Automated Sorting of Plastics for Recycling

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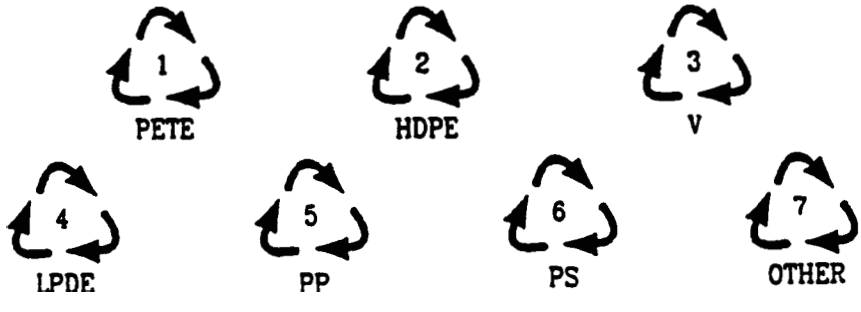
ABSTRACT

This paper presents a synthesis of available information on automated sorting of plastics. The material includes technologies that are commercially available and those that are still in the research phase of development. The information is broken into two categories: macrosorting and microsorting. The macrosorting section deals with the sorting of whole bottles or containers. The section covers the following technologies: infrared spectroscopy, x-ray, laser-aided identification, and marker systems. The microsorting section follows the sorting of plastic after it has been chopped into pieces. The section covers the following areas: Sink float Systems, froth-floatation, and selective dissolution. As a final note, future areas of research are suggested.

INTRODUCTION

Sorting of plastics into resin categories is important due to the various characteristics that each of the different resin types hold. In order to recycle plastic into useable resins with the desired characteristics, a pure stream of resin categorized waste must be achieved. Companies that buy recycled resins want those recycled resins to have the same characteristics as virgin resins. Otherwise, it is not efficient to use recycled materials. Therefore, plastics sorted by resin type hold the highest market value. Another key example of the need for properly sorted plastics for recycling is the case of PET and PVC, which are sometimes indistinguishable by sight. These two resins are contaminants to each other. combinations of PVC and PET resins can result in the release of hydrochloric gases. The PET resin will be ruined even with only a few parts per million of PVC resin (Scott 1995).

Most of the current plastic sorting is done by hand. Manual sorting is a simple process that needs very little technology, but it leaves much room for improvement. Manual sorting is a very labor intensive, costly, and inefficient method for sorting plastics. One problem with efficiency is that the labor force involved in manual sorting has a high turnover rate. This high turnover rate creates an improperly trained or inexperienced workforce. Also, it is difficult to differentiate between the resin types used in packages through the visual means employed by-manual sorting. For this reason, the Society of the Plastics Industry instituted a voluntary labeling system. The system created a set of codes (figure 1) for each of the six most commonly used resin types.



1. Polyethylene terephthalate
2. High–density polyethylene
3. Vinyl
4. Low–density polyethylene
5. Polypropylene
6. Polystyrene
7. Other. including multilayer

Figure 1: Resin code labeling system (US EPA 1991).

Even with this labeling system, it is still difficult to manually distinguish polymer types due to the condition of the plastics as they reach the separation facility. The bottles may be crushed, cracked, or covered rendering the resin label useless.

Macrosorting deals with the separation of whole bottles or containers. This type of sorting is the only one currently available commercially. It has the advantage of needing very little or no preparation before sorting. Microsorting deals with plastic after it has been chopped up into pieces. This system has the advantages of lower shipping costs and larger volume processing.

MACROSORTING

SPECTROSCOPY

Near-infrared spectroscopy is one of the most promising prospects for automated sorting of post-consumer plastics. This technique involves irradiating the unsorted, unidentified plastic: with near-infrared waves (600 to 2500 nanometers in wavelength). When the infrared light reflects off the surface of the plastic, each resin's characteristic infrared absorption band can be measured (figure 2). These measurements can then be compared to known polymer values to determine the resin type.

