Near Infrared (NIR) Sorting of Whole Rigid Packages in the Plastics Recycling Process

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Background

In modern single-stream material recovery facilities (MRF), the large volume of incoming material necessitates automated processing equipment able to move and sort material at high speed. At the same time, the highest value is obtained from the purest, least contaminated streams. To accomplish these somewhat contradictory goals, today's single stream MRFs employ automated equipment that sorts plastic packaging by evaluating the NIR (near infrared) signature of the plastic used to make the container. NIR sorting machines are both faster and more accurate than manual sorters. Automatic sorters interface NIR sensing with air nozzles to sort plastic items of various resin compositions, for example separating PET bottles from HDPE bottles.

To obtain the highest yield and material value, the equipment must first positively identify the plastic used to make the container and then use the air nozzles to direct the positively identified items effectively and accurately. Otherwise, the article is either directed to the waste stream or becomes a contaminant in another recyclable stream where it is likely to not be recycled.

It is also common for some plastic reclaimers, especially those reclaiming PET packaging, to use NIR and color sorting equipment to sort individual packages obtained from in-coming bales to remove contamination.

This resource document presents:

- Description of how NIR sorting of plastic containers is employed by MRFs and plastic reclaimers.
- Package design features that are known to interfere with NIR sortation of containers.
- Background on APR test methods that can be employed to evaluate NIR sortation of plastic packages.

Plastic reclaimers can also use NIR technology to sort finished washed flake resulting from the reclaiming process. Sorting of plastic flakes, however, is not the focus of this resource document.

Employing the technology

NIR sortation at the MRF: Whole plastic bottles are sorted at MRFs using a light source along with NIR sensors positioned above very high-speed conveyor belts after other recyclables such as cardboard, glass, or metal containers have already been separated from the plastic stream. The plastic packages are ideally presented on a wide conveyor belt in a single layer. Other materials may still be present on the conveyor belt as contaminants. To recover a targeted package for recycling, the NIR machine, also referred to as an NIR optical sorter, must positively detect the unique NIR wavelength signature in the infrared energy reflected from the of the targeted plastic used to make the package, and then, air jets direct the targeted packages to their specific recovery stream.

Packaging made with non-targeted plastics, or contaminants are passed through the unit for further processing.

For illustration, if the NIR unit is used to identify and sort PET packaging, the NIR unit must positively identify the PET package, and then direct the package with air jets into a specific PET stream to produce compressed bales of PET packaging. Other packaging such as HDPE or PP packages are not detected and pass through the unit. Contamination that is not detected as PET is passed through the unit.

In the PET illustration, it is necessary that the NIR unit positively detect the package as PET. Labels with high surface area coverage, or high coverage of metallic coatings or inks made with metallic pigments, may interfere with positive NIR detection of PET beneath the label. PET bottles that are dark in color may absorb NIR energy and not reflect the NIR signature of PET back to the detector; such dark bottles will not be detected.

Further, the NIR units are optimized to detect and sort bottles that are crushed lying flat and relatively motionless on the conveyor belt. Small packages may be difficult to detect because of their smaller surface area for evaluation. Small and round containers that are made with thick side walls are difficult to crush and are free to roll on the conveyor belt can; these also can be difficult to detect and direct into the correct stream with air jets.

Some MRFs may also employ color detection using visible light sensors or cameras. Color detection can be mounted on a separate machine or integrated alongside the NIR sensor in the NIR machine. For example, MRFs might use a color sorter to separate natural HDPE from the mixed color HDPE stream. It is important to keep in mind that NIR and color sorters employ different detectors and software and so NIR and color sorting are two separate and completely different evaluations!

NIR sortation at the plastic reclaimer: There are two major stages of the plastics reclaiming process - whole container processing and flake processing. A grinder or granulator sits between the two stages and creates flake from whole packages. Typically, a plastic reclaimer specializes in one resin type, therefore NIR sortation during whole container processing is designed to eliminate contaminants and improve plastic quality from incoming baled packaging. NIR sortation of flake provides a final quality control step by removing very fine contaminants.

a. Whole container processing: Bales of a particular plastic enter the plastics reclaimer. The first step is to remove the baling wire and break up the bale into independent singulated packages. This enables each item to be sorted on its own characteristics. Several different processing technologies including washes and de-labeling, are then used to remove contaminants from the desired polymer. Automatic sorting using NIR and color sensors is often used following other technologies, especially at PET reclaimers.

   Some PET reclaimers use NIR sorters that employ “in-flight” NIR detection where light is transmitted through the containers and the NIR characteristics of the package are evaluated in transmission, not reflection.

b. Flake processing: NIR sortation can be used following grinding during flake processing to improve quality and remove contamination by unwanted polymer types. However, most polymer contamination is removed prior to NIR flake sortation by a variety of other technologies, particularly float/sink.

Flake sorters can integrate NIR, color and metal sensors into one machine to remove a variety of unwanted materials, otherwise two sorters are used, one for color sorting and another for flake sorting.

