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Evaluation of an Automated Sorting Process for Post-Consumer Mixed Plastic Containers

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EVALUATION OF AN AUTOMATED SORTING PROCESS FOR POST-CONSUMER MIXED PLASTIC CONTAINERS

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This publication is part of a series of publications for the Municipal Solid Waste Innovative Technology Evaluation (MITE) Program. The purpose of the MITE program is to: 1) accelerate the commercialization and development of innovative technologies for solid waste management and recycling, and 2) provide objective information on developing technologies to solid waste managers, the public sector, and the waste management industry.

E. Timothy Oppelt
Risk Reduction Engineering Laboratory

PREFACE

The Municipal Solid Waste Innovative Technology Evaluation (MITE) Program is managed by the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD). The purpose of the MITE program is to: 1) accelerate the commercialization and development of innovative technologies and programs for solid waste management and recycling, and 2) provide objective environmental and cost information on developing technologies and programs to solid waste managers in the public and private sectors.

These goals are met by selecting, through a competitive process, technologies and programs whose sponsors have submitted proposals to EPA through its annual solicitation. The proposals are reviewed and the most promising projects are selected for inclusion in the program. Once selected, EPA, with the cooperation of the technology developer, formulates an evaluation plan which emphasizes the costs, effectiveness and environmental impacts of the technology. Each project consists of a field demonstration and an associated evaluation. The MITE program is administered by the Solid Waste Association of North America (SWANA). SWANA coordinates an Advisory Committee review as well as assisting in the formulation of the evaluation plans.

The technology developer, the Rutgers University Center for Plastics Recycling Research, conducted this demonstration. wTe Corporation conducted the on-site performance evaluation, analyzed the data collected, and prepared the subject report.

A limited number of copies of this report will be available at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268. Requests should include the EPA document number found on the report's cover. When the supply is exhausted, additional copies can be purchased from the National Technical Information Service, Ravensworth Building, Springfield, Virginia 22161 (telephone number - 703-487-4600).

ABSTRACT

This project evaluates a proof-of-concept, pilot-scale, automated sorting system for mixed post-consumer plastic containers developed by the Rutgers University Center for Plastics Recycling Research (CPRR). The study qualifies the system's ability to identify and separately recover five types of plastic containers representative of those found in plastics recycling programs. It also addresses the system's potential for full-scale commercial application.

Three series of tests were performed: single composition, short-term tests; mixed composition, short-term tests; and mixed composition, extended tests. A total of 82 test runs were performed during which 66,632 bottles were processed.

The five bottle types considered were natural HDPE, PVC, clear PET, green PET, and opaque HDPE. The containers recovered at each product collection station were counted and the results compared to pre-established recovery goals. Bottle counts were then converted to weight recoveries using average bottle weights. The resulting product purity/contamination weight percents were compared to allowable product contamination limits representative of industry practice. From a detailed video tape analysis of a representative test, an exact profile of bottle feed timing and sequence was reconstructed. This analysis provided valuable insight into system feed and transport dynamics as well as an understanding of how product contamination occurs.

The system produced statistically reproducible results and proved to be mechanically reliable. However, it failed to achieve all of the commercial level container recovery and product contamination limit goals. It was concluded that bottle singulation and spacing greatly influenced the effectiveness of the identification/separation equipment.

This work was submitted by wTe Corporation in fulfillment of Contract No. 850-1291-4. The contract was administered by the Solid Waste Association of North America and sponsored by the U.S. Environmental Protection Agency. This report covers a period from May, 1992 to July, 1993.

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The principal system developers were Henry Frankel, Jose Fernandes, and Sergey Miroshnichenko of the Rutgers University Center for Plastics Recycling Research.

wTe Corporation evaluated the technology and prepared the report. The principal authors were Charles Faulstich and David Bubenick, who also served as wTe's Program Manager. Report reviewers included Diana Kirk and Lynnann Hitchens of the U. S. EPA, Charlotte Frola of SWANA, Aarne Vesilind of Duke University and James Abert, consultant.

SECTION 1

INTRODUCTION

BACKGROUND

The significant differences in plastic resin properties require that post-consumer plastic containers be separated by resin type before they can be processed into a form that can be used as a substitute for virgin resin. Until recently, manual sorting has been the only method commercially available for accomplishing this separation. Manual sorting has been found to be less than ideal, however, owing to high labor and training expenses and its susceptibility to error. While some identification/separation errors involving polyethylene terephthalate (PET) and high density polyethylene (HDPE) can be tolerated, very few such errors involving polyvinyl chloride (PVC) can be tolerated due to the physical/chemical incompatibility of PVC with PET. Compounding the manual separation problem is the visual similarity of some PVC and PET bottles.

Automated sorting systems are the latest technological development for the recycling of post-consumer plastic containers. These systems hold the promise of fast, cost-effective, and accurate resin separation from a mixed plastic container feed stream. The pilot automated sortation system for mixed post-consumer plastic containers developed by the Rutgers University Center for Plastics Recycling Research (CPRR) is one of the first such systems developed during the past few years, and is believed to be the first system to be rigorously tested by an independent party.

The Rutgers system integrates equipment that separates whole, uncrushed, mixed rigid plastic containers into the five most common household plastic bottle types: PVC, clear PET, green PET, natural HDPE, and opaque HDPE. A bottle presentation subsystem and an identification/separation subsystem comprise the overall system. The bottle presentation subsystem incorporates material handling equipment for the purpose of presenting the bottles to the identification/separation subsystem in an orderly and uniform manner, with each container separate and distinct from its predecessor and from its follower. The identification/separation subsystem consists of equipment for selectively identifying and removing bottles from the feed stream.

The system uses various techniques to perform the identification and separation of plastic containers. First, oversize containers consisting predominantly of natural HDPE milk and water jugs are removed by mechanical means. X-ray fluorescence is then used to identify the chlorine atom-containing bottles, namely PVC, and air jets force the detected containers away from the flow stream. Optical sensors then detect the transparent clear and green PET bottles which are also removed from the flow stream by air jets. The remaining containers consist primarily of opaque HDPE bottles which are collected at the end of the presentation subsystem.

PROJECT OVERVIEW

Three series of tests were performed in order to evaluate the Rutgers CPRR system, as described in the detailed Quality Assurance (QA) Plan prepared specifically for this project[1]. Single composition, short-term tests were performed in order to evaluate the recovery of each of the five

container types without interference from containers of a different type. Mixed composition, short-term tests were performed in order to evaluate the effectiveness of separating containers by type from a mixed stream of known composition; to collect reliability, availability and maintainability (RAM) data; and to establish the operating conditions for the third test series, the mixed composition, extended tests. Finally, mixed composition, extended tests were run in order to evaluate the system performance over a longer operating period, and to obtain additional RAM data to the extent permitted with a pilot scale system. A total of 82 test runs were performed over two weeks of testing during which 66,632 bottles were processed. Fifty tests were single composition tests; 17 were mixed composition, short-term tests; and 15 tests involving approximately 2,000 bottles each comprised the extended mixed composition test series.

The test procedure generally consisted of processing a known quantity and mixture of bottles through the system, collecting the resulting products, and counting the bottles in each product to determine the exact composition of each product. The numerical counts were compared to recovery goals established in the QA Project Plan. These goals were: a recovery of 90 percent for natural HDPE, opaque HDPE, clear PET and green PET; and a recovery of 100 percent for PVC. The numerical counts were converted to weights using average bottle weights, and resulting product purity/contamination values were calculated. These results were compared to the contamination limits generally established in the Project QA Plan and later supplemented with data from industry practice.

Several test runs were video taped, and one of these runs was used to reconstruct an exact test profile of the bottle feed timing and sequence. This analysis provided valuable insight into the dynamics of the presentation subsystem and the nature of the recovery errors occurring at one representative identification/separation station.

TECHNOLOGY STATUS

At the time of its development (1989 through 1991), the Rutgers CPRR system contained state-of-the-art technology for PVC detection and innovative optical sensor technology for PET detection. It was developed jointly by Rutgers University and the Asoma Instrument Company, the manufacturer of the PVC identification equipment, with support from industry, academic and government sources. The primary purpose of the Rutgers system was to demonstrate the PVC detection and optical sensor technology at pilot scale. It therefore was designed to process bottles of round cross section and limited size such as those used for soft drinks and edible oil. Inclusion of oversize bottle control allowed the recovery of an oversize product, consisting of predominantly natural HDPE. Because the collection of residuals is inherent in any conveyor system, it was possible to passively collect another product at the end of the system, namely opaque HDPE.

The major emphasis during system development was on the detection and separation technology, rather than on the material handling system. The feed system was constructed principally to provide a means of delivering bottles of limited size and shape to the sensors at rates and mixtures consistent with pilot-scale processing. No attempt was made to refine the feed system to deliver containers at commercial-scale processing levels. This is unfortunate, because it is well recognized in the industry that the limiting factor on the recovery accuracy of sorting systems is determined more by the mechanical details of the material handling system than by the performance of the identification/separation equipment. This axiom was generally supported by the results of this investigation.

In weighing the results of this system evaluation, consideration must be given to the fact that the Rutgers material handling system was not designed to deliver bottles at commercial-scale rates and in commercial-scale mixtures. Thus, the CPRR system should not necessarily be viewed as a system with direct commercial application.

As one of the first automated systems developed, the Rutgers system uses the first generation of Asoma PVC detection equipment, the XRF detector. A second generation PVC detection device, the VS-2, has since been developed by Asoma. The VS-2 detector is mounted on the underside of a chute over which the bottles are conveyed, rather than being mounted vertically as with the XRF detector. The VS-2 arrangement eliminates the potential error inherent in the XRF detector caused by its sensitivity loss with distance.

The VS-2 reportedly can identify PVC bottles anywhere over a 12-inch wide channel at a speed of 10 feet per second and reportedly has a miss rate of less than one bottle in 100,000[2]. Asoma claims that this detector is capable of a bottle detection rate of well over 100 bottles per second, but they acknowledge that practical delivery rates are more in the range of 3 to 5 bottles per second. It was not possible to incorporate this new technology into the Rutgers system prior to evaluating the system. Therefore, the results of this investigation must be considered in light of the fact that the most advanced PVC detection technology was not employed.

Several commercial systems have been developed simultaneously with and subsequent to the development of the Rutgers system. These include the BottleSort System (Magnetic Separation Systems), the VinylCycle System (National Recovery Technologies), and the PolySort System (Automation Industrial Control). However, the recovery accuracy and throughput reported in the literature for these systems have not been demonstrated in a rigorous testing program similar to that described in this report on the Rutgers system. These commercial systems are briefly described in Section 6.

SECTION 2

CONCLUSIONS/RECOMMENDATIONS

Prior to this MITE evaluation, rigorous testing of the Rutgers system had never been performed on mixed bottle feedstock at elevated feed rates. The emphasis during development of the system was on the performance of the optical and X-ray fluorescence sensors. The material handling system was constructed to deliver bottles in a manner consistent with pilot scale processing so that the sensors could be tested. The goals established in the Project Quality Assurance Plan are more suited to a commercial-scale system. Failure to meet the commercial-scale expectations does not necessarily indicate that the pilot scale system developed by the CPRR cannot be upgraded to a successful commercial scale system.

CONCLUSIONS

The individual unit operations employed in the Rutgers system were found to be reasonably effective in reproducibly separating and recovering bottles by type from a mixed stream. However, as a whole, the Rutgers system did not achieve the recovery and product purity goals established prior to testing. The deficiencies of the material handling system and the lack of a state-of-the-art PVC detector severely limited the performance of the overall system in terms of recovery and throughput. Exactly how much system error was due to material handling and how much was due to equipment malfunction could not be established.

The overall system was found to be capable of correctly recovering, with 95 percent confidence, 90.9 percent of the bottles fed during a 4.8-hour mixed composition extended test. The average bottle feed rate was 74 bottles per minute, or 782 pounds per hour using average bottle weights. Of the five products recovered in the extended test series, only natural HDPE and clear PET achieved their respective recovery goals with 95 percent confidence. Only the opaque HDPE product met the established contamination criteria. All other products exceeded the contamination limits for at least one other bottle type.

The material handling equipment exhibited several deficiencies that lowered the overall system performance. For example, it could not deliver a consistently spaced mixed bottle stream to the identification/separation equipment at an average feed rate of 74 bottles per minute. In some cases, bottles were either too closely spaced or not properly aligned to allow them to be properly identified and/or ejected. In many cases, the bottles were widely spaced, reducing the system throughput considerably. Also, some components of the material handling system could not consistently accommodate the range of bottle sizes, shapes and orientations encountered in the testing, as evidenced by the large number of bottle jams observed.

Although no consistent correlation between bottle recovery and feed rate was observed, bottle to bottle interference during mixed composition testing was found to negatively affect bottle recovery. During the single composition tests, bottle recoveries were generally much higher than during the mixed

composition testing despite much higher feed rates. As the system was designed to process only whole, uncrushed bottles, only undamaged bottles were used in the evaluation. No determination of the system's separation efficiency on crushed, dented, or heavily scratched bottles was made.

The video tape analysis of the clear PET station during one extended test showed that approximately one-half of the bottle recovery mistakes occurred during the relatively short period of time when bottles were spaced less than 2 inches apart. At this close spacing, the air jet separation equipment could not selectively remove single bottles consistently. Approximately 8 percent of the bottles were so spaced. The remaining mistakes, also approximately one-half of the total, are attributable to presentation subsystem problems with bottle alignment and orientation, and identification/separation subsystem errors due to non-optimal bottle size, shape, and condition.

RECOMMENDATIONS

The existing system was designed to pilot-scale standards and as such is not substantial enough for the demands of long term commercial-scale operation. Certain components of the Rutgers system are expected to require only minor redesign to improve throughput, container recovery accuracy, and reliability, and to prevent feed jams. Other recommended changes are more significant in that they substantially add to or change the basic process flow of the system. An example of this type of design change is the incorporation of the Asoma VS-2 PVC sensor into the system to improve PVC recoveries and therefore decrease PVC contamination. Also, a multiple pass system could improve recovery by allowing more than one opportunity to detect and remove the target products. For example, additional PVC sensors may be required to assist in the cleanup of certain product streams if primary PVC recovery is insufficient to meet product purity requirements. Use of the new Asoma VS-2 sensor may at least partially eliminate the need for secondary PVC cleanup, however. Re-design of the system to allow bottle detection from below rather than from the side might allow the system to process crushed bottles. The effectiveness of the air jets at removing crushed bottles is unknown, however, and a new separation technique for crushed natural HDPE bottles would need to be developed.

Specific design recommendations are described in Section 6, Commercial Potential. The less extensive modifications that improve the material handling aspects of the system may in themselves be successful in raising system performance to acceptable commercial-scale levels. However, the degree of improvement in performance resulting from any of the recommended equipment modifications cannot be ascertained without additional testing.

SECTION 3

SYSTEM DESCRIPTION

Figure 1 presents a flow diagram of the Rutgers system that separates, by type, a mixture of the following rigid plastic containers: translucent or clear high density polyethylene (natural HDPE), polyvinyl chloride (PVC), clear polyethylene teraphthalate (clear PET), green polyethylene teraphthalate (green PET), and opaque high density polyethylene (opaque HDPE). Figure 2 presents a scale plan view of the actual equipment layout, and Figures 3 through 8 are photographs of the system. The conveying system is described in Table 1.

Gaylord boxes containing the bottle feedstock are manually emptied into a live bottom feed bin (Figure 3). An inclined cleated belt conveyor (C2) draws the bottles out at a regulated rate. The live bottom consists of a short conveyor (C1) controlled by a level sensor mounted on the feed bin wall. When the bin level drops below the sensor level, the conveyor is activated, moving the feedstock pile against the inclined drag conveyor.

A variable speed controller allows conveyor C2 to operate at any percentage of the maximum speed from 0 to 100, and the container feed rate is controlled by adjusting this speed. The cleats on conveyor C2 are 3-1/2 inches high, allowing only one layer of containers to be carried by the conveyor. Burden depth and bottle alignment is automatically controlled by fallback caused by the conveyor's inclination and by a leveling bar mounted inside the live bottom storage bin.

At the head end of conveyor C2, the first stage of a two-stage mechanical separation process takes place; a counter-clockwise rotating paddle wheel mounted above the belt ejects oversize containers into a chute. At the lower end of the chute, the second stage of mechanical separation occurs. Another paddle or "kick" wheel is set at a height above the chute sufficient to eject bottles of a size similar to that of one-gallon natural HDPE containers, while allowing containers that are smaller in profile to pass. Ejected containers are diverted onto conveyor C6 (Figure 4), and a plow then diverts the containers from the conveyor into gaylord boxes. Containers not ejected by the kick wheel are dropped back into the feed bin and are fed again.

The containers that are discharged by conveyor C2 drop onto conveyor C3 through a dual discharge chute (Figure 5). The two parallel chutes serve as the first step in singulating the feed. Conveyor C3 is equipped with two flexible metal strips that first divert the containers against one side of the conveyor, and then back to the original side. The intent of these strips is to assist in the aligning and singulation of the containers. Conveyor C3 feeds a three section singulating conveyor system (C4a, C4b, C4c). This conveyor system consists of three adjacent overlapping conveyor sections, each section operating at a slightly higher speed than the previous section. A diagonal plow diverts the bottles from one section to the adjacent section. The increasing speeds of the conveyor sections are designed to draw each container apart from its follower. Conveyor section C4c discharges onto presentation conveyor C5, which conveys the containers past the identification/separation stations.

Conveyor C5 is axially inclined such that the containers are in contact with the lower edge skirting of the conveyor as they move downstream (Figure 6). The X-ray fluorescence and optical sensors are located along the lower edge skirting. A bank of three air jets is located at the beginning of conveyor C5 to assist in directing the containers against the lower edge skirting. These air jets were ineffective, and were eventually disconnected to conserve air pressure.

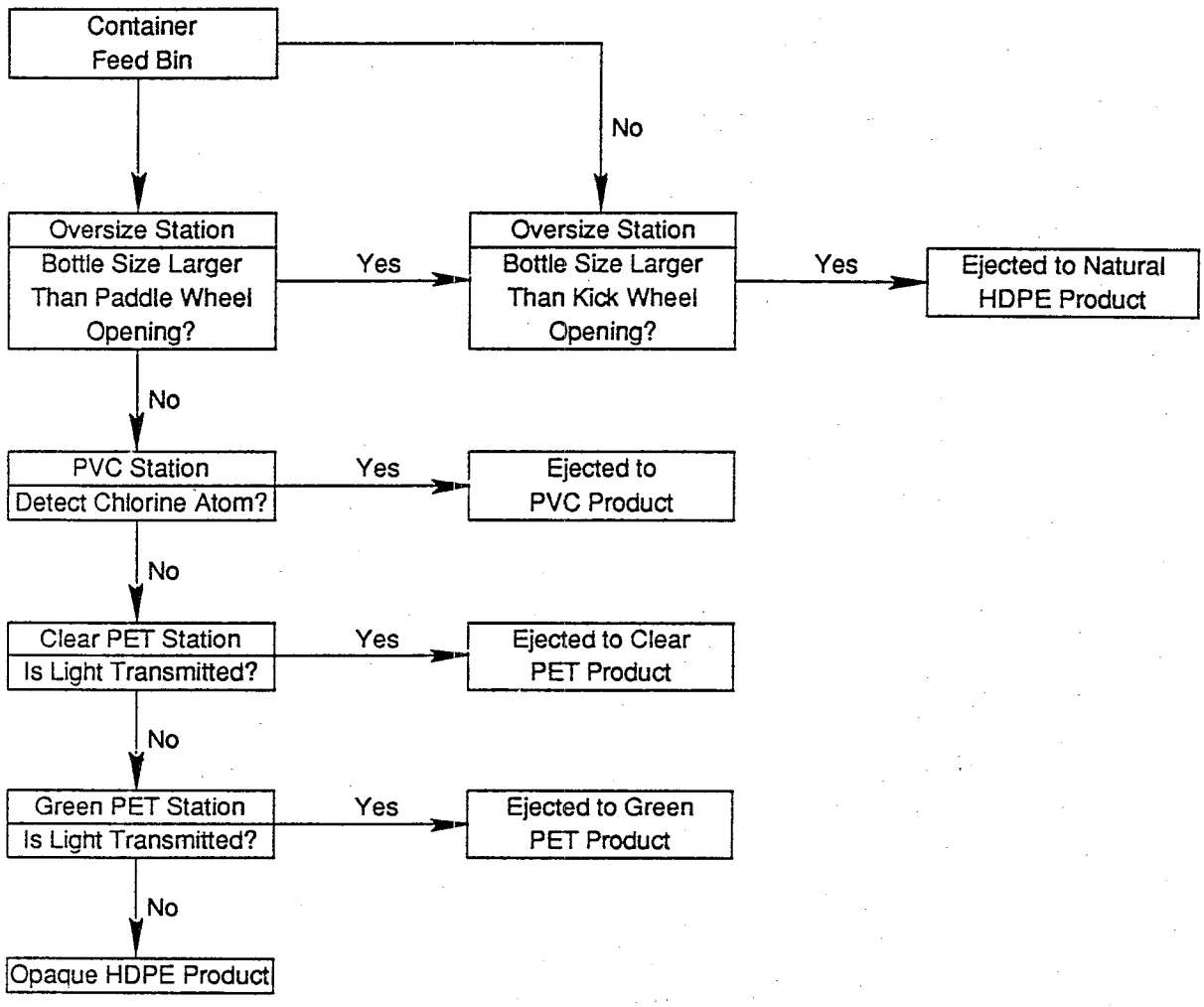

Figure 1. Process flow diagram.

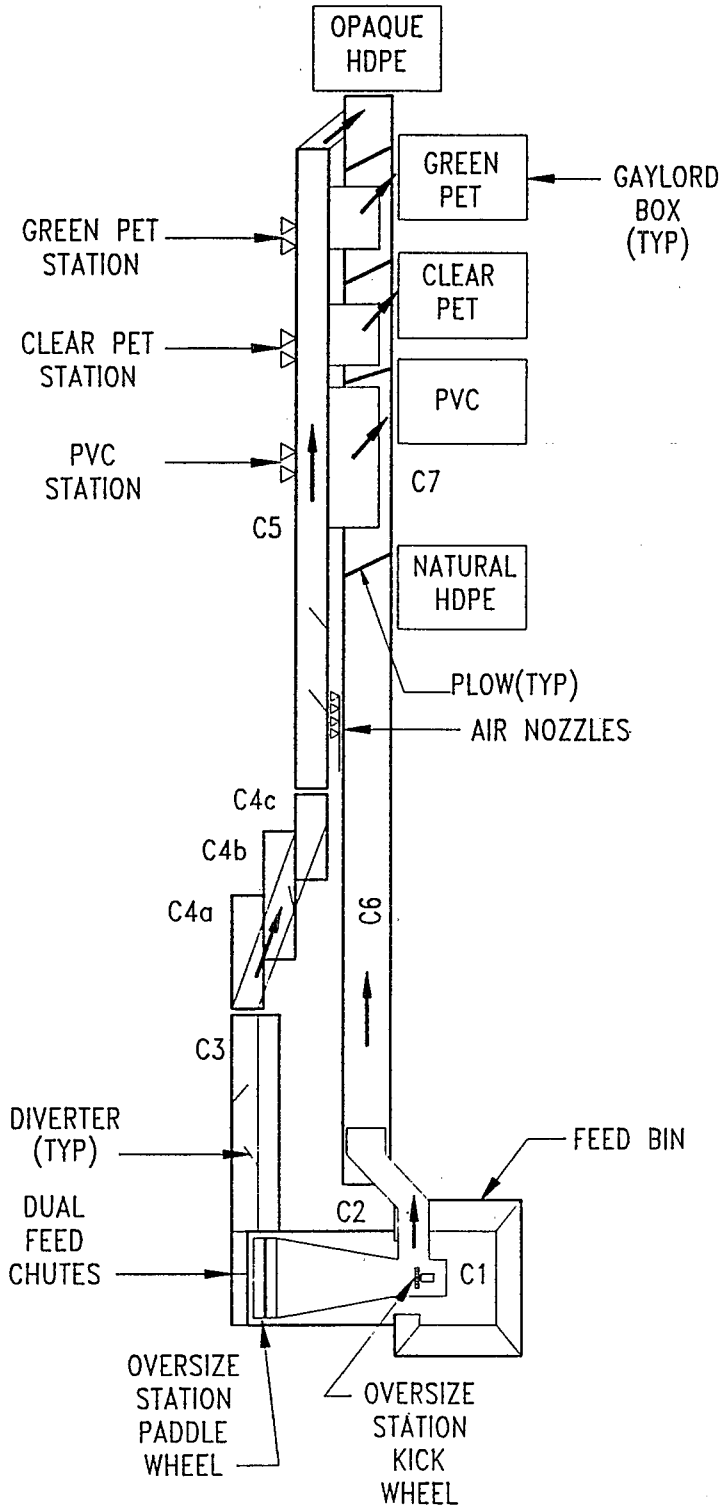

Figure 2. Equipment layout.

