

### **3. Emerging Methods for Processing and Separation of Plastics**

Because the manual sorting of heterogeneous plastic mixtures is the current level of technology in all but a few applications of plastics recycling, methods to effectively separate them on a more automated basis is receiving attention. Methods for automated sorting rely on such responses as specific gravity changes, x-ray diffraction, optical recognition and dissolution in solvents. No one of the above methods can completely sort any type of plastic mixture.

The sorting methods being worked on can be classified into macro, micro or molecular scale sorting. Macro sorting involves separating plastic based on an entire product such as using optical sensing to separate whole bottles by color. Manual separation is also a macro sorting method. Micro sorting involves the initial processing to a uniform criteria, such as size, with subsequent separation. An example of micro sorting is the commercially viable PET bottle/HDPE base cap separation method where bottles are ground up and sent through a hydrocyclone; the PET and aluminum cap grind sinks while the HDPE floats. Molecular separation involves processing plastic by dissolving the plastic and then separating plastics based on temperature.

#### *3.1 Optical Color Sorting of Glass and PET Containers*

This method currently exists as a laboratory prototype with a larger prototype being designed and fabricated for a local recycling center. The clear/color sorting system (CCSS), being developed at the University of Illinois Urbana-Champaign (UIUC), is for the clear/color separation of glass and PET plastic beverage bottles using optical sensors coupled with a control circuit to activate diversion of clear glass or PET from colored glass and plastic.

While processing glass at the Champaign, Illinois Recycling Center, the CCSS will be a separation aid in that the automated sorter will divert a majority of clear glass containers from the glass recycle stream while leaving green and amber glass containers. A manual sorter will then have to remove brown bottles from the green glass stream. A simplified diagram of the container separation system is shown in Figures 3.1(a) and 3.1(b). The laboratory prototype consisted of a manually fed trough followed by an alignment device which aligned bottles so they would not jam the conveyor and would pass over the optical sensing device. Directly below the alignment section was the optical sensing section and then the diversion section, which consisted of a plywood diverting gate moved by an electric solenoid with a one inch actuation stroke [Newell and Lewis, 1990].

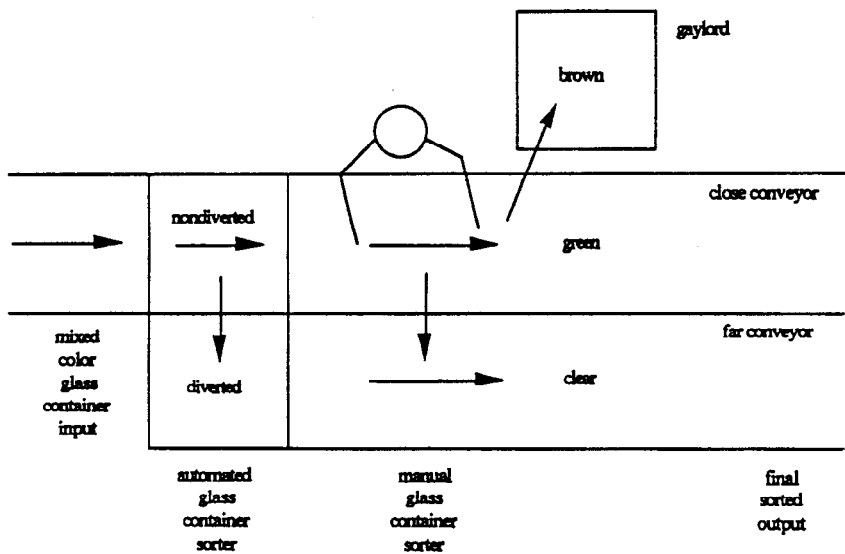


Figure 3.1(a) Clear/Color Sorting System Picking Station Arrangement [Newell and Lewis, 1990]

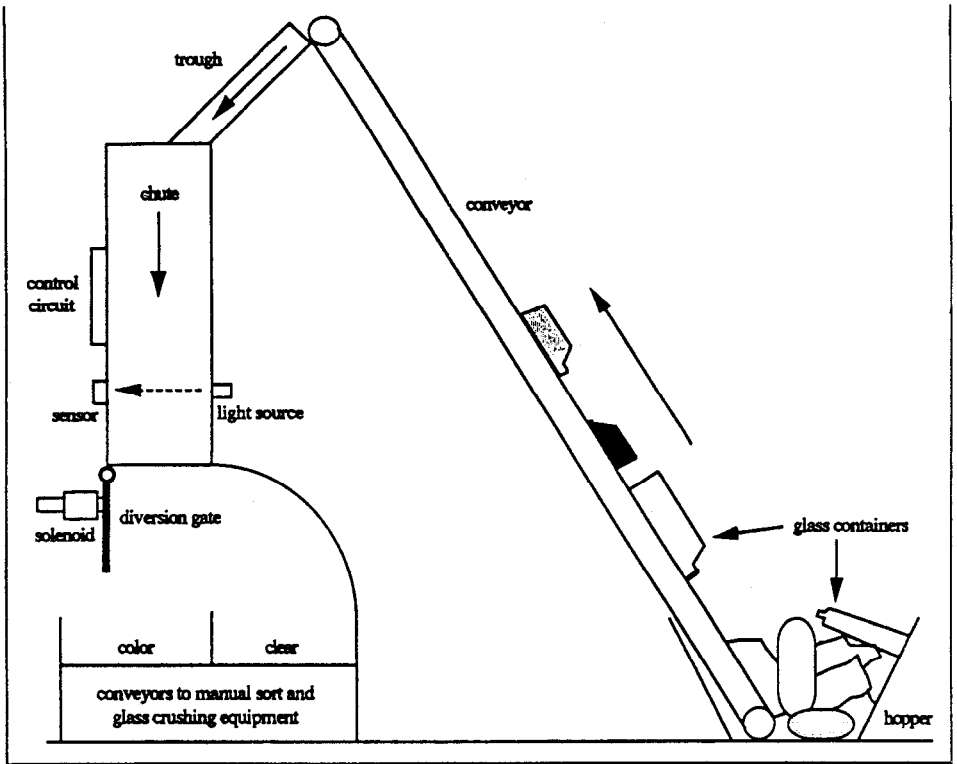


Figure 3.1(b) Clear/Color Sorting System Schematic [Newell and Lewis, 1990]

The researchers reported difficulties with alignment of PET bottles due to their light weight. There was also some problem with glass bottles such as long neck beer bottles, small baby food bottles and large apple cider jugs either not being fully diverted far enough away (specifically large bottles) or not properly passing through the feed/alignment chute. Development of a better alignment system has been indicated for the larger scale prototype.

Test sorting runs on glass bottles using the laboratory prototype ranged from 2,118 to 7,660 bottles per hour. An overall ratio of 60% clear to 40% colored containers was used because it represents that which is found in the waste stream. Results of different sorting speeds and color arrangements tested with glass bottles are shown in Table 3.1. There were no reported problems with the sensing or diverting system, but generally unsuccessful runs were reported to occur due to the trough feed chute (bottles ganging up at the chute entrance). The overall results show that 87% of the containers were separated correctly, 98% of the clear stream had clear glass containers and 76% of the colored stream had colored glass containers. The mass rate of glass can be estimated using 0.5 lbs/bottle for all runs except drop no. 1 (0.481 lbs./bottle) and drop nos. 11-13 (0.469 lbs/bottle).