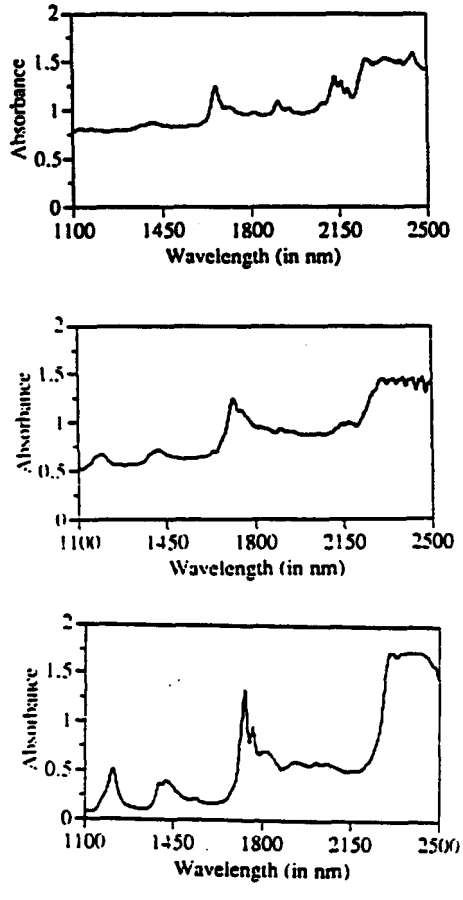


Figure 2: Examples of the different polymer absorption spectrums of green PET, PVC, and red HDPE respectively (Scott and Waterland 1995).

This separation method has many advantages. Probably the most significant advantage of using spectroscopy is the speed of identification. Because of the great scanning speed of the spectroscopic instrument, many readings of one sample can be taken in short periods of time. This allows multiple checks to ensure proper identification. The speed also provides for increased volume of plastics sorted in smaller amounts of time. A second advantage is the lack of specimen preparation. Labels, or other obstructions like dirt, do not interfere with readings. Another advantage of this system is that color docs not interfere with proper resin identification. Except for black, the readings are independent of the color of the resin. Black is a strong absorber in the near-infrared region, and scanning of black plastics result in a featureless spectrum (Huth-Fehre et al. 1995). However, a new instrument manufactured by Bruker Instruments Incorporated can identify black-colored plastics (Ashley 1995).

A few different models of spectroscopic units for mixed plastic separation are in commercial use today. These include Magnetic Separation System's BottleSort system and Automation Industrial Control's Poly-Sort system.

BottleSort (The Society of the Plastics Industry, Inc. 1996)

The MSS BottleSort system begins with a debaler and screening system to remove any materials that do not meet size requirements. This first step also removes any contaminants from the system. Next, a mechanical and air driven singulator separates the containers into single file and moves them onto a high speed acceleration conveyor belt. This belt carries the containers through a detection unit where sixteen infrared beams take over 5,000 readings per second. Here, resin classification is made in less than five milliseconds. The system also detects whether or not there is an error in identification due to multiple containers being detected at once. The BottleSort system treats the bottles as one if they are of the same resin type. If the bottles are of different types, they proceed through the entire system to a bin whose contents are later sent back through the system.

After identification, each plastic container is tracked along the conveyer until reaching the location of its separation and a pulsed air jet ejects the bottle onto the correct category conveyor. The initial BottleSort system sorts bottles into three different categories: PET and PVC, unpigmented HDPE and PP, and mixed-color HDPE. This grouping separation allows for greater sorting speed. Additional components can be added to the system for further sorting. The color sorting of green and clear PET, and the separation of unpigmented HDPE from unpigmented PP, are performed by a system similar to the original. The separation of PVC from PET can be performed with an x-ray transmission sensor. A vision-system sensor can also be added to sort pigmented HDPE by color using video and computer technology. Depending on the system, the MSS BottleSort sorts around 1,250 pounds per hour for a basic model (Powell 1995) or up to 5,000 pounds per hour for the fully integrated system (Dinger 1992b).

Poly-Sort (The Society of the Plastics Industry, Inc. 1996)

The Poly-Sort system, like the BottleSort, begins by separating the bottles into single file order. In this case the job is performed by a vibrating singulator that also removes contaminants. A near-infrared beam is shown through each container at a rate of fifty times per second. In less than 19 milliseconds, the plastic's characteristics are processed and resin characterization takes place. This sensor detects whether the resin is PET,

HDPE, LDPE, PVC, PP, PS, or polycarbonate (PC). A color camera and strobe light combination allow for color identification down to different shades of one color,. if necessary. The resin and color identification information is stored and the position of each bottle is tracked. When the container passes by a sensor at the edge of the appropriate sorting chute, a pulse of air sends the bottle onto its proper conveyor belt. If any material is unidentifiable, it is carried through the entire process to a special container at the end of the the. According to 1992 figures, the sorting rates performed by the Poly-Sort system range from 1,500 pounds per hour up to 3,000 pounds per hour (Dinger 1992b).