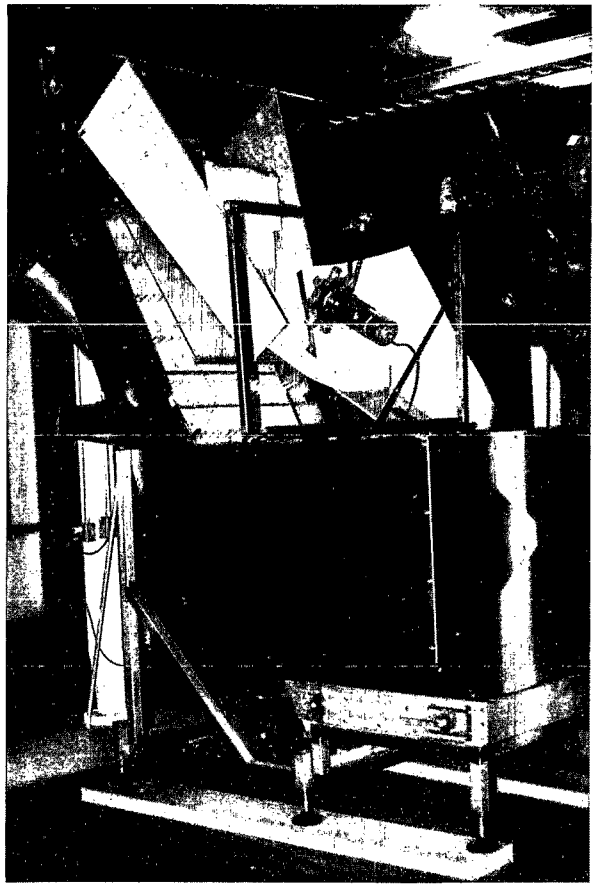

Figure 3. Feed bin, infeed conveyor, and oversize discharge chute.

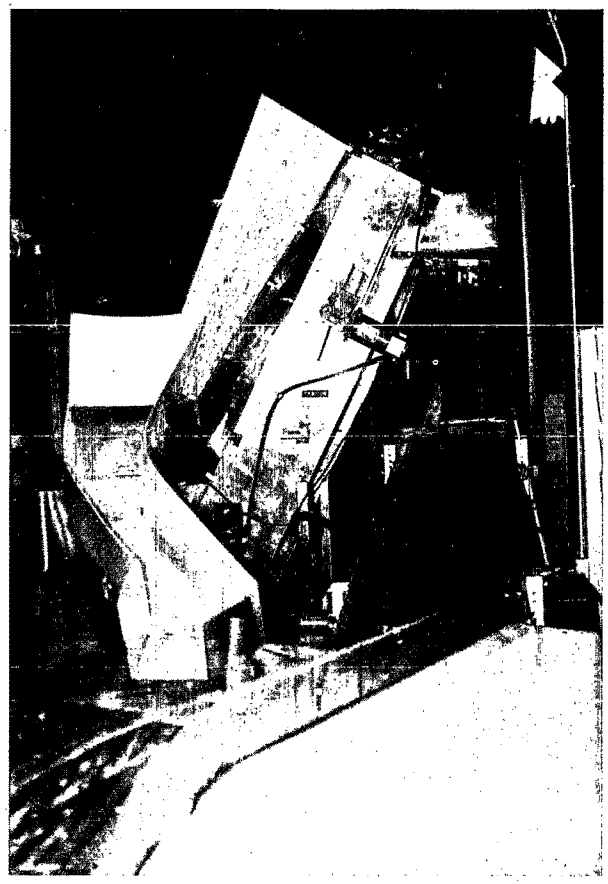

Figure 4. Infeed arrangement viewed from C4/C5 transition; conveyor C4 in foreground, oversize discharge chute on left, discharge chute and C3 on right.

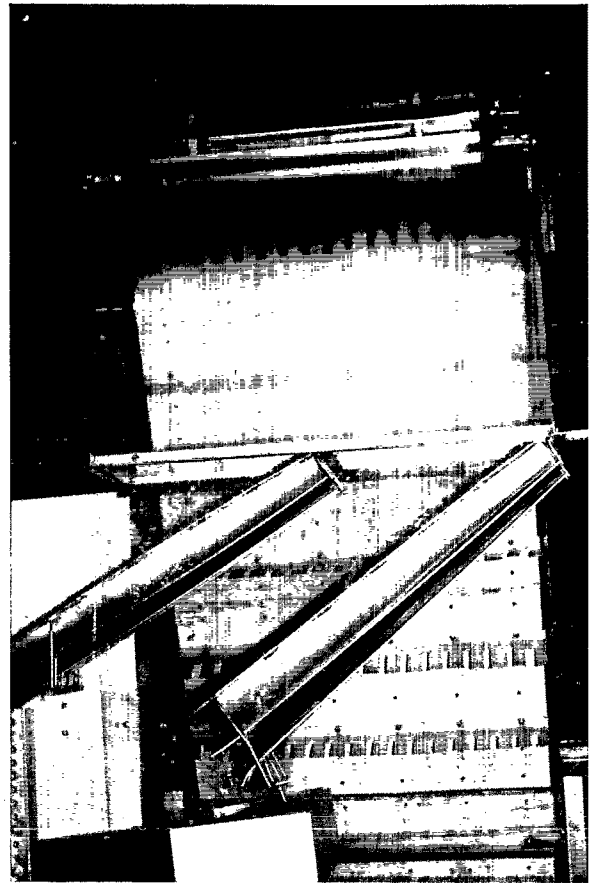

Figure 5. Dual discharge chutes and underside of infeed conveyor.

Figure 6. Conveyors C4b and C4c in foreground, C6 at right, and C5 in background.

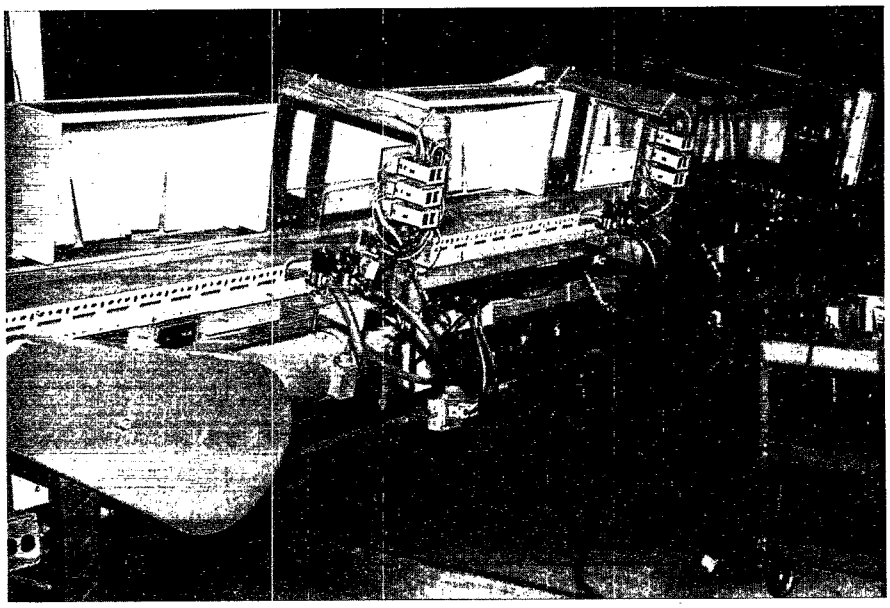

Figure 7. Green PET, clear PET, and PVC identification/separation stations (left to right).

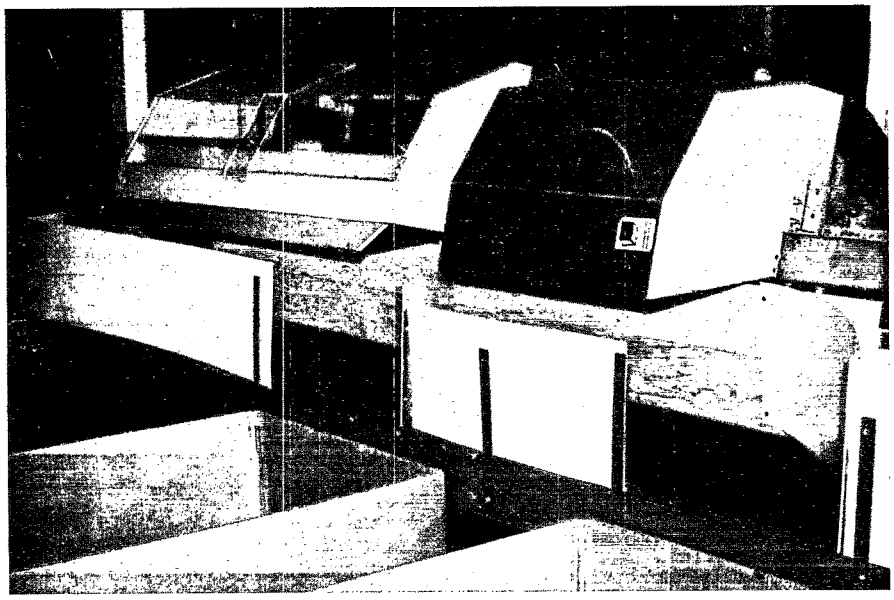

Figure 8. PVC and clear PET product chutes, conveyor C7 in foreground with plows and gaylord boxes.

TABLE 1. CONVEYOR SCHEDULE

Conveyor	Width, inches	Approx. length	Motor HP	Pulley diameter, inches	Comments
C1	24	4'-0"	1/2	4	Forms live bottom in feed bin
C2	36	8'-6"	1/2	4	3-1/2" deep cleats, inclined at 60 degrees
C3	18	10'-0"	2	4	Skirting reduces effective width to 10"
C4a	12	3'-8"	1	6	Common motor for C4a, C4b, and C4c, 8 V-belts, inclined at 17 degrees
C4b	12	4'-2"		6	Common motor for C4a, C4b, and C4c, 8 V-belts, inclined at 17 degrees
C4c	12	2'-9"		6	Common motor for C4a, C4b, and C4c, 8 V-belts, inclined at 17 degrees
C5	12	20'-6"	N/A	4	Inclined at approximately 17 degrees, motor size not available
C6	12	19'-6"	2	4	Plow diverts bottles to gaylords
C7	18	19'-6"	2	4	Plows divert bottles to gaylords

The identification/separation stations are positioned along conveyor C5 in the following sequence: PVC, clear PET, and green PET (Figure 7). To identify and remove PVC bottles, X-ray fluorescence is used to detect the chlorine atom found only in these containers. When detected, two air nozzles deliver a blast of compressed air that forces the detected container off conveyor C5 and onto conveyor C7. The air nozzles are aimed such that they create a concentrated pressure wave to cleanly force the container off the presentation conveyor without imparting any spin to the bottle.

PET containers are detected by a technique based on the optical transmission of visible light. The opposed mode sensing technique consists of light emitting diodes (LEDs) as sources and phototransistors as receivers. In this technique, the LEDs point directly at the phototransmitters with the bottles passing between the two. The bottles either absorb, reflect, or refract the light, diminishing the intensity of the light falling on the phototransistor. If the intensity of the light detected at the receiver is above a selected adjustable level, a digital signal is sent to the ejector solenoid.

The light sources actually consist of a bank of three LEDs; two outer LEDs to detect the physical presence of a container, and one center LED to sample a region of the bottle unobscured by a label or basecup. The center LED at the clear PET station uses a red light, whereas the center LED at the green PET station uses a green light. The red light is capable of being transmitted through clear PET but is optically blocked by green PET. Hence, green PET will not be detected at the clear PET station. The light emitted by the LED at the green PET station is transmitted through both clear and green PET, and thus is incapable of distinguishing between the two colors. Thus, any missed clear PET will be detected at the green PET station. Both clear and green PET optical stations are equipped with air jets similar to those used in the PVC identification/separation station to move the detected containers from conveyor C5 onto conveyor C7.

The plows on conveyor C7 divert the PVC and PET products into separate gaylord boxes (Figure 8). Containers not removed from conveyor C5 by the identification/separation stations are discharged off the end of conveyor C5 into a gaylord container. This product will consist primarily of opaque HDPE containers since they should pass through the system undetected.

The system was originally designed to collect all materials removed by the identification/separation stations onto conveyors C6 and C7 for discharge into a common container. In order to keep each product separate from one another during the testing, plows were installed on the conveyors immediately downstream of each identification/separation station to divert each product into a separate gaylord container. Modifications to the system were also made voluntarily by the project developers in the interim between the first week of testing and the second week of testing. Two flexible metal diverters were added along the upper skirting of conveyor C5 to direct the bottles against the sensor side of the conveyor skirting. The air jets located in this position for this same purpose were found to be ineffective and were de-activated to conserve air pressure. Also, the axial tilt of conveyor C5 was reduced slightly from its 17 degree slope. Prior to the start of the extended test series, the house air pressure was increased from 100 to 130 psi, and the blast duration at each separation station was decreased by approximately 20 percent.

SECTION 4

TESTING METHODOLOGY

PROJECT OBJECTIVES

The project objectives initially envisioned were as follows:

- Determination of the maximum container feed rate, with 95 percent confidence, that will assure 90 percent recoveries for natural HDPE, opaque HDPE, clear PET, and green PET, as well as 100 percent recovery of PVC, while meeting specified product contamination levels.

- Determination of the mechanical reliability, availability, and maintainability (RAM) of the overall system

- Projection of the performance and operating economics for a commercial scale system.

Early in the project, it was determined that there was little advantage to collecting RAM data for a pilot scale system. The system was not designed and constructed according to commercial-scale standards, and the test results demonstrated that the equipment failures that occurred were a direct result of the pilot-scale quality of the equipment. No information was available on the operation and maintenance history of the equipment, data that are essential for a RAM analysis to be meaningful. Nonetheless, data were collected regarding equipment failures and problems; however, no major conclusions could be drawn from these data.

Similarly, the requirement for major system changes in order to scale the system up to commercial level (which is beyond the scope of this MITE evaluation) rendered a detailed economic analysis of the capital and operating costs meaningless. Rather, recommendations are offered for several process modifications that may prove successful in upgrading the system to commercial-scale quality (see Section 6). As indicated earlier, such performance improvements can only be quantified after extensive additional testing, and therefore, no commercial scale cost estimate can be offered. However, in order to provide a baseline cost reference, as required in all MITE program technology evaluations, an estimate of the material costs for the Rutgers system as designed is provided in Section 6 (see Table 25).

To satisfy the primary project objective, a series of three tests were conducted. Single composition, short-term tests evaluated the recoveries of a specific type of container without any interference from other container types. Mixed composition, short-term tests evaluated the effectiveness of the system in separating containers by type from a mixed stream and established the operating conditions for the third test series, the mixed composition, extended tests. The mixed composition, extended tests were conducted to verify the system's capability to operate over a longer period of time, based on the operating conditions established in the mixed composition, short-term tests. Qualitative RAM data were obtained to the extent that a pilot-scale system can permit a meaningful evaluation of such data. Testing was conducted during the weeks of September 21, 1992 and October 5, 1992.

QUALITY ASSURANCE OBJECTIVES

The quality assurance objectives, established prior to testing, were as follows:

- Container Recovery: A minimum recovery of 90 percent for natural HDPE, clear PET, green PET, and opaque HDPE, and 100 percent recovery of PVC based on containers actually presented for inspection.

- Container Recovery Accuracy: Bottle recoveries at the primary identification/separation stations of sufficient accuracy such that other product contamination levels are below typical industry contamination limits.

- System Reliability: An overall system reliability of 90 percent.

- System Availability: An overall availability of 90 percent.

- Test Completeness: A minimum of 60 percent of the test replicates be judged valid. This objective is applicable to all but the extended tests.

- Data Set Comparability: Ensure that all data collected are capable of being compared on an equal basis. This objective was met given the fact that all data sets within a test group (i.e., the same feed material) are directly comparable since the feedstock for each test replicate is identical and all bottles are accounted for at the end of each test.

- Data Set Representativeness: Ensure that the data collected are representative of materials typically encountered in the recycling industry. This objective was met given the fact that the majority of the bottles was obtained directly from actual curbside collection programs.

FEED MATERIAL

The majority of the containers used in the tests were obtained through local curbside collection programs. The required number of post-consumer PVC and opaque HDPE bottles could not be obtained from local curbside collection programs. Thirty unused PVC bottles and 110 unused opaque HDPE bottles were obtained from local manufacturers to supplement the 150 post-consumer PVC bottles and the 658 post-consumer opaque HDPE bottles needed to perform the testing. Only whole, uncrushed bottles were selected for processing; all badly damaged containers were removed from the supply. The opaque HDPE feedstock was selected so as to exclude large bottles that, because of their physical size, would consistently report to the oversize station. Some bottles became deformed by the mechanical separation equipment as a result of repeated testing; these were replaced with the same type of bottle so as not to affect reproducibility of the recovery data for that bottle type.

The types of containers used in the testing were as follows:

- Natural HDPE: Milk bottles, spring water bottles, and kitty litter containers. All were one gallon in size, and all were virtually identical in shape.

- PVC: Primarily edible oil containers, shampoo containers, and household cleaner containers. The shape and size of these bottles varied widely.

- Clear and Green PET: All soda bottles, ranging in size from 1 to 3 liters. Over half were 1 liter; less than a dozen were 3 liter. Some included basecups while others did not.

- Opaque HDPE: Primarily laundry detergent, orange juice, and bath lotion containers, as well as a few dozen small size "pill" bottles.

Average bottle weights were determined for each of the five bottle types used in the testing, as follows: natural HDPE - 64 grams, PVC - 59 grams, clear PET - 71 grams, green PET - 78 grams, and opaque HDPE - 101 grams. The difference in clear and green PET average weights was due to the difference in the relative quantities of 1, 2, and 3 liter bottles.

The mixed composition test feedstock was prepared to approximate the average of four mixed plastics compositions reported in the literature by third party sources. When the representative published data included other miscellaneous plastics, the data were normalized to include only the five resin types used in the testing. These compositions are presented in Table 2.

TABLE 2. TYPICAL PLASTICS COMPOSITIONS, PERCENT BY WEIGHT

	Source				
Bottle type	1	2	3	4	Average
Natural HDPE	23.4	24.6	23.1	20.4	22.9
PVC	7.4	5.8	7.0	5.4	6.4
Clear PET	16.3	18.5	17.8	21.7	18.6
Green PET	5.4	6.1	5.9	5.4	5.7
Opaque HDPE	47.5	45.1	46.1	47.1	46.5

Sources

Note: Numbers provided were normalized to include only the five bottle types of interest.

1 - Chemical Week, July 25, 1990.
Overall HDPE number provided - assumed 33% natural HDPE, 67% opaque HDPE.
Overall PET number provided - assumed 25% green, 75% clear.
Numbers provided are weight percents of total plastics packaging.

2 - Wrapped in Plastics, The Environmental Case for Reducing Plastics Packaging, Jean Wirka, Environmental Action Foundation, Washington DC, August 1988.
Numbers provided are 1987 sales in millions of pounds.

3 - Resource Recycling's Plastics Recycling Update, February 1991.
Numbers provided are 1990 Modern Plastics data for plastics production in millions of pounds.
Overall PET number provided - assumed 25% green, 75% clear.

4 - Resource Recycling's Plastics Recycling Update, February 1991.
Numbers provided are Rhode Island data for the plastics composition in MSW.

PRODUCT CONTAMINATION

Product contamination in the context of this report refers to the unintentional mixing of one resin with another. Industry-wide product purity standards have not been established for the plastics products generated by primary collectors/processors such as Material Recycling Facilities (MRFs). Each end user or intermediate processor that purchases the materials from the primary collectors/processors establishes the purity requirements for the materials they purchase. The basis for the specific requirements extend beyond the chemical compatibility of resins to include facility-specific processing capabilities and economic tradeoffs between purchase, processing, and sell costs. Thus, the specifications for MRF-generated plastics are somewhat subjective and can vary considerably from processor to processor.

From a chemical compatibility viewpoint, the major concern is PVC/PET contamination. PVC and PET are virtually incompatible with one another in the reformulation of either PVC or PET pellets. As such, they require nearly complete separation in any bottle sorting system. The specific gravity of PVC and PET are very close, rendering the conventional gravity separation techniques used by intermediate processors ineffective. Manual separation at a MRF is not reliable or sufficiently accurate because of the visual similarity between some PVC and PET bottles.

The maximum allowable concentration of PVC in PET depends on the end use of the PET product but generally is only in the range of 10 to 200 parts per million (ppm). High end use PET products such as packaging require PVC contamination no greater than 10 ppm, while lower end uses of PET in fiber production and some chemical recycling processes permit higher levels of PVC contamination. The limitation on PET in PVC is similar. Since the PET and PVC cannot be easily and reliably separated by the intermediate processor, the intermediate processor typically transfers material quality responsibility to the MRF. To better illustrate the nature of the quality requirements, in a load of equally sized bottles, 10 ppm is one bottle in 100,000 or 0.001 percent, and 200 ppm is one bottle in 5,000, or 0.02 percent. In practice, this stringent level of contamination is essentially zero for all practical purposes.

Of the five bottle types used in the testing, the second major material combination limited by chemical incompatibility in product reformulation involves opaque (copolymer) and natural (homopolymer) HDPE. Each of these two HDPE resins can only accommodate a limited amount of contamination by the other, above which its physical properties deteriorate.

All other combinations of resins are restricted by color incompatibility or by economics. The economics of both the MRF's and the intermediate processor's operations are affected by the product contamination levels. The party that performs the contamination removal receives the economic benefit either through higher product revenues or through lower purchase costs. With proper economies of scale, the economic benefit can exceed the cost.

The standards presented in Table 3 represent the contamination specifications in weight percent that typically could be required by an intermediate processor purchasing baled plastics from a MRF. The specifications are based on the material purchase specifications currently in use by five secondary processors. Less stringent specifications may be required by some processors, while more stringent requirements may be required by others. The specific circumstances of each case will determine the exact limits.

The feedstock for the test program contained little if any incidental contamination. Incidental contamination can be miscellaneous materials not associated with or related to the container types to be recovered, and from items typically found on or related to bottles such as caps, safety seals, bottle

pieces, custom colored PET bottles, PET-G bottles (containing glycol), residue from the containers' product, and metallized labels. These contaminants can serve to reduce the allowable contamination contribution from whole bottles.