The test results for PET bottle processing are shown in Table 3.2. The optical sensing mechanism for glass was reported to be compatible for PET bottles without recalibration. Smaller one liter PET bottles jammed at the chute entry, as previously indicated. Ninety-five percent of the processed clear PET bottle stream contained clear bottles while 100% of the color stream contained colored PET bottles when considering bottle runs where alignment was not a problem. An estimate of the mass flow rate can be made using 0.113 lbs/1 liter bottle and 0.163 lbs/2 liter bottle.

A primary feature of the sorting method, in addition to high separation efficiency and simple design, is the low capital and operating cost of the system. It is projected to cost \$2,000 to \$4,000 to install a unit which processes 1,000 tons/yr glass and 60 tons/yr PET, based on the estimated recycling rates for the local Urbana/Champaign recycling center. The total usage time for this amount is 177 hours annually. It is estimated that a minimum of 136 person-hours would be saved annually by the sorter removing 81% of the clear glass automatically. This does not include time to separate color glass from the clear stream and clear glass from the color stream. It is also estimated that the CCSS would reduce the time required to sort PET bottles by 50%. The cost of the feed/conveying system is the most significant portion of capital expense. A facility with 10 times the glass/PET load (10,000 tons/year glass and 600 tons/year PET), which could make better use of operating time, is estimated to result in a savings of \$11,000 to \$22,000 per year resulting in a payback of less than one year.

Table 3.1 Results of Glass Container Color Sorting Tests [Newell and Lewis, 1990]

| Drop no. | Pattern <sup>a</sup><br>(colors) | Clear bottles<br>triggering<br>solenoid | Color bottles<br>not triggering<br>solenoid | Total %<br>correct<br>response | Total time<br>elapsed<br>(seconds) | Time /<br>bottle<br>(sec/bottle) | Rate<br>(bottles/<br>hour) |
|----------|----------------------------------|---|---|--------------------------------|------------------------------------|----------------------------------|----------------------------|
| 1        | 10 brown (B)                     | 0/0                                     | 9/10  | 90                             | 5.42                               | 0.542                            | 6,642                      |
| 2        | 10 clear (C)                     | 10/10                                   | 0/0   | 100                            | 6.37                               | 0.637                            | 5,651                      |
| 3        | 10C                              | 9/10                                    | 0/0   | 90                             | 16.14                              | 1.614                            | 2,230                      |
| 4        | 10 green (G)                     | 0/0                                     | 9/10  | 90                             | 10.30                              | 1.030                            | 3,495                      |
| 5        | 8C                               | 5/8                                     | 0/0   | 63                             | 7.02                               | 0.878                            | 4,100                      |
| 6        | 10C                              | 8/10                                    | 0/0   | 80                             | 11.94                              | 1.194                            | 3,015                      |
| 7        | 5B, 5G                           | 0/0                                     | 10/10                                       | 100                            | 14.45                              | 1.445                            | 2,491                      |
| 8        | 5B, 5C                           | 4/5                                     | 5/5   | 90                             | 9.61                               | 0.961                            | 3,746                      |
| 9        | C,B,G,C,B,G,<br>C,B,G,C          | 4/4                                     | 6/6   | 100                            | 10.15                              | 0.882 <sup>b</sup>               | 4,082                      |
| 10       | B,C,G,C,B,C,<br>G,C,B,C          | 4/5                                     | 5/5   | 90                             | 6.86                               | 0.686                            | 5,248                      |
| 11       | 10C                              | 8/10                                    | 0/0   | 80                             | 7.60                               | 0.470 <sup>c</sup>               | 7,660                      |
| 12       | 10C                              | 8/10                                    | 0/0   | 80                             | 8.10                               | 0.810                            | 4,444                      |
| 13       | 10C                              | 8/10                                    | 0/0   | 80                             | 17.00                              | 1.700                            | 2,118                      |
| 14       | C,C,B,G,C,C,<br>B,B,G,C          | 5/5                                     | 5/5   | 100                            | 9.94                               | 0.994                            | 3,622                      |
| 15       | B,B,C,B,C,G,<br>C,C,B,C          | 5/5                                     | 5/5   | 100                            | 8.98                               | 0.898                            | 4,009                      |
| 16       | C,B,C,G,C,G,<br>C,B,C,B,C,G      | 3/6                                     | 6/6   | 75                             | 12.71                              | 1.059                            | 3,399                      |
| 17       | C,G,C,G,C,B,<br>C,B,C,B,C,B      | 4/6                                     | 5/6   | 75                             | 14.68                              | 1.223                            | 2,943                      |
| 18       | C,G,C,B,C,B,<br>C,B,C,G,C,G,C    | 5/7                                     | 6/6   | 85                             | 15.95                              | 1.227                            | 2,934                      |
| 19       | C,C,C,C,B,B,<br>G,G,C,C,C,C,C    | 7/9                                     | 4/4   | 85                             | 20.50                              | 1.577                            | 2,283                      |
| 20       | B,C,C,G,C,G,<br>C,B,C,C          | 5/6                                     | 3/4   | 80                             | 17.10                              | 0.874 <sup>d</sup>               | 4,118                      |
| Totals   |                                  | 102/126<br>(81%)                        | 78/82<br>(95%)                              | 87                             |                                    |                                  |                            |

Clear containers diverted to the clear holding bin = 98%

Colored containers diverted to the colored holding bin = 76%

a. Number, color and order in which bottles were processed are shown (B=Brown, C=Clear, G=Green)

b. Time adjusted from 1.015 sec/bottle due to feed discrepancy

c. Time adjusted from 0.760 sec/bottle due to feed discrepancy

d. Time adjusted from 1.710 sec/bottle due to feed discrepancy

Table 3.2 Results of PET Beverage Bottle Color Sorting Tests [Newell and Lewis, 1990]

| Drop no.             | Pattern <sup>a</sup><br>(colors) | Clear bottles<br>triggering<br>solenoid | Color bottles<br>not triggering<br>solenoid | Total %<br>correct<br>response | Total time<br>elapsed<br>(seconds) | Time /<br>bottle<br>(sec/bottle) | Rate<br>(bottles/<br>hour) |
|----------------------|----------------------------------|---|---|--------------------------------|------------------------------------|----------------------------------|----------------------------|
| 21                   | 5G (2L)<br>1G (1L)               | 0/0                                     | 5/6   | 83%                            | 12.82                              | 2.137                            | 1,685                      |
| 22                   | 4G (2L)<br>1G (1L)               | 0/0                                     | 5/5   | 100%                           | 12.33                              | 0.837 <sup>b</sup>               | 4,303                      |
| 23                   | 4C (1L)<br>3C (2L)               | 6/7                                     | 0/0   | 86%                            | 12.57                              | 1.796                            | 2,005                      |
| 24                   | 4C (1L)<br>3C (2L)               | 4/7                                     | 0/0   | 57%                            | 7.12                               | 1.017                            | 3,539                      |
| 25                   | G,C,G,C,G,C<br>G,G               | 3/3                                     | 4/5   | 88%                            | 11.46                              | 1.433                            | 2,513                      |
| 26                   | G,C,G,G,C,G,<br>C,G              | 3/3                                     | 5/5   | 100%                           | 8.13                               | 1.016                            | 3,542                      |
| 27                   | C,C,G,C,C                        | 1/4                                     | 1/1   | 40%                            | 4.79                               | 0.958                            | 3,758                      |
| 28                   | G,G,C,G,G,C,<br>C,G              | 3/3                                     | 5/5   | 100%                           | 9.64                               | 0.894 <sup>c</sup>               | 4,026                      |
| 29                   | C,G,G,G,C,G,<br>C,G              | 3/3                                     | 5/5   | 100%                           | 6.11                               | 0.764                            | 4,714                      |
| 30                   | G,C,C,G,G,C,<br>G,G              | 3/3                                     | 5/5   | 100%                           | 5.58                               | 0.698                            | 5,161                      |
| <hr/>                |                                  |   |   |                                |                                    |                                  |                            |
| Totals               |                                  |   |   |                                |                                    |                                  |                            |
| 1 liter <sup>d</sup> |                                  | 5/12<br>(42%)                           | 2/3<br>(67%)                                | 47%                            |                                    |                                  |                            |
| 2 liter              |                                  | 21/21<br>(100%)                         | 33/34<br>(97%)                              | 98%                            |                                    |                                  |                            |
| Combined             |                                  | 26/33<br>79%                            | 35/37<br>95%                                | 86%                            |                                    |                                  |                            |

