AUTOMATED SEPARATION OF COMMINGLED PLASTIC CONTAINERS

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ABSTRACT

A plastic separation system is described that accepts commingled, whole, baled plastic containers and which automatically separates the containers into specific plastic types. Color separation is also provided for the mixed color, opaque plastic containers. First, a mechanical device debales and screens out small and non-plastic contamination.

Next, the containers are manipulated into a single line for presentation to the sensors. Optical sensors identify PET, Polypropylene, natural HDPE and mixed color, opaque HDPE containers. Another optical sensor can be used to further identify green and amber PET from clear PET containers.

A surface sensing X-ray based system identifies PVC containers. An intelligent, vision based system identifies mixed color HDPE according to seven color classifications. Using microprocessor control, each container is ejected onto the proper take away conveyors by pulsed air jets. A commercial system with a throughput capability of 5000 lb/hr, using components of this process, was placed in operation in December 1991.

INTRODUCTION

For economic feasibility, manufacturers who use post-consumer plastics as a raw product need a "pure" product, in relatively high quantities and at a low cost. Currently, plastics separation is almost universally done by hand sorting, which is both expensive and error prone. Cost efficient automated sorting will enhance the economics of plastics recycling and increase the viability of recycling both mixed color plastics and less common recyclable plastics such as polypropylene and PVC containers. Cost efficiency requires that the automated system be relatively easy to operate and to maintain.

Studies by Eaglebrook Plastics, Inc. show that commingled plastic containers currently received at their facility, in both compacted bales and loose semi-crushed form, consist of approximately 70% High Density Polyethylene (HDPE), 20% Polyethylene Terephthalate (PET), 5% Polyvinyl Chloride (PVC), 4% Polypropylene (PP), and 1% Polystyrene (PS) by weight. The received baled plastic generally contains several percent contaminants in the form of loose dirt and aluminum beverage containers.

PROCESS DESCRIPTION

The challenges in designing an automated plastics separation system are threefold:

(a) The diversity of plastic container types. This diversity is increased when it is desired to color sort the opaque HDPE into red, green, blue, yellow, orange, white and black colors or combination of these colors. For this case a system would be required to provide

(with PET, PVC and Natural outputs) ten different output streams.

(b) Materials handling constraints due to the low bulk density of plastic containers. The weight of the containers ranges from 0.15 to 0.5 lb (0.07–0.20 kg) per container with a volume ranging from 0.003 to 0.2 ft^3 (0.0001–0.01 m^3) per container.

(c) The varying capacity requirements of recyclers. Currently the required capacity for industrial process systems is in the range of 1000–5000 lb/hr.

A modular processing system, as shown in Fig. 1, meets these challenges. Process capacity of each individual line is approximately 1250 lb/hr (568 kg/h). To expand process capacity, more lines are installed. This approach satisfies the sensor requirement that containers be presented individually to the sensor. Our work indicates that an average of three containers per second is realistic for reliable, individual container identification and separation on a single process line. Four parallel process lines would provide 5000 lb/hr (2273 kg/h) capacity with 8–12 containers per second being identified and separated.

The need for varying polymer separation requirements is met in the process line by adding additional sensing and ejection stations. Several sensor types are required to perform the varied identification requirements. Additional sensors can be added to each individual process line. For certain separations it is more economic if the sensors are employed as an additional processing step on the take away conveyor (Fig. 1) after a primary separation has been made.

The complete processing system consists of six unit functions:

(a) Debaling or reducing of the bales to individual containers.

(b) Screening contaminants from the debaled components.

(c) Singulating, or regulating and individualizing the plastic containers for single container presentation to the sensors.

(d) Sensing, or identifying the plastic polymer type.

(e) Separating the output of the classes of plastic onto take away conveyors.

(f) Control of the system operation via a motor control center.

Debaling

The Eaglebrook facility, like most large plastic recyclers, receives a majority of their incoming plastic in baled form. Thus, the first process step is to reduce the bales to loose containers. Screening of the debaled plastic is necessary to remove dirt, broken container pieces and other contamination such as aluminum cans, rocks and fines. A disk screen, used in wood processing and solid waste applications, was selected as a means to perform both the debaling and screening functions.

The basic design of the screen was significantly modified to provide for debaling and screening requirements. In addition, a feed system was incorporated which allowed several bales to be loaded onto the system at one time, and provided a more uniform output feed. During testing, it was found that control of the bale input speed was important in order to minimize the requirements of the singulation system. After modification based on test results, a full size unit was fabricated.