Current Research

There are many current research projects involved with the near-infrared spectroscopy method of sorting plastics. Much of this research deals with creating even more efficiency in the process. One such research initiative includes the development of a simplified spectrometer for rapid and reliable sorting (Scott 1995). The method developed involves finding the dominant peak in each of the studied plastics' absorbence spectrum. Two different peaks were noted for PVC and PET. The identification of each plastic is then based solely on readings taken at the peak wavelengths. This would allow future plastic sorting machines to use fined-filter spectroscopic instruments that would be cheaper and more rugged than continuous spectra machines.

Further study was also done into using three different wavelengths for identifying three different resin types (Scott and Waterland 1995). The three-resin study also analyzed the use of artificial neural networks for quick identifications. Artificial neural networks are sets of combined processors that learn how to identify plastics. This learning is developed through multiple exposures to the identification process where the computer guesses the correct answer and is then shown the correct answer (Coghlan 1993). This system, when used in conjunction with a spectroscopy identification system, allows for quicker identification of resin type. Previous systems used comparisons with a library of known plastic absorption spectrum. Other research has also been conducted into the use of artificial neural networks in conjunction with infrared spectroscopy for the efficient sorting of plastics (Coghlan 1993) (Huth-Fehre et al. 1995).

Another research effort strove to compare the efficiencies of two common spectroscopy methods for plastic identification (Florestan et al. 1994). The two spectroscopy instruments studied were the Fourier Transform Middle Infra Red Spectroscopy (FTMIR) and the Fourier Transform Raman Spectroscopy (FT Raman). This study determined that the FT Raman spectroscopy method is much better than the FTMIR for plastic identification (Florestan et al. 1994).

X-RAYS

Another sorting option lies in the field of x-ray transmission and reflection. Similar to the infrared spectroscopic methods discussed previously, this separation method exposes the unknown plastic to waves and studies the object's response. In this case, the transmission and reflection from waves in the x-ray region of the spectrum are studied. Most of this technology is being applied to the sorting of PVC. The chlorine atoms in PVC give a unique peak in the x-ray spectrum that is readily detectable (Dinger 1992b).

A few x-ray detection units are commercially available today. These include the

VS-2, developed by ASOMA instruments. and the Vinylcycle, developed by National Recovery Technologies Incorporated (NRT). As previously mentioned, one optional component to the MSS Bottlesort system also uses x-ray transmission.

VS-2

This system uses the x-ray reflection to detect PVC in plastic waste streams and can sort around ten bottles per second (Powell 1992). As in the previously mentioned BottleSort and Poly-Sort systems, plastic containers need to be ordered in single file before detection. The VS-2 has a fast analysis capability of around 200 analysts per second with a very low miss rate of around only one bottle per l00,000 (Dinger 1992b). In use, the VS-2 system sorts two to three bottles per second at a rate of 800 to 1,200 pounds per hour (Powell 1992).

VinylCycle

The VinylCycle system developed by National Recovery Technologies (NRT) uses x-ray transmission to identify and separate PVC from a plastic waste stream. The outstanding feature of this system is the ability to sort without the necessity of a single file ordering system. When the Vinylcycle system detects PVC, an air burst separates the plastic from the rest of the waste stream (figure 3).