TABLE 3. ASSUMED PRODUCT CONTAMINATION LIMITS

	Contaminant, weight percent [a]				
Product	Natural HDPE	PVC	Clear PET	Green PET	Opaque HDPE
Natural HDPE	--	2 *	2 *	2 *	1
PVC	5 *	--	0 **	0 **	5 *
Clear PET	5 *	0	--	1	5 *
Green PET	5 *	0	10	--	5 *
Opaque HDPE	5	2 *	2 *	2 *	--

(a) All weight percentages marked with a single or double asterisk (* or **) are the total weight percentages allowable for all such marked contaminants combined in the total product. For example, in the natural HDPE product, up to 2% of either PVC, clear PET, or green PET is allowed as a contaminant. Also, when more than one contaminant is present, the combined contamination may not exceed 2%.

In order to compare the test results to the product specifications, the numerical count data collected were converted to weights using the average bottle weights. Direct conversion from counts to weights in this manner assumes that each bottle type's average weight can be reasonably applied to all of that type's bottle counts without regard to the station at which that type of bottle was recovered. For example, it is assumed that the average weight of the opaque HDPE bottles recovered at any particular station is not biased away from the average weight of the entire supply of opaque HDPE bottles because of some characteristic of the system or the feedstock, such as the bottle's shape or size.

TESTS PERFORMED

A total of 82 test runs were performed over the 2 weeks of testing. Table 4 summarizes the test conditions and number of replicates for each test series.

Single Composition Tests

The purpose of evaluating the performance of the system in processing single composition feedstock was to determine the recovery capability of the system without the influence of dissimilar bottle types. Investigation of this process mode is not purely academic, as single composition feed could effectively occur in a commercial system when large slugs of similar bottles are being fed or if the system were to be used for a quality control check on pre-sorted bottles.

TABLE 4. TESTS PERFORMED

Feed material	Conveyor C2 speed, %	Number of replicates
Natural HDPE	75	5
PVC	25	3
	40	4
Clear PET	50	4
	75	5
	90	3
Green PET	25	2
	50	4
	75	4
	90	2
Opaque HDPE	25	2
	75	7
	90	5
1,000 mixed bottles	50	3
	75	3
2,000 mixed bottles	50	1
	75	6
	90	1
2,000 mixed bottles *	60	15

* Extended mixed bottle tests

The QA Plan specified that a total of 75 single composition tests would be performed (five repetitions of three speeds for five bottle types). Longer than estimated post-test bottle counting (subsequently shortened as discussed in Section 5) and repeated failure of the kick wheel motor reduced the available test time. Selected tests were eliminated to meet the time constraints, resulting in a total of 50 tests being performed. The selection of which tests to eliminate was based on an evaluation of previous test results together with a consideration of the relative magnitude of the single composition feed rate versus the "effective bottle feed rate" expected in the mixed composition test. This concept is defined in the Glossary of Terms and is discussed later in Section 5. Thus, the intent of each test series was maintained. Justification for test elimination is presented below.

Single composition testing of natural HDPE was limited to one speed setting because of the high recoveries achieved at that speed, and to minimize the physical damage to the bottles from the paddle wheel.

Testing was limited to two replicates in three test series: green PET at the 25 percent and the 90 percent speed settings, and opaque HDPE at the 25 percent speed setting. Several factors were influential in the decision to abbreviate the green PET testing. First, green PET testing followed the successful completion of the clear PET testing. Both PET sensors operate on the same principle, and both types of PET are similar in size and shape (the ideal size and shape of bottles for which the system was designed). As such, the performance of the clear PET sensor is a good indicator of the performance of the green PET sensor. The excellent recoveries achieved for the two green PET test replicates (97 and 98 percent) combined with the similarity with the clear PET results justified termination of this test series. Another factor was the extremely low bottle feed rates at the 25 percent speed setting. Completion of several replicate tests at these very low feed rates was not practical, since more informative tests could be run at higher feed rates. This factor applied to both the green PET and the opaque HDPE tests.

The calculated bottle recoveries were numerically equal for the two 90 percent green PET tests. This, in addition to the justification provided for the 25 percent test series, resulted in the decision to abbreviate the 90 percent green PET test series so that additional time would be available for the mixed composition testing.

The 25 percent opaque HDPE test series was abbreviated for similar reasons as those for the green PET testing. Recovery results from the first two replicates were well above the desired value, and the bottle feed rate was very low at 23 bottles per minute (bpm). This test series was considered to be low in priority and was therefore terminated at two test replicates.

PVC testing was restricted to the 25 and 40 percent speed settings because of the poor results obtained at those levels. Processing at higher speed settings was considered to be meaningless as recoveries were not expected to improve and most likely would decrease. Moreover, the effective bottle feed rates (see Glossary of Terms) for individual bottle types in mixed bottle processing are expected to be much lower than the single composition feed rates, which was confirmed during the mixed composition testing.

Approximately 300 bottles were processed during each of the single composition short-term tests with the exception of the PVC tests. The PVC tests consisted of only 180 bottles due to an insufficient supply of these containers.

Mixed Composition, Short-Term Tests

The purpose of the mixed composition, short-term tests was to evaluate the bottle recoveries resulting from the processing of a mixed feed stream, to obtain RAM data to the extent that a pilot scale system would permit a meaningful evaluation, and to establish the operating conditions for the mixed composition extended tests. Three series of mixed composition, short-term tests using approximately 1,000 bottles were performed at 50, 75, and 90 percent feed conveyor settings. Three replicates were performed at each feed conveyor setting, for a total of nine tests.

The nine short-term 1,000 bottle tests were supplemented with eight mixed composition, 2,000 bottle tests. One test was performed at the 50 percent speed setting, six at 75 percent, and one at 90 percent. This resulted in a total of 17 mixed composition, 1,000 and 2,000 short-term tests being

performed, compared to the 25 short-term tests specified in the QA Project Plan. Although the number of test runs was reduced, the total number of bottles actually processed (approximately 25,000) was the same as that originally planned.

Several voluntary system changes were implemented by the technology developer between the conclusion of the mixed composition, short-term tests and the initiation of the extended tests. The PVC sensor was lowered to allow detection of low profile PVC bottles. Flexible metal diverters were added to conveyor C5 to assist in aligning the PVC bottles against the conveyor skirting. These changes were designed to position PVC bottles closer to the sensor in an attempt to improve the PVC recovery accuracies. The air jet pressure was increased from 100 psia to 130 psia to minimize line pressure fluctuations when more than one station required air pressure at the same time.

One mixed composition, 2,000 bottle short-term test was performed at both the 50 percent and 90 percent speed settings strictly to provide bracketing data to assist in the selection of test conditions for the mixed composition extended tests. These tests provided data for comparison to the mixed composition 1,000 bottle test results to roughly assess the effect of the system changes.

Mixed Composition Extended Tests

The mixed composition, extended test series consisted of 15 segments using the 2,000 bottle mix at a 60 percent feed conveyor speed setting. Four of the tests were found to be statistically nonrepresentative (i.e., outliers) and were consequently eliminated from analysis. A total of 21,115 bottles were fed during the remaining 11 statistically valid test replicates. The total run time for the 11 test replicates was 4 hours, 47 minutes and 36 seconds.

Determination of Bottle Feed Rate

It was originally believed that the system performance would be inversely related to the bottle feed rate in that recovery would decrease with increasing feed rates. However, the test results from the single composition and short-term mixed composition tests did not show any clear, consistent relationship between bottle recovery and bottle feed rate for the individual materials. Initially this was surprising, but careful consideration of the test results provided insight into the mechanics of feed rate control and its relationship to system performance.

All conveyors operate at the same speed regardless of the desired overall bottle feed rate with the exception of conveyor C2. This is because the sensor/air jet timing and air blast duration are set for a specific presentation conveyor (C5) speed, approximately 330 feet per minute. The overall target bottle feed rate is set by adjusting the speed of conveyor C2. This conveyor discharges in slugs (a slug consisting of the contents of one cleat pocket of conveyor C2). By slowing or speeding up this conveyor, the time between slugs is either decreased or increased. A slug may consist of any number of bottles up to the capacity of the cleat pocket, which is approximately five bottles depending on the bottle types involved.

The slug of bottles is discharged onto conveyor C3 which feeds the three-section singulating conveyor C4. If the cleat pocket contained oversize bottles that were removed by the oversize station paddle wheel, no bottles would be delivered to conveyor C3 and a feed gap would occur. Feed gaps also occurred as a result of the fallback of improperly seated bottles as they were conveyed up inclined conveyor C2 or when knocked down by the paddle wheel. Falling bottles often knocked other bottles out of their cleat pocket, reducing the number of bottles in that cleat.

Because conveyor C4a operates at a lower speed than conveyor C3, it, rather than conveyor C2, truly serves as the metering device for the presentation conveyor C5. If a constant supply of bottles is provided to conveyor C4a, the bottles are drawn apart (i.e., singulated) by conveyor C4 at a uniform rate. The increasing speeds of conveyors C4a, C4b, and C4c automatically separate the bottles provided they are presented sequentially without any significant overlap. The resulting feed rate is the maximum feed capacity of the system. It can be increased only by delivering bottles at a rate such that they overlap on conveyor C4 and cannot be properly singulated, leading to recovery problems.

On the other hand, the feed rate can be decreased if bottles are delivered to conveyor C4a by conveyor C2 at a rate below the singulating capacity of conveyor C4a. Again, it is stressed that all bottles are presented to the sensors at a constant speed. The sensors only require milliseconds to identify bottles and do not require any equipment recovery time between bottles. Sufficient bottle spacing by conveyor C4 and correct bottle orientation are the two requirements for the identification sensors and the air jets. Thus, the bottle recovery capabilities of the identification/separation equipment should be relatively constant at feed rates that do not exceed conveyor C4's singulation capability provided that proper bottle alignment with respect to the sensors is maintained.

Generally speaking, the bottle feed rate range utilized for the testing did not exceed the capacity of conveyor C4 to properly singulate the bottles. This is not to say that all bottles were properly singulated and aligned with the sensors; bottle interaction and bouncing contributed to improper presentation. The slug feed method employed combined with the step down in conveyor speed at the C3-C4a transition have the potential for temporarily overloading conveyor C4's capability to properly singulate bottles. This can occur at any speed since it is a characteristic of the system.

A characteristic of the system that was affected by feed rate was feed chute and conveyor plugging. Because of the frequency of occurrence, all plugs were manually cleared and the affected bottles manually metered back into the flow as evenly as possible. At high speed settings, the plugs typically involved more bottles than at low speed settings, making the manual metering of the affected bottles more difficult. Bottles not properly reintroduced into the stream had the potential for erroneous identification and separation. This was a consideration when selecting the speed for the extended test series.

No one bottle feed rate resulted in all QA objectives being met. Because of this and because the feed rate was not found to be directly related to the system performance, selection of the speed setting for the extended tests was somewhat subjective. The feed conveyor speed setting selected for the mixed composition, extended tests was 60 percent. This speed was considered to be a good, representative speed that accommodated the characteristics of both the delivery system and the identification/separation system equipment.

DATA REDUCTION, CALCULATION, AND VALIDATION METHODS

The data collected during each mixed composition, 2,000 bottle extended test run are presented in Appendix A. The data show all raw data bottle counts recorded during these tests, test duration, calculated feed rate, and any observations noted during the tests. Appendix B contains the calculated results of the raw data for the mixed composition 2,000 bottle extended tests without outliers. Appendix C contains the bottle counts and weight percentages for each component of the products generated in the mixed composition 2,000 bottle extended tests. Data sheets similar to those shown in Appendices A, B, and C were prepared for all test runs. Only the mixed composition, 2,000 bottle extended test data are included, however, as these data represent the most meaningful and relevant conditions for assessing the system's commercialization potential. Data for all test conditions including single and short-term mixed composition tests are available from the EPA Project Officer.

To demonstrate the calculations, Tables 5 and 6 present PVC data excerpted from Appendices A and B. Table 5 presents the raw PVC data and Table 6 presents the calculated PVC results for the extended test. Data for tests identified as outliers are not included in Table 6. Subtable B-2.1 of Table 6 contains the actual bottle recovery counts and the effective bottle feed rates. A check total is provided for each test replicate. Also, a total is provided for each identification/separation station.

Subtable B-2.2 of Table 6 contains the bottle recoveries expressed as a percentage of the PVC bottles fed into the system. Sample mean, standard deviation, relative standard deviation, and 95 percent confidence intervals on the mean and standard deviation are included. The data presented in this subtable define the ability of the system to recover the intended bottles at the intended stations. For example, from the PVC column in Table 5 (or the Test 1 column, Table 6, subtable B-2.1), the number of PVC bottles fed into the system is 108, calculated as the total number of PVC bottles used (112) less the unfed bottles (4), and the number of PVC bottles recovered at the PVC station is 93. Thus, the percentage of PVC bottles recovered at the PVC station based on the number of PVC bottles fed is 100 x 93/108 = 86.1 percent recovery, as shown in subtable B-2.2 of Table 6.

TABLE 5. TEST DATA AS COLLECTED (REPLICATE 1 OF EXTENDED TEST)
(Extracted from Appendix A, Table A-1)

A-1.1 TEST 1 — DATE: 10/07/92
FEED: 2,000 MIXED BOTTLES — DURATION: 27.0 minutes
SPEED: 60% — FEED RATE: 71 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	479	1	3		42	525
Station 2 - PVC		93	3	2	11	109
Station 3 - Clear PET		10	424	7	30	471
Station 4 - Green PET		2	13	121	8	144
Station 5 - Opaque HDPE		1	4	8	639	652
Station - Unfed	15	4	9	5	36	69
Station - Spillage		1		1	2	4
Total	494	112	456	144	768	1974

Observations:

Noted that bottles can jam sideways on conveyor C3 - the skirting width is nearly identical to the length of a 1 liter PET bottle.

Four jams were caused by PET bottles, and 10 jams were caused by HDPE bottles.

Three PVC bottles were detected and blown at the PVC station but failed to enter the chute. They ended up in the clear PET station.

The fallback from the infeed conveyor was noted as fallback occurrences per minute: 13, 18, 28, 25, and 16.

The number of oversize chute pass-through occurrences were noted per minute: 11, 12, and 12.

TABLE 6. PVC DATA CALCULATIONS (EXTENDED TEST, OUTLIERS NOT INCLUDED)
(Appendix B, Table B-2)

B-2.1 PVC BOTTLE RECOVERY COUNTS

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL
1 - Natural HDPE	1			1	3	0	1			0	1	1	0	0	2	10
2 - PVC	93			100	104	97	102			99	102	100	97	97	95	1086
3 - Clear PET	10			6	0	6	3			6	4	5	10	10	8	68
4 - Green PET	2			4	4	3	4			3	3	6	4	5	6	44
5 - Opaque HDPE	1			0	0	1	0			1	1	0	1	0	1	6
- Unfed	4			1	1	5	1			3	1	0	0	0	0	16
- Spillage	1			0	0	0	1			0	0	0	0	0	0	2
TOTAL	112			112	112	112	112			112	112	112	112	112	112	1232
FEED RATE, BPM	4			4	4	4	4			4	4	4	4	4	5	4

B-2.2 PVC BOTTLE RECOVERIES AS A PERCENTAGE OF THE PVC BOTTLES FED INTO THE SYSTEM

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.9			0.9	2.7	0.0	0.9			0.0	0.9	0.9	0.0	0.0	1.8	0.8%	0.85	1.04	0.2	1.4	0.15	2.61
2 - PVC	86.1			90.1	93.7	90.7	91.9			90.8	91.9	89.3	86.6	86.6	84.8	89.3%	2.88	0.03	87.3	91.3	0.50	8.86
3 - Clear PET	9.3			5.4	0.0	5.6	2.7			5.5	3.6	4.5	8.9	8.9	7.1	5.6%	2.88	0.52	3.6	7.6	0.50	8.86
4 - Green PET	1.9			3.6	3.6	2.8	3.6			2.8	2.7	5.4	3.6	4.5	5.4	3.6%	1.11	0.31	2.8	4.4	0.19	3.41
5 - Opaque HDPE	0.9			0.0	0.0	0.9	0.0			0.9	0.9	0.0	0.9	0.0	0.9	0.5%	0.47	0.96	0.2	0.8	0.08	1.45
- Spillage	0.9			0.0	0.0	0.0	0.9			0.0	0.0	0.0	0.0	0.0	0.0	0.2%	0.36	2.25	0.0	0.5	0.06	1.11

B-2.3 PVC BOTTLE RECOVERIES AS A PERCENTAGE OF THE PVC BOTTLES PRESENTED TO EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.9			0.9	2.7	0.0	0.9			0.0	0.9	0.9	0.0	0.0	1.8	0.8%	0.85	1.04	0.2	1.4	0.15	2.61
2 - PVC	87.7			90.9	96.3	90.7	93.6			90.8	92.7	90.1	86.6	86.6	86.4	90.2%	3.21	0.04	87.9	92.5	0.56	9.87
3 - Clear PET	76.9			60.0	0.0	60.0	42.9			60.0	50.0	45.5	66.7	66.7	53.3	57.6%	20.17	0.38	43.4	71.9	3.50	62.03
4 - Green PET	66.7			100.0	100.0	75.0	100.0			75.0	75.0	100.0	80.0	100.0	85.7	88.0%	13.19	0.15	78.7	97.3	2.29	40.57
5 - Opaque HDPE	100.0			--	--	100.0	--			100.0	100.0	--	100.0	--	100.0	100.0%	0.00	0.00	100.0	100.0	0.00	0.00

B-2.4 PVC BOTTLE RECOVERIES AS A PERCENTAGE OF THE TOTAL BOTTLES RECOVERED AT EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.2			0.2	0.6	0.0	0.2			0.0	0.2	0.2	0.0	0.0	0.4	0.2%	0.18	1.04	0.1	0.3	0.02	0.57
2 - PVC	85.3			90.1	94.5	89.8	82.9			86.8	83.6	86.2	82.2	88.2	91.3	87.4%	3.83	0.04	85.1	89.6	0.66	11.80
3 - Clear PET	2.1			1.3	0.0	1.4	0.7			1.3	1.0	1.1	2.2	2.2	1.7	1.4%	0.67	0.49	1.0	1.8	0.12	2.06
4 - Green PET	1.4			2.3	2.5	1.9	2.7			2.1	1.6	4.0	2.5	3.3	4.2	2.6%	0.91	0.35	2.0	3.1	0.16	2.80
5 - Opaque HDPE	0.2			0.0	0.0	0.1	0.0			0.1	0.1	0.0	0.1	0.0	0.1	0.1%	0.06	1.04	0.0	0.1	0.01	0.19
- Unfed	5.8			3.3	2.0	5.6	1.4			4.1	2.4	0.0	0.0	0.0	0.0	2.2%	2.22	0.99	0.9	3.6	0.38	6.83
- Spillage	25.0			0.0	0.0	0.0	12.5			0.0	0.0	0.0	0.0	0.0	0.0	3.4%	8.08	2.37	0.0	8.2	1.40	24.86

RSD = RELATIVE STANDARD DEVIATION, LACI = LOWER AVERAGE FOR 95% CONFIDENCE INTERVAL, UACI = UPPER AVERAGE FOR 95% CONFIDENCE INTERVAL,
LSCI = LOWER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL, USCI = UPPER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL.
-- IN TABLE 3 INDICATES THAT NO BOTTLES REPORTED TO THIS STATION.

Subtable B-2.3 of Table 6 contains bottle recoveries as a percentage of the PVC bottles actually presented to the PVC station. As with subtable B-2.2, the sample mean, standard deviation, relative standard deviation, and 95 percent confidence intervals are included. These data describe the ability of the identification/separation equipment to recover bottles correctly without their being biased by the premature bottle recovery of prior stations. Because most spillage occurred in the feed process, spillage is assumed to occur prior to any of the identification/separation stations. For example, from the PVC column in Table 5, the number of PVC bottles presented to the PVC station is the sum of the bottles removed by the PVC station and all downstream stations, or 93+10+2+1 = 106. Also from Table 5, the number of PVC bottles removed at the PVC station is 93. Thus, the percentage of PVC bottles recovered at the PVC station based on the number of PVC bottles presented to the PVC station for test 1 is 100 x 93/106 = 87.7 percent, as shown in Table 6.

Data are presented for all stations, however, only specific combinations of bottle types and stations have any practical meaning. Most meaningful is bottle recovery expressed as a percentage of bottles of the same type presented to its own station. For example, PVC recovery at the PVC station expressed as a percentage of the PVC bottles presented to the PVC station is far more meaningful than PVC recovery at the green PET station expressed as a percentage of the PVC bottles recovered at the green PET station. Other combinations such as clear PET recovery at the green PET station expressed as a percentage of the clear PET bottles presented to the green PET station is also meaningful since clear PET can be legitimately removed by the green PET station.

Subtable B-2.4 of Table 6 contains bottle recoveries expressed as a percentage of the total bottles recovered at each station (i.e., the product), and as such is only applicable to the mixed composition tests. The percentages at stations other than the proper station for the subject bottle type show the contamination level in terms of bottle counts for that bottle type in that product. As with subtable B-2.2, the sample mean, standard deviation, relative standard deviation, and 95 percent confidence intervals are included. These values represent the product purity or grade in terms of numbers of bottles. For example, the Station 2 line in Table 5 shows the total number of bottles recovered at the PVC station to be 93+3+2+11 = 109. Also from Table 5, the number of PVC bottles removed at the PVC station is 93. Thus, the percentage of PVC bottles recovered at the PVC station based on the total number of all types of bottles recovered at the PVC station is 100 x 93/109 = 85.3 percent, as shown in subtable B-2.4 of Table 6. This represents the product purity expressed in terms of numbers of bottles; the contamination level expressed in terms of numbers of bottles is 100 - 85.3 = 14.7 percent.

Table 7 (excerpted from Appendix C, Table C-1) demonstrates the calculation of component weight percentages. The component weight percentages describe the product purity and contamination. Subtable C-1.0 shows the average bottle weight for the five bottle types used in the testing and the allowable weight percentage of each type in each product. Using these average bottle weights, the weight percentage of each product component was calculated and compared to the allowable contamination limit. If the weight percentage exceeded the allowable limit, it is identified with an asterisk (*). If a product is contaminated by at least one contaminant, the product total is identified with an asterisk preceded by the number of materials excessively contaminating the product. These calculations are demonstrated in the following paragraph using the PVC product numbers and weight percentages shown in Table 7.

TABLE 7. BOTTLE COUNTS AND WEIGHT PERCENTAGES (REPLICATE 1 OF EXTENDED TEST)

(Appendix C, Table C-1)

C-1.0	ALLOWABLE WEIGHT PERCENT CONTAMINATION LIMITS				
Bottle Type Average Bottle Weight	Nat HDPE 64 grams	PVC 59 grams	Clear PET 71 grams	Green PET 78 grams	Opaque HDPE 101 grams
Natural HDPE Product	100.00	2.00	2.00	2.00	1.00
PVC Product	5.00	100.00	0.00	0.00	5.00
Clear PET Product	5.00	0.00	100.00	1.00	5.00
Green PET Product	5.00	0.00	10.00	100.00	5.00
Opaque HDPE Product	5.00	2.00	2.00	2.00	100.00

Maximum combined opaque and natural HDPE contamination in either clear PET, green PET, or PVC is 5%.
Maximum combined PVC, clear PET, and green PET contamination in either natural or opaque HDPE is 2%.
Maximum combined PET contamination in PVC is 0%.