The debaler was designed to provide an output feed of up to 8000 lb/hr (3636 kg/h). The feedrate requirement for the Eaglebrook system was specified as 5000 lb/hr (2273 kg/h). The maximum debaling capacity is primarily limited by the speed of the input bale feed, the debaler has the capability of reducing up to 15,000 lb/hr (6818 kg/h) of bales.

Singulation

An extensive research and testing program was necessary to develop a means to take feed from the debaler and provide four output streams of spaced, individual containers. The system evolved into a mechanical and air driven system coupled with high speed [350 ft/min (1.8 m/sec)] output conveyors. The system provides container singulation of greater than 95% with both flattened and whole containers, when fed reasonably uniform output as provided by the above described debaler.

Sensing

The container identification portion of the process system uses both optical and X-ray scanning as the primary means of identifying plastic container type. An intelligent vision based system identifies mixed color HDPE containers by color. All three sensing methods require that a majority of the containers be individually presented to the sensors with a minimum spacing of 0.5–1 in. (17–25 mm) as provided by the singulation system.

The ability to distinguish among various plastic polymers using optical transmission methods is well known [1, 2]. However, reliable identification of post-consumer containers requires that measurements from much of the container area be ignored. These areas include closures or necks, labels, edges, bottoms and areas with container residue or dirt.