Issues with NIR sortation

Most plastic packages employ a label that only covers a portion of the container. In these common cases, there is sufficient packaging plastic exposed that the NIR unit can positively detect the package in the presence of the label. But there are a few specific package design and label situations that can interfere with NIR detection of a targeted package. These special situations are discussed below.

Shrink sleeve labels: Some applications use full wrap shrink sleeve labels. Full wrap shrink sleeve labels cover the entire bottle sidewall with a label that might be a different polymer than the bottle itself. Depending on the design of the label, NIR machines may not be able to "see" through a label to identify the polymer beneath it. If the label is a different polymer the bottle can be at risk of being directed to the wrong stream at the MRF, or to waste in a plastic reclaiming facility. The APR Design Guide recommends testing to evaluate the impact of the label on NIR sortation.

It is common to use PET co-polymer films to make shrink labels for PET packaging applications. Based on industry experience, PET co-polymer films on PET bottles are generally not expected to interfere with NIR sortation. However, there is not sufficient publicly available data to confirm that this is always the case. There may be cases where inks or coatings on a label film might impact detection thus the APR Design Guide recommends testing NIR sorting capability of PET co-polyester films on PET bottles as well.

The APR Design® Guide for Plastics Recyclability recommends NIR sortation testing for sleeve labels that cover more than a given surface area of the container side wall, to determine whether the label interferes with NIR polymer sortation. The specific surface area that triggers a recommendation for testing is given in the Design Guide. It is extremely important to follow APR label guidance when using high surface area coverage shrink labels to ensure that the label does not render the bottle unsortable.

High surface area coverage pressure sensitive or cut and stack labels – Similar to high coverage shrink labels, other label styles that cover a high surface area percent of the package side wall can prevent NIR detection of the plastic used to make the container. The APR Design Guide recommends that these high coverage labels also be tested for their impact on NIR sortation. This recommendation applies to both film and paper labels that have high surface area coverage.

Black and dark colored items: NIR sortation cannot be considered reliable in detecting black or dark colored plastic bottles or items unless the colorant used in the plastic was especially designed to support NIR detection of the plastic package. Carbon black pigment, widely used in color formulations to make black and dark colors in plastics, strongly absorbs NIR energy. Most NIR sensors cannot "see" black items as the black colorant absorbs NIR wavelengths and provides no reflected signature of the packaging plastic. Dark colors that contain carbon black can attenuate the reflected NIR energy and limit detection. Dark colors are at risk for being mis-sorted.

To address this color impact issue, APR's Design® Guide for Plastics Recyclability recommends testing for items with low NIR reflectance, or with a low L value when color is measured. The specific reflectance or L values that trigger a recommendation for NIR testing are given in the Design Guide. It is extremely important to follow APR color guidance when using black or dark colors to ensure that the color does not render the bottle unsortable.

Some companies that supply color concentrates for plastics have developed color formulations for black and dark colored plastics that do not employ carbon black and are specially developed to enable good NIR sorting performance. There are color concentrate suppliers who have earned APR Recognition for black and dark colored concentrates that allow NIR detection.

Small packages – As mentioned earlier, NIR sorting units are optimized to sort common package sizes such as ½ liter to 2-liter size bottles. These common package sizes provide a large surface area for the unit to evaluate and these packages generally lay flat and motionless on the conveyor belt used to carry the packages through the NIR detection unit. Further, the air jets used to direct packages work better with targeted package sizes.

On the other hand, one can imagine a small, say 100 ml, container that is round with a thick side wall and base section. The label is likely to cover a large surface area of these smaller containers. Further, such smaller containers have a smaller surface area for the unit to detect; these heavy wall containers may roll on the conveyor making them harder to detect, and the air jets used to direct packages to the desired stream may not accurately direct small packages.

While the APR Design Guide gives guidance on package size as it relates to size sorting of packages in a MRF, the Design Guide does not give specific guidance today on when package size, shape, or

wall section can impact NIR detection. Tests presented below can be used to investigate whether package size or shape can impact NIR sortation.

APR NIR Sorting Evaluation Methods

Because NIR sorting of packages is fundamental to successful recycling of packages, the APR Design Guide offers three different approaches to testing that can be used to investigate and/or confirm the impact of package design on NIR sorting performance of complete packages. These test approaches are:

SORT-S-01, The NIR SORT Potential Test – this is considered APR's "definitive test" for NIR sortation. The test involves mixing 20 test packages with a variety of other packages and confirming that a commercial or pilot scale NIR sortation unit is capable of both identifying the target package and accurately directing the package into the proper stream. Good results in this test indicate that a plastic article has the potential to be sorted well in production conditions. Poor results indicate that an improvement in plastic product design is desirable to promote recovery.