C-1.1 TEST 1 — DATE: 10/07/92
FEED: 2,000 MIXED BOTTLES — DURATION: 27.0 minutes
SPEED: 60% — FEED RATE: 71 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	479/87.17%	1/ 0.17%	3/ 0.61%		42/12.06%*	525 /100% 1*
PVC Product		93/78.76%	3/ 3.06%*	2/ 2.24%*	11/15.95%*	109 /100% 3*
Clear PET Product		10/ 1.72%*	424/87.84%	7/ 1.59%*	30/ 8.84%*	471 /100% 3*
Green PET Product		2/ 1.05%*	13/ 8.18%	121/83.62%	8/ 7.16%*	144 /100% 2*
Opaque HDPE Product		1/ 0.09%	4/ 0.43%	8/ 0.95%	639/98.52%	652 /100%

The PVC product consisted of four components: PVC, clear PET, green PET, and opaque HDPE. The total weight of the PVC component is calculated as the product of the number of PVC bottles and the average weight of a PVC bottle, or 93 x 59 = 5,487 grams. Likewise, the weight of the clear PET component is 3 x 71 = 213 grams, the weight of the green PET component is 2 x 78 = 156 grams, and the weight of the opaque HDPE component is 11 x 101 = 1,111 grams. The total weight of the PVC product is 5,487 + 213 + 156 + 1,111 = 6,967 grams. The weight percentage of the PVC component is therefore 100 x 5,487/6,967 = 78.76 percent, and the weight percentage of the clear PET component is 100 x 213/6,967 = 3.06 percent. Similar calculations for green PET and opaque HDPE yield 2.24 and 15.95 percent, respectively. The clear PET, green PET, and opaque HDPE weight percentages exceed the allowable contamination limits shown in the table, hence they are identified with an asterisk.

TEST PROCEDURES AND QA CHECKS

Procedures Common to All Tests

Prior to each test, a sample of bottles were run through the system to verify the operation of the identification/separation equipment. For the single composition tests, five bottles of the appropriate type were run, and for the mixed composition tests, two of each bottle type were run. This quick check ensured that all sensors and air jets were operational.

After loading the feed bin with the appropriate feedstock, the system was "primed" by running conveyor C2, along with the paddle and kick wheels, to fill up the cleats with bottles. As the first filled cleat approached the paddle wheel, C2 was halted. In this way, each test began with an "instantaneous"

flow. Each test was terminated when there was an insufficient amount of containers in the feed bin to fill the cleats of conveyor C2. Conveyor C2 was stopped at the test end, and all other conveyors were allowed to run out so that bottles fed during the test period could be separated by the system and included in the test results. This procedure ensured that feeding was initiated exactly at the start of the test and that there was no appreciable feed rate drop-off at the end of the test due to an insufficient supply of bottles in the feed bin. All test times were recorded using 24 hour time, and all clocks used for timing were synchronized at the start of each day.

The only available method of controlling the bottle feed rate, by virtue of the system design, is by varying the speed of conveyor C2. The speed setting is adjustable from 0 to 100 percent. Actual bottle feed rates vary by type of feed for the same speed setting percentage, since the number of bottles per cleat is a function of the bottle size and shape, and bottle sizes vary by type. Speed setting selections were based on advice from the CPRR operators. All test speeds were recorded in terms of the percent of the maximum speed of conveyor C2, and resulting bottle feed rates were calculated.

Procedures Specific to Single Composition Tests

Prior to conducting the single composition tests, the bottles were counted and stored in marked gaylord containers. Initially, every bottle was counted at the conclusion of each test. Subsequently, the counting procedure was changed such that only the bottles spilled, unfed, or those that reported to an incorrect station were counted. The sum of these counts was subtracted from the total number of bottles to arrive at the quantity reporting to the proper station. This procedure dramatically accelerated the counting procedure since the majority of the bottles reported to their proper station. At the conclusion of the testing for each material type, all bottles of that type were again counted to ensure that all were present and accounted for.

Spot feed rate checks were performed at various times throughout the single composition tests to note the variability in bottle feed rate. A continuous, quantitative analysis of bottle feed rates was performed on a representative extended test, discussed later.

Procedures Specific to Mixed Composition Tests

The same feedstock used for the single composition test was used to prepare the mixed composition feedstock. Bottles were added as necessary to meet the required total count. As indicated earlier, the mixed composition feedstock followed the proportions specified in Table 3. Following each test run, re-mixing of the feed for the subsequent test was required. Re-mixing was accomplished through the sequential layering of the five types of bottles into gaylord boxes according to their percentage in the mixture. Small gaylords were used to facilitate filling and feed bin loading; approximately 125 mixed bottles could be placed in a box. Eight boxes were required for the 1,000 bottle tests, and 16 were required for the 2,000 bottle tests. Each box was filled with two layers of each bottle type. For example, the sequence for remixing one box for the 1,000 bottle test feed was: 1/16 of the total natural HDPE, 1/16 of the total PVC, 1/16 of the total clear PET, 1/16 of the total green PET, and 1/16 of the total opaque HDPE; all steps were repeated twice. Although the polymer type sequence may have varied across test re-mixes, one layer of each type was placed before the second layering sequence was begun. This procedure helped to achieve a somewhat controlled mixture of bottles across the mixed composition tests.

At the conclusion of each test, the spilled containers and the unfed containers were collected and boxed. The products from each station were sorted to remove all foreign bottles. These improperly separated bottles or "mistakes" and the spilled and unfed bottles were counted by type by two independent counters. The total mistakes for each type were subtracted from the total number of each type fed to arrive at the number of bottles correctly reporting to the proper stations. At the conclusion of

the mixed testing, the total bottle count was rechecked to ensure that no bottles were lost during the testing. This procedure eliminated the time-consuming and tedious chore of counting every bottle after each test run without compromising quality assurance. The fact that the initial and final bottle counts agreed for the two short-term and the one extended mixed composition test series attests to the effectiveness of this procedure.

Data Validation

Selected results from each test series were subjected to the Modified Three-Sigma Test for the determination of outliers. This method is a modification of the standard Three-Sigma Test, and accounts for the fact that the probability of outliers increases as the sample size (defined as the number of test replicates performed) increases[3]. Observations rejected on the basis of the Modified Three-Sigma Test have a 99 percent chance of being an outlier.

Since the number of bottles fed out of the feed bin varied from test to test, the actual bottle recovery counts could not be used in the determination of outliers. To normalize the data, each bottle recovery count was first expressed as the percentage of bottles of the same type fed into the system (percent of bottles fed) and then as the percentage of the product in which it appeared (percent of total recovered). The resulting values were used in two separate outlier calculations. A third outlier calculation was performed using the overall bottle feed rate for each test. Any test identified as an outlier by any of the three calculations was rejected.

The 95 percent confidence intervals were established for sample means using the "Student's" t distribution. Because these values are percentages, all negative confidence intervals were reported as zero, and all confidence intervals exceeding 100 were reported as 100. Similar confidence intervals were established for sample standard deviations using the Chi-Square Distribution.

SECTION 5

TEST RESULTS

The single composition, mixed composition short term, and mixed composition extended tests were performed for different and distinct reasons. Each test type provided valuable data and knowledge that benefited subsequent tests. Single composition tests, performed first, were the simplest test type and thus provided baseline level data on the performance of each identification/separation station. The next test type, the mixed composition short term tests, provided data needed to establish the test conditions for the mixed composition extended tests. Finally, the mixed composition extended tests provided system performance data at specific conditions for an extended period. The results obtained for each test type are discussed separately in this section in the order in which they were performed.

SINGLE COMPOSITION TESTS

Single Composition Bottle Recovery, Percent of Bottles Fed

Table 8 presents the mean and average lower 95 percent confidence limit for the bottle recoveries as well as the average feed rates for the single composition test series. All recoveries are based on the number of bottles fed.

As shown in Table 8, natural HDPE easily exceeded the 90 percent QA recovery objective with 95 percent confidence at a feed rate of 101 bpm. PVC failed to achieve the QA goal of 100 percent recovery at any feed rate, and at best achieved a 95 percent confident recovery of only 77 percent at 51 bpm. It was subsequently discovered that the PVC sensor was set too high to detect the range of PVC bottle sizes used in the testing. Following the single composition tests, the PVC sensor was lowered and bottle recoveries improved in subsequent tests. Clear PET recovery exceeded the 90 percent objective with 95 percent confidence at feed rates up to 126 bpm. Green PET recoveries exceeded the 90 percent objective with 95 percent confidence at feed rates up to 120 bpm with the exception of the 24 bpm test series (see discussion below).

Opaque HDPE recoveries failed to achieve 90 percent with 95 percent confidence at any feed rate, although mean recoveries exceeded the desired criteria at feed rates up to 101 bpm. Because the opaque HDPE station is a passive recovery station, poor recovery is the direct result of the prior removal of opaque HDPE bottles by upstream stations. Opaque HDPE bottles generally did not have a round cross-section, the shape for which the system was designed. This fact may have contributed to the low bottle recovery.

The lower 95 percent confidence limit of green PET and opaque HDPE recovery at the 25 percent speed setting were lower than that at higher bottle feed rates because only two replicates were performed at the 25 percent level. The lower 95 percent confidence limit of green PET at the 90 percent speed setting escaped a similar fate despite the fact that only two replicates were performed because both results were numerically equal.

TABLE 8. BOTTLE RECOVERIES BASED ON BOTTLES FED INTO THE SYSTEM, SINGLE COMPOSITION TESTS

Bottle type	Conveyor C2 speed setting, percent of full speed				
	25	40	50	75	90
Natural HDPE					
- Mean recovery, %				99.6	
- Lower 95% confidence limit, %				98.9	
- Feed rate, bottles per minute				101.0	
PVC					
- Mean recovery, %	79.0	74.6			
- Lower 95% confidence limit, %	77.0	67.7			
- Feed rate, bottles per minute	51.0	80.0			
Clear PET					
- Mean recovery, %			96.6	97.5	97.4
- Lower 95% confidence limit, %			94.0	95.1	95.7
- Feed rate, bottles per minute			72.0	109.0	126.0
Green PET					
- Mean recovery, %	98.0		97.9	97.4	93.8
- Lower 95% confidence limit, %	85.4		95.1	94.3	93.8
- Feed rate, bottles per minute	24.0		65.0	97.0	120.0
Opaque HDPE					
- Mean recovery, %	94.8			91.4	90.7
- Lower 95% confidence limit, %	82.2			88.7	87.3
- Feed rate, bottles per minute	23.0			80.0	101.0

As can be seen in Table 8, clear PET, green PET, and opaque HDPE recoveries were relatively unaffected by changes in the bottle feed rate. PVC recovery dropped off considerably as the feed rate increased from 51 to 80 bottles per minute.

It was observed during the first natural HDPE test replicate that to efficiently feed only natural HDPE bottles, it was necessary to manually assist the bottles onto the infeed conveyor. The large size and low weight of these bottles made pick up by conveyor C2's cleats difficult at high process rates without manual intervention. This was done in subsequent natural HDPE tests. Also, the oversize chute was not designed to handle a continuous feed of natural HDPE bottles at high throughput rates in a single composition test. Considerable manual prodding was required to keep the chute unplugged.

During testing, it was noted that heavily scratched and abraded green PET bottles were often not detected due to an apparent scattering of the light beam by the roughened surface. Also, it was noted that some bottles were dented from repeated impacts with the paddle wheel, affecting their presentation to the sensors. These bottles were replaced with undamaged bottles when discovered.

Single Composition Bottle Recovery, Percent of Bottles Presented

Table 9 presents the bottle recovery results based on the number of bottles of the same type presented to each station. These data define the performance of each recovery station as if it were completely isolated from all other stations. The results are not affected by bottles prematurely removed as contaminants prior to their proper station. Table 9 presents only data for each material at its own station. Perhaps the most meaningful bottle type/station combination is the data describing the capability of the green PET station to recover clear PET. Recoveries at the opaque HDPE station are naturally 100 percent, since all bottles presented to this station cannot report elsewhere, by virtue of its passive recovery method and its position at the end of the processing system.

TABLE 9. BOTTLE RECOVERIES BASED ON BOTTLES PRESENTED TO EACH STATION, SINGLE COMPOSITION TESTS

	Conveyor C2 speed setting, percent of full speed				
Bottle type	25	40	50	75	90
Natural HDPE					
- Mean recovery, %				99.6	
- Lower 95% confidence limit, %				99.1	
- Feed rate, bottles per minute				101.0	
PVC					
- Mean recovery, %	79.1	74.8			
- Lower 95% confidence limit, %	77.2	68.2			
- Feed rate, bottles per minute	51.0	80.0			
Clear PET					
- Mean recovery, %			96.8	97.8	98.2
- Lower 95% confidence limit, %			90.7	95.1	96.1
- Feed rate, bottles per minute			72.0	109.0	126.0
Green PET					
- Mean recovery, %	99.2		99.2	98.8	96.5
- Lower 95% confidence limit, %	91.2		98.4	97.8	94.7
- Feed rate, bottles per minute	24.0		65.0	97.0	120.0
Opaque HDPE					
- Mean recovery, %	100.0			100.0	100.0
- Lower 95% confidence limit, %	100.0			100.0	100.0
- Feed rate, bottles per minute	23.0			80.0	101.0

Bottle recoveries at the natural HDPE, PVC, and clear PET stations based on the number of bottles presented to these stations did not increase over those based on bottles fed due to the low number of bottles spilled and removed by prior stations. Bottle recoveries based on the number of green PET bottles presented to the green PET station were considerably higher than those based on green PET bottles fed into the system due to the loss of green PET to spillage and to the clear PET station. The 95 percent confidence green PET recovery at the 25 percent level met the 90 percent QA objective when based on bottles presented while it did not meet the objectives based on bottles fed.

Any clear PET bottles not recovered at the clear PET station were candidates for removal by the green PET station because of the similarity in the optical techniques used to identify the PET bottles. The average removal efficiency of the green PET station with respect to clear PET bottles presented to it ranged from 94.2 to 73.3 percent. Surprisingly, these recovery rates decreased significantly with increasing feed rate, whereas similar values for the clear PET station actually increased slightly. The difference in recovery cannot be definitively explained.

Single Composition Test Bottle Feed Rates

As shown in Table 8, the single composition test data show that there is no correlation between the infeed conveyor speed setting and the bottle feed rate for bottle types that vary considerably in size and shape from one another. For example, a 25 percent feed setting for PVC resulted in an average feed rate of 51 bpm, whereas the same setting resulted in an average feed rate of 23 bpm for opaque HDPE. Many opaque HDPE bottles were much larger than most PVC bottles, consequently fewer can be contained in a cleat pocket on the infeed conveyor. Further, infeed conveyor fallback was much more pronounced with opaque HDPE bottles due to their large size.

Spot rate feed rate checks were performed randomly during the testing. The check consisted of counting the bottles passing a selected point for a certain period of time. The selected point was located on conveyor C6 for natural HDPE and on conveyor C3 for all other bottle types. The feed rates determined from conveyor C3 naturally varied considerably due to the periodic removal of natural HDPE bottles prior to conveyor C3 and bottle fallback on conveyor C2. Short term feed rates were found to vary considerably.

MIXED COMPOSITION, SHORT-TERM TESTS

Bottle Recovery, Percent of Bottles Fed

Table 10 presents the mean and average lower 95 percent confidence limit for bottle recoveries based on bottles fed, and the overall and effective bottle feed rates for the mixed composition, short-term tests. As defined in the Glossary of Terms, the effective bottle feed rate is the average rate at which a specific type of bottle was fed during a mixed composition test, whereas the overall bottle feed rate is the average rate at which all bottles taken as a group were fed during a test.

As discussed in Section 4, the 50 percent and 90 percent 2,000 bottle, mixed composition, short-term tests were performed for bracketing purposes only. They are presented in Table 10, but are not considered in the discussion that follows. As shown in Table 10, natural HDPE and both types of PET achieved the QA objective for recovery of 90 percent with 95 percent confidence at least at one of the feed rates investigated. The maximum conveyor C2 speed setting and corresponding overall feed rates allowing a minimum of 90 percent recovery of HDPE and PET with 95 percent confidence are as follows: natural HDPE - 75 percent at 98 bpm; clear PET - 50 percent at 59 bpm; and green PET - 50 percent at 59 bpm. Opaque HDPE failed to achieve 90 percent recovery with 95 percent confidence and PVC failed to achieve its QA objective for recovery of 100 percent at any of the feed rates investigated.

TABLE 10. BOTTLE RECOVERIES BASED ON BOTTLES FED INTO THE SYSTEM, MIXED COMPOSITION, SHORT-TERM TESTS

	1,000 Bottles			2,000 Bottles		
Conveyor C2 speed setting, % of full speed	50	75	90	50	75	90
Overall feed rate, bottles per minute	59	90	111	57	98	125
Natural HDPE						
- Mean recovery, %	98.6	97.8	93.5	99.8	95.9	95.8
- Lower 95% confidence limit, %	97.9	95.3	66.0	99.8	92.7	95.8
- Feed rate, bottles per minute	14.0	22.0	27.0	14.0	24.0	31.0
PVC						
- Mean recovery, %	77.3	79.6	79.2	92.9	82.6	90.2
- Lower 95% confidence limit, %	71.2	41.3	72.9	92.9	76.2	90.2
- Feed rate, bottles per minute	3.0	5.0	6.0	3.0	6.0	7.0
Clear PET						
- Mean recovery, %	93.9	90.6	88.3	92.6	88.5	92.4
- Lower 95% confidence limit, %	90.6	84.1	84.2	92.6	82.9	92.4
- Feed rate, bottles per minute	14.0	21.0	26.0	13.0	23.0	29.0
Green PET						
- Mean recovery, %	93.8	94.2	85.9	88.7	77.9	69.2
- Lower 95% confidence limit, %	91.3	83.0	59.6	88.7	70.7	69.2
- Feed rate, bottles per minute	4.0	7.0	8.0	4.0	7.0	9.0
Opaque HDPE						
- Mean recovery, %	90.9	88.8	86.1	91.1	88.0	81.7
- Lower 95% confidence limit, %	88.8	80.7	77.9	91.1	84.7	81.7
- Feed rate, bottles per minute	23.0	36.0	44.0	22.0	38.0	49.0

As previously stated, the opaque HDPE recovery station is a passive recovery station; that is, the bottles recovered are those remaining in the system after passing by other recovery stations. Thus the performance of the opaque HDPE station is determined by the performance of the prior stations.

Bottle Recovery, Percent of Bottles Presented

Table 11 presents the bottle recovery results based on the number of bottles of the same type presented to each station. Data are presented only for each material at its own station. Recoveries based on bottles presented naturally improved, albeit slightly, over those based on bottles fed. Excluding opaque HDPE, only one test series (green PET at the 75 percent speed setting) saw its lower average 95 percent confidence limit elevated from below 90 percent (Table 9) to above the 90 percent level (Table 11).

TABLE 11. BOTTLE RECOVERIES BASED ON BOTTLES PRESENTED TO EACH STATION, MIXED COMPOSITION, SHORT-TERM TESTS

	1,000 Bottles			2,000 Bottles		
Conveyor C2 speed setting, % of full speed	50	75	90	50	75	90
Overall feed rate, bottles per minute	59	90	111	57	98	125
Natural HDPE						
- Mean recovery, %	98.6	98.0	93.6	99.8	96.2	96.4
- Lower 95% confidence limit, %	97.9	95.1	66.6	99.8	93.3	96.4
- Feed rate, bottles per minute	14.0	22.0	27.0	14.0	24.0	31.0
PVC						
- Mean recovery, %	77.8	82.0	80.1	95.4	83.3	90.2
- Lower 95% confidence limit, %	72.8	44.5	71.3	95.4	76.8	90.2
- Feed rate, bottles per minute	3.0	5.0	6.0	3.0	6.0	7.0
Clear PET						
- Mean recovery, %	94.6	93.7	91.6	94.5	91.5	97.2
- Lower 95% confidence limit, %	91.9	87.0	86.3	94.5	86.1	97.2
- Feed rate, bottles per minute	14.0	21.0	26.0	13.0	23.0	29.0
Green PET						
- Mean recovery, %	97.0	99.0	92.8	92.6	85.5	83.9
- Lower 95% confidence limit, %	92.6	95.5	80.6	92.6	78.4	83.9
- Feed rate, bottles per minute	4.0	7.0	8.0	4.0	7.0	9.0
Opaque HDPE						
- Mean recovery, %	100.0	100.0	100.0	100.0	100.0	100.0
- Lower 95% confidence limit, %	100.0	100.0	100.0	100.0	100.0	100.0
- Feed rate, bottles per minute	23.0	36.0	44.0	22.0	38.0	49.0
- Feed rate, bottles per minute						

Recovery accuracies based on the number of opaque HDPE bottles actually presented to the opaque HDPE station were naturally 100 percent since this station is the last station on the process line.

Table 12 compares selected bottle feed rates and recoveries for the single and mixed composition tests. The values compared are effective bottle feed rates corresponding to the maximum bottle recoveries achieved based on bottles presented. In determining the maximum recovery values, only the lower limit of the average 95 percent confidence interval was considered. For the single composition tests, the effective bottle feed rate is the overall bottle feed rate. This table shows that bottle recoveries in the single composition tests were comparable to or better than those in the mixed composition tests despite significantly higher effective bottle feed rates. This comparison serves to illustrate the effect of bottle to bottle interference on recovery and bottle throughput rate when processing mixed bottles typical of post-consumer recycling streams.

TABLE 12. COMPARISON OF SINGLE AND MIXED COMPOSITION SHORT-TERM TEST EFFECTIVE FEED RATES FOR MAXIMUM RECOVERIES BASED ON BOTTLES PRESENTED TO EACH STATION

	Single composition		Mixed composition	
Bottle type	Maximum recovery, percent	Effective feed rate, bpm	Maximum recovery, percent	Effective feed rate, bpm
Natural HDPE	99.1	101	97.9	14
PVC	77.2	51	76.8	6
Clear PET	96.1	126	91.9	14
Green PET	98.4	65	95.5	7
Opaque HDPE	100.0	101	100.0	44

Product Composition

Table 13 presents the averages of the five product compositions in weight percent for each of the replicates comprising a mixed composition, short-term test series. Also included are the allowable limits for the product components. The primary bottle type's percentage of the total weight represents the product's purity, and the percentages of other bottle types represent the contamination. The 50 and 90 percent 2,000 bottle test series consisted of only one replicate each. The data are presented but are not considered in the analysis.

As can be seen from Table 13, nearly all products were excessively contaminated by at least one material. Although the results varied somewhat with infeed conveyor speed, generally the natural HDPE product was contaminated by opaque HDPE, the PVC product by PET and HDPE, the clear PET product by PVC (and green PET and HDPE in two of the four test series), and the green PET product by PVC, clear PET, and HDPE. The opaque HDPE product was contaminated by heavy resins in two of the four test series. Product purities also varied with infeed conveyor speed. The opaque HDPE product had the highest purity (95 to 98 percent), followed by clear PET (86 to 94 percent), natural HDPE (85 to 90 percent), PVC (72 to 89 percent), and green PET (62 to 76 percent). There is no readily apparent reason for the low green PET product purity.

Equipment Failure/Downtime

One equipment failure was experienced during the mixed composition, short-term 1,000 bottle tests. Conveyor C4 developed a belt tracking problem, resulting in an 88 minute downtime during test 1 of the 75 percent speed series.

TABLE 13. AVERAGE PRODUCT COMPONENTS, MIXED COMPOSITION, SHORT-TERM TEST (IN WEIGHT PERCENT)

	1,000 Bottles			2,000 Bottles *			
Conveyor C2 Speed Setting	50%	75%	90%	50%	75%	90%	Limit
			Natural HDPE Product				
Natural HDPE	89.00	84.53	88.21	86.45	90.45	88.40	100
PVC	0.00	0.46	0.00	0.17	0.06	0.00	
Clear PET	0.14	1.10	0.98	0.60	0.84	0.43	
Green PET	0.16	0.15	0.39	0.22	0.20	0.23	
Total Heavies	0.30	1.71	1.37	0.99	1.10	0.66	2
Opaque HDPE	10.71	13.76	10.42	12.56	8.45	10.94	1
			PVC Product				
PVC	89.47	84.49	78.29	83.44	71.61	57.71	100
Clear PET	2.56	9.28	9.19	4.83	9.23	11.00	
Green PET	0.91	1.56	0.78	2.12	3.22	3.02	
Total PET	3.47	10.84	9.97	6.95	12.45	14.02	0
Natural HDPE	0.00	0.84	0.64	0.00	1.43	1.86	
Opaque HDPE	7.06	3.82	11.10	9.61	14.51	26.41	
Total HDPE	7.06	4.66	11.74	9.61	15.94	28.27	5
			Clear PET Product				
Clear PET	93.16	94.17	91.27	95.02	85.59	80.42	100
PVC	2.33	1.83	1.52	0.57	1.85	1.79	0
Green PET	0.33	0.86	1.67	0.50	1.84	4.08	1
Natural HDPE	0.00	0.00	0.13	0.00	0.34	0.35	
Opaque HDPE	4.19	3.13	5.41	3.91	10.39	13.36	
Total HDPE	4.19	3.13	5.54	3.91	10.73	13.71	5

* 50% and 90% test series consisted of only one replicate each and were used strictly for bracketing purposes.