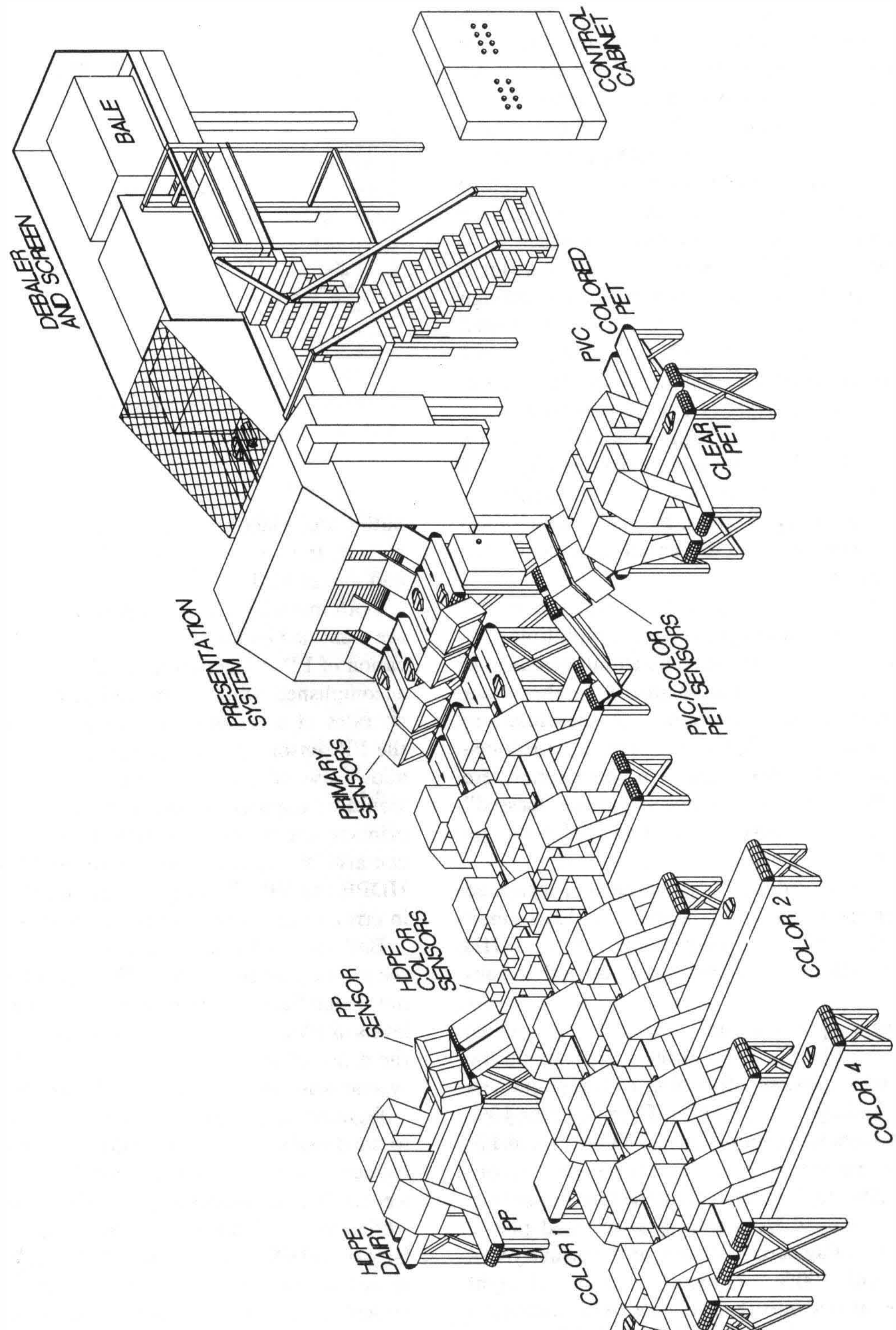


FIG. 1 PLASTIC SEPARATION SYSTEM

To discriminate among these misleading areas, a software algorithm was implemented for each sensor using a microprocessor based electronic circuit. Several thousand measurements are made of each container as it passes through the sensor. The data from the measurements are stored and then examined by the microprocessor program. Questionable areas are first identified and deleted from the data table. A decision based on the valid data identifies the container's polymer.

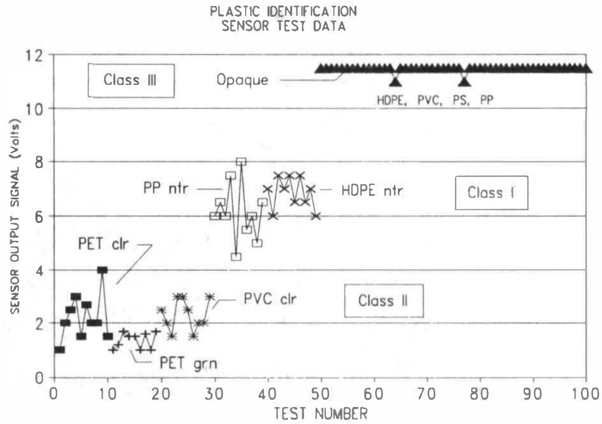
An identification decision is typically made within 5 milliseconds (ms) after the container passes through the sensor. This allows the containers to be transported through the sensors at up to 10 ft/sec (3 m/s) with a 1 in. (25 mm) spacing between the containers. In practice, a container speed of 6 ft/sec (1.8 m/s) with a spacing of 1 in. (25 mm) was found to be practical. Identification decision times less than 5 ms can be obtained by using high speed microprocessors, but is not anticipated to be necessary in this application. Physical presentation of the plastic containers to the sensor is currently the capacity limiting element.

A subroutine of the main program looks for potential errors in the identification process due to multiple containers passing through the sensors simultaneously. If the containers are of the same polymer type, the circuit signals for ejection. If the containers are dissimilar, no output signal is provided. Those containers are transported off the end of the separation conveyor, where they are collected in a bin. Alternately, the "passed" containers may be conveyed to the debaler for reprocessing by the system.

Eaglebrook required that the containers be separated into three primary classes: (I) Natural HDPE — milk containers; (II) PET — beverage containers; and (III) mixed color HDPE — detergent, oil and other containers.

The primary optical sensor, operating at a specific frequency, can identify these three classes of plastic containers which account for 90% of the containers received at the Eaglebrook facility. The remaining 10% of the containers are comprised of PVC, PP, and PS, and require the use of X-ray or optical sensors operating at a different frequency than the primary sensor.

The data obtained from testing as-received plastic containers from Eaglebrook show that the primary sensor placed, with 100% accuracy (see Graph 1), eight types of containers into three classes. The containers were dropped in random orientation through the prototype sensor assembly to simulate a normal operation. Each type of plastic was represented by 10–15 containers. The testing included containers which were distorted, crushed, partially filled and coated with oil and other liquids. A clear PET jar coated inside with peanut



GRAPH 1

butter was placed by the primary sensor in the same class as the rest of the clear PET as well as the green and amber PET.

Both monolayer and multilayer Polypropylene (PP) are identified by the primary sensor as HDPE. Identification of PP in the natural HDPE container stream is accomplished with a modified primary sensor which operates at a different optical frequency. Positioning the PP sensor on the HDPE/PP take away conveyor allows use of only one sensor, whereas four sensors would be required if they were positioned next to the primary sensors on each process line. The PP sensor can also distinguish mixed color HDPE from natural HDPE and PP, allowing mixed color HDPE reporting in error to the natural conveyor to be detected.

