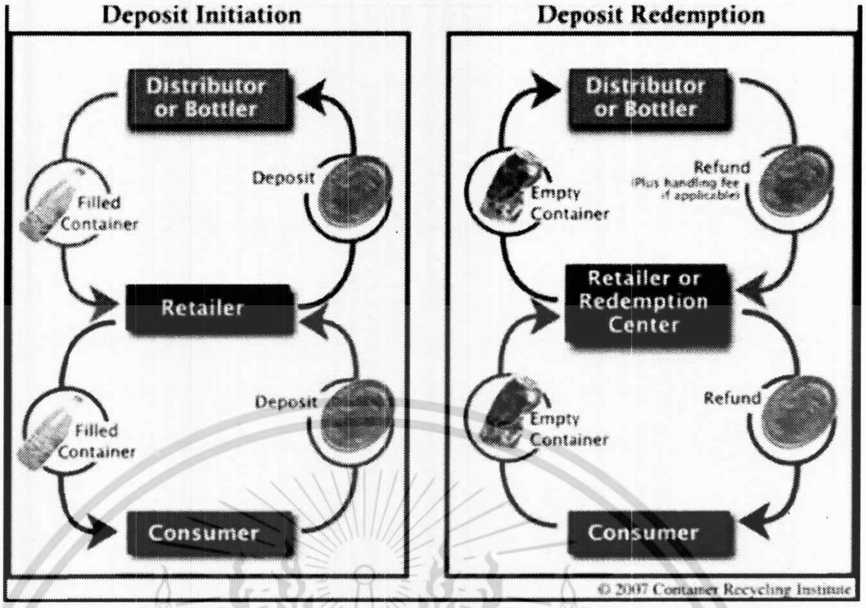

Figure 2.12: Bottle Bills Deposit Collection and Refund (Sierra Club, 2013)

Bottle Bills helps in preventing litter, reducing wastes and greenhouse gases, create jobs, produce higher quality materials and many more (Thelizzygaunt, 2010).

2.3.1.2 Curbside Collection

The second method is curbside collection of recyclables, most widely accessible collection method. Curbside recycling programs yield high recovery rates as a result and are generally the most convenience for residents to participate. It is estimated that 70%-90% of available recyclables gathers by curbside collection based on research conducted by the Center for Plastics Recycling Research at Rutgers University. In addition, approximately 55% of all the PET plastic containers were collected through curbside programs which were estimated by National Association for Plastic Container Recovery (Hurd, 2013).

Usually communities that provide curbside collection will requests its residents to separate designated recyclables from their household garbage and place them into special bags or receptacles, which are then set out at the curb for collection by municipal. Some communities allow their residents to mix recyclable materials of different kinds into the same bag or receptacles. Other required some level of material segregation which is known as "source separation" (Hurd, 2013).

2.3.1.3 Drop-off Recycling

Third collection method is drop-off recycling; containers for designated recyclable materials are placed at central collection locations throughout the community, for example churches, schools, or parking lots. Usually the containers are marked according to which recyclable material should be placed in them as on Figure 2.13. Residents are requested to drop their recyclables at the drop-off location, which recyclables are separated by material type into their respective collection containers. Drop-off centers does not required much investment to establish compare to curbside program, but yet it is not as convenience as curbside collection. However, in rural area drop-off collection centers work better than curbside collection (Hurd, 2013).

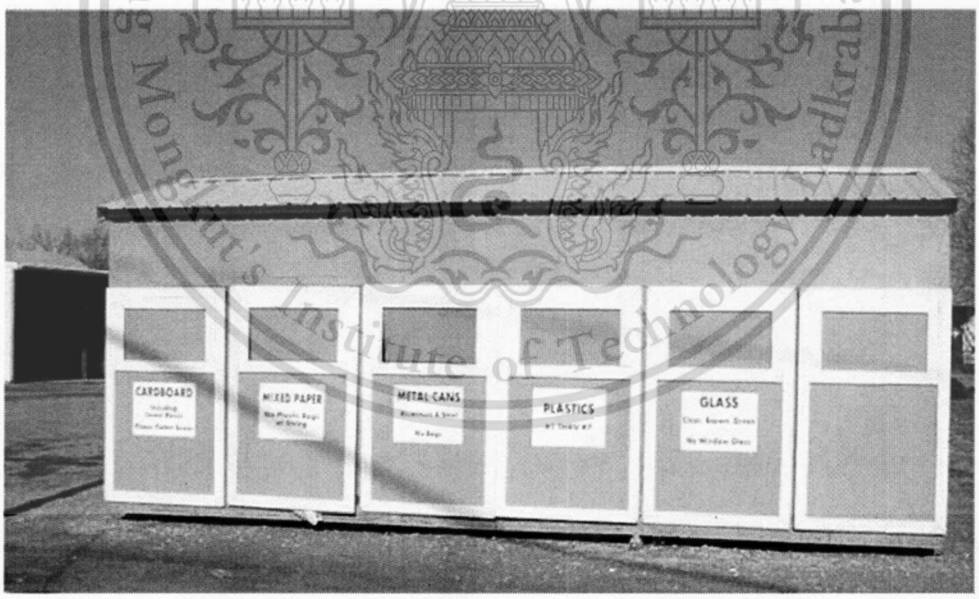

Figure 2.13: Drop-off Recycling (Miami County, 2013)

2.3.1.4 Buy-back Centers

Usually buy-back recycling centers are operated by private companies. Consumers brought recyclable materials to buy-back centers for an incentive. Most buy-back centers required consumers to separate recyclable material which were brought for sale according to their purchasing specification, for example removal of caps and labels from bottles. These purchase specifications help to reduce contamination which allow buy-back center to immediately begin processing the recyclables they purchase, which in turn providing economic incentive to consumers to comply with their specifications (Hurd, 2013).

2.3.1.5 Reverse Vending Machine

First automated bottles return machine in the world was invented in 1972 by Tomra Company, this provides efficient and convenient systems for handling the return of beverage containers. The machine collect, scan, sort and in some of the models compacts used beverage containers for recycling. Refer to Figure 2.14, example of reverse vending machine (RVM) model "T63 TRISORT" from Tomra Company. The machine captures plastic, aluminium and glass containers with fast processing up to 30 containers per minute. It also contains intelligent and easy accumulation of glass crushed (Tomra, 2013a).

Figure 2.14: RVM Model "T63 TRISORT" (Tomra, 2013b)

Most RVM contains a flat cabinet surface to support branding and advertising. Interactive video is another feature of RVM, which provide self-explanatory information for users and/or advertisement. RVM could include discount coupons and special offers on the refund receipt (Tomra, 2013b).

RVM reads barcode from label of beverage containers to determine if the container is returnable. Beverage containers should not be crushed so that the barcode can be read (Michigan, 2013). RVM helps to increase the quantity of returned containers, save labor cost and wages, and encourage consumers to empty their beverage containers, which led to quality improvement.

2.3.2 Post-collection

In post-collection, collected materials are being resorted and prepared for sale. Each step in recycling processes is meant to add value to post-materials and puts into marketable form, which manufacturer will use them to produce into new products. Sorting and processing process depend upon purchaser specification (Hurd, 2013).

Once post-materials are being sold, it is then delivered to plastics intermediate processing facility (IPC) or a materials recovery facility (MRF) to begin the next recycling process. The value of recycled material and its ability to be economically remanufactured into new products depends greatly on quality of materials as it passes through the recycling process (Hurd, 2013).

MRFs again re-sorted commingled collected recyclables materials into their respective categories, then baled for sale to IPCs, plastics recycling facilities (PRFs), or reclaimers. PRF accepts only plastic containers, unlike MRFs and IPCs. Recyclable materials are generally being accepted in both loose and baled form. PET bottles are usually being sorted by resin category and its color and being bale for shipment to reclaimers (Hurd, 2013).

However, sorting alone is not sufficient for the preparation PET bottles for remanufacturing. There are many items such as labels and caps, which are physically attached to PET bottles that require further process for their removal (Hurd, 2013).