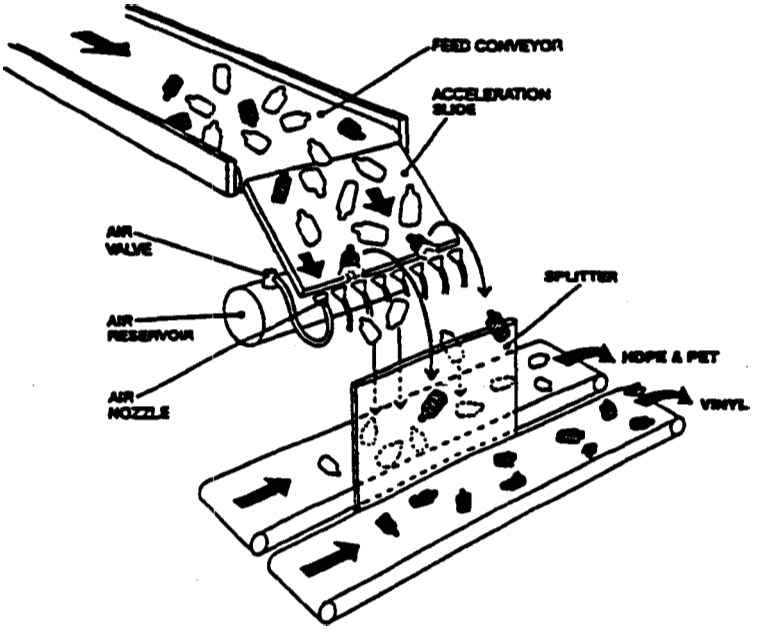


Figure 3: NRT Vinylcycle system (NRT pamphlet b).

Vinylcycle is available in different size models to handle different source amounts. The output levels of the different models range from 3.5 bottles per second and approximately 1,500 pounds per hour to 10 bottles per second and 4,500 pounds per hour(NRT pamphlet b). As a side note, NRT also manufactures the MultiSort system that separates different colors of resins by optical and vision methods (NRT pamphlet a).

LASER-AIDED IDENTIFICATION

Another possibility for the automatic identification of plastics for sorting is laser-aided identification. This system identifies plastics by shining a laser beam onto the surface to be identified and then analyzing the material's response (figure 4). At the Laser Zentrurn Hannover, a sorting method was developed which sorts out different plastics using a heat impulse response to identify different materials. Their process uses a CO_2 laser to project a small beam spot onto the material to be identified. Through use of an infrared thermographic system, various material properties including absorption coefficient, thermal conductivity, thermal capacity, and surface temperature distribution are recorded (Haferkamp, Bumester, and Engel 1993). These properties can then be analyzed to identify plastic type. The resulting system is suitable for quick analysis and identification of various plastics.

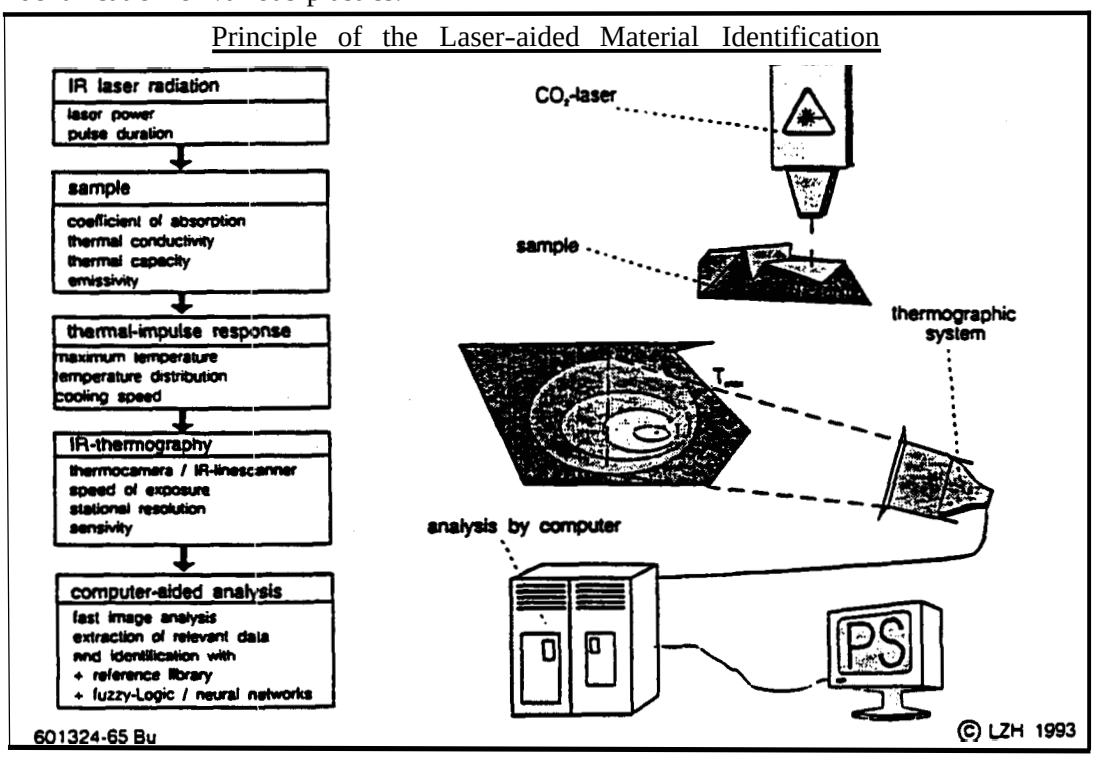


Figure 4: Principle of the laser-aided material identification (picture and text, Haferkamp, Burmester, and Engel 1993).