Both clear PVC and PS containers are identified by the primary sensor as PET. The clear PS containers are not a significant contaminant for the PET. Allowable levels of PVC in PET are, however, quite low, being on the order of 50 parts per million. An X-ray detection system was employed to identify the PVC containers.

Pigmented, opaque PVC containers are also routed to the mixed color, opaque HDPE take away conveyor. However, when the mixed color HDPE is ground and wet-washed for processing, the pigmented PVC sinks, while the HDPE floats, providing in most cases a satisfactory HDPE purity level. PVC detection can be placed on each process line adjacent to the primary optical sensors. But it is more economical to place the PVC sensor only on the main PET take away conveyor where fewer sensors are required.

The X-ray sensor operates on the basis of the strong interaction of the chlorine atom with the proper X-ray frequency electromagnetic radiation. The PVC containers are identified by either X-ray transmission intensity or by specific frequency re-radiation from X-ray stimulation of the PVC container surface. The X-ray sensor used in the Eaglebrook system was supplied by ASOMA Instruments, Inc. and is a surface sensing type system.

Identification of PVC plastic containers with a smallest dimension of 3 in. (76 mm) which were presented to the sensor within a 1 in. (25 mm) distance has been found in testing to be greater than 99% efficient.

Color Separation

Two approaches were investigated during the development of a color identification system for the mixed color, opaque HDPE containers, machine vision and photoelectric sensing.

The machine vision approach to color sensing relys on a video camera which outputs color information from each pixel of the camera array in the form of red, green, and blue intensities. The array data is then input to a microprocessor which utilizes a software program to determine the container color.

Photoelectric sensors use filters or beam splitters to separate the received colors into their primary components. A color is determined by taking the ratio of the sensor outputs for the three colors. Photoelectric systems use relatively low cost components and have a history of reliable service in a number of industries. However, in testing we found the photoelectric sensor reliability to be strongly affected by object distance, surface texture and detector to surface angle, as well as illumination quality. For these reasons, the machine vision approach was selected, even though the equipment is more costly at the present time.

Color Identification Software

Machine vision systems have the ability to distinguish thousands of colors. The challenge in reliable color identification of HDPE plastic containers is to distinguish the container from labels, closures and contamination. This was accomplished using a software program which provided an intelligence based decision algorithm. The data obtained from each video camera image is processed and compared to a histogram of selected object characteristics. The histogram is generated by storing the pixel characteristics from containers of known color. The histogram from a container of unknown color is then compared to the stored reference histograms. Differences are rejected with a high weighting factor while similarities are accepted with a moderate weighting factor [3].

TABLE 1 EAGLEBROOK PLASTIC CONTAINER FEED STREAM

CLASS	CONTAINER TYPE	PERCENT OF FEED	CONTAINERS/MIN
CLASS I	HDPE NATURAL	20.0 %	168
	PP NATURAL	2.0 %	17
CLASS II	PET GREEN	10.0 %	84
	PET CLEAR	10.0 %	84
	PVC CLEAR	2.5 %	21
	PS CLEAR	1.0 %	8
CLASS III	HDPE COLORED	50.0 %	420
	PP COLORED	2.0 %	17
	PVC COLORED	2.5 %	21

The data processing required a computer capable of operating at approximately 10 MIPS (million instructions per second) in order to identify three containers per second. This processing speed is available with a 386 type processor operating at 33 Mhz.

Ejection

After identifying the polymer type or color, the container position is tracked as it moves along the separation conveyor. The ouput pulse from a proximity sensor mounted on the separation conveyor drive gear is supplied to a PLC (programmable Logic Controller). Each pulse shifts a data location in the PLC to track the position of the container. The PLC provides an output to a pulsed air jet when a container arrives at its take away conveyor. A stainless steel collection hood is provided at each separation/take away conveyor junction to direct the ejected container onto the take away conveyor.

Based on communication with a number of plastic recycling industry sources, the following perceived colors were identified as the target color separations, red, green, blue, yellow, orange, white and black. The vision system software was "trained" on the above colors with a variety of containers for each color. After training, it was found that an identification reliability of 99% was possible with properly applied lighting and for containers no smaller than oil containers. The hood also provides operator protection from the moving swing arm or air jet pulse.

Eaglebrook System Requirements

The Eaglebrook system has a design capacity of 5000 lb/hr (2273 kg/h), four parallel process lines. Table 1 shows the typical bale composition received by Eaglebrook as well as the number of containers required to be processed per minute for each class of plastic.