PRFs sent PET plastics to reclaimers, and then recycled PET plastic into a commodity-grade form that can be used by end-users to manufacture new products. At a reclaiming facility, PETs are put into sorting and cleaning stages to remove other contaminants. First, regrind material is passed through an "air classifier" which removes materials that is lighter than PET such as paper labels (Hurd, 2013).

The flakes are being washed with special detergent in a scrubber. This step helps to remove food residue that might remain inside PET bottles, glue that is used to stick labels to PET bottles, and any dirty substance that might be present (Hurd, 2013).

Next, the flakes are then move to what is known as a "float/sink" classifier. During this process, things that are heavier than water will sink in the classifier such as PET, while things that are lighter than water will float such as caps and rings which are made from polypropylene plastic (PP). In this stage, there might still be some contaminants, which may sink with PET. Some reclaimers may use different device known as "hydrocyclone" to perform this step. This device works like a centrifuge, which separate materials according to its weight (density) differences. Following the float/sink stage, the flakes are then thoroughly dried (Hurd, 2013).

Once the flakes are being dried, it is then process through the next stage which is known as an electrostatic separator. The machine uses magnetic field to separate PET flakes from any aluminum that might be present as a result of bottle caps. Some reclaimers used different separation machine such as x-ray separation devices. PET flakes purity level depends on end-use applications for which they are intended (Hurd, 2013).

After all the mentioned processes have been completed, PET is now resulted in a form of "clean flake". Some reclaimers may perform a further process which is "repelletizing", this turns the flakes into "pellet".

Clean PET flake or pellet is then processed by reclaimers to transform flakes into commodity-grade raw materials such as sheet, fiber or compounded pellet, which is finally sold to end-user to manufacturer into new products (Hurd, 2013).

RPET can be manufactured into numerous products, which can be divided into five (5) major categories which are packaging application such as new bottles, sheet and film application such as laundry scoops, strapping, engineered resin applications such as automobile components, and fiber application such as carpets. However, currently one of the highest values of RPET is to manufacture into new PET bottles but not limited to; due to the emerging of new technology (Hurd, 2013).

Recycling process throughput and cost depends greatly on efficient sorting methods. Increasing sorting efficiency helps to improves quality of recycled plastics. This will then provide economic benefits and reduced waste disposal in the environment (Teichmann et al., 2013).

2.4 Reverse Vending Machine in Thailand

P'PET machine is a reverse vending machine (RVM) of PET bottles in Thailand. It helps in reducing the use of new plastic resin, reduce energy consumption, and helps in reducing greenhouse gas emission to more than 30 percents. The implementation of this machine took approximately one (1) year. The machine was introduced in the year of 2011 (Matichon, 2011); it is not only being used in Thailand but also was produced in Thailand by Thai people. Another objective of this invention is to reduce RVM storage space by shredded PET bottles, which allow machines to accept greater numbers of containers which in turn required less frequent services of collection (Schulze, 1992).

P'PET machine works similarly to automatic teller machine (ATM). The usage instructions are being displayed on monitor or in other word "screen". This machine only accept a transparent PET bottle refer to Figure 2.1.

2.4.1 P'PET Machine Specifications

- Electricity usage: 1 phase 220 volt 900 watt
- P'PET size: 1.20x1.00x1.80 meters
- Maximum capacity: 50kg of PET
- Self member registration
- Touch screen monitor 15.6 inches
- Type of provided coins are 1, 5, and 10 baht
- Size of outcome PET: 1x2 square centimeter
- Fraud system (Burintarajati, 2013)

- 5 years warranty
- Price: start with 400,000 THB (Matichon, 2011)

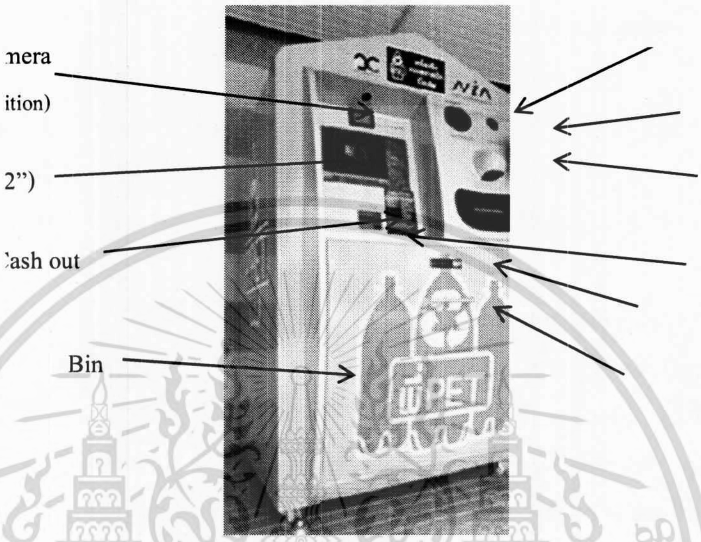

Figure 2.15: P'PET Machine Components (Ananchon, 2011)

2.4.2 P'PET Software

Machine functional software

1) Accept bottle and check quality
    - Users are required to scan bottle's barcode to identify bottle acceptance by the machine.
    - Once the bottle was inserted into bottle insertion hole, quality of bottle is checked by software through using of weighing machine and image sensor.
    - Machine only accept quality PET bottles, which means without any contamination. Otherwise bottle is automatically being returned to user.
    - Quality bottle is then being move to shredding process.
2) Membership system
    - Users are able to perform a self-membership
    - After self-membership registration, users' information is being saved in server.

- Users are required to use their telephone or mobile phone number for their next log-in.
- A card with user's photo, such as identity card or driver license is required for membership registration.
- Four (4) digits password needed to be set similarly to an ATM.

3) Accounting system
    - Two (2) methods in price calculation:
        1. Calculate according to bottle's weight.
        2. Calculate according to type of bottle, for example type A will be paid 1 baht instead of paying according to weight.
    - Bottle's price is provided by server for calculation according to bottle's weight.
    - Machine is able to calculate and provide change precisely.
    - Users able to withdraw their money during the next log-in, if money does not want to be withdraw right away.
4) Online system
    - Machine are being online 24 hours
    - If machine are facing connection problem, machine service will be stopped immediately.

Machine non-Functional software

1) Human-interaction
    - Communication between user and machine are done by touchscreen or number pad, depending on machine's version.
    - Attractive and user-friendly interface
2) Advertisement
    - Advertisement will be displayed once machines are not in use.
    - Aside from showing advertisement, the machine is able to display current PET bottle's price.

3) Security
    - Users' information is kept confidential.
    - System able to calculate and give change precisely.

2.4.3 P'PET Server Software

Server functional software

1) PET bottles information
    - Bottle's price can be updated anytime by System Administrator.
    - Bottle information can be added or updated anytime.
2) Server and P'PET machine connection
    - Server minimum connection is one-hundred (100) P'PET machines.
    - Twenty-four (24) hours monitoring on other P'PET machines.
    - Notify System Administrator, if one of the P'PET machine is not responding within one (1) hour.
    - Server is always tracking on P'PET machines, for example how much money are left inside P'PET machines and how many bottles had been accepted.
    - Server will notify System Administrator if money inside P'PET machines is lesser than its limit.
    - System Administrator can check records of any P'PET machine on number of bottles being accepted or rejected, and also bottle types in specific time period.
3) Account system
    - Server stored users' information by using Database management system (DBMS) for easy data management.
    - Users are able to log-in their account through web log-in for checking user's money.

Server non-functional software

1) Security

- System back-up.
- Server is able to recall data from backup once original data got corrupted.

2) Management

- Easy to manage.
- Server should support upgrades in the future.

2.4.4 P'PET Machine Usage Procedure

P'PET machine does not require users to be a membership, however being a member would benefit user themselves. First, show identity card to P'PET camera, enter phone number, and set four (4) digits password. Secondly, remove cap and empty the container. Then scan the bottle's barcode which can be found on label, bottles with unreadable barcode are unaccepted. Place the bottle and cap into bottle/cap insertion hole. The prices given by the machine are varying upon weight of bottle. The prices are being updated daily according to a market price. Once PET bottle is being accepted by the machine, the shredder inside the machine will shred PET into small pieces; this is to maximize the storage space as on Figure 2.16. End-users were given three (3) options after the insertion of the bottle which is to donate money, redeem money, or to get a special deal.