Haferkamp, Burmester, and Engel (1993) have provided the following results of their investigation of laser-aided identification of plastics:

1. Due to the small energy input, very little damage occurs on the plastic surface.

2. Different thickness, forms, and surface structures do not play any role in identifying plastics.

3. Printing and different additives (softeners) also do not play any role.

4. A problem of the definite classification of the base plastic has been highly .concentrated fillings, particularly of carbon.

5. Due to the evaluation of the maximum temperatures directly after laser radiation a clear identification of the plastics could be proved.

6. Consequently, it can be shown that even with these non-optimized parameters, plastic identification within only 1/10 second is possible.

MARKER SYSTEMS

One option for the automated sorting of plastics lies in the area of marker systems. This method entails marking either the container or the resin itself with something readily detectable. There are seemingly no insurmountable barriers standing in the way of an automated sorting system that would read a hidden marker and identify resin type (US EPA 1991).

One marker system option is to mark all containers with an invisible ink that is readily detectable. This system, developed by Continental Container Corporation, allows for the separation by resin type, color, resin additive package, and package contents (Dinger 1992b). This system is costly, at least initially. Every packaging production line would have to install a marking system on their line. Also, each recycler would need to install a machine to scan for the marking on the containers.

Another alternative is being developed by the Eastman Chemical Company. Their system uses a molecular marker to identify the type of resin (Dinger 1992b). On the positive si& of this method, there would be a relatively low cost increase for the addition of the marker to the resin, and their system would only requirerecyclers and resin manufacturers to participate. That is a significantly smaller group than all of the packaging producers (Dinger 1992b).

A polymer dye for resin identification is being studied by the resin firm Bayer AG. Their marker system would use a different florescent dye or dye combination for every grade of thermoplastic (Mapleston 1992).

> Florescent dyes have high detection sensitivity and can be added in minute quantities. Bayer says that based on development work, 5 g. of dye per ton of polymer appear to be sufficient for identification by a diode device it is also developing. Bayer says that the dyes don't affect part appearance or properties. (Mapleston 1992)

Alike the other possible marker systems, cooperation with the recyclers and resin manufacturers is necessary. Bayer AG has a head start in dealing with recyclers since it is already developing the device to be used along with the dyes for identification.

MICROSORTING

SINK FLOAT SYSTEMS

Sink float separation systems are very common and simple methods of separating materials of different densities. The method simply involves depositing the materials in a

tank filled with water or other liquid. The lighter materials float and the heavier ones sink. For a sink float system to work efficiently the materials' densities must differ greatly from one another. Some plastics, like PVC and PET, have very similar densities (table 1) and cannot be separated by normal sink float system. A few studies have been undertaken to develop sink float methods that would be effective with plastics.

	Density range (g/cm^3)
Polyolefins	
Polypropylene	0.916-0.925
Low-density polyethylene	0.936-0.955
High-density polyethylene	0.956-0.980
Non-olefins	
Bulk polystyrene	1.050-1.220
Polyvinyl chloride	1.304- 1336
Polyethylene terephthalate	1.330—1.400

Table 1: Polymer density ranges (Atland et al. 1995)

One such study is being performed at the University of Pittsburgh (Atland et al. 1995). The system being developed uses high-pressure, near-critical liquids as the separation media. At a critical point, the fluid's density is changed by altering the pressure. Therefore, by decreasing the pressure in small increments, the liquid density is also decreased in small increments (Dinger 1992a). According to the study, the fluid density is then adjusted to an intermediate level between two types of plastics to be separated, causing one type to float and the other to sink The low viscosity of the fluid causes the materials to rise or fall rapidly, even with small differences in densities between the particles and the liquid (Atland et al. 1995).

The Pittsburgh study developed a gameplan (figure 5) for separating the most common post-consumer plastics including PP, HDPE, LDPE, PS, PET, and PVC (Atland et al. 1995).