TABLE 13. CONTINUED

Conveyor C2 Speed Setting	1,000 Bottles 0.50	1,000 Bottles 0.75	1,000 Bottles 0.90	2,000 Bottles * 0.50	2,000 Bottles * 0.75	2,000 Bottles * 0.90	Limit
			Green PET Product				
Green PET	76.23	70.44	61.99	83.30	69.72	75.91	100
PVC	3.81	2.19	3.64	0.50	2.88	0.00	0
Clear PET	10.45	9.96	12.72	12.74	14.59	0.00	10
Natural HDPE	0.00	0.28	0.27	0.00	0.59	1.26	
Opaque HDPE	9.52	17.13	21.37	3.45	12.22	22.83	
Total HDPE	9.52	17.41	21.64	3.45	12.81	24.09	5
			Opaque HDPE Product				
Opaque HDPE	98.31	97.94	95.22	98.41	95.52	95.46	100
PVC	0.23	0.40	0.39	0.08	0.18	0.00	
Clear PET	0.40	0.62	0.94	0.30	1.03	1.30	
Green PET	0.45	0.30	1.02	1.11	2.06	2.26	
Total Heavies	1.08	1.32	2.35	1.49	3.27	3.56	2
Natural HDPE	0.61	0.74	2.43	0.09	1.22	0.98	5

* 50% and 90% test series consisted of only one replicate each and were used strictly for bracketing purposes.

Two equipment failures were experienced during the mixed composition, short-term 2,000 bottle tests. Two of the eight rubber flaps on the paddle wheel failed, resulting in downtimes of 33 and 51 minutes for repair. These failures occurred during tests 2 and 3, respectively, of the 75 percent series. The paddle wheel rubber flap connection was noted to be deficient following these two failures, and subsequent failure of the remaining six unmodified flaps was expected. Repeated flexing of the rubber flap caused the rubber to shear at the connection to the paddle wheel drum. The connection detail did not provide sufficient bearing area to prevent flexure-induced failure. This type of failure would not be expected when using a commercial-grade mechanical paddle wheel. Repair of these flaps was performed when necessary during the counting time between tests.

MIXED COMPOSITION, EXTENDED 2,000 BOTTLE TESTS

Mixed Composition, Extended Test Results

Bottle Recovery, Percent of Bottles Fed --

Table 14 presents the mean and average lower 95 percent confidence limit for bottle recoveries based on bottles fed, and the effective bottle feed rates for the mixed composition extended tests. The average overall bottle feed rate for the extended test was 74 bpm. Using the average bottle weights, the overall throughput rate was 782 pounds per hour.

As shown in Table 14, only the natural HDPE and clear PET bottle recoveries met their QA objectives of 90 percent with 95 percent confidence despite the low effective bottle feed rates. PVC recovery, at 87.3 percent, was considerably below its QA objective of 100 percent. At 87.8 percent, opaque HDPE recovery was close to the 90 percent QA objective. Overall, the system correctly recovered 90.9 percent of the bottles fed with 95 percent confidence.

TABLE 14. BOTTLE RECOVERIES AND EFFECTIVE FEED RATES BASED ON BOTTLES FED INTO SYSTEM, EXTENDED TESTS

Bottle type	Average recovery, percent	LACI* of recovery, percent	Effective feed rate, bpm
Natural HDPE	99.1	98.7	18
PVC	89.3	87.3	4
Clear PET	92.8	90.7	17
Green PET	86.5	83.8	5
Opaque HDPE	89.4	87.8	29
All bottles	92.4	90.9	74

* lower average 95 percent confidence limit

Bottle Recovery, Percent of Bottles Presented --

Table 15 presents the mean and average lower 95 percent confidence limit for bottle recoveries based on bottles presented to each station, and the effective bottle feed rates for the mixed composition, extended tests. Table 15 lists only the recovery of bottle types at their own stations; Appendix B contains bottle recovery data for every combination of recovery station and bottle type.

TABLE 15. BOTTLE RECOVERIES AND EFFECTIVE FEED RATES BASED ON BOTTLES PRESENTED TO EACH STATION, EXTENDED TESTS

Bottle type	Average recovery, percent	LACI* of recovery, percent	Effective feed rate, bpm
Natural HDPE	99.1	98.6	18
PVC	90.2	87.9	4
Clear PET	95.1	93.3	17
Green PET	91.1	89.6	5
Opaque HDPE	100.0	100.0	29

* lower average 95 percent confidence limit

Being the last recovery station, the opaque HDPE station recovered all of the opaque HDPE bottles presented to it. Other than opaque HDPE, the only other bottle type to see a substantial increase in recovery over that based on bottles fed was green PET (83.6 percent based on bottles fed and 89.6 percent based on bottles presented). The value based on the number of green PET bottles presented to the green PET station was, at 89.6 percent, very close to the QA objective of 90 percent. This indicates that the green PET identification/separation equipment by itself was effective in recovering green PET, but the system as a whole was not.

The green PET recovery station recovered on average 81.4 percent of the clear PET presented to it (see Appendix B, Table B-3.3). From Table 15, this same station recovered on average 91.1 percent of the green PET presented to it. Thus, the green PET station is much less effective in recovering clear PET as it is in recovering its primary product. This is surprising, since the optical difference between clear and green PET should make clear PET easier to identify. Much of this difference may be due to misalignment of the clear PET bottles presented to the green PET station. The fact that nearly 20 percent of the clear PET bottles presented to the green PET station were missed by both the clear and the green PET stations implies that the sensors alone are not to blame for the missed recovery.

Product Composition --

Table 16 presents the weight percentages of each component in the five products. The contamination limits set forth in Table 3 are also included. Only the opaque HDPE product met contamination criteria. All other products were contaminated by at least one other resin type. Natural HDPE had excessive opaque HDPE contamination, PVC had excessive PET and HDPE contamination, and both clear and green PET had excessive PVC and HDPE contamination. The product purities followed the same pattern found in the mixed composition, short-term tests. Opaque HDPE was highest at 98 percent, followed by clear PET at 92 percent, natural HDPE 88 percent, PVC at 83 percent, and green PET at 77 percent.

TABLE 16. AVERAGE PRODUCT COMPOSITIONS, EXTENDED TESTS

Component	Weight Percent	Limit
Natural HDPE Product		
Natural HDPE	87.83	100
PVC	0.15	
Clear PET	0.58	
Green PET	0.24	
Total Heavies	0.97	2
Opaque HDPE	10.71	1
PVC Product		
PVC	83.07	100
Clear PET	6.53	
Green PET	1.94	
Total PET	8.47	0
Natural HDPE	0.34	
Opaque HDPE	8.11	
Total HDPE	8.45	5
Clear PET Product		
Clear PET	91.78	100
PVC	1.12	0
Green PET	0.89	1
Natural HDPE	0.02	
Opaque HDPE	6.19	
Total HDPE	6.21	5
Green PET Product		
Green PET	76.91	100
PVC	1.94	0
Clear PET	9.61	10
Natural HDPE	0.19	
Opaque HDPE	11.35	
Total HDPE	11.54	5
Opaque HDPE Product		
Opaque HDPE	97.89	100
PVC	0.05	
Clear PET	0.40	
Green PET	1.34	
Total Heavies	1.79	2
Natural HDPE	0.32	5

Recovery Mistakes --

The extended test data resulted in a total of 7.6 mistakes for every 100 mixed bottles fed. The mistake distribution did not conform to the proportions of the bottle mixture actually fed, as shown in Table 17.

As can be seen in Table 17, green PET had the largest mistakes/feed mix ratio, followed by PVC, opaque HDPE, clear PET, and natural HDPE. With ratios larger than 1.0, green PET, PVC, and opaque HDPE contributed more than would be expected based on the percentages of the bottles actually fed. Natural HDPE's low ratio of 0.1 indicates that it contributed much less than expected toward the overall mistakes than its percentage in the overall mix might suggest.

TABLE 17. COMPARISON OF MISTAKE DISTRIBUTION TO FEED MIX PROPORTIONS, EXTENDED TESTS

Bottle type	Percent of total fed	Percent of mistakes	Ratio of mistakes/mix
Natural HDPE	24.7	3.0	0.1
PVC	5.8	8.1	1.4
Clear PET	23.3	21.9	0.9
Green PET	7.3	12.9	1.8
Opaque HDPE	38.9	54.1	1.4
Total	100.0	100.0	1.0

Another way of viewing the data is to compare the number of bottles of each type processed for every one mistake. These data as tabulated in Table 18, show a wide range of error frequency. In the worst case, one green PET bottle reports to the opaque HDPE product for every 12 green PET bottles fed. In the best case, one natural HDPE bottle reports to the clear PET product for every 5,228 natural HDPE bottles fed.

Unfed Bottles --

The method used to terminate a test resulted in unfed bottles remaining in the feed bin and on the infeed conveyor. The composition of unfed bottles varied somewhat from the original mix composition. Table 19 compares the mix composition to the unfed bottle composition.

The major difference between the original mix and the unfed compositions involves natural HDPE and PVC containers. PVC bottles, being typically small and less prone to fallback on conveyor C2, were more efficiently fed than the relatively large natural HDPE bottles. Also, the relative bulk densities and bottle sizes may have affected the movement of bottles within the feed bin, and thus

influenced the unfed bottle mix composition. Natural HDPE bottles, being large and thin walled, have the lowest bulk density of the five bottle types comprising the mix. These bottles were more prone to fallback from conveyor C2 than other types of bottles.

TABLE 18. ERROR FREQUENCY, EXTENDED TESTS

	Recovery error frequency - number of bottles fed per one mistake					
Bottle Type	Natural HDPE station	PVC station	Clear PET station	Green PET station	Opaque HDPE station	Spillage
Natural HDPE	--	1307	5228	1307	138	2614
PVC	122	--	18	28	203	608
Clear PET	159	67	--	26	115	290
Green PET	128	81	38	--	12	257
Opaque HDPE	19	130	37	53	--	746

TABLE 19. UNFED BOTTLES, EXTENDED TESTS

Bottle Type	Mix composition, numerical %	Unfed composition, numerical %
Natural HDPE	25.0	37.9
PVC	5.7	1.3
Clear PET	23.1	17.8
Green PET	7.3	6.0
Opaque HDPE	38.9	37.0
Total	100.0	100.0

Equipment Failure/Downtime

A total of 91 jams were noted during the 11 valid test runs comprising the extended test. These jams were cleared immediately and did not result in any process down time.

The only equipment failures that were experienced during this test series were associated with the oversize product paddle wheel. The rubber flaps on the paddle wheel failed five times; each flap was replaced after it failed. The test was suspended for two of the five repairs, while the other three repairs were made during the bottle counting and mixing period between tests. The flap replacement time was approximately 60 minutes.

Bottle Delivery and Clear PET Station Recovery Analysis

Different views of the process line were recorded on videotape during several extended test runs to document various aspects of the system. The clear PET and PVC stations were taped on test run 7. The video was used to document the bottle delivery sequence and timing of all bottles not removed at the natural HDPE (oversize) station, as well as the types of identification and recovery mistakes that occurred at the clear PET station.

Delivery Sequence and Timing--

The videotape was viewed at 1/6 of normal speed, resulting in virtually no time lag in recording the delivery time of each bottle on conveyor C5. The range of view in the video included the PVC station air jets and the entire clear PET station. The enclosure around the PVC station precluded a view of the approach to that station. Bottles removed at the PVC station could only be viewed as they were ejected by the air jets. Thus, the delivery time recorded for bottles removed at the PVC station was the actual time of removal.

Using the delivery time difference noted between bottles, the distance between each bottle was calculated using a conveyor speed of 330 feet per minute, and assuming an average bottle length of 12 inches. Also calculated were the distances between bottles of similar types.

Table 20 lists the actual counts of bottles fed onto conveyor C5 and the counts determined from the video. The accuracy of the visual rendering of the video is considered high, with only five bottles out of 1,377 missed, or 0.36 percent. Even when viewed at slow speed, the high speed of the bottles as they were ejected coupled with the bottle transparency contributed to the occasional difficulty in identifying or seeing some bottles.

To better understand the overall bottle delivery, the distances between bottles must be considered. Table 21 lists the number of gaps and their percentage of the total number of bottle gaps for various ranges of bottle separation distances. As shown in Table 21, approximately 91 percent of the bottle gaps are more than 2 inches. More than half the gaps are greater than 3 feet. The separation distance required to avoid the air blast from sweeping adjacent bottles is not definitively known. CPRR personnel report that approximately 2 inches is an adequate distance, and this was qualitatively observed during the testing. With 91 percent of the gaps exceeding this separation distance, the majority of the bottles appear to have been more than adequately separated. The average separation distance was 5.1 feet with a standard deviation of 5.61. The maximum value was 61.7 feet, and the minimum was 0. The >10 feet distance grouping in Table 21 shows many gaps far exceeding 10 feet, skewing the mean distance between bottles.

TABLE 20. COMPARISON OF VIDEO VS FIELD BOTTLE COUNT, EXTENDED TESTS

Bottle Type	Field count	Video count	Difference
Natural HDPE	1	1	0
PVC	109	106	-3
Clear PET	443	443	0
Green PET	132	132	0
Opaque HDPE	692	690	-2
Total	1377	1372	-5

TABLE 21. BOTTLE SEPARATION DISTANCES (CONVEYOR C5, EXTENDED TEST 7)

Distance range	Number of Gaps	Percentage	Cumulative Percentage
<= 2"	117	8.5%	8.5%
> 2" and <= 12"	127	9.3%	17.8%
> 12" and <= 24"	169	12.3%	30.1%
> 24" and <= 36"	193	14.1%	44.2%
> 36" and <= 48"	149	10.9%	55.0%
> 48" and <= 60"	134	9.8%	64.8%
> 60" and <= 120"	292	21.3%	86.1%
> 120"	191	13.9%	100.0%
Total	1372		

While some of the bottle separation distances are due to the presence of natural HDPE bottles in the mix (which if properly recovered do not appear on conveyor C5 and therefore leave a gap), many are due to the manner in which the feed conveyor extracts bottles from the feed bin and discharges onto the singulating and presentation conveyors. The cleated feed conveyor discharges in distinct slugs rather than in a continuous manner. If bottles could be conveyed on conveyor C5 with a consistent 2-inch gap, a maximum feed rate of approximately 285 bottles per minute could be achieved. Assuming 25 percent of the entire mix is natural HDPE, the entire system would be capable of delivering approximately 380 bottles per minute.

The overall bottle feed rate for test 7 was 75 bottles per minute. This is approximately one fifth of the theoretical maximum feed rate calculated above. Clearly the feed system was not capable of delivering uniformly singulated bottles to the identification/separation stations at an average feed rate of 75 bottles per minute. Its delivery capabilities limited the throughput capacity of the system.

There was a general trend of relatively short periods of high delivery rates dispersed among relatively long periods of average or low delivery rates. Table 22 lists the delivery rates for discrete short time segments during the first five minutes of the test and compares them to the average feed rates for bottles delivered to conveyor C5. The data show the irregular feed pattern containing spikes several times greater than the average rate. This pattern arises from the batch method of remixing the bottles, the removal of natural HDPE and other oversize bottles at the oversize station, and the slug feed characteristic of the feed conveyor, i.e., with filled and unfilled cleats.

TABLE 22. BOTTLE DELIVERY RATES, EXTENDED TESTS

Bottle type	Average rate, bpm	Rate range, bpm
PVC	4	2 - 18
Clear PET	17	18 - 90
Green PET	5	4 - 60
Opaque HDPE	29	6 - 90

Clear PET Station Mistakes--

Following the recording of the bottle type and delivery times, the video tape was viewed to determine the types of recovery mistakes occurring at the clear PET station. Three general groupings of recovery mistakes were used: miss, sweep, and incorrect recovery (reporting to the wrong station). A miss can be the result of the failure of the sensor to detect or identify a bottle, or the failure of the air blast to carry the bottle off the belt. A sweep is the simultaneous removal of an incorrect bottle with a correct bottle. An incorrect recovery is the misidentification and removal of the wrong type of bottle.

Table 23 lists the mistakes noted at the clear PET station. Included are the distances from the previous bottle and to the following bottle to demonstrate whether the bottle was grouped or isolated. A grouped bottle is considered to be one 2 inches or less from either the leading or to the trailing bottle. Nearly one-half (29 out of 60) of the mistakes itemized in this table are associated with grouped bottles. These are marked with an asterisk (*) following the bottle number. Therefore, approximately one-half of the mistakes at the clear PET station are the result of poor bottle spacing.

Table 24 lists the ranges of separation distances for bottles presented to the clear PET station. It considers both the distance to the previous bottle regardless of its type and the distance to the following bottle regardless of its type and groups the bottle according to the lesser of the two distances.

From Table 24, it can be seen that 8 percent of the bottles presented to the clear PET station were spaced 2 inches or less from adjacent bottles. Together with the data presented in Table 22, this demonstrates that approximately 8 percent of the bottles presented to the clear PET station were responsible for 50 percent of the mistakes at the clear PET station.

The tape analysis failed to account for a total of three recovery mistakes at the clear PET station, as determined by the actual bottle counts (given in Appendix A). From the actual counts, it can be reasoned that these three bottles consisted of one PVC bottle and two opaque HDPE bottles. These three bottles correspond with three of the video rendering count mistakes listed in Table 20 and are assumed to be the same bottles. The error in documenting the clear PET station mistakes using the video tape analysis was 3 out of the 448 bottles reporting, or 0.67 percent.

Types of Identification/Separation Mistakes

Several different types of identification/separation mistakes were noted during the testing program. Table 23 groups these into three classes (sweep, miss, and report to wrong station). The conditions causing these mistakes vary, several of which are discussed herein.

- Critical Distance - If a pair of bottles is not singulated properly so that a very small distance separates them, they can be detected as one bottle by the optical "presence" sensors, and can be identified as a clear PET bottle if the identification sensor reads the clear air gap between the two bottles. CPRR personnel have determined that a gap of approximately 2 inches or less can cause this type of error.

- Deterioration of Bottle Surface - Severe abrasion or other deterioration of the bottle surface was observed to cause clear and green PET to be viewed as opaque rather than transparent.

- Valley Effect - Although the testing was performed on whole, uncrushed bottles, the paddle wheel for oversize bottle removal occasionally dented PET or opaque HDPE bottles. If passed by the identification/separation station in an orientation such that the bottle is deformed and part of the bottle is crushed below the identification sensor height, the bottle can be identified as a clear PET bottle whether or not it is. Repetitive use of the same bottles tended to increase the number of bottles with this condition. When noted, deformed bottles were replaced with another uncrushed or undented bottle of the same type.

- Handle Effect - If opaque HDPE bottles pass by the identification/separation station in an orientation where the handle opening is exposed to the sensor, the bottle can be identified as a clear PET bottle in a manner similar to a critical distance mistake.

TABLE 23. BOTTLE DELIVERY/RECOVERY ERRORS. CLEAR PET STATION ONLY

BOTTLE NUMBER	BOTTLE TYPE	ERROR CODE - DESCRIPTION	FT-IN TO PREVIOUS BOTTLE	FT-IN TO FOLLOWING BOTTLE
28	Clear PET	M - Clear PET bottle missed.	15-08	3-11
120	Clear PET	M - Clear PET bottle missed.	10-03	4-02
211	Clear PET	M - Clear PET bottle missed.	3-06	4-08
324 *	Clear PET	M - Clear PET missed - air jets fired & carried subsequent opaque HDPE.	0-00	11-08
328 *	Clear PET	M - Clear PET missed - very close to previous bottle.	0-01	1-10
364	Clear PET	M - Clear PET bottle missed.	5-09	8-03
388 *	Clear PET	M - Clear PET overlapped with a green PET and was missed.	1-03	0-00
396 *	Clear PET	M - Clear PET was lapped with an opaque HDPE and was missed.	0-00	1-01
438	Clear PET	M - Clear PET bottle missed.	7-03	5-11
495	Clear PET	M - Clear PET bottle missed.	6-07	2-06
550	Clear PET	M - Clear PET disrupted by previous PVC removal and was missed.	0-05	4-02
587 *	Clear PET	M - Clear PET bunched with another clear PET was missed.	0-00	5-08
690	Clear PET	M - Clear PET bottle missed.	12-08	3-03
744	Clear PET	M - Clear PET bottle missed.	1-00	10-08
810 *	Clear PET	M - Clear PET bottle missed.	1-07	0-00
937	Clear PET	M - Clear PET bottle missed.	6-10	23-04
1075	Clear PET	M - Clear PET bottle missed.	2-11	3-00
1186 *	Clear PET	M - Clear PET was butted with previous opaque HDPE bottle and was missed.	0-00	6-02
1198 *	Clear PET	M - Clear PET was butted with previous opaque HDPE bottle and was missed.	0-00	1-05
1199	Clear PET	M - Clear PET bottle missed.	1-05	7-07
1278	Clear PET	M - Clear PET bottle missed.	2-04	5-08
1281	Clear PET	M - Clear PET bottle missed.	6-09	5-00
272	Green PET	R - Green PET reported to clear following a small jam on C5.	1-10	0-04
531 *	Green PET	R - Green PET lapped with opaque HDPE and reported to clear PET station.	0-00	14-10
739	Green PET	R - Green PET bottle reported to clear PET station.	1-07	4-06
747	Green PET	R - Green PET reported to clear PET.	5-09	14-11
753	Green PET	R - Green PET bottle reported to clear PET station.	18-10	4-09
950	Green PET	R - Green PET bottle reported to clear PET station.	4-06	2-01
83 *	Green PET	S - Swept into clear PET station with following clear PET bottle.	0-03	0-00
910 *	Green PET	S - Green PET swept into clear PET with following clear PET bottle.	1-06	0-00
17 *	Opaque HDPE	R - Opaque HDPE reported to clear PET station.	1-02	0-00
63 *	Opaque HDPE	R - Removed incorrectly by clear PET station.	0-02	5-00
212	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station - "Handle Effect".	4-08	8-10
378 *	Opaque HDPE	R - PVC station fired on opaque HDPE & it bounced into clear PET station.	0-01	0-00
508 *	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	0-00	0-00
509 *	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	0-00	1-10
530 *	Opaque HDPE	R - Opaque HDPE lapped with Green PET and reported to Clear PET station.	6-05	0-00
729	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET.	3-11	3-06
730	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET.	3-06	1-01
782 *	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	0-00	2-01
830	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	0-05	15-04
971	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	3-03	6-06
1065	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station, knocked by PVC blast	0-05	2-04
1069	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	5-03	0-09
1134	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	4-05	7-04
1179	Opaque HDPE	R - Opaque HDPE reported to clear PET station - "Handle Effect".	3-11	4-03
1271	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	3-09	2-11
1274 *	Opaque HDPE	R - Opaque HDPE bottle reported to clear PET station.	0-07	0-00
22 *	Opaque HDPE	S - Opaque HDPE swept to clear PET station with following clear PET.	0-07	0-00
90 *	Opaque HDPE	S - Swept into clear PET station with following clear PET bottle.	13-07	0-00
325 *	Opaque HDPE	S - Opaque HDPE swept into clear - note preceding clear was not caught.	11-08	0-00
342 *	Opaque HDPE	S - Opaque HDPE swept into clear PET station with following clear PET.	0-00	0-03
430 *	Opaque HDPE	S - Opaque HDPE swept into clear PET with following clear PET bottle.	28-00	0-00
581 *	Opaque HDPE	S - Opaque HDPE swept into clear PET with following clear PET bottle.	4-05	0-00
594 *	Opaque HDPE	S - Small opaque HDPE swept into clear PET with following clear PET.	1-01	0-00
612 *	Opaque HDPE	S - Opaque HDPE swept into clear PET with following clear PET bottle.	7-05	0-00
1007 *	Opaque HDPE	S - Opaque HDPE swept into clear PET with following clear PET bottle.	2-04	0-00
1073 *	Opaque HDPE	S - Small opaque HDPE swept into clear PET with following clear PET.	0-10	0-00
182	PVC	R - PVC bottle was missed and reported to clear PET station.	9-01	2-03
1163	PVC	R - PVC bottle missed and reported to clear PET station.	3-01	6-01

Distances assume conveyor C5 speed of 330 feet per minute and an average bottle length of 12 inches.
Error codes: S = sweep, M = miss, R = report to wrong station.
All delivery data transcribed from a video tape of the clear PET and PVC stations.
Only the errors visible at the clear PET are included.
Bottles marked with an asterisk (*) are located within 2 inches of an adjacent bottle.