Clear containers diverted to the clear holding bin = 95%

Green containers diverted to the green holding bin = 100%

- a. Number, color and order in which bottles were processed are shown (C=Clear, G=Green).  
 d. Time adjusted from 2.466 seconds/bottle due to feed discrepancy  
 c. Time adjusted from 1.205 seconds/bottle due to feed discrepancy  
 d. Minor alignment difficulty occurred with 1 liter containers

### 3.2 Separation of PVC Bottles from Other Plastic Containers

The separation of PVC bottles from other plastic in sorting programs has become important due to the adverse effects of even small amounts of PVC present in other plastic, such as PET. Upon being melted with PET, which is what PVC is most often mistaken to be, hydrochloric acid can form and corrode the metal parts used in plastic extrusion machines.

Work at B.F. Goodrich Co. and the Rutgers CPRR has yielded separation methods for PVC bottles. The CPRR separation method is based on using x-ray fluorescence to detect characteristic backscattering from chlorine atoms in PVC which is higher than that detected by polyolefin plastic without chlorine. Mechanical separation can then occur. The x-ray detection is reported sensitive enough to trigger removal of a PET bottle with a PVC label, and can also detect other chlorine containing polymers such as polyvinylidene chloride (PVDC) which is used in laminates and films [Monks, 1990]. Although the detection of small amounts of chlorine is possible, the chlorine x-ray is weak and does not penetrate paper labels. There is also a rapid decrease in measured x-ray chlorine intensity as a particular sample is moved away from an x-ray source and detector. This could lead to a potential problem for bottles of uneven shape [Summers et al, 1990a]. Figure 3.2, which shows responses for two different type detectors, indicates that the chlorine reading decreases by about half for every 3 mm of air space between the sample and the detector.

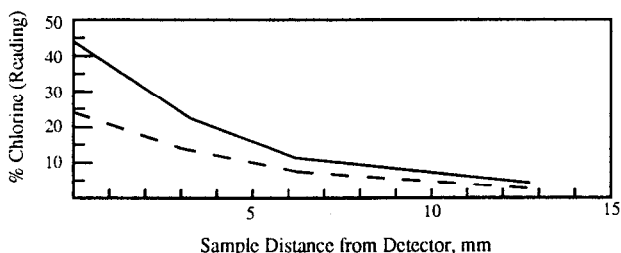


Figure 3.2 Chlorine Detection Strength Versus Bottle Distance from Detector [Summers et al, 1990b] Shown are responses from two detector models

In addition to chlorine intensity being affected by the distance from the detector, the intensity will also vary across the length of a bottle. Figure 3.3 shows the x-ray detector

response to a uncrushed bottle and Figure 3.4 shows the response of a crushed bottle, both measured at 1 cm intervals across the bottle from the face and profile views. Both figures show that a chlorine reading at a minimum of 2 cm intervals will identify the peak reading for the bottle. Based on this limitation it is projected that any bottle should be measured several times at 2 cm intervals. Because the detector can make a reading in 0.005 seconds, a maximum belt speed of  $2 \text{ cm}/0.005 \text{ sec}$ , or 400 cm/second is recommended. A 10 cm spacing between bottles would allow approximately 10 bottles/second to be analyzed.

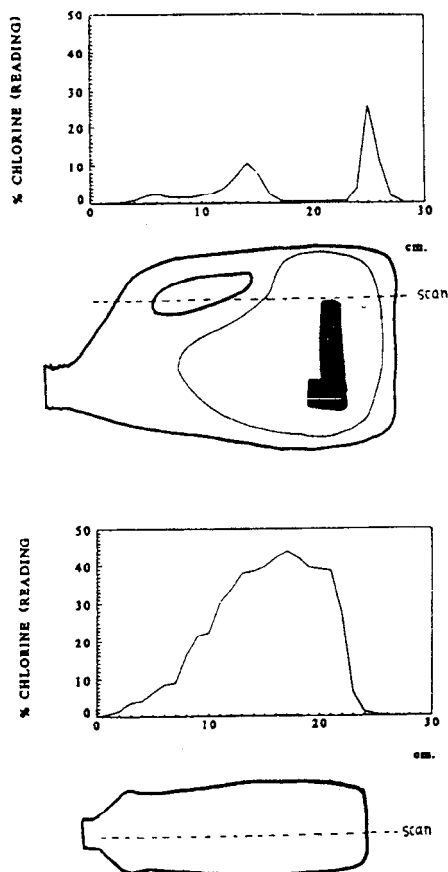


Figure 3.3 X-Ray Fluorescence of PVC Oil Bottle from Front and Profile View [Summers et al, 1990b] The black marking represents bottle labeling



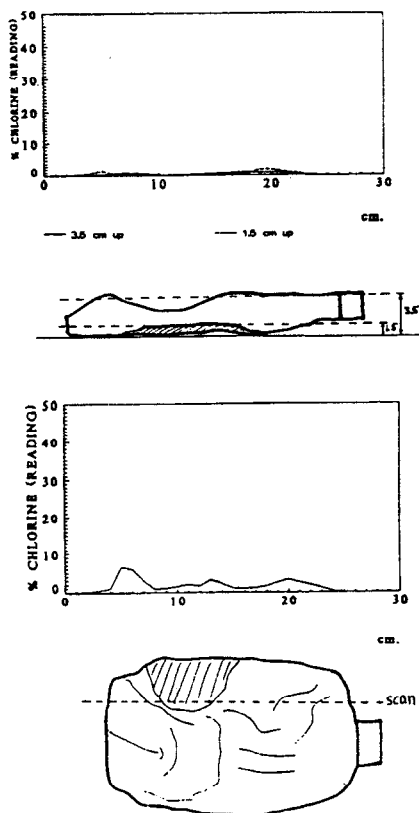


Figure 3.4 X-Ray Fluorescence of Baled PVC Bottle from Front and Profile View [Summers et al, 1990b]

Two other companies, International Food Machinery and National Recovery Technologies (NRT), the latter receiving funding from the U.S. EPA and the Vinyl Institute, also have processes to separate PVC bottles. The exact sensing processes used by these two companies are not available; however, it is believed to be similar to CPRR. A simplified diagram of the NRT sorting system is shown in Figure 3.5. Other companies are marketing a sensing device as well.