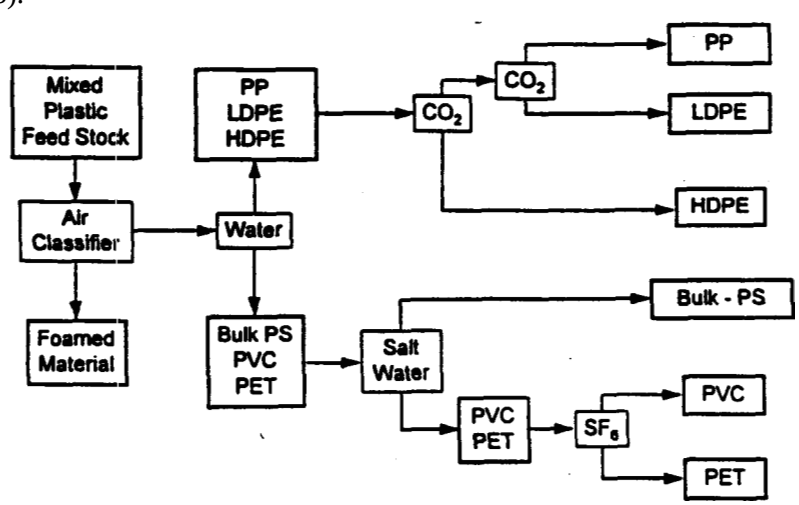


Figure 5: Proposed plastic recycling schematic with high-pressure separations (picture and text, Atland et al. 1995).

The first step is to separate the lighter polyolefins (HDPE, LDPE, PP) from the heavier non-olefins (PS, PET, PVC). This is achieved using water as the sink-float medium. Next, HDPE is separated from LDPE and PP using a sink-float medium composed of near-critical carbon dioxide (CO_2). Also using CO_2, LDPE is then separated from PP. On the non-olefin side of the separation scheme, PS is removed in a saltwater solution. The remaining plastics (PVC and PET) are separated with near-critical sulfur hexaflouride (SF4). This technique is demonstrated to have the ability to separate differing colors of HDPE from their slightly different densities (Dinger 1992a).

The results of the study look promising:

> There was no overlap between the polyolefins, and they were cleanly separated (100% purity and 100% recovery) in float-sink experiments with liquid CO_2 used as the separation medium. There was a single PVC packaging material that had a density in the range associated with the PET samples, however, that resulted in 95% recovery of the PET in a stream of 99% PET purity. (Atland et al. 1995)

An economic study on the effectiveness of this separation method was also conducted with promising results (Atland et al. 1995).

FROTH-FLOTATION

Froth-flotation is another possible method developed to microsort plastics. This method works similarly to sink float systems. In froth-floatation, the materials to be separated are first treated with a surfactant and then suspended in water. Because of a reaction with the surfactant material, plastics that would normally sink in water are suspended in the water mixture. Air is then pumped into the system. The air bubbles adhere to some particles depending on their resin type causing the particles to float to the surface. Materials that are not affected by the bubbles sink to the bottom. Collection systems at the top and bottom of the system can then collect the now separated materials (Dinger 1992a).

There are some key advantages to the froth-flotation system. First, the process is very simple: no high technology is necessary. Second, the chemicals used are inexpensive and do not pose any serious environmental hazards. Third, froth-flotation can separate PET from PVC. That posed a. problem to the most common sink float separation processes (Separating 1993).

SELECTIVE DISSOLUTION AND FLASH DEVOLITIZATION

Selective dissolution and flash devolitization is a plastic sorting option that is still in the research stage. The process separates mixed or commingled plastics waste into nearly pure reusable polymers without mechanical presorting techniques (Recycling 1992).

In research performed at the Renesselaer Polytechnic Institute (RPI), xylene is used to individually dissolve five of the most common post-consumer plastics: PVC, PS, LDPE, HDPE, and PP. When xylene is placed into the plastic chip system at room temperature, the PS dissolves leaving the remaining plastics untouched. The xylene/PS solution is next drained to another tank where the solution is heated above xylene's boiling point. The solution is then sent to another chamber where the pressure is lowered quickly causing the xylene to rapidly vaporize. This leaves behind the pure polymer PS in a flash

devolitization step (Recycling 1992). The xylene is recovered and fed back into the plastic chip system where the process is repeated at different temperatures, each plastic with its own individual dissolution temperature in xylene. The other common post-consumer plastic, PET, needs to be removed using a separate solvent.