TABLE 24. MINIMUM SEPARATION DISTANCES FOR EACH BOTTLE PRESENTED TO CLEAR PET STATION

Distance range	Number	Percentage	Cumulative Percentage
<= 2"	100	8.0%	8.0%
> 2" and <= 12"	110	8.8%	16.8%
> 12" and <= 24"	150	12.0%	28.8%
> 24" and <= 36"	179	14.3%	43.1%
> 36" and <= 48"	142	11.4%	54.5%
> 48" and <= 60"	123	9.8%	64.3%
> 60" and <= 120"	270	21.6%	85.9%
> 120"	176	14.1%	100.0%
Total	1250		

SECTION 6

COMMERCIAL POTENTIAL

As previously stated, the Rutgers system was designed to be a proof-of-concept pilot-scale process rather than a commercial-scale model. Its development emphasized the bottle identification aspects rather than the material handling aspects of the system. These facts coupled with the lack of the most recent PVC detection equipment complicates an evaluation of the system's true commercial potential. Significant design changes would be required in order to upgrade the equipment to commercial status and to improve the overall system performance so that all products meet commercially acceptable contamination limits. Process design changes that may enhance the Rutgers bottle sorting system's performance are discussed below.

PILOT SYSTEM DESIGN COMMENTS AND SUGGESTED MODIFICATIONS

Conveyor Speeds

Comment: The conveyor speeds are not cascaded. Normally, each conveyor in a series is designed to operate at a speed slightly above that of the conveyor immediately preceeding it. In the CPRR system, conveyor C3 serves as a feed buffer and as such operates at a higher speed than the subsequent conveyor, C4a. As a result, containers separated by the dual feed chute that feeds C3 are often brought back together at the transition from C3 to C4a.

Modification: Proper cascading of the conveyor speeds (i.e., progressively increasing speeds for downstream conveyors) would improve bottle singulation by allowing both the dual feed chute and conveyor C4a to assist in the singulation process.

Dual Feed Chute

Comment: The dual feed chute is not properly sized for the range of bottle sizes tested. The chute clearances are such that large bottles, particularly large opaque HDPE and 3-liter soda bottles, frequently became jammed inside the chute. Such jams, when cleared, can result in slugs of containers that are insufficiently singulated for the identification/separation stations to process accurately.

Modification: Enlarging the feed chute to accommodate the range of bottle sizes anticipated would eliminate most feed chute jams.

Conveyor C3 Skirting

Comment: The skirting on conveyor C3 is too narrow for the sizes of bottles tested. Conveyor C3 has an 18-inch wide belt, yet the skirting width is set at 10 inches, nearly exactly the length of a 1-liter soda bottle. Bottles occasionally became jammed perpendicular to the skirting, and when cleared, sometimes resulted in slugs of improperly singulated containers.

Modification: A vertical tapering of the conveyor skirting would eliminate most jams at this location.

Conveyor C3 Diverters

Comment: The flexible metal diverter strips were mounted on alternating sides of conveyor C3 to direct the bottles in a zig zag path while being transported by conveyor C3. This was done to help singulate the bottles. However, these diverters often served to slow the movement of bottles. When returning to their resting position after bending to allow a bottle to pass, they often impacted a trailing bottle, momentarily halting it completely, thereby reducing the spacing between it and trailing bottles.

Modification: These diverters should be removed completely as they did little to improve bottle presentation.

Paddle Wheel Construction

Comment: The paddle wheel, as constructed, was unable to function for extended operation. The rubber flaps used to eject the bottles repeatedly broke free from the aluminum angle used to hold them to the pulley. The rubber flaps were fastened to the angle with five small diameter bolts, providing little bearing area at the connection. The flaps flexed with each impact, and the soft rubber eventually failed at the connections. This failure was the major source of the downtime experienced during the extended test series.

Modification: Suggestions include using large diameter flat washers between each bolt head and the rubber flap, or a continuous section of flat stock under the bolt heads to provide a continuous bearing surface. The modifications implemented following each flap failure were adequate to ensure adequate performance of that flap during subsequent operation. However, more than one flap failed during the tests.

Paddle Wheel Fastening

Comment: The paddle wheel was held in place with C-clamps to allow adjustment of the clearance to enable the "target" oversize bottle (i.e., natural HDPE containers) to be diverted from the material stream. Fastened in this manner, the paddle wheel was subject to movement from vibration and impact.

Modification: Providing a more permanent and stable connection of the unit to the feed conveyor frame would eliminate the problem.

Conveyor C4 (a,b, and c) Belting

Comment: Conveyor C4 (a, b, and c) uses V-belts in lieu of solid rubber belting. Bottle caps liberated during processing occasionally became jammed under the V-belts, occasionally causing the belts to disengage from the pulleys. This was the cause of one major downtime during the first week of testing.

Modification: Use of rubber belting in place of V-belts would improve the mechanical operation of this unit.

Conveyor C4 Construction

Comment: The three overlapping segments of conveyor C4 could not properly singulate the bottles under all feed conditions. Very small light weight containers such as the small opaque HDPE "pill" bottles often could not be adequately separated from the container immediately following them. Their short length did not sufficiently span two segments of conveyor C4, and thus they could not be pulled away from closely following containers.

Modification: The separation efficiency of this unit could be improved by extending the length of this section and including more overlapping sections of narrower width.

Conveyor C5 Diverters

Comment: The flexible metal diverters added to conveyor C5 after the first week of testing were effective in aligning PVC bottles, but often had the opposite effect on PET soda bottles if fed base cup first. When fed in this orientation, the bottles, upon impact with the diverters, would often rotate vertically on the rounded portion of the bottle just below the neck. Once tipped, they would bounce and often loose their parallel alignment with conveyor C5, and therefore would not be presented properly to the sensors.

Modification: Use of the Asoma VS-2 PVC detector would eliminate the need for these diverters. They were added to assist in aligning the bottles along the conveyor skirting on which the PVC sensor was mounted. With the Asoma VS-2 unit mounted underneath the conveying surface, it would not be necessary to pass the bottles close to a vertically-mounted sensor. The PET stations do not require a close bottle/sensor alignment since the optical sensors used for PET detection are not sensitive to distance when used in bottle sorting applications.

Control of Bottle Feed Rate

Comment: As shown previously, the feed rate varied considerably throughout the tests. With the exception of conveyor C2, all conveyors operate at the same speed regardless of the desired bottle feed rate. This is because the sensor/air jet timing and air blast duration are set for a specific presentation conveyor speed. Bottle feed rates are set by adjusting the speed of conveyor C2. This conveyor discharges in slugs, a slug consisting of the contents of one cleat. By slowing or speeding up this conveyor, the time between slugs is either increased or decreased. What this means is that a slug of bottles is presented to the identification/separation equipment at a uniform rate regardless of bottle feed rate. The contents of a typical slug did not appear to change as a result of changes in the feed rate, and operation of the identification/separation equipment is not affected by the gaps between slugs.

Speed control in the manner used by the CPRR can affect bottle recovery only if the slugs are delivered with such frequency that the ability of conveyors C3 and C4 to singulate the slugs of bottles is exceeded, or by magnifying the consequences of a feed chute jam. Recovery efficiencies were noted to be relatively unaffected by changes in feed rate within the range investigated. The time between slug discharges varied depending on the composition of the feed material in each cleat. Many cleats contained mostly or only natural HDPE bottles and therefore contributed little or nothing to conveyor C3. Fallback of opaque HDPE bottles often knocked other bottles out of their cleat, contributing to a sparse feed for that cleat.

Modification: The feed rate could be evened out by employing a two bin feed system. Under such a system, mixed bottles would be fed in the same manner as the Rutgers system except that instead of discharging directly onto the conveyor system feeding the sensors, all bottles that passed the oversize station would drop into a second metering bin with sufficient buffer capacity. The first feed conveyor would be equipped with fairly short cleats similar to those used by the Rutgers system so that oversize bottles could be removed by the mechanical paddle wheel. The bottles in the second feed bin could be fed using a variable speed conveyor with deep cleats to eliminate fallback and to ensure a constant supply of bottles to the conveyor system. Proper adjustment of conveyor speeds and lengths will enable the bottles to be more uniformly presented to the sensors. This step should result in a significantly increased throughput without affecting bottle recovery.

PVC Recovery

Comment: Use of the improved Asoma VS-2 PVC sensor system should significantly improve PVC recoveries and therefore decrease PVC contamination. Bottles are typically presented to this sensor via a sloping plate and not with a belt conveyor as with the first generation XRF detector. The overall system configuration would need to change to accommodate this feed arrangement.

Modification: A multiple pass system will improve recovery by allowing more than one opportunity to detect and remove target products. For example, additional PVC sensors may be required to clean up certain product streams if primary PVC recovery is insufficient to meet product purity requirements. Use of the new Asoma VS-2 sensor may eliminate the need for secondary PVC clean-up, however.

EQUIPMENT COST ESTIMATE

As previously discussed, because of the extensive modifications necessary to upgrade the Rutgers system to commercial level, a commercial scale capital or operating cost analysis is not justified. Rather, it may be useful to establish a capital cost for the current configuration thereby providing a baseline against which to measure the cost of future changes. Table 25 presents the equipment costs for the Rutgers system as constructed. No installation costs are included, nor are the costs of such items as motor starters, power wiring, gaylord boxes, spare parts, and the air compressor. It should be noted that the Asoma I PVC detector is no longer in production and has been replaced by a newer model, the cost of which may be different from that included in this estimate.

TABLE 25. EQUIPMENT COSTS

Component	Number	Unit Cost	Total Cost
PVC Detector	1	$40,000	$40,000
Optical Station			
Includes sensors, air nozzles, hose	3	$500	$1,500
Infeed System			
Includes feed hopper, infeed conveyor, paddle and kick wheels, dual discharge chute, and oversize chute	1	$5,000	$5,000
Conveyor C4a,b,c	1	$5,000	$5,000
Conveyors C3, C5, C6, C7	1	$3,000	$3,000
			$54,500

EXISTING COMMERCIAL SYSTEMS

There are currently three existing commercial systems for the identification and separation of individual resins in a mixed plastics stream[2,4,5]. These systems are briefly described below for background comparison purposes. All three report container recoveries and throughput rates in excess of those found for the Rutgers system, and all reportedly can accommodate crushed bottles. These manufacturer claims, however, have not been independently verified.

The commercial systems have encountered some processing problems [5]. Air jets are typically used to remove the detected bottle from the stream, and flattened bottles can pose removal problems in that they can act as an airfoil and actually become forced down on the conveyor belt instead of being blown off the belt. Color sensors can mistakenly read the color of the labels or the container residue. Bale breaking and subsequent bottle singulation (if required) can be difficult, especially with bales of various sizes and bottles of varying degrees of deformation.

Magnetic Separation Systems, Inc. - BottleSort System

The basic Magnetic Separation Systems (MSS) system uses different intensities of light to distinguish clear bottles consisting of PET and PVC, translucent bottles consisting of HDPE milk and juice containers, polypropylene (PP) syrup and ketchup bottles, and opaque bottles consisting of detergent and shampoo bottles. Air jets are used to remove the detected bottles from the conveyor belt. Further resin separation can be accomplished using additional modules consisting of an Asoma VS-2 PVC detector, a computer-controlled HDPE color detector, an optical PET color sensor, and an optical PP sensor. The color detectors employ computer software to identify seven bottle colors, ignoring the labels and residue contamination. Each bottle is scanned by an array of 16 sensors which make 5,300 readings per second to determine the bottle type.

The base separation system was installed at Eaglebrook's Chicago facility in January of 1992, and the color separation system was installed in September of 1992. Four parallel sorting lines are claimed to be able to identify and separate 8 to 12 bottles per second (120 - 180 bottles per minute per line), providing a total capacity of 5,000 pounds per hour. Problems have been experienced with the feed system, and manual inspection was used to enhance the PVC removal. MSS claims that the basic three-way separation system can achieve a 96 to 99 percent resin separation and that over 99 percent of the PVC bottles can be captured[4].

National Recovery Technologies, Inc. - VinylCycle System

The National Recovery Technologies (NRT) system uses an electromagnetic sensor that separates PVC bottles from a mixed stream of whole or crushed HDPE, PET, and PVC bottles. The mixed stream is passed down a slide. Air jets mounted below the slide are used to blow detected PVC bottles over a partition. Undetected bottles fall on the opposite side of the partition. The air jets cannot necessarily remove only the detected PVC bottle as adjacent bottles can be swept over the partition with the PVC. Hence this system produces two product streams, one consisting of mixed bottles and one PVC-rich stream. It is claimed that the bottles need not be oriented or singulated before being presented to the detector.

NRT currently has three models, the highest production model is reportedly capable of processing 10 bottles/second or 4500 pounds/hour, and yields a product with less than 50 parts per million (ppm) PVC contamination.(4) NRT guarantees a PVC contamination limit of 50 ppm if the PVC content of the infeed mixed stream does not exceed 1 percent. The PVC recovery is reportedly greater than 99.4 percent, with 100 percent PVC removal possible with two passes. According to The Vinyl Institute, 18 NRT systems have been installed worldwide.(2)

Automation Industrial Control - PolySort System

The Automation Industrial Control (AIC) system uses infrared spectrographic analysis of light transmitted through singulated bottles to distinguish containers by resin type and color.(5) Air jets segregate the detected bottles into polypropylene, PVC, natural HDPE, colored HDPE, green PET, and clear PET product streams. Two sensors read the bottle and the information is processed in a 486-chip microprocessor. A time of 19 milliseconds is required to determine the bottle type and color. Actual processing rates are reported to be 700 - 800 pounds per hour (6). The system reportedly can process either compacted or uncrushed bottles. Unread bottles remain on the belt and can be recycled through the system or discarded. The first commercial system was installed in 1992 at the North American Plastics Recycling Corporation plant in Ft. Edward, NY. No performance information is available at this time.

REFERENCES

1. wTe Corporation. MITE Program for Automatic Sortation Process for Post-Consumer Plastic Containers, Draft Quality Assurance/Quality Control Project Plan, 1992.

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3. Lipson C. and N.J. Sheth. Statistical Design and Analysis of Engineering Experiments. McGraw-Hill Book Company, NY, 1973.

4. Schut, J.H. Automatic Resin & Color Sorting Proves a Boon to Recyclers, Technology News, September 1992. pp. 15-19.

5. Powell, J. Automated Plastic Bottle Sorting: An Emerging Technology, Resource Recycling, August 1992. pp. 62-69.

6. Personal communication between D. Kirk and C. McCourt.

APPENDIX A

TEST DATA AS COLLECTED
MIXED COMPOSITION 2,000 BOTTLE EXTENDED TESTS

TABLE A-1. DATA FOR MIXED FEED 2,000 BOTTLE TEST AT 60% FEED CONVEYOR SETTING

A-1.1 TEST 1
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/07/92
DURATION: 27.0 minutes
FEED RATE: 71 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	479	1	3		42	525
Station 2 - PVC		93	3	2	11	109
Station 3 - Clear PET		10	424	7	30	471
Station 4 - Green PET		2	13	121	8	144
Station 5 - Opaque HDPE		1	4	8	639	652
Station - Unfed	15	4	9	5	36	69
Station - Spillage		1		1	2	4
Total	494	112	456	144	768	1974

Observations:

Noted that bottles can jam sideways on conveyor C3 - the skirting width is nearly identical to the length of a 1 liter PET bottle.

Four jams were caused by PET bottles, and 10 jams were caused by HDPE bottles.

Three PVC bottles were detected and blown at the PVC station but failed to enter the chute. They ended up in the clear PET station.

The fallback from the infeed conveyor was noted as fallback occurrences per minute: 13, 18, 28, 25, and 16.

The number of oversize chute pass-through occurrences were noted per minute: 11, 12, and 12.

A-1.2 TEST 2
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/07/92
DURATION: 28.0 minutes
FEED RATE: 69 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	479	1	4	1	37	522
Station 2 - PVC		106	1	1	7	115
Station 3 - Clear PET		5	427	6	34	472
Station 4 - Green PET			15	117	9	141
Station 5 - Opaque HDPE			4	13	663	680
Station - Unfed	15		2	6	17	40
Station - Spillage			3		1	4
Total	494	112	456	144	768	1974

Observations:

Four jams were noted.

Paddle wheel lost a ruber paddle during the test. It was repaired following the test - approximately one hour required to repair.

Clear was firing on opaque HDPE and was adjusted during the test.

The sweeping effect is very noticeable. Two bottle will be removed as one if they are closely spaced.

TABLE A-1. CONTINUED

A-1.3 TEST 3
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/07/92
DURATION: 28.0 minutes
FEED RATE: 69 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	473	4	7	2	50	536
Station 2 - PVC		99	9	3	7	118
Station 3 - Clear PET		5	409	2	22	438
Station 4 - Green PET	1	4	15	125	8	153
Station 5 - Opaque HDPE			3	8	664	675
Station - Unfed	20		8	4	15	47
Station - Spillage			5		2	7
Total	494	112	456	144	768	1974

Observations:

Video taped this test - green PET station only.

Time for one revolution of Conveyor C5 is 7.5 seconds.

A-1.4 TEST 4
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/07/92
DURATION: 27.6 minutes
FEED RATE: 70 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	481	1	2	2	47	533
Station 2 - PVC		100	5		6	111
Station 3 - Clear PET		6	415	4	23	448
Station 4 - Green PET		4	24	122	24	174
Station 5 - Opaque HDPE	2		5	14	655	676
Station - Unfed	11	1	3	2	13	30
Station - Spillage			2			2
Total	494	112	456	144	768	1974

Observations:

Rubber flap on paddle wheel came loose and test was halted. Flat was removed and test resumed. 2 minutes, 45 seconds required to remove flap.

Video taped the clear PET and the PVC stations.

Eleven jams were noted.

Three PVC bottles were undetected because of inproper positioning on the conveyor.

Two PVC bottles bounced back from the PVC chute, one ended up in clear PET, one in opaque HDPE.

Sweeping effect carried opaque HDPE into clear PET.

A-1.5 TEST 5
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/08/92
DURATION: 28.0 minutes
FEED RATE: 69 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	471	3	4	3	43	524
Station 2 - PVC		104	2	2	2	110
Station 3 - Clear PET			417	2	22	441
Station 4 - Green PET		4	20	124	13	161
Station 5 - Opaque HDPE	1		1	10	669	681
Station - Unfed	20	1	10	2	18	51
Station - Spillage	2		2	1	1	6
Total	494	112	456	144	768	1974

Observations:

12 jams were noted.

Another rubber paddle was lost - test was not halted.

TABLE A-1. CONTINUED

A-1.6 TEST 6 — DATE: 10/08/92
FEED: 2,000 MIXED BOTTLES — DURATION: 26.9 minutes
SPEED: 60% — FEED RATE: 70 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	459		3	1	52	515
Station 2 - PVC		97	6	1	4	108
Station 3 - Clear PET		6	397	4	14	421
Station 4 - Green PET		3	26	118	12	159
Station 5 - Opaque HDPE	3	1	6	15	654	679
Station - Unfed	32	5	17	5	31	90
Station - Spillage			1		1	2
Total	494	112	456	144	768	1974

Observations:

Two paddle wheel flaps failed on separate occasions. Both times the test was halted, the flap removed, and the test resumed.

5 jams were noted.

Infeed conveyor fallback counts per minute: 30, 31, and 37.

Oversize chute returns per minute: 12, 12.

A-1.7 TEST 7 — DATE: 10/08/92
FEED: 2,000 MIXED BOTTLES — DURATION: 25.3 minutes
SPEED: 60% — FEED RATE: 75 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	460	1	4	4	51	520
Station 2 - PVC		102	14	3	4	123
Station 3 - Clear PET		3	407	8	30	448
Station 4 - Green PET		4	18	107	19	148
Station 5 - Opaque HDPE	1		4	14	639	658
Station - Unfed	33	1	6	6	23	69
Station - Spillage		1	3	2	2	8
Total	494	112	456	144	768	1974

Observations:

Clear PET sensor adjusted during test.

Infeed conveyor fallback counts per minute: 36, 30, and 30.

Oversize chute returns per minute: 10, 9, and, 22.

A-1.8 TEST 8 — DATE: 10/08/92
FEED: 2,000 MIXED BOTTLES — DURATION: 26.5 minutes
SPEED: 60% — FEED RATE: 73 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	471		1		45	517
Station 2 - PVC	3	101	6	1	8	119
Station 3 - Clear PET	2	7	424	4	33	470
Station 4 - Green PET		4	14	123	15	156
Station 5 - Opaque HDPE	3		5	13	659	680
Station - Unfed	15		5	3	8	31
Station - Spillage			1			1
Total	494	112	456	144	768	1974

Observations:

Two PVC bottles reported to clear PET station because of a jam.

17 jams were noted.

A PVC bottle and a natural HDPE bottle were observed to be ejected simultaneously at the clear PET station.

TABLE A-1. CONTINUED

A-1.9 TEST 9
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/08/92
DURATION: 26.1 minutes
FEED RATE: 74 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	475		5	4	40	524
Station 2 - PVC	1	95	2	1	4	103
Station 3 - Clear PET		9	411	6	69	495
Station 4 - Green PET	2	5	30	112	9	158
Station 5 - Opaque HDPE	1	2	5	18	631	657
Station - Unfed	14		2	3	13	32
Station - Spillage	1	1	1		2	5
Total	494	112	456	144	768	1974

Observations:

Eleven jams were noted.

Of the 69 opaque HDPE bottles in the clear PET station, 22 were small bottles.

A-1.10 TEST 10
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/09/92
DURATION: 26.0 minutes
FEED RATE: 73 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	460		5	2	36	503
Station 2 - PVC		99	7	3	5	114
Station 3 - Clear PET		6	421	1	18	446
Station 4 - Green PET	2	3	4	120	17	146
Station 5 - Opaque HDPE	5	1	2	12	670	690
Station - Unfed	27	3	15	6	22	73
Station - Spillage			2			2
Total	494	112	456	144	768	1974

Observations:

Sixteen jams were noted.

Clear PET optical sensors adjusted during the test.

Appears that large PVC bottles are not passed quiescently past the PVC detector and often are not detected.