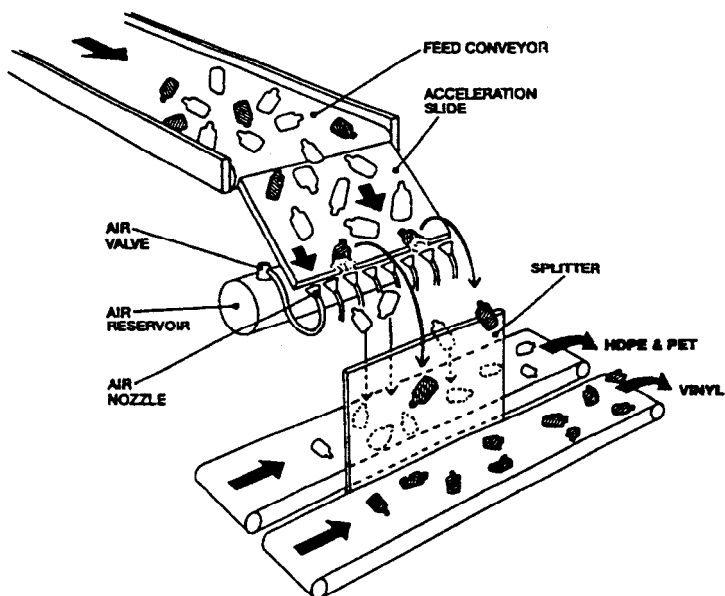


Figure 3.5 National Recovery Technologies Vinyl Separation System

A study of PVC bottles in the Akron, Ohio RPC mixed plastic recycling program showed that a manual separation to achieve a PVC stream will be about 80% accurate in identifying which bottles are PVC. Even with automated x-ray separation, additional cleaning is necessary and a method to perform cleaning and non-specified plastic separation using a 1.35 and 1.30 specific gravity calcium nitrate solution has been proposed as shown in Figure 3.6 [Summers et al, 1990b].

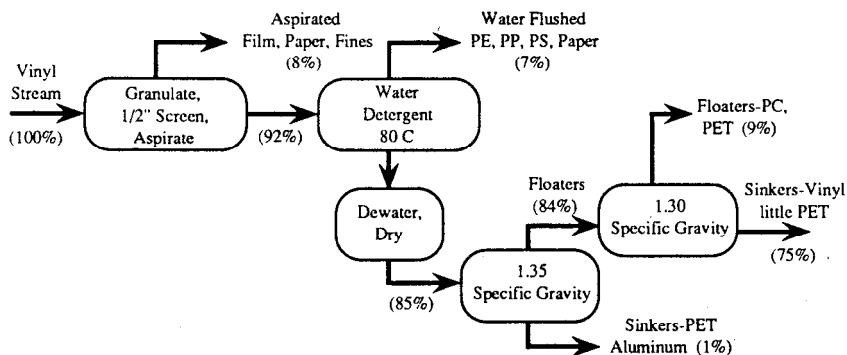


Figure 3.6 Vinyl Stream Purification Process [Summers et al, 1990b]

### 3.3 Separation of HDPE Base Cups from PET Beverage Bottles

The Center for Plastics Recycling Research (CPRR) at Rutgers University was commissioned to develop a process for the reclamation of soda bottles that could be widely demonstrated and transferred to the public to spur increased recycling in this area. This was done because there are a number of companies in the U.S. which recycle PET soda bottles, but their methods are generally proprietary and not licensed out. The Rutgers Beverage Bottle Reclamation Process (BBRP) is not meant to separate PET soda bottle colors or other type plastics, but rather to provide clean PET flake separated from caps, labels, base cups and adhesives.

Because there are differences in the way PET beverage bottles are produced, it was necessary to determine the composition of soda bottles collected. The primary differences among bottles is the label materials used, cap material used, and whether a HDPE base cup is used. The average composition of PET soft drink bottle constituents are shown in Table 3.3.

Table 3.3 Average Composition of Mixed Soda Bottles Received at Rutgers, NJ During 1988-1989 [Dittman, 1990]

| Compound                        | Average Composition<br>(Weight %) |
|---------------------------------|-----------------------------------|
| PET (including green and clear) | 73.6                              |
| HDPE <sup>a</sup>               | 20.0                              |
| Paper (label) <sup>b</sup>      | 2.9                               |
| EVA <sup>c</sup>                | 1.3                               |
| Aluminum                        | 1.0                               |
| PP (labels) <sup>d</sup>        | 0.8                               |
| PP (cap liner)                  | 0.4                               |

- a. Actual HDPE quantity is 23% for bottles with base cups and 0% without base cups.
- b. Value goes to 0% for bottles with plastic labels.
- c. Actual ethylene-vinyl acetate (EVA) quantity, which is a base cup adhesive, is 1% for bottles without base cups and 3% for bottles with base cups. EVA is a copolymer adhesive in the polyethylene
- d. Value goes to 0.2% for bottles with paper labels. For those bottles, PP is used for cap liners only.

The process also provides clean polyolefin flakes which are mainly the HDPE base cup and PP caps, and aluminum chips from caps. The process, a schematic of which is shown in

Figure 3.7, is summarized as follows [Rankin, 1990, Dittman, 1990]:

- Collection of waste plastic
- Sortation of waste plastic into uniform types
- Granulation or cutting of the sorted plastics into chips of about 3/8" mesh size. This may be accompanied by air classification to remove loose dirt, paper shreds and other "fines."
- Mixing of the plastic chips with a heated aqueous detergent bath, and agitating the resulting slurry for sufficient time to achieve the desired degree of cleanliness, including label removal, EVA removal and disintegration of any paper present.
- Separation of the wash bath from the plastic chips via a dewatering screening device. Paper fibers and dirt are removed along with the bath; except for that portion which remains clinging to the wet chips. The wash bath is then filtered and reused. Make-up detergent solution is added as required.
- The wet and washed chips are re-slurried in rinse water in an agitated tank, and pumped through a set of hydrocyclones to separate the "light" components (polyethylene base cups and polypropylene labels) from the "heavy" components (PET and aluminum bottle tops). The specific gravities are as follows:

|         |              |
|---------|--------------|
| a) HDPE | 0.96         |
| b) PP   | 0.90         |
| c) PET  | 1.29 to 1.40 |
| d) Al   | 2.60         |

Thus items a) and b) will float in water, while c) and d) will sink.

- The light and heavy components are individually dewatered to 3-7% H<sub>2</sub>O using high-speed rotating fine screens and dried. Thermal separation is used to remove residual water from the two fractions after dewatering. One dryer is used for each stream, with the PE/PP stream dried to 1% H<sub>2</sub>O and the PET/Al stream dried to 0.179% H<sub>2</sub>O or less. The low moisture content of the latter is necessary for electrostatic removal of the aluminum.
- The light component stream is then ready for sale, or an optional step can be used to remove PP from PE. PE/PP separation can be done by increasing the air velocity in the light stream hot-air drier. PP chips will be carried out by the air. It has been found, however, that most purchasers are satisfied to buy HDPE chips containing 7-8% PP by weight. They can be used as a mixture in injection molding, since their melting point temperatures are not far apart:

|      |             |
|------|-------------|
| HDPE | 130 - 137°C |
| PP   | 168 - 175°C |

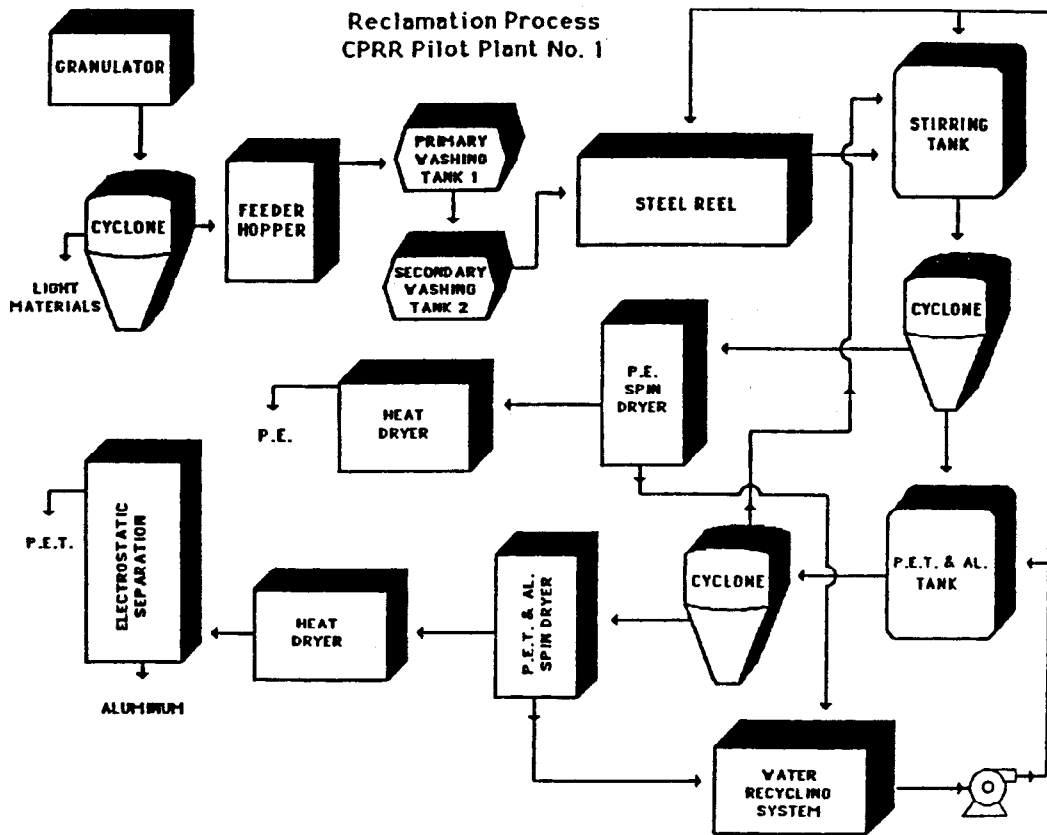


Figure 3.7 Schematic of Rutgers Beverage Bottle Reclamation Process [Morrow and Merriam, 1989]

- The heavy component stream is sent to an electrostatic Carpc separator for removing aluminum. The PET and Al mixture is fed continuously onto a rotating steel roll maintained at high voltage. The electrostatic aluminum removal process takes aluminum from 1.2% (12,000 ppm) to 50-100 ppm residual aluminum in the cleaned PET flake. The aluminum by-product contains approximately 50% Al and 50% PET by weight. An additional smaller separator is necessary to attain a higher purity aluminum material.

Average analysis of the PET flake and HDPE product is shown in Table 3.4. The wastewater from the process should not be much different from a large cafeteria and generally does not require pretreatment. Byproducts are reported to be wet sludge (mainly paper fibers), dirty rinse water (dishwater) and dirty wash solution (concentrated dishwater). Rutgers has installed a 5 million pound per year pilot plant to demonstrate the operation.

Table 3.4 Product Analysis of Rutgers Beverage Bottle Reclamation Process [Dittman, 1990]

| Component                               | Mean PET Product | Mean HDPE Product |
|---|------------------|-------------------|
| PET, including EVA (wt %)               | 99.756%          | 0.02 to 0.63%     |
| PET, EVA free basis <sup>a</sup> (wt %) | 99.995%          | -                 |
| HDPE                                    | 10.3 ppm         | 92.4 - 99.4%      |
| PP                                      | 1.2 ppm          | 0.0 - 7.5 ppm     |
| Aluminum                                | 25 - 100 ppm     | 0.0 - 2.0 ppm     |
| Average moisture content                | ≤0.25%           | 1%                |

a. Ethylene-vinyl acetate (EVA) can be removed to as high a degree as desired.

The BBRP license and technology is available for a license issuance fee of \$3,000 and a royalty fee equal to 1/4% of the gross sales price of the licensed products that are used, leased or sold by or for the licensee [Rutgers]. After the license agreement royalties reach \$25,000, no more royalty fees will be due. The license issuance fee includes a technology transfer manual which provides detailed equipment and process description, process economic estimates, safety and health parameters and quality control requirements and measurements. A detailed cost estimate was performed by CPRR for a 20 million

pound per year facility in a leased building which was based on attaining 20¢/lb for PE flake and 34¢/lb for aluminum. Plant operation was based on 24 hours/day, 330 days/year. Investment costs and revenues resulting from varying clean flake PET prices of 31¢/lb, 36¢/lb and 41¢/lb are shown in Table 3.5. It estimates a return on investment of 34%/yr, 50%/yr and 66%/yr for the three PET prices, respectively. Similar analysis for a 10 million pound per year plant shows a return on investment of approximately 4%/yr, 16%/yr and 29%/yr for PET flake prices of 31, 36 and 41¢/lb, respectively [Phillips and Alex, 1990].

Table 3.5 Cost Analysis Summary of Rutgers PET Bottle Processing Plant [Phillips and Alex, 1990]

| Description                 | Value (\$M/yr)   |       |       |
|-----------------------------|------------------|-------|-------|
|                             | PET Price (¢/lb) |       |       |
|                             | 31¢              | 36¢   | 41¢   |
| Revenue <sup>a</sup>        | 5255             | 5915  | 6574  |
| Operating cost              | -4000            | -4000 | -4000 |
| Taxes                       | -464             | -708  | -952  |
| Profit after tax            | 791              | 1207  | 1622  |
| Total capital investment    | 2351             | 2406  | 2460  |
| Return on investment (%/yr) | 34               | 50    | 66    |
| Payback period (years)      | 2.4              | 1.7   | 1.4   |

a. Based on polyethylene product price of 20¢/lb and aluminum price of 34¢/lb.

### 3.4 Separation Using Selective Dissolution

This method is currently being studied at a laboratory level. Selective dissolution involves the separation of mixed plastics on a molecular scale by dissolving resin mixtures in a solvent. Examining this process as a method to separate mixed plastics was started in the mid 70s. There are two methods being approached in the dissolution process. The first method uses one solvent to dissolve all resin types and the second method uses one solvent to dissolve one particular type of resin, but not others. Both methods have received attention because the plastic stream can be heterogeneous in nature and contaminants such as metals, glass, cellulose and some pigments can be removed. Selective dissolution can allow for microdispersion of polymer combinations, thereby rendering innocuous certain plastic components that may lead to manufacturing difficulties or poor physical properties.