Other research performed at Cornell University finds that a one solvent system is not enough. Problems that the Cornell research team found with the RPI method include the following: high pressures involved in the process lead to high energy and equipment costs, high temperatures increase the risk of thermally degrading the polymers, and reduced purity of polymers due to a single solvent system (Vane and Rodriguez 1990). The reduction in polymer purity results from partial dissolution of polymers at lower temperatures than intended and undissolved particles adding to the mix to be dissolved at higher temperatures'.

The Cornell study suggests the use of a combined technology process for sorting plastics. Their process would begin with separation of non-olefins and polyolefins by a simple sink float system. Then selective dissolution would be the next step with a different solvent for each plastic group (figure 6). 'This technique would combine the ease and cost-effectiveness but low purity of sink float systems with the high purity but high cost of selective dissolution (Vane and Rodriguez 1990).

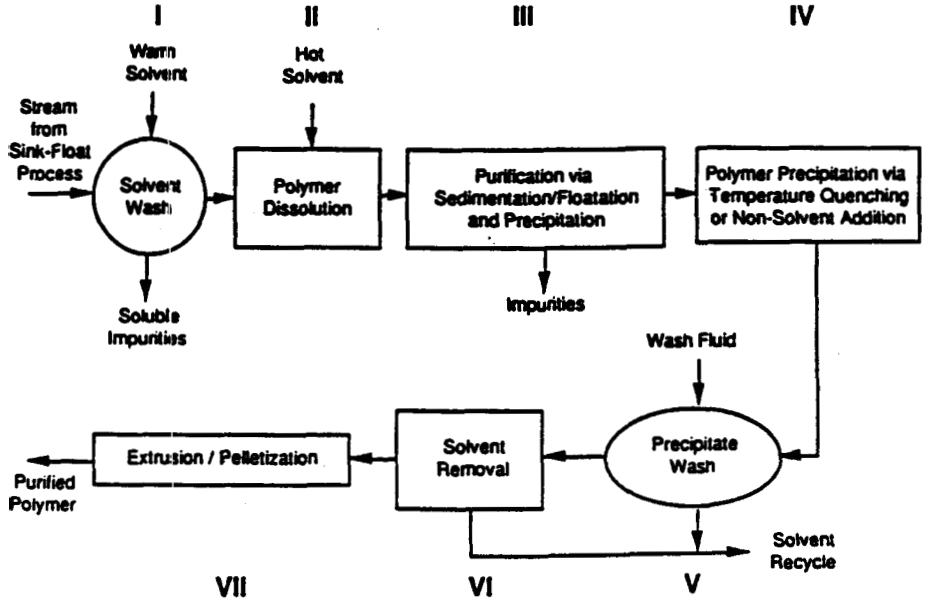


Figure 6: Example of the multi-solvent selective dissolution process (Vane and Rodriguez 1990).

The suggested solvent for the dissolution of PET (formerly a problem plastic in the original all xylene RPI process) is n-methyl-2-pyrrolidinone (NMP). This choice of solvent was determined upon the criteria of cost, toxicity, solvent recovery, favorable PET solution behavior, and incompatibility with polyolefins (HDPE, LDPE, PP) (Vane and Rodriguez 1990).

CONCLUSIONS

Most of the current commercial technologies have process capabilities and price ranges that limit their users to large volume recyclers. The current systems would be best applied to facilities that handle plastic shipped in from many sources including multiple numbers of municipal recycling facilities (MRFs). Some MRFs may qualify to employ these technologies if their plastic intake volume is large enough. Each of the sorting methods currently being researched show great promise. In all cases, a combined technology process seems to be the ideal choice. That type of process joins cheap inefficient methods with expensive efficient ones thus creating a more cost-effective situation. More study needs to be done to determine the ideal system.

FURURE RESEARCH AREAS

Research is needed into the economics of the commercially available technologies, This would include feasibility studies involving finding the amount of plastic intake to warrant the purchase of automated sorting equipment and timelines to profit. Although there is a proven need for this technology, the study of automated technology for plastic identification and sorting is still in its infancy. Further research is needed into all of the sorting technologies. These studies should be focused on improvements in the efficiencies of all techniques. Research is also needed in building large scale systems to test the full capabilities of the newer technologies.

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