Figure 2.16: Outcome PET (Matichon, 2011)

2.5 Related Studies

Automated recycling machines from U.S. patent number 5,111,927 are able to received and handled glass, plastics, and metal containers for recycling purpose. The objective of this invention is to provide more efficient crushing of containers to permit a greater density of crushed materials so that the storage bins employed in conjunction with recycling machines will be able to accept greater numbers of containers, thus requiring less frequent servicing and collection (Schulze, 1992).

Automatic waste recycling machine and disposal system help to improve the quality and thereby the value of recyclable materials, first, by efficient sorting, second, by crushing and compacting to minimize the volume, thereby reducing conveying expenses per pound of waste. The recycling industry would also gain a benefit from a higher quality and cleaner raw material by saving on sorting and cleaning expenses. Basically, it is easier to sort and clean waste materials when it is still fresh. Than to sort and clean it after weeks, when it smells and messy (Becher et al., 1995)

The pre-process sorting of plastic bottles consists of separating the bottles by color and type of plastics, to achieve the highest sales values. The quality and applicability of the recycled plastic resins can be enhanced greatly, if more efficient and economical sorting methods were made available (Teichmann et al., 2013).

CHAPTER 3
METHODOLOGY

This chapter describes the methodology used in this study to achieve its objectives. As mentioned in Chapter 1, the objectives of the study are to investigate the impacts of RVM on the quantity and quality of recycled PET bottles. Parameters used for data collection were set based on literature review and some interviews with waste management professionals. For the data collection, the study was divided into 3 phases including: pre-installation of RVM, pre-installation of RVM and separate bins for recyclable wastes and post-installation of RVM. Details of the study are described in the following subsections:

3.1 Study Area and Population

The study area was set to be in the vicinity of the 55th Anniversary Chalermprakiat building, King Mongkut's Institute of Technology Ladkrabang (KMITL) hereafter referred to as '55th ACB'. The building is an 8-storage building, which consists of three (3) academic units of KMITL including the International College, the College of Nano Technology, and the College of Data Storage Innovation.

This study area was selected because the building is part of an academic institution, which its population tends to be well-educated and are likely to accept such an innovation like the reverse vending machine. The study area also fits with the resources made available for the study. Study population in the 55th ACB is shown in Table 3.1

Table 3.1: Population in 55th Anniversary Chalermprakiat Building (KMITL, 2013)

Academic Unit / Population	International College	College of Nano Technology	College of Data Storage Innovation	Total
Number of students	270	167	79	516
Number of administrative staff	6	4	9	19
Number of academic staff	16	17	6	39

*Updated as of 6 Jan. 2013

As presented in Table 3.1, there are a total of 574 people, who occupied the study area during the study period. The population includes a total of 516 students in both undergraduate and graduate levels; 19 administrative staff (e.g., secretaries, clerks, etc.); 39 academic staff (i.e., lecturers and researchers).

It should be noted that the area was also occasionally occupied by other KMITL staff and students. However, this temporary population deemed insignificant compared to regular population in the study area. Additionally, the data collection period was set during the closed semester of other Thai academic programs (approximately from March to May); during the same period, students in international programs were in their 2nd semester (January to May). This selected data collection period was expected to further focus the study on targeted study population. Details of data collection are presented in Section 3.3.

3.2 Parameter Setting

To set up parameters for data collection, information regarding parameters in terms of quality and quantity of recyclable wastes were reviewed through academic journals and databases and publicly available guideline and manuals on the Internet. Additionally, some interviews were conducted with waste management professionals affiliated with Wongpanit, Co., Ltd., one of the largest business chains of recycling facilities in Thailand (3RKH).

First, a requesting letter for interview approval was sent to Wongpanit headquarter. The headquarter suggested three Wongpanit branches nearby KMITL area. The location and interviewed personnel are listed below:

1) Saparnsoong Branch: Mr. Preecha Kamsri, Branch Owner

2) Baanpho Branch: Mr. Sakchai Damrongsuthipong, Branch Owner

3) Chaengwattana: Mr. Sittikorn Panapitakkul, Branch Owner

An interview form presented as Appendix A was used for the interview. Each interview took approximately 30 minutes.

Based on the literature review and the interviews, level of homogeneousness; amount of contamination; and amount of caps and labels were used as parameters for the quality of recycled PET bottles. Quantity of PET bottles was measured in terms of the number and weight of bottles recycled.

3.3 Baseline Data Collection

Baseline data collection was conducted into 3 phases: pre-installation of separate bins for recyclable wastes, pre-installation of RVM and separate bins for recyclable wastes, and post-installation of RVM. Details of baseline data collection are presented below:

3.3.1 Pre-installation of Separate Bins for Recyclable Wastes

Prior to the installation of the RVM for this study (P'PET), used PET bottles in the study area were collected by maids. There are three maids in 55th ACB. Each maid was assigned to conduct housekeeping at different floors. The general practice regarding collection of recyclable PET bottles was that PET bottles were to be collected daily from mixed and unsorted regular trash bins. No separate bins for recyclable wastes were placed in the study area.

The maids would accumulate the PET bottles into a considerable amount before they sold the bottles to waste buyers in Saleng or small pick-up trucks. Saleng is a Thai traditional small vehicle generally used for commuting around and buy recyclable wastes from households. The waste buyers would pay direct money to the maids. Price of the wastes was generally 3 baht per kilogram lower than the market price if the wastes were to be sold at a recycling facility nearby.

Based on personal conversations with the maids, they were suggested by the waste buyers that PET bottles should not be mixed with other kinds of wastes or with other colors of PET bottles. The maids shall empty the PET bottles and step on PET bottles to empty air from the container to reduce volume of wastes. Failure in sorting and emptying PET bottles would result in lower selling price.

To collect baseline data prior to installation of separate bins for recyclable wastes, the amount of PET bottles in the mixed and unsorted bins were collected during 2-week period between 17 February to 2 March 2013.

Two types of scales were used in this study. An analog scale was used for weighing PET bottles and a digital scale was used for weighing caps and labels. The scales are presented as Figure 3.1

Figure 3.1: Weighing Machine

Results of this phase of data collection are presented later in Table 4.1.

3.3.2 Pre-installation of RVM and Separate bins for recyclable wastes

After the above period, separated recyclable bins were installed to investigate the impacts of RVM on behavior of consumers and quantity and quality of recycled PET bottles compared to the data collected during post-installation of RVM period.

A total of 30 separate bins for recyclable PET bottles and small bins for collecting caps and labels were installed in all 8 floors of the 55^{th} ACB as presented on Figure 3.2. Locations of the bins were selected based on visibility and greater number of people passing by. The PET bottles bins and caps and labels bins are presented as Figure 3.3.

Floor	CAP	LABEL	PET
8	2	2	2
7	1	1	1
6	2	2	2
5	1	1	1
4	1	1	1
3	1	1	1
2	1	1	1
G	1	1	1
TOTAL	10	10	10

Figure 3.2: Number of Bins in each Floor

Figure 3.3: PET Bottle, Cap and Label Recycling Bins

Similar to pre-installation of recycle bins period, the wastes were collected during two weeks period starting from 24 March to 6 April 2013. The parameters of wastes including weight and numbers of bottles, caps, and labels, were measured and recorded on daily basis. Results of this phase of data collection are presented in Table 4.2.

3.3.3 Post-installation of RVM

Last experiment of this study was also to observed people behavior in the selected area, quantity, and quality once P'PET machine has been launched. The provided recycling bins were still remained in the same locations with the same method of data collection in the previous phase. However, weights of PET bottles collected by P'PET can be directly recorded from database of the machine.

It is expected that, with the existence of RVM, the numbers of PET bottles, caps, and labels disposed in the recycling bins should be reduced. This stage of data collection took place for two weeks in a period during 21 April – 4 May 2013. Results of this phase of the study are presented in Table 4.4 and Table 4.5.

CHAPTER 4
RESULTS AND DISCUSSIONS

This chapter presents the results of the study, which is summarized according three (3) phases of the study including: 1) Pre-installation of separate bins for recyclable wastes; 2) pre-installation of RVM and separate bins for recyclable wastes; and 3) post-installation of RVM. Discussions and key findings are also summarized.