The process using single solvent addition (flowchart shown in Figure 3.8) involves the separation of mixed plastics using two primary steps [Lynch and Nauman, 1989]:

- Selective dissolution - A solvent and a sequence of solvation temperatures are used in a sequential batch mode to selectively extract a single polymer group from the commingled stream. The polymer obtained from the single extraction is isolated using flash devolatilization. The recovered polymer is then pelletized and the condensed solvent is returned to the dissolution reservoir to remove the next group of polymers at a higher temperature. Typical conditions consisted of placing 25 kg of plastic waste (virgin polymers used) into the column with screens at each end. A pump circulated 20 liters of solvent through the heat exchanger and dissolution column.
- Flash devolatilization - Once separated by selective dissolution, flash devolatilization of the solvent from the mixture is used to produce solvent free polymers. This process is an outgrowth of the polymer process of compositional quenching, where two incompatible polymers are dissolved in a common solvent, and then the solvent devolatilized such that phase separation between the two polymers occurs and a microdispersion of one polymer within the other occurs. The microdispersion renders the minor constituents innocuous. Figure 3.9 shows an experimental flash devolatilization apparatus. The polymer concentrations in the solvent are typically 5 to 10% by weight. The pressure in the heat exchanger is sufficient to prevent boiling with pressure maintained by the flash valve at 10 - 40 atm, and a typical temperature upstream of the flash valve of 200 - 300°C. The temperature upstream of the flash valve and the flash chamber pressure (typically 5 - 100 torr) are the two variables which govern the devolatilization step. They determine the polymer concentration after flashing (typically 60 - 95%) and the after flash temperature, 0 - 100°C.

Equal volumes of the six major thermoplastics were used: HDPE, LDPE, PET, PP, PS and PVC. Tetrahydrofuran was selected as the first trial solvent due to the data acquired in previous compositional quenching work [Lynch and Nauman, 1989]. Xylene has also been used. Results achieved are shown in Table 3.6. It shows that a four way split between plastic types can be achieved with good separation efficiencies. A lower separation efficiency is expected with an actual commingled waste plastic stream due to variations in polymer properties among manufacturers. However, it is expected that compositional quenching will overcome the problems. Preliminary economics has indicated a 50 million pound per year plant will process waste plastic for around 15¢/pound [Lynch and Nauman, 1989].



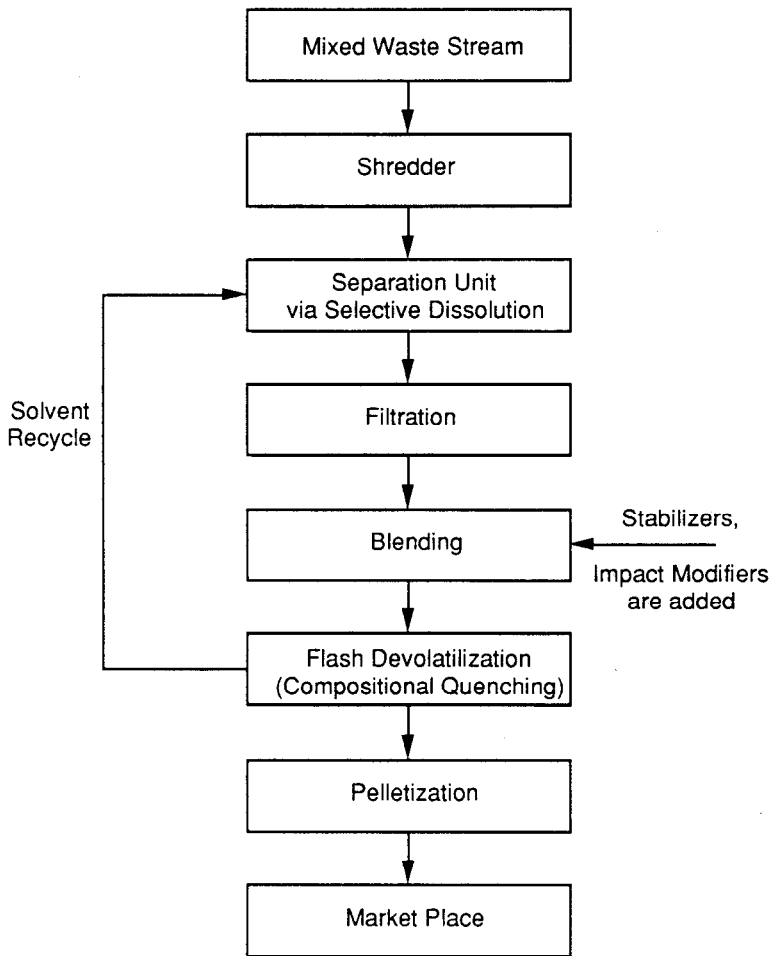


Figure 3.8 Single Solvent Selective Dissolution Process Flow Sheet [Lynch and Nauman, 1989]

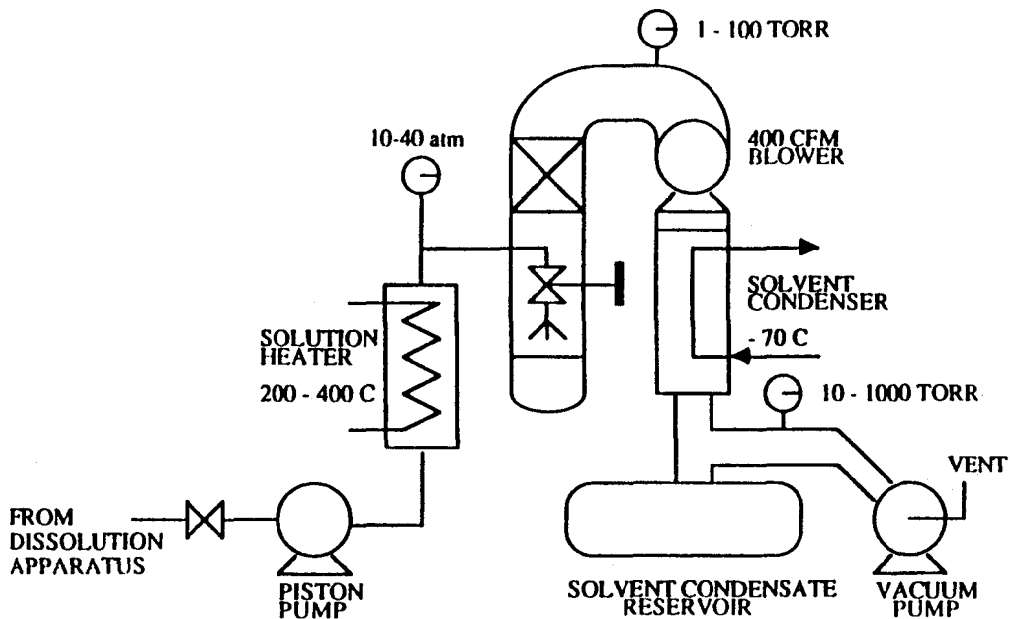


Figure 3.9 Selective Dissolution Single Solvent Flash Devolatilization Miniplant [Lynch and Nauman, 1989]

Table 3.6 Experimental Extraction Efficiencies Using Single Solvent Selective Dissolution <sup>a</sup> [Lynch and Nauman, 1989]

| Material | Extraction | Temperature (°C) | Efficiency (%) |
|----------|------------|------------------|----------------|
| PVC      | First      | 25               | >99            |
| PS       | First      | 25               | >99            |
| LDPE     | Second     | 70               | >99            |
| PP       | Third      | 160              | >99            |
| HDPE     | Third      | 160              | >99            |
| PET      | Fourth     | 190              | >99            |

a. Experiments were conducted using virgin polymers. Tetrahydrofuran was the solvent used in dissolution.