A-1.11 TEST 11
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/09/92
DURATION: 25.8 minutes
FEED RATE: 75 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	470	1	3		37	511
Station 2 - PVC	1	102	10		9	122
Station 3 - Clear PET		4	390	2	10	406
Station 4 - Green PET	1	3	42	125	16	187
Station 5 - Opaque HDPE	7	1	5	13	678	704
Station - Unfed	15	1	4	4	17	41
Station - Spillage			2		1	3
Total	494	112	456	144	768	1974

Observations:

Ten jams noted: three at the C3/C4 transition, three on conveyor C3, two on conveyor C4, and two in the feed chute.

TABLE A-1. CONTINUED

A-1.12 TEST 12 — DATE: 10/09/92
FEED: 2,000 MIXED BOTTLES — DURATION: 26.0 minutes
SPEED: 60% — FEED RATE: 75 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	477	1	4		37	519
Station 2 - PVC	1	100	7	2	6	116
Station 3 - Clear PET		5	417	2	12	436
Station 4 - Green PET	1	6	17	125		149
Station 5 - Opaque HDPE	5		5	14	694	718
Station - Unfed	10		5		19	34
Station - Spillage			1	1		2
Total	494	112	456	144	768	1974

Observations:

Seven jams noted: two in the feed chute, two at the C3/C4 transition, and three on conveyor C3.

The flexible metal diverters on conveyor C3 appear to do little good and perhaps slow down the bottles, reducing the spacing achieved by the dual discharge chutes.

A-1.13 TEST 13 — DATE: 10/09/92
FEED: 2,000 MIXED BOTTLES — DURATION: 25.3 minutes
SPEED: 60% — FEED RATE: 76 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	486				22	508
Station 2 - PVC		97	12	1	8	118
Station 3 - Clear PET		10	421	3	28	462
Station 4 - Green PET		4	10	128	20	162
Station 5 - Opaque HDPE	4	1	3	8	663	679
Station - Unfed	4		10	4	25	43
Station - Spillage					2	2
Total	494	112	456	144	768	1974

Observations:

Seven jams noted: two in the feed chute, and five on conveyor C3.

Small opaque HDPE bottles do not have enough length to be pulled away from trailing bottles by the singulating conveyor C4.

One large PVC noted to be too far from the sensor to be detected.

A-1.14 TEST 14 — DATE: 10/09/92
FEED: 2,000 MIXED BOTTLES — DURATION: 25.3 minutes
SPEED: 60% — FEED RATE: 76 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	470		3		26	499
Station 2 - PVC		97	4	2	7	110
Station 3 - Clear PET		10	432	3	17	462
Station 4 - Green PET		5	4	127	16	152
Station 5 - Opaque HDPE	5		5	8	675	693
Station - Unfed	19		6	4	27	56
Station - Spillage			2			2
Total	494	112	456	144	768	1974

Observations:

Four jams on conveyor C3 noted.

Grreen and clear PET sensors were adjusted during the test.

A group of two PVC and one clear PET were observed - 1 PVC and 1 clear PET removed at PVC station, other PVC went undetected.

Flexible metal diverter on conveyor C5 caused an opaque HDPE bottle to be removed at the PVC station.

TABLE A-1. CONTINUED

A-1.15 TEST 15
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/09/92
DURATION: 24.4 minutes
FEED RATE: 79 BPM

	COMPONENT					
	Nat HDPE	PVC	Clear PET	Green PET	Opaque HDPE	Total
Station 1 - Natural HDPE	466	2			28	496
Station 2 - PVC	2	95	3	3	1	104
Station 3 - Clear PET	1	8	430	5	15	459
Station 4 - Green PET		6	11	115	10	142
Station 5 - Opaque HDPE	5	1	3	14	702	725
Station - Unfed	20		7	6	10	43
Station - Spillage			2	1	2	5
Total	494	112	456	144	768	1974

Observations:

Five jams noted: three on conveyor C3, one on conveyor C4, and one in the feed chute.

Flexible metal diverters on conveyor C5 disorient PET bottles.

APPENDIX B

EXTENDED TEST RESULTS, OUTLIERS NOT INCLUDED
MIXED COMPOSITION 2,000 BOTTLE EXTENDED TESTS

TABLE B-1. NATURAL HDPE DATA FOR MIXED FEED 2,000 BOTTLE TEST AT 60% FEED CONVEYOR SPEED SETTING - OUTLIERS NOT INCLUDED

B-1.1 NATURAL HDPE BOTTLE RECOVERY COUNTS

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL
1 - Natural HDPE	479			481	471	459	460			460	470	477	486	470	466	5179
2 - PVC	0			0	0	0	0			0	1	1	0	0	2	4
3 - Clear PET	0			0	0	0	0			0	0	0	0	0	1	1
4 - Green PET	0			0	0	0	0			2	1	1	0	0	0	4
5 - Opaque HDPE	0			2	1	3	1			5	7	5	4	5	5	38
- Unfed	15			11	20	32	33			27	15	10	4	19	20	206
- Spillage	0			0	2	0	0			0	0	0	0	0	0	2
TOTAL	494			494	494	494	494			494	494	494	494	494	494	5434
FEED RATE, BPM	18			17	17	17	18			18	19	19	19	19	19	18

B-1.2 NATURAL HDPE BOTTLE RECOVERIES AS A PERCENTAGE OF THE NATURAL HDPE BOTTLES FED INTO THE SYSTEM

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	100.0			99.6	99.4	99.4	99.8			98.5	98.1	98.6	99.2	98.9	98.3	99.1%	0.63	0.01	98.7	99.5	0.11	1.94
2 - PVC	0.0			0.0	0.0	0.0	0.0			0.0	0.2	0.2	0.0	0.0	0.4	0.1%	0.13	1.86	0.0	0.2	0.02	0.40
3 - Clear PET	0.0			0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.2	0.0%	0.06	3.00	0.0	0.0	0.01	0.18
4 - Green PET	0.0			0.0	0.0	0.0	0.0			0.4	0.2	0.2	0.0	0.0	0.0	0.1%	0.13	1.86	0.0	0.2	0.02	0.40
5 - Opaque HDPE	0.0			0.4	0.2	0.6	0.2			1.1	1.5	1.0	0.8	1.1	1.1	0.7%	0.48	0.66	0.4	1.0	0.08	1.48
- Spillage	0.0			0.0	0.4	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.12	3.00	0.0	0.1	0.02	0.37

B-1.3 NATURAL HDPE BOTTLE RECOVERIES AS A PERCENTAGE OF THE NATURAL HDPE BOTTLES PRESENTED TO EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	100.0			99.6	99.8	99.4	99.8			98.5	98.1	98.6	99.2	98.9	98.3	99.1%	0.67	0.01	98.6	99.6	0.12	2.06
2 - PVC	--			0.0	0.0	0.0	0.0			0.0	11.1	14.3	0.0	0.0	25.0	8.5%	8.81	1.75	2.3	14.7	1.53	27.10
3 - Clear PET	--			0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0	16.7	2.3%	5.28	3.16	0.0	6.0	0.92	16.24
4 - Green PET	--			0.0	0.0	0.0	0.0			28.6	12.5	16.7	0.0	0.0	0.0	9.5%	10.11	1.75	2.4	16.7	1.76	31.09
5 - Opaque HDPE	--			100.0	100.0	100.0	100.0			100.0	100.0	100.0	100.0	100.0	100.0	100.0%	0.00	0.00	100.0	100.0	0.00	0.00

B-1.4 NATURAL HDPE BOTTLE RECOVERIES AS A PERCENTAGE OF THE TOTAL BOTTLES RECOVERED AT EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	91.2			90.2	89.9	89.1	88.5			91.5	92.0	91.9	95.7	94.2	94.0	91.7%	2.24	0.02	90.3	93.0	0.39	6.90
2 - PVC	0.0			0.0	0.0	0.0	0.0			0.0	0.8	0.9	0.0	0.0	1.9	0.3%	0.61	1.87	0.0	0.7	0.10	1.89
3 - Clear PET	0.0			0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.2	0.0%	0.06	3.14	0.0	0.1	0.01	0.19
4 - Green PET	0.0			0.0	0.0	0.0	0.0			1.4	0.5	0.7	0.0	0.0	0.0	0.2%	0.46	1.92	0.0	0.5	0.08	1.42
5 - Opaque HDPE	0.0			0.3	0.1	0.4	0.2			0.7	1.0	0.7	0.6	0.7	0.7	0.5%	0.31	0.64	0.3	0.7	0.05	0.96
- Unfed	21.7			36.7	39.2	35.6	47.8			37.0	36.6	29.4	9.3	33.9	46.5	34.0%	10.87	0.32	27.5	40.5	1.88	33.44
- Spillage	0.0			0.0	33.3	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0	3.0%	10.03	3.31	0.0	9.0	1.74	30.86

RSD = RELATIVE STANDARD DEVIATION, LACI = LOWER AVERAGE FOR 95% CONFIDENCE INTERVAL, UACI = UPPER AVERAGE FOR 95% CONFIDENCE INTERVAL,
LSCI = LOWER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL, USCI = UPPER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL.
-- IN TABLE 3 INDICATES THAT NO BOTTLES REPORTED TO THIS STATION.

TABLE B-2. PVC DATA FOR MIXED FEED 2,000 BOTTLE TEST AT 60% FEED CONVEYOR SPEED SETTING - OUTLIERS NOT INCLUDED

B-2.1 PVC BOTTLE RECOVERY COUNTS

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL
1 - Natural HDPE	1			1	3	0	1			0	1	1	0	0	2	10
2 - PVC	93			100	104	97	102			99	102	100	97	97	95	1086
3 - Clear PET	10			6	0	6	3			6	4	5	10	10	8	68
4 - Green PET	2			4	4	3	4			3	3	6	4	5	6	44
5 - Opaque HDPE	1			0	0	1	0			1	1	0	1	0	1	6
- Unfed	4			1	1	5	1			3	1	0	0	0	0	16
- Spillage	1			0	0	0	1			0	0	0	0	0	0	2
TOTAL	112			112	112	112	112			112	112	112	112	112	112	1232
FEED RATE, BPM	4			4	4	4	4			4	4	4	4	4	5	4

B-2.2 PVC BOTTLE RECOVERIES AS A PERCENTAGE OF THE PVC BOTTLES FED INTO THE SYSTEM

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.9			0.9	2.7	0.0	0.9			0.0	0.9	0.9	0.0	0.0	1.8	0.8%	0.85	1.04	0.2	1.4	0.15	2.61
2 - PVC	86.1			90.1	93.7	90.7	91.9			90.8	91.9	89.3	86.6	86.6	84.8	89.3%	2.88	0.03	87.3	91.3	0.50	8.86
3 - Clear PET	9.3			5.4	0.0	5.6	2.7			5.5	3.6	4.5	8.9	8.9	7.1	5.6%	2.88	0.52	3.6	7.6	0.50	8.86
4 - Green PET	1.9			3.6	3.6	2.8	3.6			2.8	2.7	5.4	3.6	4.5	5.4	3.6%	1.11	0.31	2.8	4.4	0.19	3.41
5 - Opaque HDPE	0.9			0.0	0.0	0.9	0.0			0.9	0.9	0.0	0.9	0.0	0.9	0.5%	0.47	0.96	0.2	0.8	0.08	1.45
- Spillage	0.9			0.0	0.0	0.0	0.9			0.0	0.0	0.0	0.0	0.0	0.0	0.2%	0.36	2.25	0.0	0.5	0.06	1.11

B-2.3 PVC BOTTLE RECOVERIES AS A PERCENTAGE OF THE PVC BOTTLES PRESENTED TO EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.9			0.9	2.7	0.0	0.9			0.0	0.9	0.9	0.0	0.0	1.8	0.8%	0.85	1.04	0.2	1.4	0.15	2.61
2 - PVC	87.7			90.9	96.3	90.7	93.6			90.8	92.7	90.1	86.6	86.6	86.4	90.2%	3.21	0.04	87.9	92.5	0.56	9.87
3 - Clear PET	76.9			60.0	0.0	60.0	42.9			60.0	50.0	45.5	66.7	66.7	53.3	57.6%	20.17	0.38	43.4	71.9	3.50	62.03
4 - Green PET	66.7			100.0	100.0	75.0	100.0			75.0	75.0	100.0	80.0	100.0	85.7	88.0%	13.19	0.15	78.7	97.3	2.29	40.57
5 - Opaque HDPE	100.0			--	--	100.0	--			100.0	100.0	--	100.0	--	100.0	100.0%	0.00	0.00	100.0	100.0	0.00	0.00

B-2.4 PVC BOTTLE RECOVERIES AS A PERCENTAGE OF THE TOTAL BOTTLES RECOVERED AT EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.2			0.2	0.6	0.0	0.2			0.0	0.2	0.2	0.0	0.0	0.4	0.2%	0.18	1.04	0.1	0.3	0.02	0.57
2 - PVC	85.3			90.1	94.5	89.8	82.9			86.8	83.6	86.2	82.2	88.2	91.3	87.4%	3.83	0.04	85.1	89.6	0.66	11.80
3 - Clear PET	2.1			1.3	0.0	1.4	0.7			1.3	1.0	1.1	2.2	2.2	1.7	1.4%	0.67	0.49	1.0	1.8	0.12	2.06
4 - Green PET	1.4			2.3	2.5	1.9	2.7			2.1	1.6	4.0	2.5	3.3	4.2	2.6%	0.91	0.35	2.0	3.1	0.16	2.80
5 - Opaque HDPE	0.2			0.0	0.0	0.1	0.0			0.1	0.1	0.0	0.1	0.0	0.1	0.1%	0.06	1.04	0.0	0.1	0.01	0.19
- Unfed	5.8			3.3	2.0	5.6	1.4			4.1	2.4	0.0	0.0	0.0	0.0	2.2%	2.22	0.99	0.9	3.6	0.38	6.83
- Spillage	25.0			0.0	0.0	0.0	12.5			0.0	0.0	0.0	0.0	0.0	0.0	3.4%	8.08	2.37	0.0	8.2	1.40	24.86

RSD = RELATIVE STANDARD DEVIATION, LACI = LOWER AVERAGE FOR 95% CONFIDENCE INTERVAL, UACI = UPPER AVERAGE FOR 95% CONFIDENCE INTERVAL,
LSCI = LOWER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL, USCI = UPPER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL.
-- IN TABLE 3 INDICATES THAT NO BOTTLES REPORTED TO THIS STATION.

TABLE B-3. CLEAR PET DATA FOR MIXED FEED 2,000 BOTTLE TEST AT 60% FEED CONVEYOR SPEED SETTING - OUTLIERS NOT INCLUDED

B-3.1 CLEAR PET BOTTLE RECOVERY COUNTS

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL
1 - Natural HDPE	3			2	4	3	4			5	3	4	0	3	0	31
2 - PVC	3			5	2	6	14			7	10	7	12	4	3	73
3 - Clear PET	424			415	417	397	407			421	390	417	421	432	430	4571
4 - Green PET	13			24	20	26	18			4	42	17	10	4	11	189
5 - Opaque HDPE	4			5	1	6	4			2	5	5	3	5	3	43
- Unfed	9			3	10	17	6			15	4	5	10	6	7	92
- Spillage	0			2	2	1	3			2	2	1	0	2	2	17
TOTAL	456			456	456	456	456			456	456	456	456	456	456	5016
FEED RATE, BPM	17			16	16	16	18			17	18	17	18	18	18	17

B-3.2 CLEAR PET BOTTLE RECOVERIES AS A PERCENTAGE OF THE CLEAR PET BOTTLES FED INTO THE SYSTEM

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.7			0.4	0.9	0.7	0.9			1.1	0.7	0.9	0.0	0.7	0.0	0.6%	0.36	0.56	0.3	0.9	0.06	1.11
2 - PVC	0.7			1.1	0.4	1.4	3.1			1.6	2.2	1.6	2.7	0.9	0.7	1.5%	0.87	0.58	0.9	2.1	0.15	2.68
3 - Clear PET	94.9			91.6	93.5	90.4	90.4			95.5	86.3	92.5	94.4	96.0	95.8	92.8%	2.99	0.03	90.7	94.9	0.52	9.20
4 - Green PET	2.9			5.3	4.5	5.9	4.0			0.9	9.3	3.8	2.2	0.9	2.4	3.8%	2.44	0.64	2.1	5.5	0.42	7.50
5 - Opaque HDPE	0.9			1.1	0.2	1.4	0.9			0.5	1.1	1.1	0.7	1.1	0.7	0.9%	0.34	0.39	0.7	1.1	0.06	1.05
- Spillage	0.0			0.4	0.4	0.2	0.7			0.5	0.4	0.2	0.0	0.4	0.4	0.3%	0.21	0.64	0.2	0.4	0.04	0.65

B-3.3 CLEAR PET BOTTLE RECOVERIES AS A PERCENTAGE OF THE CLEAR PET BOTTLES PRESENTED TO EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.7			0.4	0.9	0.7	0.9			1.1	0.7	0.9	0.0	0.7	0.0	0.6%	0.36	0.56	0.4	0.9	0.06	1.11
2 - PVC	0.7			1.1	0.5	1.4	3.2			1.6	2.2	1.6	2.7	0.9	0.7	1.5%	0.87	0.58	0.9	2.1	0.15	2.68
3 - Clear PET	96.1			93.5	95.2	92.5	94.9			98.6	89.2	95.0	97.0	98.0	96.8	95.1%	2.69	0.03	93.3	97.1	0.47	8.27
4 - Green PET	76.5			82.8	95.2	81.3	81.8			66.7	89.4	77.3	76.9	44.4	78.6	81.4%	13.16	0.17	72.2	90.7	2.28	40.47
5 - Opaque HDPE	100.0			100.0	100.0	100.0	100.0			100.0	100.0	100.0	100.0	100.0	100.0	100.0%	0.00	0.00	100.0	100.0	0.00	0.00

B-3.4 CLEAR PET BOTTLE RECOVERIES AS A PERCENTAGE OF THE TOTAL BOTTLES RECOVERED AT EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.6			0.4	0.8	0.6	0.8			1.0	0.6	0.8	0.0	0.6	0.0	0.6%	0.32	0.58	0.4	0.8	0.05	0.99
2 - PVC	2.8			4.5	1.8	5.6	11.4			6.1	8.2	6.0	10.2	3.6	2.9	5.7%	3.10	0.54	3.9	7.6	0.53	9.54
3 - Clear PET	90.0			92.6	94.6	94.3	90.8			94.4	96.1	95.6	91.1	93.5	93.7	93.3%	1.99	0.02	92.1	94.5	0.34	6.13
4 - Green PET	9.0			13.8	12.4	16.4	12.2			2.7	22.5	11.4	6.2	2.6	7.7	10.6%	5.90	0.55	7.1	14.1	1.02	18.16
5 - Opaque HDPE	0.6			0.7	0.1	0.9	0.6			0.3	0.7	0.7	0.4	0.7	0.4	0.6%	0.23	0.41	0.4	0.7	0.04	0.71
- Unfed	13.0			10.0	19.6	18.9	8.7			20.5	9.8	14.7	23.3	10.7	16.3	15.0%	5.01	0.33	12.1	18.0	0.87	15.42
- Spillage	0.0			100.0	33.3	50.0	37.5			100.0	66.7	50.0	0.0	100.0	40.0	52.5%	36.39	0.69	30.8	74.2	6.31	111.92

RSD = RELATIVE STANDARD DEVIATION, LACI = LOWER AVERAGE FOR 95% CONFIDENCE INTERVAL, UACI = UPPER AVERAGE FOR 95% CONFIDENCE INTERVAL, LSCI = LOWER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL, USCI = UPPER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL.

TABLE B-4. GREEN PET DATA FOR MIXED FEED 2,000 BOTTLE TEST AT 60% FEED CONVEYOR SPEED SETTING - OUTLIERS NOT INCLUDED

B-4.1 GREEN PET BOTTLE RECOVERY COUNTS

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL
1 - Natural HDPE	0			2	3	1	4			2	0	0	0	0	0	12
2 - PVC	2			0	2	1	3			3	0	2	1	2	3	19
3 - Clear PET	7			4	2	4	8			1	2	2	3	3	5	41
4 - Green PET	121			122	124	118	107			120	125	125	128	127	115	1332
5 - Opaque HDPE	8			14	10	15	14			12	13	14	8	8	14	130
- Unfed	5			2	2	5	6			6	4	0	4	4	6	44
- Spillage	1			0	1	0	2			0	0	1	0	0	1	6
TOTAL	144			144	144	144	144			144	144	144	144	144	144	1584
FEED RATE, BPM	5			5	5	5	5			5	5	6	6	6	6	5

B-4.2 GREEN PET BOTTLE RECOVERIES AS A PERCENTAGE OF THE GREEN PET BOTTLES FED INTO THE SYSTEM

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.0			1.4	2.1	0.7	2.9			1.4	0.0	0.0	0.0	0.0	0.0	0.8%	1.03	1.34	0.1	1.5	0.18	3.17
2 - PVC	1.4			0.0	1.4	0.7	2.2			2.2	0.0	1.4	0.7	1.4	2.2	1.2%	0.81	0.65	0.6	1.8	0.14	2.49
3 - Clear PET	5.0			2.8	1.4	2.9	5.8			0.7	1.4	1.4	2.1	2.1	3.6	2.7%	1.60	0.60	1.6	3.8	0.28	4.92
4 - Green PET	87.1			85.9	87.3	84.9	77.5			87.0	89.3	86.8	91.4	90.7	83.3	86.5%	3.81	0.04	83.8	89.2	0.66	11.72
5 - Opaque HDPE	5.8			9.9	7.0	10.8	10.1			8.7	9.3	9.7	5.7	5.7	10.1	8.4%	1.99	0.24	7.0	9.8	0.35	6.12
- Spillage	0.7			0.0	0.7	0.0	1.4			0.0	0.0	0.7	0.0	0.0	0.7	0.4%	0.48	1.26	0.1	0.7	0.08	1.48

B-4.3 GREEN PET BOTTLE RECOVERIES AS A PERCENTAGE OF THE GREEN PET BOTTLES PRESENTED TO EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.0			1.4	2.1	0.7	2.9			1.4	0.0	0.0	0.0	0.0	0.0	0.7%	1.03	1.34	0.1	1.5	0.18	3.17
2 - PVC	1.4			0.0	1.4	0.7	2.3			2.2	0.0	1.4	0.7	1.4	2.2	1.2%	0.82	0.66	0.7	1.8	0.14	2.52
3 - Clear PET	5.1			2.9	1.5	2.9	6.2			0.8	1.4	1.4	2.2	2.2	3.7	2.7%	1.67	0.61	1.6	3.9	0.29	5.14
4 - Green PET	93.8			89.7	92.5	88.7	88.4			90.9	90.6	89.9	94.1	94.1	89.1	91.1%	2.19	0.02	89.6	92.7	0.38	6.74
5 - Opaque HDPE	100.0			100.0	100.0	100.0	100.0			100.0	100.0	100.0	100.0	100.0	100.0	100.0%	0.00	0.00	100.0	100.0	0.00	0.00

B-4.4 GREEN PET BOTTLE RECOVERIES AS A PERCENTAGE OF THE TOTAL BOTTLES RECOVERED AT EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	0.0			0.4	0.6	0.2	0.8			0.4	0.0	0.0	0.0	0.0	0.0	0.2%	0.29	1.33	0.0	0.4	0.05	0.90
2 - PVC	1.8			0.0	1.8	0.9	2.4			2.6	0.0	1.7	0.8	1.8	2.9	1.5%	0.98	0.64	0.9	2.1	0.17	3.03
3 - Clear PET	1.5			0.9	0.5	1.0	1.8			0.2	0.5	0.5	0.6	0.6	1.1	0.8%	0.48	0.57	0.5	1.1	0.08	1.48
4 - Green PET	84.0			70.1	77.0	74.2	72.3			82.2	66.8	83.9	79.0	83.6	81.0	77.6%	6.03	0.07	74.1	81.2	1.05	18.55
5 - Opaque HDPE	1.2			2.1	1.5	2.2	2.1			1.7	1.8	1.9	1.2	1.2	1.9	1.7%	0.37	0.22	1.5	1.9	0.06	1.15
- Unfed	7.2			6.7	3.9	5.6	8.7			8.2	9.8	0.0	9.3	7.1	14.0	7.3%	3.55	0.48	5.2	9.4	0.61	10.93
- Spillage	25.0			0.0	16.7	0.0	25.0			0.0	0.0	50.0	0.0	0.0	20.0	12.4%	16.51	1.32	2.6	22.3	2.86	50.79

RSD = RELATIVE STANDARD DEVIATION, LACI = LOWER AVERAGE FOR 95% CONFIDENCE INTERVAL, UACI = UPPER AVERAGE FOR 95% CONFIDENCE INTERVAL, LSCI = LOWER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL, USCI = UPPER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL.