4.1 Pre-installation of Separate Bins for Recyclable Wastes

This phase of the study collects the amount of PET bottles prior to the installation of recyclable bins and the RVM. PET bottles were collected by building housekeepers. This phase covered a total of 2 weeks of sample collection as presented in Table 4.1.

Floor 1 and 2-8 are separated, due to the area; usually in 1st floor was also occasionally occupied by other KMITL staffs and students. However, this temporary population deemed insignificant compared to regular population in the study area. Additionally, the data collection period was set during closed semester for other Thai academic program; during the same period, students in international program were in 2nd semester. This selected data collection period was expected to further focus the study on targeted study population.

According to Table 4.1, data are being collected in the period of 17-23 February 2013 for 1st week and 24 February 2013 for 2nd week, which had come up with an average amount of PET bottles per week that had been collected in the building by building housekeepers of 2.70 kilograms (kg) in 1st floor and 10.45kg in 2nd - 8th floor.

Table 4.1: Results of Pre-installation of Separate Bins for Recyclable Wastes (in kilogram)

Duration / Floor	Week 1 17 - 23 February 2013	Week 2 24 February - 2 March 2013	Average between 17 February - 2 March 2013
1	1.60	3.80	2.70
2 - 8	12.50	8.40	10.45

4.2 Pre-installation of RVM and Separate Bins for Recyclable Wastes

Data collection in this phase covered a period of 24 March 2013 to 6 April 2013, with a total of two weeks. There are three (3) provided bins in each of the assigned locations, which are bins for PET bottles, labels, and caps. Each bin was used to observed target recyclable material and contaminant(s) that were placed inside the provided bins. Amount of target recyclable materials were recorded by number pieces and its weights, contaminants are being weighed and recorded in kilograms; this result in a weekly average of target recyclable materials and contaminants that had been collected as in Table 4.2.

Table 4.2: Result of pre-installation of RVM and separate bins for recyclable wastes

Date / Floor / Provided bins	24 - 30 March 2013				31 March - 6 April 2013				Average between 24 March - 6 April 2013			
	1		2 - 8		1		2 - 8		1		2 - 8	
	PCS	KG	PCS	KG	PCS	KG	PCS	KG	PCS	KG	PCS	KG
PET bottle bin												
PET	28	0.57	350	6.82	23	0.50	416.0	8.80	26	0.54	383	7.81
Other contaminant	-	2.93	-	4.12	-	1.48	-	5.65	-	2.21	-	4.89
Label bin												
Label	18	0.01	285	0.18	9	0.01	430	0.37	14	0.01	358	0.28
Other contaminant	-	0.00	-	0.01	-	0.00	-	0.01	-	0.00	-	0.01
Cap bin												
Cap	13	0.02	246	0.43	12	0.02	430	0.77	13	0.02	338	0.60
Other contaminant	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00
PET bottle(s) outside provided bin	25	0.53	144	2.99	28	0.62	176	3.62	27	0.58	160	3.31

According to Table 4.2, the average weights of PET bottles collected from provided PET bottle recycling bins located on Floor 1 and Floors 2 to 8 are 0.54 and 7.81 kilograms, respectively. The contaminants inside provided PET bottle recycling bins located on Floor 1 and Floors 2 to 8 weigh an average of 2.21 and 4.89

kilograms, respectively. For provided label bins, the average weights of labels from provided label recycling bins located on Floor 1 and Floors 2 to 8 are 0.01 and 0.28 kilograms, respectively; with average contaminant on Floor 1 and Floors 2 to 8 are 0.00 and 0.01 kilograms. For provided cap recycling bins, the average weights of caps from provided cap recycling bins location on Floor 1 and Floors 2 to 8 are 0.02 and 0.60 kilograms, respectively; with no contaminant. Lastly, the average weight of PET bottles that were found outside the provided recycling bins are 0.58 kilograms from Floor 1 and 3.31 kilograms from Floors 2 to 8.

4.3 Post-installation of RVM

In this phase of the study, bins for recyclable wastes were still provided at the same locations. Additionally, a RVM (P'PET) was located on the 1st floor of the 55th ACB. Therefore this phase of the study covered data collection both from bins for recyclable wastes, similar to Section 4.1.2, and from the RVM. The data collection period was originally supposed to cover approximately starting from 21 April 2013 to 4 May 2013.

However, after the first week of data collection, the RVM was malfunction and in need of replacement. The new machine was delivered on 11 May 2013 and the data collection was planned to extend for another 2 weeks starting from 12 May 2013 to 25 May 2013. Unfortunately, another technical problem was experienced. Some data loss due to computer harddisk breaking down was occurred. As a result, the data collection period of 21 - 27 April 2013 and 12 – 18 May 2013 were used to calculate for a weekly average.

A summary of data collection periods of this phase of study is presented in Table 4.3. A summary of results of this phase of study is presented in Tables 4.4 and 4.5. In Table 4.4, the same explanation applied to Section 4.2.

Table 4.3: Post-installation of RVM data collection period

<table>
<tr><th>Month</th><th colspan="10">APRIL</th><th colspan="25">MAY</th></tr>
<tr><td>Date</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td></tr>
<tr><td>Data collection</td><td colspan="7">Week 1 (Old machine)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="7">Week 2 (New machine)</td><td colspan="7">Week 3 (New machine)</td></tr>
<tr><td>Problems</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="14">Pending machine replacement</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="7">Harddisk broken (data lost)</td></tr>
</table>

Table 4.4: Result of post-installation of RVM from provided recycling bin

Date / Floor Provided bins	21 - 27 April 2013				12 - 18 May 2013				~~19 – 25 May 2013~~ 19 - 21 May 2013				Average between 21 April - 18 May 2013			
	1		2 - 8		1		2 - 8		1		2 - 8		1		2 - 8	
	PCS	KG	PCS	KG	PCS	KG	PCS	KG	PCS	KG	PCS	KG	PCS	KG	PCS	KG
PET bottle bin																
PET	17	0.48	522	11.71	21	0.48	349	7.27	10	0.18	131	2.54	19	0.48	436	9.49
Other contaminant	-	2.98	-	6.45	-	3.98	-	19.43	-	1.23	-	9.48	-	3.48	-	12.94
Label bin																
Label	16	0.01	513	0.75	37	0.03	427	0.39	21	0.01	180	0.15	27	0.02	470	0.57
Other contaminant	-	0.00	-	0.00	-	0.00	-	0.01	-	0.00	-	0.00	-	0.00	-	0.01
Cap bin																
Cap	18	0.03	582	1.22	38	0.10	450	0.81	35	0.06	209	0.38	28	0.07	516	1.02
Other contaminant	-	0.00	-	0.12	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.06
PETbottle outside provided bin	43	1.03	139	3.29	41	0.94	148	3.38	19	0.4	61	1.21	42	0.99	144	3.34

Table 4.5: Result of post-installation of RVM from RVM (P'PET machine)

Week 1 (Old)	21 April 2013 (Sun)	22 April (Mon)	23 April (Tue)	24 April (Wed)	25 April (Thurs)	26 April (Fri)	27 April (Sat)	Total
PET (pcs, kg)	28, 0.87	30,0.90	13, 0.35	22, 0.50	6, 0.12	13, 0.37	15, 0.41	127, 3.52
Label (pcs)	28	30	13	22	6	13	15	127
Cap (pcs, kg)	31, 0.05	32, 0.05	16, 0.02	23, 0.03	8, 0.01	15, 0.03	17, 0.03	142, 0.22
Contaminant in cap's hole (kg)	0	0	0	0	0	0	0	0
Week 2 (new)	12 May 2013 (Sun)	13 May (Mon)	14 May (Tue)	15 May (Wed)	16 May (Thurs)	17 May (Fri)	18 May (Sat)	Total
PET (pcs, kg)	18, 0.49	0, 0	0, 0	7, 0.19	15, 0.40	3, 0.05	0, 0	43, 1.13
Label (pcs)	18	0	0	7	15	3	0	43
Cap (pcs, kg)	24, 0.04	0, 0	0, 0	10, 0.02	20, 0.03	5, 0.01	12, 0.02	71, 0.12
Contaminant in cap's hole (kg)	0	0	0	0	0	0	0	0
Week 3 (new)	19 May 2013 (Sun)	20 May (Mon)	21 May (Tue)	22 May (Wed)	23 May (Thurs)	24 May (Fri)	25 May (Sat)	Total
PET (pcs, kg)	24, 1.01	3, 0.08	0, 0	1, 0.02	18, 0.45	12, 0.27	7, 0.14	65, 1.97
Label (pcs)	24	3	3	1	18	12	7	68
Cap (pcs, kg)	26, 0.03	5, 0.01	10, 0.02	7, 0.01	22, 0.04	14, 0.02	7, 0.01	91, 0.14
Contaminant in cap's hole (kg)	0	0	0	0	0	0	0	0

*Note: Weights in PET's row are included with label's weight.