The multiple solvent process involves the use of a solvent compatible with a limited number of polymers. It has advantages over the single solvent process in that lower pressures and temperatures are necessary which results in reduced energy requirements. Because a different solvent is used for each polymer, a potentially higher purity product can be obtained. Work in this area has focused on PET bottle flake purification following mechanical cleaning from other soda bottle constituents of HDPE, PP, paper and aluminum. This purification process would result in a high purity PET polymer at an increased cost.

A flowsheet of the multiple solvent process, shown in Figure 3.10, is described as follows [Vane and Rodriguez, 1990]:

- Stage I - Dried chips from a mechanical, density based, float-sink system (such as the Rutgers BBRP process) are fed in, where they are washed with the process solvent at a temperature sufficient to remove insoluble impurities (up to 130°C), but insufficient to dissolve the intended polymer. For example, in the PET train, this washing will remove any adhesives, PS or PVC which may be present from use in 2 liter bottles or from sortation error.
- Stage II - The intended polymer is dissolved by the process solvent at higher temperatures (around 170°C). Once dissolution is complete, the solution can be purified.
- Stage III - Undissolved materials are removed using sedimentation/flotation and filtration. Dissolved materials, such as dyes, catalysts and inks are removed by adsorbents.

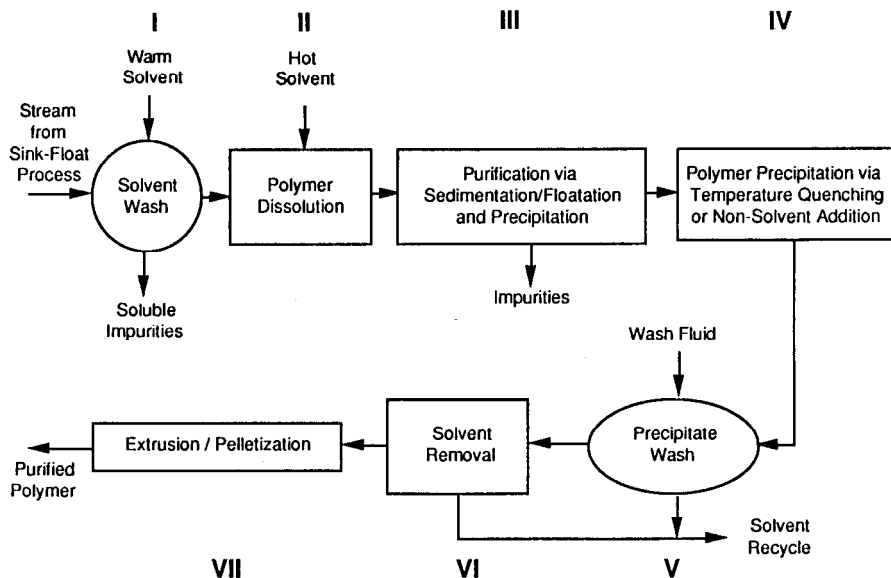


Figure 3.10 Flow Sheet for Multiple Solvent Selective Dissolution Showing Seven Processing Stages [Vane and Rodriguez, 1990] The feed material would be pre-cleaned by a sink-float system such as the Rutgers Beverage Bottle Reclamation Process

- Stage IV - The polymer is recovered by temperature quenching or by adding the solution to a non-solvent causing immediate precipitation of the polymer.
- Stage V - Rinsing to remove dissolved impurities from the polymer precipitate
- Stages VI and VII - Removal, extrusion and pelletization.

Based on criteria of cost, toxicity, solvent recovery and favorable PET solution behavior, and incompatibility with polyolefins, the solvent utilized for dissolution was n-methyl-2-pyrrolidinone (NMP). Figure 3.11 shows the dissolution rate of bottle PET in NMP. From this figure, the PET dissolution rate is achievable without elevated pressures.

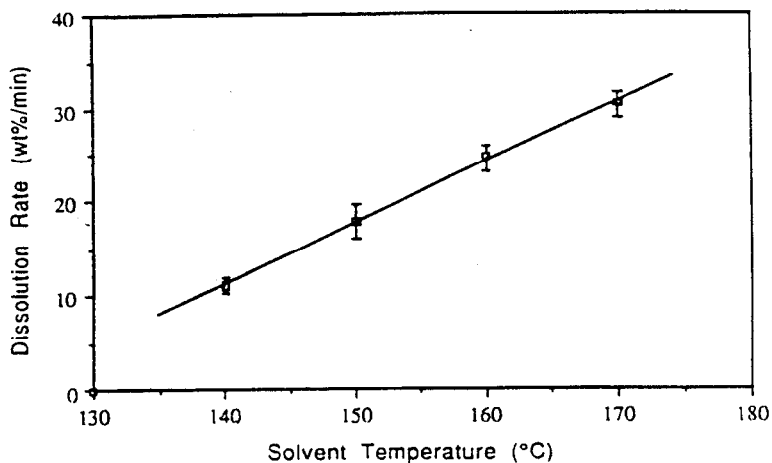


Figure 3.11 Dissolution Rate of Bottle PET in N-Methyl-2-Pyrrolidinone (NMP) as a Function of Temperature [Vane and Rodriguez, 1990]

as the boiling point of NMP is 202°C. At 170°C, a 2 liter bottle will dissolve completely in about 4 minutes. Conversely, HDPE immersed in NMP at 175°C for 30 minutes will hardly be dissolved (0.2% by weight). At 130°C, PET did not dissolve appreciably even after 4 hours in the solvent.

Testing has not reached the level of determining overall process purity. It is estimated that if a 2 liter bottle (assumed to be of a 70% PET, 30% HDPE composition) was immersed in NMP at 175°C for 30 minutes followed by the previous process stages described, the resulting polymer would be 99.91% by weight PET. If the process were preceded by the Rutgers BBRP process, with 90% HDPE removal, PET quality would be 99.991% PET by weight. Although this does not examine other bottle impurities, a 99.99% pure PET resin is obtainable.

### 3.5 Separation Using Soluble Acrylic Polymers

This work is under development by a private company, Belland AG - Switzerland, which specializes in acrylic polymers. The solubility and subsequent precipitation potential is available by using acrylic plastics. Applications are envisioned in recyclables, protective coatings, disposables and temporary packaging. An important use for such a material would be to make recycling of other products easier without being directly incorporated into the recycling stream. For example, producing telephone books using an easily soluble adhesive binding would allow telephone books to be more readily recycled. A labeling system consisting of alkaline soluble label film stock, adhesive and ink has been developed for this purpose [Wielgolinski, 1990].

The soluble polymers are based on acrylic monomers which contain a definitive percentage of carboxyl groups. The carboxyl additives render the polymers soluble in an alkaline solution such as 2% ammonia solution or a dishwashing detergent. Solubility can then be reversed to precipitate the polymer after lowering the pH of the solution by acidification. The polymer is water repellant and therefore would not be damaged during its normal life. The polymer properties can range from stiff and strong for injection molding, to tough and flexible for extrusion molding, and down to soft and sticky for adhesive applications; over 1,500 different materials have been prepared which differ in acrylic composition, molecular weight and dispersity [Wielgolinski, 1989]. Of these, 25 co- and terpolymers have been chosen as standard products for coatings, adhesives, films and injection and extrusion molding resins.