TABLE 2 CAPITAL COSTS, PAYBACK AND NET PRESENT VALUE

	Automated Separation	Manual Separation	Cost Difference	Payback (Months)
Capital Costs (One-Time)	$770,000	$500,000	$270,000	
Monthly Labor Cost				
SCENARIO 1: 24 hrs/Day, 7 days a week	$60,480	$169,920	($109,440)	2.5
SCENARIO 2: 24 hrs/Day, 5 days a week	$43,200	$121,371	($78,171)	3.5
SCENARIO 3: 16 hrs/Day, 5 days a week	$28,800	$80,914	($52,114)	5.2
SCENARIO 4: 8 hrs/Day, 5 days a week	$14,400	$40,457	($26,057)	10.4

	NPV @ 11%	NPV @ 15%	NPV @ 20%	NPV @ 25%
Scenario 1	$4,674,903	$4,220,713	$3,730,866	$3,313,497
Scenario 2	3,262,774	2,938,605	2,589,026	2,291,215
Scenario 3	2,086,000	1,870,181	1,637,493	1,439,313
Scenario 4	$909,227	$801,757	$685,960	$587,412

Net Present value Calculations assume that capital outflows occur at the end of the first month, and that labor savings begin at the end of the third month and continue for 60 months (5 years).

Eaglebrook requested that a number of operator control and output functions be implemented in the separation system.

(a) Operator control of the baler feedrate.

(b) Ability to retrofit a totalizer readout of the number of containers processed, by class, as a function of time.

(c) Provision for fork lift feeding of the debaler with room for two bales storage while debaling a third bale.

(d) Provision for operator selection of a nonsorting mode (e.g., only Natural HDPE would be fed to the system and output would be distributed uniformly on each take away conveyor).

(e) Layout of the system to allow for future increase in the process capacity (additional process lines).

(f) Provision for nonbaled containers to be fed into the system.

Economic Analysis of Automated Sorting

A financial analysis, based on the above assumptions, for manual and automated sorting is presented in the following Tables 2–5. The payback time for the difference in capital cost of the manual versus the automated sorting system is also developed.

The following assumptions are made in the economic analysis of automated separation versus manual separation.

(a) Feedstock for separation/grinding is post-consumer commingled bales.

(b) Automatic separation system full operating capacity is 5000 lb/hr (2273 kg/h).

(c) Analysis addresses separation and grinding only and does not include washing, extruding, and other subsequent processing.

(d) Grinders are used in both the automated and manual systems for three automated sorts:

(1) Clear—Clear and Green PET.

(2) Natural—Natural HDPE and PP.

(3) Opaque—Mixed Color HDPE and pigmented.

(e) An automatic debaler is used in the automated separation system, while bales are manually broken in the manual separation scenarios.

(f) Facility installation costs are site specific and considered to be consistent between scenarios, hence are not included in the analysis.

(g) Downtime is assumed to be 12% in scenarios with 7 day/week production, and 10% in 5 day/week production scenarios.

(h) Preventive maintenance and grinder blade changes are assumed to be performed on the weekend in scenarios with three shifts/day and 5 day/week production. These costs are not included in the analysis.

(i) Preventive and planned maintenance are assumed to be part of the estimated downtime percent-

TABLE 3 CONSTANT ASSUMPTIONS FOR A 5000 lb/hr SYSTEM ACROSS VARIOUS PRODUCTION SCENARIOS

CAPITAL

AUTOMATED SEPARATION	Total
4 Grinders	$250,000
MSS System- singularization, screen, separation conveyors, sensors, take-away conveyors, balebreaker, installation	450,000
Incline conveyors & installation	70,000
Total Capital Costs	$770,000

MANUAL SEPARATION	Total
4 Grinders	$250,000
Incline conveyors & installation	70,000
Manual Separation Conveyors	54,000
Manual Separation Tables+Magnets	18,000
Installation of Conveyors	13,000
Conveyors: Sortlines-Grinders (4)	95,000
Total Capital Costs	$500,000

TABLE 4 HOURLY LABOR REQUIREMENTS AND COSTS

LABOR

AUTOMATED SEPARATION Ongoing Labor Costs/hour	# employees	$Rate/ Hour	Total $/hr
Material Provider	1	$8	$8
Oversized Piece remover	1	$8	$8
Material Remover	1	$8	$8
Pickers	4	$8	$32
Mechanic	1	$13	$13
Supervisor	1	$15	$15
Total Labor $/Hr	9	$9.33	$84