According to Table 4.5, the amount of PET bottles, labels and its weight were recorded by P'PET machine's database. However, for caps and contamination(s) in cap hole were manually recorded.

Table 4.6: RVM (P'PET machine)'s acceptant and rejection rate

Day \ Date / Status	21 - 27 April 2013		12 - 18 May 2013		19 - 25 May 2013	
	Accepted	Rejected	Accepted	Rejected	Accepted	Rejected
SUNDAY	28	46	18	32	24	21
MONDAY	30	22	0	0	3	7
TUESDAY	13	9	0	0	0	15
WEDNESDAY	22	44	7	7	1	18
THURSDAY	6	0	15	19	18	45
FRIDAY	13	34	3	10	12	6
SATURDAY	15	43	0	10	7	1
TOTAL	127	198	43	78	65	113

Table 4.6 summarizes acceptance and rejection rates recorded by P'PET machine. Rejections occurred based on 4 major events 1) Scramble barcode 2) Transparent label 3) Unregister of PET bottle information in P'PET machine's database 4) Contamination(s) inside PET bottle.

4.4 Discussions

Study results presented in Section 4.1 are discussed in the following subsections.

4.4.1 Quantity

Weights of collected PET bottles in all 3 phases of the study detailed in Section 4.1 are summarized in Table 4.7. The unit of measurement is in kilogram. The data presented covered all PET bottles which had been collected from the building, floor 1 to 8 of the 55th ACB.

Table 4.7: PET bottles collection's quantity

Quantity	Weight of all PET bottles in kilogram					
	Pre-installation of Separate Bins for Recyclable Wastes		Pre-installation of RVM and Separate Bins for Recyclable Wastes		Post-installation of RVM	
	Week 1 17 - 23 Feb. 2013	Week 2 24 Feb. - 2 Mar. 2013	Week 1 24 - 30 Mar. 2013	Week 2 31 Mar. - 6 Apr. 2013	Week 1 21 - 27 Apr. 2013	Week 2 12 - 18 May 2013
Floor 1 - 8	14.10	12.20	10.91	13.54	20.03	13.20
Average of week 1 and 2 for each phase	13.15		12.23		16.62	

On Figure 4.1, shows the demonstration of Table 4.7 in a graphical form. This helps to shows data in a clearer point of view and easier for comparison.

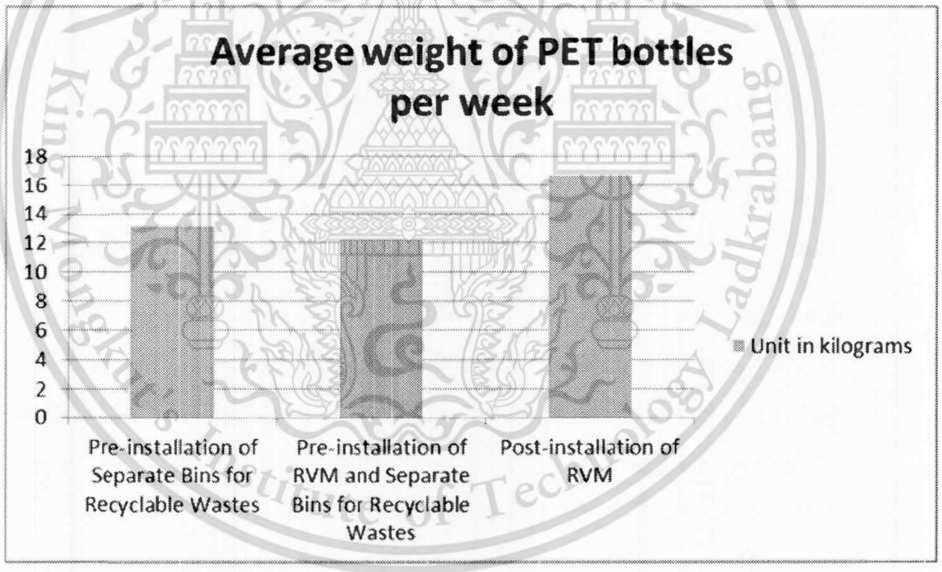

Figure 4.1: Graph on Average Weight of PET Bottles per Week

According to Figure 4.1, during phase 1 of the study, which is pre-installation of separate bins for recyclable wastes, an average weight for PET bottles of 13.15 kilograms (kg) per week was recorded. During phase 2, which is pre-installation of RVM with the existence of separate bins for recyclable wastes, an average weight for PET bottles of 12.23 kg was recorded. Lastly, an average weight for PET bottles of 16.62 kg was recorded during the last phase of the study when P'PET machine was already in place.

The data imply that with the existence of P'PET machine, quantity of PET bottles in the building were increased approximately 20.88% from phase 1 and 26.41% from phase 2. However, based on the results presented in Tables 4.2 and 4.4 it was previously assumed that; once P'PET machine was launched, PET bottles from provided bin should be reduced and instead go to P'PET machine. The results turned out to be the other way around.

One of the possible explanations is that, based on some observations, students usually brought their used PET bottles from their dormitory. However, P'PET machine had rejected some bottles as presented in Table 4.6. Main reasons of the rejection include impurity of bottle over the threshold limit set; unreadable barcode; or non-registered data in P'PET machine's database. The rejected bottles then went to the bins provided nearby the P'PET machine.

4.4.2 Quality

Quality refers to purity or in other term, homogeneousness, of recycled wastes. There are evidences indicating that poorly-sorted recycled plastics can lead to poor quality of raw materials that produced from the recycled plastics (Brachet et al., 2008). Reliable and efficient pre-process and in-process sorting methods play an important role in throughput and cost of recycling process (Teichmann et al., 2013).

Results in term of qualities in this section are divided into two (2) main parts which are quality of PET bottle with remaining liquid contents and quality of recyclable materials from provided bins (PET bottles, labels, and caps) with other contaminants.

4.4.2.1 Remaining Liquid Contents

During phrase one, which is "Pre-installation of separate bins from recyclable waste", water from PET bottles was normally drained out by maids. Minimal amount of remaining liquid contents was recorded as presented in Table 4.8. However, it is noticeable that more amounts of remaining liquid contents in the bins for recyclable were recorded during phases 2 and 3 of the study.

In contrasts, no remaining liquid contents in PET bottles disposed at the RVM were detected. This is because the machine was set not to accept bottles with remaining liquid contents exceeding the threshold limit set; the threshold is weight of PET Bottle together with label and cap of specific brand and size of inserted bottle, which is very low. Therefore, the RVM is likely to be a good solution to resolve the quality issue due to remaining liquid contents.

Table 4.8: Water Contamination

Phase	Pre-installation of Separate Bins for Recyclable Wastes				Pre-installation of RVM and Separate Bins for Recyclable Wastes				Post-installation of RVM (from provided bin)				Post-installation of RVM (from P'PET machine)			
Week	1		2		1		2		1		2		1		2	
Floor	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8
PET Bottle (kg)	1.60	12.50	12.50	8.40	0.57	6.82	0.50	8.80	0.48	11.71	0.48	7.27	0.48	11.71	0.48	7.27
Water (kg)	0.00	0.00	0.00	0.00	0.20	5.61	0.23	0.51	0.01	0.18	0.32	0.33	0.00	0.00	0.00	0.00

4.4.2.2 Other Contaminations

As presented in Section 2.1.3, PET bottle, label, and cap are made up from different type of materials. Therefore, recycled PET bottles mixed with labels and caps would result in lower quality of recycled PET as a whole. This would eventually result in lower price of recycled PET bottles. Results of the study present the impact of RVM on the amount of caps and labels disposed with recycled PET bottles as shown in Tale 4.9.