The application to plastic recycling lies in the separation of a family of different property acrylics by changing the pH of the acrylic solution. A recycling system has been examined for the fast-food industry where all eating utensils, straws, foamed cups, thermoformed cup lids and foamed clam shells are envisioned as being composed of different formulations of alkaline soluble acrylic. This fast food waste would be subject to alkaline solution digestion with mechanical agitation which would dissolve away and separate organic waste from the plastic. The liquor and insoluble solids would then be separated and the solids given two washes for removal of trace solvated plastic. Polymer containing liquors would be combined and purified of color factors by adsorption in carbon filters and molecular sieves. The purified acrylic solution would then be fractionated into separate polymers by virtue of their pH sensitivity. The fractions are then dried, re-extruded and recycled into a primary recycling application. The pH sensitivity of each polymer is a function of its percentage carboxyl functionality and other related factors [Wielgolinski, 1989].

The applications to recycling include use as an allowable material which would not hinder recycling (because it would be easily dissolved) and as a recyclable product. A PET beverage bottle which is affixed with such a soluble film plastic label, cup adhesive and ink, would allow for less contaminant in the PET recycle. Contamination of paper label residue and adhesives is a problem with PET bottle recycling. This also allows for recycle of the adhesive and film by precipitation from the alkaline wash.

### *3.6 Initial Activities in Polyurethane Recycling*

There has been little past nationwide activity in the recycle of polyurethanes (PUR) or phenolics even though these resins are among the largest produced. These two resins comprised 9.5% by weight of the resins produced in the U.S. in 1989 (refer to Table 1.2 in Part I). An overview of some recent work is summarized here.

For polyurethanes, the sixth largest resin produced resin in the U.S., the Society of the Plastics Industry has formed a Polyurethane Recycle and Recovery Council (PRRC) to address PUR re-use. The group has established a goal of finding commercially viable ways to recycle or recover materials and energy from 25% of available PUR annually by 1995. Approximately 2/3 of annual PUR production ( $\approx 3.3$  billion pounds) is consumed by four industries: transportation, construction, furniture and bedding. It is estimated that 335 million pounds of PUR were recycled in 1989. Most of it came from the flexible foam (e.g., padding, cushions) segment of the industry.

### *3.7 Initial Activities in Automotive Plastics Recycling*

In order to make the recovery of automobiles more feasible and reduce their landfilling, automotive companies are examining the recycling of plastic automotive parts. Recycling of plastic auto components is being studied at three different levels: a) through identification of plastic types and subsequent dismantlement for recycling; b) through solvent dissolution of thermoplastic mixtures from auto shredder residue; c) through pyrolyzing of auto thermoset plastics for further use.

#### *Identification of Plastic Auto Parts*

To support the dismantlement and direct recycling of plastic auto parts, a voluntary coding system for identification of plastics used in automotive parts has been established by the Society of Automotive Engineers (SAE). The purpose of Recommended Practice SAE J1344 (March, 1988) is to provide information with regards to recycling as well as the selection of materials and procedures for the repairing and repainting of plastic parts. The recommended practice provides a listing of the plastic types used in automotive parts, the

common trade name of a material, and the abbreviation which is to be imprinted or molded on the part. In addition, symbols for commercial plastic blends are also shown. The recommended practice can be obtained from SAE. The identification of plastic type used in automotive parts along with the design of modular plastic components would make ease of recovery simple and would allow for recycling of homogeneous plastic types with minimal contamination.

#### *Solvent Dissolution of Plastic Auto Shredder Residue*

Obsolete automobiles are typically shredded for the recovery of ferrous scrap. The nonmetallic fraction of shredded automobiles is auto shredder residue (ASR), a heterogeneous mixture of plastics, glass, rubber, fibers, foam, upholstery, dirt and fines. ASR may typically be contaminated with any of the original constituents of an automobile such as brake fluid, steering fluid, motor oil, gasoline or heavy metals. It is estimated that 250-275 lb. of plastic are used in a 3,500 lb. auto and that up to 1.2 million tons of waste plastic from ASR are generated per year [Bonsignore et al., 1991]. A breakdown of automotive plastic scrap for the 1981 model year has shown that the thermoplastics ABS, PUR, PP and PVC comprise 65% of waste plastic.

Mechanical separation and solvent dissolution of the thermoplastic portion of ASR is being studied at Argonne National Laboratories (ANL) as a way to recover additional resources from scrap autos and reduce landfill disposal of ASR. ASR samples from an auto shredder in the Chicago area were used in laboratory studies to identify the effectiveness of the mechanical cleaning and solvent dissolution. The mechanical cleaning portion, which also included removal of PUR foam, was accomplished using a vibrating screen separator. PUR foam chunks (greater than the initial screen size of 1") floated on top of the screen and was vacuumed off. The PUR was severely contaminated with residual oils. For the PUR foam scrap, an acetone wash followed by a water detergent wash removed most of the impregnating oils and entrapped dirt and fines. The remaining mixture of plastics (the "bottoms" from the 1" screen) was separated from ASR fines by passing the material over a 1/4" vibrating screen. The plastic "overs" mixture was washed with acetone at room temperature to remove oil, grease and mastics, and then it was subject to boiling ethylene dichloride (EDC). The EDC soluble plastics were recovered by solvent evaporation and yielded a blend of approximately 50% ABS and 50% PVC by weight [Bonsignore et al., 1991]. The soluble solids after EDC extraction were subject to xylene dissolution. Filtration and precipitation of the xylene solution yielded a high purity PP with some PE.



An initial charge of 2968 g of raw ASR was separated by vibrating screen into the following fractions: PUR foam (with contaminated oil), 275 g; plastic rich stream, 1906 g; and fines, 787 g. The composition of the resulting solvent cleaned products were as follows [Bonsignore et al., 1991]: cleaned PUR foam, 178 g; PVC/ABS composite, 180 g; PP, 54.5 g. Due to the size of the setup, no conclusions can yet be made on the effectiveness of such a system. Plans are underway to scale up to a 20 kg pilot lab size separation and solvent extraction system.

### *Pyrolyzing of Auto Thermosets*

The recycle of thermosets (often phenolics) is being studied by automotive companies as a method of re-using the sheet molded compound (SMC) thermosets used to form automotive body panels. It is estimated that about 4% of the plastic waste disposed in landfills comes from scrapped automobiles [Vernyl, 1990]. Thermosets can be recycled by grinding the material into a fine powder and using it as an inert filler or by pyrolyzing it. Pyrolysis is the primary process being studied by the automotive industry as a method of handling scrap thermosets from automotive body part production. It consists of heating the thermosets in the absence or near absence of oxygen to drive off the volatiles present in the waste feed material. The resulting products are combustible gas or fuel oil which can be used to sustain the process, as feedstocks to the chemical industry, or as filler material in new product molding.

Additionally, the Council for Solid Waste Solutions has established a program to coordinate efforts for the recycling of durable plastic goods. The program will initially examine the technical aspects of durable goods recycling with emphasis on the disposal of automobile residue.

### *3.8 Sources of Plastic Recycling Information and Plastic Recycling Systems*

Shown in Appendix B are sources of information on plastic recycling (publications, sources of markets, reports, and institutions and service organizations involved in plastic recycling).

In addition to the developing separation and cleaning systems discussed in Chapter 3, there are many cleaning and waste plastic processing vendors in the marketplace today. Most of the operations for cleaning and waste plastic processing are of a proprietary nature, and detailed information of a particular process may not be readily available to the public. However, the vendors should provide more detailed information for a specific case application and provide performance guarantees. Appendix C provides a listing of vendors in the plastics recycling field. Manufacturers of turnkey separation systems, granulators, shredders, cleaning, conveying, drying and processing equipment are also provided.