TABLE B-5. OPAQUE HDPE DATA FOR MIXED FEED 2,000 BOTTLE TEST AT 60% FEED CONVEYOR SPEED SETTING - OUTLIERS NOT INCLUDED

B-5.1 OPAQUE HDPE BOTTLE RECOVERY COUNTS

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL
1 - Natural HDPE	42			47	43	52	51			36	37	37	22	26	28	421
2 - PVC	11			6	2	4	4			5	9	6	8	7	1	63
3 - Clear PET	30			23	22	14	30			18	10	12	28	17	15	219
4 - Green PET	8			24	13	12	19			17	16	0	20	16	10	155
5 - Opaque HDPE	639			655	669	654	639			670	678	694	663	675	702	7338
- Unfed	36			13	18	31	23			22	17	19	25	27	10	241
- Spillage	2			0	1	1	2			0	1	0	2	0	2	11
TOTAL	768			768	768	768	768			768	768	768	768	768	768	8448
FEED RATE, BPM	27			27	27	27	30			29	29	29	29	29	31	29

B-5.2 OPAQUE HDPE BOTTLE RECOVERIES AS A PERCENTAGE OF THE OPAQUE HDPE BOTTLES FED INTO THE SYSTEM

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	5.7			6.2	5.7	7.1	6.8			4.8	4.9	4.9	3.0	3.5	3.7	5.1%	1.34	0.26	4.2	6.0	0.23	4.12
2 - PVC	1.5			0.8	0.3	0.5	0.5			0.7	1.2	0.8	1.1	0.9	0.1	0.8%	0.41	0.54	0.5	1.1	0.07	1.26
3 - Clear PET	4.1			3.0	2.9	1.9	4.0			2.4	1.3	1.6	3.8	2.3	2.0	2.7%	0.98	0.37	2.0	3.4	0.17	3.01
4 - Green PET	1.1			3.2	1.7	1.6	2.6			2.3	2.1	0.0	2.7	2.2	1.3	1.9%	0.89	0.47	1.3	2.5	0.15	2.74
5 - Opaque HDPE	87.3			86.8	89.2	88.7	85.8			89.8	90.3	92.7	89.2	91.1	92.6	89.4%	2.23	0.02	87.8	91.0	0.39	6.86
- Spillage	0.3			0.0	0.1	0.1	0.3			0.0	0.1	0.0	0.3	0.0	0.3	0.1%	0.14	1.00	0.0	0.2	0.02	0.43

B-5.3 OPAQUE HDPE BOTTLE RECOVERIES AS A PERCENTAGE OF THE OPAQUE HDPE BOTTLES PRESENTED TO EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	5.8			6.2	5.7	7.1	6.9			4.8	4.9	4.9	3.0	3.5	3.7	5.1%	1.36	0.26	4.2	6.1	0.24	4.18
2 - PVC	1.6			0.8	0.3	0.6	0.6			0.7	1.3	0.8	1.1	1.0	0.1	0.8%	0.43	0.53	0.5	1.1	0.07	1.32
3 - Clear PET	4.4			3.3	3.1	2.1	4.4			2.6	1.4	1.7	3.9	2.4	2.1	2.8%	1.05	0.37	2.1	3.6	0.18	3.23
4 - Green PET	1.2			3.5	1.9	1.8	2.9			2.5	2.3	0.0	2.9	2.3	1.4	2.0%	0.96	0.47	1.4	2.7	0.17	2.95
5 - Opaque HDPE	100.0			100.0	100.0	100.0	100.0			100.0	100.0	100.0	100.0	100.0	100.0	100.0%	0.00	0.00	100.0	100.0	0.00	0.00

B-5.4 OPAQUE HDPE BOTTLE RECOVERIES AS A PERCENTAGE OF THE TOTAL BOTTLES RECOVERED AT EACH STATION

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	STD DEV	RSD	LACI	UACI	LSCI	USCI
1 - Natural HDPE	8.0			8.8	8.2	10.1	9.8			7.2	7.2	7.1	4.3	5.2	5.6	7.4%	1.83	0.24	6.3	8.5	0.31	5.64
2 - PVC	10.1			5.4	1.8	3.7	3.3			4.4	7.4	5.2	6.8	6.4	1.0	5.0%	2.61	0.51	3.5	6.6	0.45	8.03
3 - Clear PET	6.4			5.1	5.0	3.3	6.7			4.0	2.5	2.8	6.1	3.7	3.3	4.4%	1.48	0.33	3.6	5.3	0.25	4.57
4 - Green PET	5.6			13.8	8.1	7.5	12.8			11.6	8.6	0.0	12.3	10.5	7.0	8.9%	3.96	0.44	6.5	11.3	0.68	12.19
5 - Opaque HDPE	98.0			96.9	98.2	96.3	97.1			97.1	96.3	96.7	97.6	97.4	96.8	97.1%	0.62	0.00	96.8	97.5	0.10	1.93
- Unfed	52.2			43.3	35.3	34.4	33.3			30.1	41.5	55.9	58.1	48.2	23.3	41.4%	11.23	0.27	34.7	48.1	1.95	34.54
- Spillage	50.0			0.0	16.7	50.0	25.0			0.0	33.3	0.0	100.0	0.0	40.0	28.6%	30.97	1.08	10.2	47.1	5.38	95.25

RSD = RELATIVE STANDARD DEVIATION, LACI = LOWER AVERAGE FOR 95% CONFIDENCE INTERVAL, UACI = UPPER AVERAGE FOR 95% CONFIDENCE INTERVAL, LSCI = LOWER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL, USCI = UPPER STANDARD DEVIATION FOR 95% CONFIDENCE INTERVAL.

APPENDIX C

BOTTLE COUNTS AND WEIGHT PERCENTAGES
MIXED COMPOSITION 2,000 BOTTLE EXTENDED TESTS

TABLE C-1. BOTTLE COUNTS AND WEIGHT PERCENTAGES FOR MIXED FEED 2,000 BOTTLE TEST AT 60% FEED CONVEYOR SETTING

C-1.0 ALLOWABLE WEIGHT PERCENT CONTAMINATION LIMITS

Bottle Type Average Bottle Weight	Nat HDPE 64 grams	PVC 59 grams	Clear PET 71 grams	Green PET 78 grams	Opaque HDPE 101 grams
Natural HDPE Product	100.00	2.00	2.00	2.00	1.00
PVC Product	5.00	100.00	0.00	0.00	5.00
Clear PET Product	5.00	0.00	100.00	1.00	5.00
Green PET Product	5.00	0.00	10.00	100.00	5.00
Opaque HDPE Product	5.00	2.00	2.00	2.00	100.00

Maximum combined opaque and natural HDPE contamination in either clear PET, green PET, or PVC is 5%.
Maximum combined PVC, clear PET, and green PET contamination in either natural or opaque HDPE is 2%.
Maximum combined PET contamination in PVC is 0%.

C-1.1 TEST 1 — DATE: 10/07/92
FEED: 2,000 MIXED BOTTLES — DURATION: 27.0 minutes
SPEED: 60% — FEED RATE: 71 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	479/ 87.17%	1/ 0.17%	3/ 0.61%		42/ 12.06%*	525 /100% 1*
PVC Product		93/ 78.76%	3/ 3.06%*	2/ 2.24%*	11/ 15.95%*	109 /100% 3*
Clear PET Product		10/ 1.72%*	424/ 87.84%	7/ 1.59%*	30/ 8.84%*	471 /100% 3*
Green PET Product		2/ 1.05%*	13/ 8.18%	121/ 83.62%	8/ 7.16%*	144 /100% 2*
Opaque HDPE Product		1/ 0.09%	4/ 0.43%	8/ 0.95%	639/ 98.52%	652 /100%

C-1.2 TEST 2 — DATE: 10/07/92
FEED: 2,000 MIXED BOTTLES — DURATION: 28.0 minutes
SPEED: 60% — FEED RATE: 69 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	479/ 88.06%	1/ 0.17%	4/ 0.82%	1/ 0.22%	37/ 10.73%*	522 /100% 1*
PVC Product		106/ 87.96%	1/ 1.00%*	1/ 1.10%*	7/ 9.94%*	115 /100% 3*
Clear PET Product		5/ 0.85%*	427/ 87.84%	6/ 1.36%*	34/ 9.95%*	472 /100% 3*
Green PET Product			15/ 9.59%	117/ 82.22%	9/ 8.19%*	141 /100% 1*
Opaque HDPE Product			4/ 0.42%	13/ 1.49%	663/ 98.10%	680 /100%

C-1.3 TEST 3 — DATE: 10/07/92
FEED: 2,000 MIXED BOTTLES — DURATION: 28.0 minutes
SPEED: 60% — FEED RATE: 69 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	473/ 83.60%	4/ 0.65%*	7/ 1.37%*	2/ 0.43%	50/ 13.95%*	536*/100% 4*
PVC Product		99/ 78.71%	9/ 8.61%*	3/ 3.15%*	7/ 9.53%*	118 /100% 3*
Clear PET Product		5/ 0.93%*	409/ 91.57%	2/ 0.49%	22/ 7.01%*	438 /100% 2*
Green PET Product	1/ 0.54%*	4/ 1.98%*	15/ 8.93%	125/ 81.77%	8/ 6.78%*	153 /100% 3*
Opaque HDPE Product			3/ 0.31%	8/ 0.92%	664/ 98.77%	675 /100%

Excessive contamination indicated by *.
Total column excessive contamination notation indicates the number of contaminants (ex. 3*).

TABLE C-1. CONTINUED

C-1.4 TEST 4
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/07/92
DURATION: 27.6 minutes
FEED RATE: 70 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	481/85.78%	1/ 0.16%	2/ 0.40%	2/ 0.43%	47/13.23%*	533 /100% 1*
PVC Product		100/85.99%	5/ 5.17%*		6/ 8.83%*	111 /100% 2*
Clear PET Product		6/ 1.09%*	415/90.79%	4/ 0.96%	23/ 7.16%*	448 /100% 2*
Green PET Product		4/ 1.70%*	24/12.28%*	122/68.56%	24/17.46%*	174 /100% 3*
Opaque HDPE Product	2/ 0.19%		5/ 0.52%*	14/ 1.61%	655/97.67%	676*/100% 2*

C-1.5 TEST 5
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/08/92
DURATION: 28.0 minutes
FEED RATE: 69 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	471/85.68%	3/ 0.50%	4/ 0.81%	3/ 0.67%	43/12.34%*	524 /100% 1*
PVC Product		104/92.47%	2/ 2.14%*	2/ 2.35%*	2/ 3.04%	110 /100% 2*
Clear PET Product			417/92.57%	2/ 0.49%	22/ 6.95%*	441 /100% 1*
Green PET Product		4/ 1.87%*	20/11.23%*	124/76.51%	13/10.39%*	161 /100% 3*
Opaque HDPE Product	1/ 0.09%		1/ 0.10%	10/ 1.14%	669/98.66%	681 /100%

C-1.6 TEST 6
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/08/92
DURATION: 26.9 minutes
FEED RATE: 70 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	459/84.13%		3/ 0.61%	1/ 0.22%	52/15.04%*	515 /100% 1*
PVC Product		97/86.31%	6/ 6.42%*	1/ 1.18%*	4/ 6.09%*	108 /100% 3*
Clear PET Product		6/ 1.17%*	397/93.13%	4/ 1.03%*	14/ 4.67%	421 /100% 2*
Green PET Product		3/ 1.42%*	26/14.84%*	118/73.99%	12/ 9.74%*	159 /100% 3*
Opaque HDPE Product	3/ 0.28%	1/ 0.09%*	6/ 0.63%*	15/ 1.72%	654/97.28%	679*/100% 3*

C-1.7 TEST 7
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/08/92
DURATION: 25.3 minutes
FEED RATE: 75 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	460/83.53%	1/ 0.17%	4/ 0.81%	4/ 0.89%	51/14.61%*	520 /100% 1*
PVC Product		102/78.67%	14/12.99%*	3/ 3.06%*	4/ 5.28%*	123 /100% 3*
Clear PET Product		3/ 0.54%*	407/88.29%	8/ 1.91%*	30/ 9.26%*	448 /100% 3*
Green PET Product		4/ 2.00%*	18/10.85%*	107/70.85%	19/16.29%*	148 /100% 3*
Opaque HDPE Product	1/ 0.10%		4/ 0.43%*	14/ 1.66%	639/97.82%	658*/100% 2*

Excessive contamination indicated by *.
Total column excessive contamination notation indicates the number of contaminants (ex. 3*).

TABLE C-1. CONTINUED

C-1.8 TEST 8 — DATE: 10/08/92
FEED: 2,000 MIXED BOTTLES — DURATION: 26.5 minutes
SPEED: 60% — FEED RATE: 73 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	471/ 86.72%		1/ 0.20%		45/ 13.08%*	517 /100% 1*
PVC Product	3/ 2.57%*	101/ 79.85%	6/ 5.71%*	1/ 1.05%*	8/ 10.83%*	119 /100% 4*
Clear PET Product	2/ 0.37%*	7/ 1.20%*	424/ 87.79%	4/ 0.91%	33/ 9.72%*	470 /100% 3*
Green PET Product		4/ 1.91%*	14/ 8.06%	123/ 77.75%	15/ 12.28%*	156 /100% 2*
Opaque HDPE Product	3/ 0.28%		5/ 0.52%*	13/ 1.49%	659/ 97.71%	680*/100% 2*

C-1.9 TEST 9 — DATE: 10/08/92
FEED: 2,000 MIXED BOTTLES — DURATION: 26.1 minutes
SPEED: 60% — FEED RATE: 74 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	475/ 86.59%		5/ 1.01%	4/ 0.89%	40/ 11.51%*	524 /100% 1*
PVC Product	1/ 1.02%*	95/ 89.07%	2/ 2.26%*	1/ 1.24%*	4/ 6.42%*	103 /100% 4*
Clear PET Product		9/ 1.43%*	411/ 78.55%	6/ 1.26%*	69/ 18.76%*	495 /100% 3*
Green PET Product	2/ 1.05%*	5/ 2.42%*	30/ 17.46%*	112/ 71.62%	9/ 7.45%*	158 /100% 4*
Opaque HDPE Product	1/ 0.10%	2/ 0.18%*	5/ 0.54%*	18/ 2.14%	631/ 97.04%	657*/100% 3*

C-1.10 TEST 10 — DATE: 10/09/92
FEED: 2,000 MIXED BOTTLES — DURATION: 26.0 minutes
SPEED: 60% — FEED RATE: 73 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	460/ 87.65%		5/ 1.06%	2/ 0.46%	36/ 10.83%*	503 /100% 1*
PVC Product		99/ 82.53%	7/ 7.02%*	3/ 3.31%*	5/ 7.14%*	114 /100% 3*
Clear PET Product		6/ 1.10%*	421/ 93.00%	1/ 0.24%	18/ 5.66%*	446 /100% 2*
Green PET Product	2/ 1.10%*	3/ 1.52%*	4/ 2.43%	120/ 80.23%	17/ 14.72%*	146 /100% 3*
Opaque HDPE Product	5/ 0.46%	1/ 0.09%	2/ 0.21%	12/ 1.35%	670/ 97.89%	690 /100%

C-1.11 TEST 11 — DATE: 10/09/92
FEED: 2,000 MIXED BOTTLES — DURATION: 25.8 minutes
SPEED: 60% — FEED RATE: 75 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	470/ 88.24%	1/ 0.17%	3/ 0.62%		37/ 10.96%*	511 /100% 1*
PVC Product	1/ 0.83%*	102/ 78.15%	10/ 9.22%*		9/ 11.80%*	122 /100% 3*
Clear PET Product		4/ 0.81%*	390/ 95.18%	2/ 0.54%	10/ 3.47%	406 /100% 1*
Green PET Product	1/ 0.44%*	3/ 1.21%*	42/ 20.44%*	125/ 66.83%	16/ 11.08%*	187 /100% 4*
Opaque HDPE Product	7/ 0.64%	1/ 0.08%*	5/ 0.50%*	13/ 1.44%	678/ 97.33%	704*/100% 3*

Excessive contamination indicated by *.
Total column excessive contamination notation indicates the number of contaminants (ex. 3*).

TABLE C-1. CONTINUED

C-1.12 TEST 12
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/09/92
DURATION: 26.0 minutes
FEED RATE: 75 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	477/88.21%	1/ 0.17%	4/ 0.82%		37/10.80%*	519/100% 1*
PVC Product	1/ 0.89%*	100/81.68%	7/ 6.88%*	2/ 2.16%*	6/ 8.39%*	116/100% 4*
Clear PET Product		5/ 0.94%*	417/94.68%	2/ 0.50%	12/ 3.88%	436/100% 1*
Green PET Product	1/ 0.56%	6/ 3.11%*	17/10.61%*	125/85.71%		149/100% 2*
Opaque HDPE Product	5/ 0.45%		5/ 0.49%*	14/ 1.52%	694/97.54%	718*/100% 2*

C-1.13 TEST 13
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/09/92
DURATION: 25.3 minutes
FEED RATE: 76 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	486/93.33%				22/ 6.67%*	508/100% 1*
PVC Product		97/76.71%	12/11.42%*	1/ 1.05%*	8/10.83%*	118/100% 3*
Clear PET Product		10/ 1.76%*	421/89.11%	3/ 0.70%	28/ 8.43%*	462/100% 2*
Green PET Product		4/ 1.82%*	10/ 5.48%	128/77.10%	20/15.60%*	162/100% 2*
Opaque HDPE Product	4/ 0.38%	1/ 0.09%	3/ 0.31%	8/ 0.92%	663/98.31%	679/100%

C-1.14 TEST 14
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/09/92
DURATION: 25.3 minutes
FEED RATE: 76 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	470/91.38%		3/ 0.65%		26/ 7.98%*	499/100% 1*
PVC Product		97/83.30%	4/ 4.13%*	2/ 2.27%*	7/10.29%*	110/100% 3*
Clear PET Product		10/ 1.78%*	432/92.35%	3/ 0.70%	17/ 5.17%*	462/100% 2*
Green PET Product		5/ 2.44%*	4/ 2.35%	127/81.86%	16/13.35%*	152/100% 2*
Opaque HDPE Product	5/ 0.46%		5/ 0.51%	8/ 0.90%	675/98.13%	693/100%

C-1.15 TEST 15
FEED: 2,000 MIXED BOTTLES
SPEED: 60%

DATE: 10/09/92
DURATION: 24.4 minutes
FEED RATE: 79 BPM

	COMPONENT					
	Nat HDPE No./Wt %	PVC No./Wt %	Clear PET No./Wt %	Green PET No./Wt %	Opaque HDPE No./Wt %	Total No./Wt %
Natural HDPE Product	466/91.01%	2/ 0.36%			28/ 8.63%*	496/100% 1*
PVC Product	2/ 2.04%	95/89.24%	3/ 3.39%*	3/ 3.73%*	1/ 1.61%	104/100% 2*
Clear PET Product	1/ 0.19%	8/ 1.43%*	430/92.60%	5/ 1.18%*	15/ 4.59%	459/100% 2*
Green PET Product		6/ 3.18%*	11/ 7.03%	115/80.70%	10/ 9.09%*	142/100% 2*
Opaque HDPE Product	5/ 0.44%	1/ 0.08%	3/ 0.29%	14/ 1.50%	702/97.68%	725/100%

Excessive contamination indicated by *.
Total column excessive contamination notation indicates the number of contaminants (ex. 3*).

GLOSSARY OF TERMS

Availability - The probability that equipment will be capable of performing its specified function when called upon at any random point in time. Calculated as the ratio of run time to the sum of run time and downtime.

Bottle - A single plastic container, also referred to as a container.

Cascade - To sequentially increase the belt speed in a series of conveyors.

Contamination - Bottles improperly removed at a station.

Effective Bottle Feed Rate - The average rate at which a specific type of bottle is fed during a mixed composition test. Calculated as the total number of bottles of a specific type fed divided by the total run time for a specific test.

Extended Test - A test series consisting of many replicates at pre-selected conditions.

Fed - Refers to bottles removed from the feed bin by conveyor C2 and either removed by the oversize station, spilled, or delivered to conveyor C3.

Confidence Interval - The range in which an estimated population statistic is expected to fall with a specified degree of confidence based on sample statistics. Confidence intervals can be calculated for statistics such as the population mean and standard deviation. The confidence interval for the mean is calculated using the Student's t Distribution, and the confidence interval for the standard deviation is calculated using the Chi-Square Distribution. The 95 percent confidence interval is a range around the statistic such that 2.5 percent of the area under the distribution curve falls in each "tail" of the distribution. For example, if the sample mean is 90 and the 95 percent confidence interval is calculated to be the mean plus or minus 2, one would be 95 percent confident that the population mean would be within the range 88 to 92.

Confidence Limit - The value below and above the sample statistic defining the limits of the confidence interval. For example, in the above example, the lower confidence limit is 88 and the upper confidence limit is 92.

Maintainability - A measure of the ease with which an equipment item or system can be maintained in proper running condition. Measured by parameters such as the Preventive Maintenance Ratio, the Corrective Maintenance Ratio, the Maintainability Index, the Mean Time To Repair, and the Mean Time Between Maintenance Actions.

Mistake - This is a bottle erroneously removed at a station.

Mixed Composition - Feedstock consisting of a mixture of resin types.

Overall Bottle Feed Rate - Calculated as the total number of bottles fed divided by the total run time for a particular test.

Outlier - A test replicate judged to be unrepresentative when compared to the entire set of test replicates.

Percent of Fed - Refers to the number of bottles of a particular type recovered at a particular station as a percentage of the number of bottles of that type fed by conveyor C2.

Percent of Presented - Refers to the number of bottles of a particular type recovered at a particular station as a percentage of the number of bottles of that type presented to that station.

Population - The entire group of data, also referred to as the universe.

Presented - Refers to the bottles available for removal at a particular identification/separation station.

RAM Analysis - An evaluation of the reliability, availability, and maintainability of an equipment item or a system.

Recovery - Refers to bottles properly removed at a station. For example clear PET removed at the clear PET station is recovered at this station. Any other bottle type removed here is considered a mistake and results in contamination of the clear PET product.

Reliability - The probability that a system and its components will perform satisfactorily according to its intended function over the duration of their mission. Measured by three factors: the mean time between failures, the mean time to repair, and the mean time between maintenance actions. In probability form it is e (2.71828) raised to minus 1 times the ratio of the desired uninterrrupted operating time divided by the mean time between failures.

Replicate - A distinct test run on a particular feedstock. Multiple replicates comprise a test series. Also referred to as a test or test replicate.

Sample - A subset of the population.

Single Composition - Feedstock consisting of only one resin type.

Slug - A group of several bottles delivered simultaneously.

Spillage - A bottle that falls or bounces out of the system after being picked up by conveyor C2 such that it is not available for identification and separation.

Station - The point of removal of each bottle type.

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