Table 4.9: Other Contaminations

Phase	Pre-installation of Separate Bins for Recyclable Wastes				Pre-installation of RVM and Separate Bins for Recyclable Wastes				Post-installation of RVM (from provided bin)				Post-installation of RVM (from P'PET machine)			
Week	1		2		1		2		1		2		1		2	
Floor	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8	1	2 - 8
PET Bottle (kg)					0.57	6.82	0.50	8.80	0.48	11.71	0.48	7.27	3.52		1.13	
Contaminant (kg)					2.93	4.12	1.48	5.65	2.98	6.45	3.98	19.43	*		*	
Label (kg)	-	-	-	-	0.01	0.18	0.01	0.37	0.01	0.75	0.03	0.39	*		*	
Contaminant (kg)					0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	*		*	
Cap (kg)					0.02	0.43	0.02	0.77	0.03	1.22	0.10	0.81	0.22		0.12	
Contaminant (kg)					0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00		0.00	

* There is no contaminant.

* PET Bottles and labels are placed in the same hole. (Weight of PET Bottles and labels are put together in PET bottle's row.)

Based on results shown in Table 4.9, phase 1 shows that there was minimal amount of caps and labels mixed with PET bottles because they were removed by building housekeepers before being sent to MRFs. During phases 2 and 3 of the study, data collected from bins for recyclable wastes show that there were higher amounts of caps and bins remaining inside the bins.

P'PET machine was designed, with the aim to address this issue. From the results, it is noticeable that there were no caps detected from bottles collected by the machine because the bottles with caps attached would be rejected. Nevertheless, PET bottles and labels were still mixed together in the same hole as on Figure 2.16 because the machine was still incapable of detecting labels attached with the bottles and still accepted such bottles.

CHAPTER 5
CONCLUSION

Environmental concerns had led to the study on waste management stream. The objective of the study is to investigate the impacts of RVM on the quantity and quality of recycled PET plastics, if any. The results of the study will be used to support decision making for enhancement of recycling industry and reverse logistics in Thailand.

There are three main phases of data collection in this study, which include 1) pre-installation of separate bins for recyclable wastes, 2) pre-installation of RVM and separate bins for recyclable wastes, and 3) post-installation of P'PET machine. The study area covered the 55th Anniversary Chalermprakiat Building, KMITL.

As a result in term of quantity, with P'PET machine installed; quantity of PET bottles in the building had been increased approximately 20.88% from phase 1 and 26.41% from phase 2. However, it was previously assumed that; once P'PET machine was launched, PET bottles from provided bin should be reduced and instead go to P'PET machine, but it has turned out oppositely. One of the reasons that can be obviously observed is that, students brought their used PET bottles from their dormitory. However, P'PET machine has rejected the bottle as the rate of rejected shows in Table 4.6. Main reasons of the rejection are impurity of bottle, unreadable barcode, or unregistered data in P'PET machine's database. Since the bottles were rejected, students look for an alternative ways to get rid of PET bottles by putting it inside the provided PET recycling bin.

In terms of quality, phase 1 shows that there is minimal amount of contaminant; due to PET bottles are being sorted by maids. During phases 2 and 3, data from provided bins show that there were still a lot contaminants remained inside the provided bins. However, P'PET machine was produced to eliminate the amount of contaminants because it will reject waste if there is still remaining content in the recycled bottles. Nevertheless, labels still cannot be separated by the machine and were stilled mixed in the shredded plastics from recycled PET bottles.

The study has shown that such a reverse vending machine like P'PET could play an important role in improving quantity and quality of recycled wastes. Some rooms for improvement have been indicated. The results of the study can be used to

upgrade the design of the machine in the future, such as RVM with function to separate label from PET bottle.

BIBILOGRAPHY

Ananchon, P. 2011. “Feasibility Study of Auto Vending Machine for PET Bottle in Kasetsart University.” Master’s independent study, Kasetsart University.

Becher et al. **Automatic Waste Recycling Machine and Disposal System.** U.S patent no. 5447017, Sep 1995.

Brachet et al. 2008. “ Modification of mechanical properties of recycled polypropylene from post-consumer containers,” **Waste Management.** 28(12) : 2456-2464.

Burintarajati A. 2013. **P’PET: Reverse Vending Machine for PET Bottle.** [PowerPoint]. Thailand : Asset Creation.

Californians Against Waste (CAW). 2012. **CalRecycle Supports Reverse Vending Machine.** [Online]. Available : http://www.cawrecycles.org/whats_new/recycling_news/feb27_replanet_reverse_vending_machines

Foppes, N. 2000. **Wongpanit: a successful waste recycling business in Phitsanulok, Thailand.** [Online]. Available : http://ms.ist.cmu.ac.th/riseat/documents/wongpan.pdf

Harrison, P. 2013. **The History of Recycling**. [Online]. Available : http://www.benefits-of-recycling.com/historyofrecycling/

Hurd, D. J. 2013. **Best Practices and Industry Standards in PET Plastic Recycling.** [Online]. Available : http://www.napcor.com/pdf/Master.pdf

Kenplas. 2013. **Recycled PET.** [Online]. Available : http://www.kenplas.com/topic/recyclepet.aspx

Kim et al. 2010. “Material and structural performance evaluation of recycled PET fiber reinforced concrete,” **Cement & Concrete Composites**. 32(3) : 232-240.

KMITL. 2013. **Personnel.** [Online]. Available : http://www.dstar.kmitl.ac.th/?q=node/79

BIBILOGRAPHY (CONT.)

KMITL. 2013. **Personnel.** [Online]. Available : http://www.nano.kmitl.ac.th/index.php?option=com_content&view=article&id=151&Itemid=22

KMITL. 2013. **Staff.** [Online]. Available : http://www.ic.kmitl.ac.th/staff/

Matichon. 2011. **P'PET Recycling Machine**. [Online]. Available : http://www.matichon.co.th/news_detail.php?newsid=1321246077&grpid=no&catid=&subcatid=

Miami County. 2013. **Recycling Drop Off Sites.** [Online]. Available : http://www.miamicountyin.gov/departments/solidwaste/recyclingdropoffsites.htm

Michigan. 2013. **Michigan Bottle Deposit Law Frequently Asked Questions.** [Online]. Available : http://www.michigan.gov/documents/deq/dnre-whmd-sw-mibottledepositlawFAQ_318782_7.pdf

National Association for PET Container Resources (NAPCOR). 2013. **What is PET?.** [Online]. Available : http://www.napcor.com/PET/whatispet.html

R.W. Beck. 1998. **Plastics Recycling Cost Optimization Project.** [Online]. Available : plastics.americanchemistry.com/Plastics-Recycling-Cost-Optimization

Recycling NJ. 2013. **Bottle Cap Recycling.** [Online]. Available : http://www.recyclingnj.com/recycle/caps.html

Rux69. 2012. **Automatic PET Plastic Recycling Process.** [Online]. Available : http://www.youtube.com/watch?v=N22tAXpnsjA

Santos et al. 2005. "Characterization of effluents through a typical plastic recycling process: An evaluation of cleaning performance and environment pollution," **Resources, Conservation and Recycling**. 45(2) : 159-171.

Schulze, Jr. **Automated Recycling Machine.** U.S patent no. 5111927, May 1992.

Siddique et al. 2008. "User of recycled plastic in concrete: A review," **Waste Management.** 28(10) : 1835-1852.

Sierra Club. 2013. **Sunshine State Bottle Bill.** [Online]. Available : florida.sierraclub.org/docs/Bottle+Bill+in+Florida.pptx

BIBILOGRAPHY (CONT.)