MANUAL SEPARATION Ongoing Labor Costs/hour	# employees	$Rate/ Hour	Total $/hr
Balebreakers	3	$8	$24
Material Handlers	1	$8	$8
Material Remover	1	$8	$8
Pickers and Sorters	21	$8	$168
Mechanic	1	$13	$13
Supervisor	1	$15	$15
Total Labor $/Hr	28	$8.43	$236

SYSTEM CAPACITY

Capacity: Lbs sorted/hour	5,000
Production Capacity:Hours	
# days/week of operation	7
Hours/shift	8
Shifts/day	3
Downtime % (Mon-Sun)+Maint	12.0%
Production hours/month	634

TABLE 5 VARIOUS PRODUCTION SCENARIOS

SCENARIO 1: 24 hrs/Day, 7 days a week	
Projected Actual Hours	
# days/week of operation	7
Hours/Shift	8
Shifts/Day	3
Downtime % (Mon-Sun)+Maint	12.0%
Machine hours per month	633.6
Staffing Hrs/Mth (no downtime)	720.0
Capacity: lbs sorted/month	3,168,000
Actual: Pounds sorted/month	3,168,000

AUTOMATED SEPARATION SYSTEM	
Staffing $/hr	$84
Staffing Hours/Month	720.0
Staffing $/Month	$60,480

MANUAL SEPARATION SYSTEM	
Staffing $/hr	$236
Staffing Hours/Month	720.0
Staffing $/Month	$169,920

SCENARIO 2: 24 hrs/Day, 5 days a week	
Projected Actual Hours	
# days/week of operation	5
Hours/Shift	8
Shifts/Day	3
Downtime % (Mon-Fri)	10%
Machine hours per month	462.9
Staffing Hrs/Mth (no downtime)	514.3
Capacity: lbs sorted/month	3,168,000
Actual: Pounds sorted/month	2,314,286

AUTOMATED SEPARATION SYSTEM	
Staffing $/hr	$84
Staffing Hours/Month	514.3
Staffing $/Month	$43,200

MANUAL SEPARATION SYSTEM	
Staffing $/hr	$236
Staffing Hours/Month	514.3
Staffing $/Month	$121,371

SCENARIO 3: 16 hrs/Day, 5 days a week	
Projected Actual Hours	
# days/week of operation	5
Hours/Shift	8
Shifts/Day	2
Downtime % (Mon-Fri)+Maint	10%
Machine hours per month	308.6
Staffing Hrs/Mth (no downtime)	342.9
Capacity: lbs sorted/month	3,168,000
Actual: Pounds sorted/month	1,542,857

AUTOMATED SEPARATION SYSTEM	
Staffing $/hr	$84
Staffing Hours/Month	342.9
Staffing $/Month	$28,800

MANUAL SEPARATION SYSTEM	
Staffing $/hr	$236
Staffing Hours/Month	342.9
Staffing $/Month	$80,914

SCENARIO 4: 8 hrs/Day, 5 days a week	
Projected Actual Hours	
# days/week of operation	5
Hours/Shift	8
Shifts/Day	1
Downtime % (Mon-Fri)+Maint	10%
Machine hours per month	154.3
Staffing Hrs/Mth (no downtime)	171.4
Capacity: lbs sorted/month	3,168,000
Actual: Pounds sorted/month	771,429

AUTOMATED SEPARATION SYSTEM	
Staffing $/hr	$84
Staffing Hours/Month	171.4
Staffing $/Month	$14,400

MANUAL SEPARATION SYSTEM	
Staffing $/hr	$236
Staffing Hours/Month	171.4
Staffing $/Month	$40,457

ages in the 7 day/week production scenario, and are assumed to be performed during nonproduction hours in the 5 day/week scenarios.

(j) Manual separation workers are assumed to sort approximately 200–300 lb/hr.

AUTOMATED SORTATION SYSTEM VS MANUAL SORTATION ECONOMIC ANALYSIS

Summary

Automated Separation requires approximately $270,000 in additional capital cost over that of a manual separation system. Savings result from labor reduction, with nine employees required to sort 5000 lb/hr with the automated system, and 28 employees required with the manual system.

Depending on the level of production achieved, payback can occur within 1 year.

A summary of the financial analysis is provided below.

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NOTICE

The Bebaler/Screen, Singulation system, optical sensor and software, and process system are subjects of existing Patents and Pending Patents, U.S. and Foreign.