Singha. 2013. **PET bottle.** [Online]. Available : http://www.singhaonlineshop.com/th/drinking-water/29--500-cc.html

Subramanian, P.M. 2000. "Plastics recycling and waste management in the U.S.," **Resources, Conservation and Recycling.** 28(3) : 253-263.

Teichmann et al. 2013. **Development of High Performance Sorting Process for Recycling of Plastics.** [Online]. Available : http://www.swinburne.edu.au/engineering/iris/pdf/profiles/DerekTeichmann.pdf

Thelizzygaunt. 2010. **Bottle Bills ~ Waste in America.** [Online]. Available : http://www.youtube.com/watch?v=skQdWasGOUQ

Tomra. 2013a. **About Tomra.** [Online]. Available : http://www.tomranorthamerica.com/?nid=338

Tomra. 2013b. **T-63 TriSort.** [Online]. Available : T-63Trisort Fact sheet.pdf

Vest, H. 2003. **Production and Recycling of PET-Bottles.** [Online]. Available: http://www.gate-international.org/documents/techbriefs/webdocs/pdfs/e018e_2003.pdf

Vining et al. 1992. "Why recycle? A comparison of recycling motivations in four communities," **Environmental Management.** 16(6) : 785-797.

Welle, F. 2011. "Twenty years of PET bottle to bottle recycling-An overview," **Resources, Conservation and Recycling.** 55(11) : 865-875.

Wikipedia, 2013. **PET bottle recycling.** [Online]. Available : http://en.wikipedia.org/w/index.php?title=PET_bottle_recycling&oldid=514759776"

Wongchaoren, S. 2008. **Household Handbook.** 1st ed. Pitsanulok : Wongpanit Group.

Wongpanit. 2013a. **Today's Recycle Materials Price.** [Online]. Available : http://www.wongpanit.com/wpnnew/

Wongpanit. 2013b. **Wongpanit Garbage Recycle Separation Plant.** [Online]. Available : http://www.rrrkh.ait.ac.th/corporate_Initiatives_files/pdf/Wongpanit.pdf

Zhwjiang Lebao. 2013. **Pet bottles.** [Online]. Available : http://lebaoplastics.en.made-in-china.com/productimage/kbeJHDmAsPWI-2f0j00oevalh TYOHcW/ China-Pet-Bottles.html

APPENDIX

Interview Form

Interview Form

Interview Date

Company name

Location

Interview ee name

Interview ee position

Phone

What are the manufacturer requirements for quality recycled PET bottle?

กรุณาระบุบคุณภาพของขวดน้ำพลาสติกที่โรงงานกำหนด

How did manufacturer solve contamination problem (eg: straw , w ater, remaining content)? What are the rate of manufacturer acceptance?

ทางโรงงานมีการกำจัดสิ่งเจือปนก่อนนำส่งโรงงานรีไซเคิลอย่างไรและปริมาณสิ่งเจือปนเท่าไหร่ที่โรงงานยอมรับ

Is it necessary to remove PET bottle label and cap (Y/N)? Why?

มีความจำเป็นหรือไม่ที่ต้องทำการคัดแยกฉลากและฝาขวด จงอธิบาย

Will it be better to remove label and cap? What benefit can manufacturer get from removing label and cap?

คุณภาพของขวดจะดีขึ้นมั้ยถ้ามีการคัดแยกฉลากและฝาขวดและทางโรงงานจะได้ประโยชน์อย่างไร

Will there be price difference for removing label and cap versus w ithout removing?

ราคาในการรับซื้อมีความต่างกันหรือไม่ระหว่างขวดน้ำที่มีการแยกฝาและฉลากกับไม่ทำการคัดแยก

How did the manufacturer usually separate label and cap from PET bottle?

ทาวโรงงานมีขั้นตอนการคัดแยกฉลากและฝาขวดอย่างไร

Will PPET help in improving the quality and quantity?

ทางโรงงานคิดเห็นอย่างไรกับเครื่องแยกขยะอัตโนมัติ ทั้งในเชิงคุณภาพและปริมาณ

PET

Name

Signature

Date

ข้อมูลประวัติคณะผู้วิจัย

ประวัติส่วนตัว

ชื่อ-สกุล รณชัย ติยะรัตนาชัย

เพศ ■ชาย □ หญิง **วันเดือนปีเกิด** **10 มีนาคม 2522 อายุ 35 ปี**

สถานภาพ ■ โสด □ สมรส

ตำแหน่งปัจจุบัน อาจารย์

ประวัติการศึกษา

ชื่อย่อปริญญา	**สาขา**	**สถาบันที่จบ**	**ปีที่จบ**
Ph.D.	Environmental Sciences	New Jersey Institute of Technology	2010
M.Sc.	Environmental Management	จุฬาลงกรณ์มหาวิทยาลัย	2003
B.E.	วิศวกรรมสิ่งแวดล้อม	จุฬาลงกรณ์มหาวิทยาลัย	2001

สาขาวิจัยที่มีความชำนาญพิเศษ (แตกต่างจากวุฒิการศึกษา)

Environmental sustainability, green logistics, site remediation, and environmental policy

รางวัลด้านวิชาการ/ด้านวิจัย/งานสร้างสรรค์ (ด้านศิลปะ หรืออื่นๆ) ที่ได้รับ

Congressional Certificate honoring work on sustainable energy practices as part of a research grant through the U.S. Environmental Protection Agency's P3 (People, Prosperity, and the Planet) student design competition. Washington, DC. May 2006.

ทุนการศึกษาและทุนวิจัยที่เคยได้รับ ปี พ.ศ. ทุนการศึกษาและทุนวิจัยสถาบันที่ให้

KMITL International College research grant of academic year 2011

ผลงานวิจัย/งานสร้างสรรค์ที่ตีพิมพ์เผยแพร่ (ระดับชาติและนานาชาติ)

Publications

Jackson, N. L., Smith, D. R., Tiyarattanachai, R. and Nordstrom, K. F. (2007). Use of a small beach nourishment project to enhance habitat suitability for horseshoe crabs. *Geomorphology.* (89), pp. 172-185.

Tiyarattanachai, R., Kanatharana, P., and Hsieh, H. (2004). Treatment of trichloroethylene contaminated wastewater using Fenton's reagent. *Malaysian Journal of Science.* (23), pp.169-177.

Conference Proceedings

Bhu-anantanondh, T., Tiyarattanachai, R., and Hollmann, N. Environmental Performance Benchmarking of Refineries in Asean Economic Community. *Proc. Of The 6th ASEAN Environmental Engineering Conference (AEEC),* Bangkok, Thailand, November 21-22, 2013,p. E-8.

Tiyarattanachai, R. and Watts, D. J. (2011). Institutional controls in the views of state regulators and licensed site professionals. *Proc. Of The 4th ASEAN Environmental Engineering Conference,* Yogyakarta, Indonesia, November 22-23, 2011.

Tiyarattanachai, R. and Watts, D. J. (2011). Institutional controls and brownfield redevelopment. *Proc. Of The 3rd AUN/SEED-Net Regional Conference on Global Environment,* Kuala Lumpur, Malaysia, February 21-22, 2011, p.22.

Tiyarattanachai, R. and Watts, D. J. (2011). Institutional controls and sustainable remediation. *Proc. Of The 10th EEAT National Environmental Conference*, March 23-25, 2011, pp. 151-152.

Tiyarattanachai, R., Kanatharana, P., and Hsieh, H. (2003). Treatment of trichloroethylene contaminated wastewater using Fenton's reagent. *Proc. of International Conf. on Environmental Management and Technology, Malaysian University Consortium for Environment and Development – Industry and Urban Areas (MUCED – I&UA),* Putrajaya, Malaysia, August 4-6, 2003, p. 20.

การเสนอผลงานวิชาการ

Tiyarattanachai, R. and Watts, D. J. (2011). Institutional controls in the views of state regulators and licensed site professionals. *Proc. Of The 4th ASEAN*

Environmental Engineering Conference, Yogyakarta, Indonesia, November 22-23, 2011.

Tiyarattanachai, R. and Watts, D. J. (2011). Institutional controls and sustainable remediation. *The 10th EEAT National Environmental Conference*, March 23-25, 2011.

Tiyarattanachai, R. and Watts, D. J. (2011). Institutional controls and brownfield redevelopment. *The 3rd AUN/SEED-Net Regional Conference on Global Environment,* Kuala Lumpur, Malaysia, February 21-22, 2011.

Tiyarattanachai, R., Song, S., Utku, M., Rock, S., Sinha, R., and Lewis, T. (2007). Innovative geostatistical technique to identify historical contaminant inventory in navigable rivers/water bodies. *The 2007 Innovative Environmental Technology Conference.* The Environmental Business Council of Commerce and Industry Association of New Jersey. Newark, NJ. October 10, 2007.

Tiyarattanachai, R., Kanatharana, P., and Hsieh, H. (2003). Treatment of trichloroethylene contaminated wastewater using Fenton's reagent. *International Conf. on Environmental Management and Technology*, Putrajaya, Malaysia, August 4-6, 2003.

ผลงานสิทธิบัตร/สิ่งประดิษฐ์/งานสร้างสรรค์ (ศิลปะ หรือ อื่นๆ)

อื่นๆ

ประวัติส่วนตัว

ชื่อ-สกุล อิสระ อนันตวราศิลป์

เพศ ■ชาย ☐ หญิง **วันเดือนปีเกิด** **22 มิถุนายน 2522 อายุ 34 ปี**

สถานภาพ ■ โสด ☐ สมรส

ตำแหน่งปัจจุบัน อาจารย์

ประวัติการศึกษา

ชื่อย่อปริญญา	**สาขา**	**สถาบันที่จบ**	**ปีที่จบ**
Doctor rer. nat.	Computer Science	Technische Universität München	2553
Master of Computer Science	Computational Logic	Technische Universität Dresden	2547
Bachelor of Science	Information Technology	Sirindhorn International Institute of Technology	2544

สาขาวิจัยที่มีความชำนาญพิเศษ (แตกต่างจากวุฒิการศึกษา)

- Software Engineering
- Machine Learning
- Computer Networks

รางวัลด้านวิชาการ/ด้านวิจัย/งานสร้างสรรค์ (ด้านศิลปะ หรืออื่นๆ) ที่ได้รับ

2553 Selected Paper Award at the 8th International Network Conference

2550 Outstanding Paper Award at IADIS International Conference on Telecommunications, Networks and Systems

ทุนการศึกษาและทุนวิจัยที่เคยได้รับ

2550 Ernst-von-Siemens Doctorate Scholarship Siemens AG

ผลงานวิจัย/งานสร้างสรรค์ที่ตีพิมพ์เผยแพร่ (ระดับชาติและนานาชาติ)

2555 Willnecker, F., Anantavraslip, I., Brügge, B.: Machine Learning Assisted Position Detection of UHF RFID Tags. In: *European Conference on Smart Objects, Systems and Technologies*, Munich, 2012.

2554 Anantavrasilp, I.: Approximating IP Traffic Characteristics Using Partial Flows. In: *The 4th Regional Conference on Information and Communication Technology*, Ho Chi Minh City, 2011.

2553 Anantavrasilp, I.: Intelligent IP traffic / flow classification system. In: *Proceedings of the 8th International Network Conference*, Heidelberg, 2010.

2552 Anantavrasilp, I.: A unified framework for flow classification. In: *Proceedings of International Conference on Computer Design and Applications*, Singapore, 2009.

2550 Anantavrasilp, I. and Schöler, T.: Automatic flow classification using machine learning. In:
Proceedings of the 15th International Conference on Software, Telecommunications and Computer Networks, Dubrovnik, 2007.

2550 Anantavrasilp, I. and Schöler, T.: Providing quality-of-service support to legacy applications using machine learning. In: *Proceedings of IADIS International Conference on Telecommunications, Networks and Systems*, Lisbon, 2007.

การเสนอผลงานวิชาการ

2555 Willnecker, F., Anantavraslip, I., Brügge, B.: Machine Learning Assisted Position Detection of UHF RFID Tags. In: *European Conference on Smart Objects, Systems and Technologies*, Munich, 2012.

2554 Anantavrasilp, I.: Approximating IP Traffic Characteristics Using Partial Flows. In: *The 4th Regional Conference on Information and Communication Technology*, Ho Chi Minh City, 2011.

2553 Anantavrasilp, I.: Intelligent IP traffic / flow classification system. In: *Proceedings of the 8th International Network Conference*, Heidelberg, 2010.

2552 Anantavrasilp, I.: A unified framework for flow classification. In: *Proceedings of International Conference on Computer Design and Applications*, Singapore, 2009.

2550 Anantavrasilp, I. and Schöler, T.: Automatic flow classification using machine learning. In:
Proceedings of the 15th International Conference on Software, Telecommunications and Computer Networks, Dubrovnik, 2007.

2550 Anantavrasilp, I. and Schöler, T.: Providing quality-of-service support to legacy applications using machine learning. In: *Proceedings of IADIS International Conference on Telecommunications, Networks and Systems*, Lisbon, 2007.

ผลงานสิทธิบัตร/สิ่งประดิษฐ์/งานสร้างสรรค์ (ศิลปะ หรือ อื่นๆ)

2550 DE102007042588 - Method for Monitoring Data Flows

2549 EP2039079 - System and Method for Data Communication

อื่นๆ

ประวัติส่วนตัว

ชื่อ-สกุล นายชัยวัฒน์ หนูทอง

เพศ ■ชาย ☐ หญิง **วันเดือนปีเกิด** **23 มิถุนายน 2517 อายุ 39 ปี**

สถานภาพ ☐ โสด ☐ สมรส

ตำแหน่งปัจจุบัน อาจารย์

ประวัติการศึกษา

ชื่อย่อปริญญา	สาขา	สถาบันที่จบ	ปีที่จบ
วศ.บ.	ไฟฟ้ากำลัง	สจล.	2538
M.Sc.	Mechatronics	University Siegen	2547
Dr.-Ing.	Control Engineering	Universitaet der Bundeswehr Muenchen	2552

สาขาวิจัยที่มีความชำนาญพิเศษ (แตกต่างจากวุฒิการศึกษา)

Control and automation, Estimation, Image processing, Machine learning

รางวัลด้านวิชาการ/ด้านวิจัย/งานสร้างสรรค์ (ด้านศิลปะ หรืออื่นๆ) ที่ได้รับ

ทุนการศึกษาและทุนวิจัยที่เคยได้รับ

ปี พ.ศ. ทุนการศึกษาและทุนวิจัย สถาบันที่ให้

2552-2555 **ทุนสร้างสรรค์นวัตกรรม, สำนักงานข้าราชการพลเรือน**

ผลงานวิจัย/งานสร้างสรรค์

ผลงานวิจัย/งานสร้างสรรค์ที่ตีพิมพ์เผยแพร่ (ระดับชาติและนานาชาติ)

S.Chatruprachewin and C. Nuthong, "A Simulation of Air Bearing Surface Materials with Copper Substrate for Corrosion Investigation", Proceedings of ECTI-CON 2013, Krabi, Thailand, 2013.

Ch. Nawakaphoom and C. Nuthong, "Applications of Image Fusion using Wavelet Transform in Slider Orientation Measurement", Proceedings of International Conference of Information Science and Computer Applications, Bali, Indonesia, 2012.

C. Nuthong, "Vision-Based Lane Departure Warning System Using A Single On-Board Camera", Proceedings of the 5th AUN/SEED-Net Regional Conference on Information and Communications Technology, Manila, Philippines, 2012.

Ch. Mahantadechakul and C. Nuthong, "HDD Contaminated Particle Detection Using Optimal Thresholding Image Analysis", Proceedings of the 4th International Data Storage Technology Conference, Bangkok, Thailand, 2011.

C. Nuthong, "Intrinsic Images of Shadow Casted Road for Lane Detection Purposes", Proceedings of the 4th AUN/SEED-Net Regional Conference on Information and Communication Technology", Ho Chi Min City, Vietnam, 2011.

การเสนอผลงานวิชาการ

ผลงานสิทธิบัตร/สิ่งประดิษฐ์/งานสร้างสรรค์ (ศิลปะ หรือ อื่นๆ)

อื่นๆ