An important note: *Companies that make NIR sortation equipment employ proprietary equipment, proprietary designs, and proprietary software. While there are similarities between the equipment suppliers, there can also be differences that might create a situation where a given package sorts well on equipment from one supplier, and may not sort well on equipment from a second supplier. Such cases are rare, but they can occur.*

The objective of SORT-S-01 is to demonstrate that a package has been designed to pass accurately through NIR sortation. ***Successful evaluation on only one NIR sortation unit is required.*** *There are rare situations where a given package may sort differently when compared on NIR equipment from different suppliers. Again, these situations are rare, and experience demonstrates that the equipment suppliers will manage and eliminate those situations over time.*

An optional, second part of this test method incorporates a means of determining whether pilot scale equipment and software can be adjusted to correctly identify and sort this article. If an article can be sorted with software adjustments, these adjustments might be incorporated into future software releases and allow detection if/when these software changes are widespread. **As a strong word of caution ------ such software changes are not often made because it is costly to change**

literally hundreds of machines at hundreds of MRF locations. And because there are several suppliers of commercial NIR sorting equipment, each of these suppliers must develop an independent software change and implement that change at locations where equipment is installed. Therefore, no recyclability claims can be made from this section of the test.

SORT-EE-01, The NIR Snap Protocol – This evaluation employs a commercial or pilot scale NIR sorter, and provides a means for quickly screening the NIR detection performance of different package and label combinations. This evaluation employs either a commercial scale or pilot scale NIR sorter. Packages can be held underneath the NIR detector by hand to determine whether the detector can positively detect the package. The test also allows for packages to be passed one-at-a-time on the conveyor beneath the detector to observe for detection as well as accurate direction of the air jets.

Further, this method presents using either a hand-held or benchtop NIR spectrophotometer to determine the average value for % reflection of NIR energy from a dark colored package. Packages with good reflection values do not need to be tested for NIR detection. The APR Design Guide gives specific guidance on the average reflection value that triggers a recommendation to either conduct the SORT-S-01 test, or to redesign the color formulation used for the package to achieve higher NIR reflectance.

SORT-EE-02, Preliminary Evaluation of the Near Infrared (NIR) Sorting Potential of a Whole Plastic Article with High Coverage Label – A hand-held or benchtop NIR spectrophotometer can be used to obtain valuable information about the potential for a label with high surface area coverage to interfere, or not interfere, with NIR detection. The gist of the method is to obtain the NIR spectrum of a base plastic package, and then evaluate the NIR spectrum of the same plastic when a label film alone, or with printing ink applied, is placed over the base plastic. Standard functions within Excel are used to obtain what is known as the Pearson correlation coefficient between the two spectra. These categories of results can be obtained:

1. If the Pearson coefficient value is high, the probability is low that the label when used at high per cent coverage of the side wall will impact automated NIR sortation.
2. If the coefficient is low, it is very likely that the label will prevent detection.

3. If the coefficient is an intermediate value, the guidance given is to either redesign the label to achieve a high coefficient, or to conduct either the SORT-EE-01 or SORT-S-01 tests to develop additional information concerning the impact of the label on NIR sortation.

Some suggested uses of the SORT-EE-02 method:

- Those that make labels films, or fully converted labels can use the method to develop foundation information concerning the variables that impact whether a high coverage label can interfere with NIR detection of the package beneath the label. Specific examples include:

    - Impact of a given label film material on a given package type. Further, evaluation of the impact of film thickness, pigmentation, or cavitation in NIR results.
    - Evaluate the impact of inks – pigments and organic binders – on NIR detection. Identify those inks that are highly transparent in the NIR wavelengths, and those that might absorb, reflect, or scatter NIR wavelengths to interfere with sortation.
    - Determine any impact of the color of the package beneath the label on NIR detection. For example, are results for a given label different when tested over a natural colored package, a light colored package, or a dark colored package?
    - Investigate the impact of any coatings or layers used with labels.
    - Understand the impact of paper labels when they cover a high surface area of the package.

    Because it only takes several minutes to conduct each measurement and complete the necessary calculations, many label variables can be evaluated in a short period of time.

- Employ the results of Sort-EE-02 to select candidate materials for additional testing employing SORT-EE-01 and SORT-S-01 and confirm that selected materials do not interfere with NIR sortation results.

The impact of high coverage area labels on NIR sortation is a new area of study and one that is evolving as suppliers and innovators gain experience on this topic. There is not sufficient publicly available information about NIR characteristics of labels to offer any “absolute truths” on the topic. But based on experience to date, the following specific items can be included in a listing of features where there is reason to believe that they can impact NIR sorting results. SORT-EE-02 is an ideal test to use for initial evaluation of these aspects of label design.

1. Paper labels – paper appears to be very opaque to NIR wavelengths and can limit NIR detection.
2. Label films that are different than the packaging material may influence the NIR spectrum. While some label films may be transparent and have no effect, other film materials may have an impact. There is not sufficient publicly available data available today to know the situations that do not have an impact, and those that do. When label films have an impact, film thickness is likely to be an important variable as well.
3. White pigmented films. White pigment increases the opacity of the film and scatters NIR energy.
4. Cavitated films may also increase opacity and scatter energy.
5. Metallic layers and metallic pigments are highly reflective of NIR energy and so can interfere with NIR detection when used on high coverage labels.
6. Color of the package can be a factor when the package is dark in color and may include pigments that absorb NIR energy and reduce reflected energy.

A Final Note

Technology associated with optical sorting is one of the more rapidly evolving technologies impacting plastic recycling! APR invites those engaged in NIR sorting evaluations to share their data and testing experience with APR. As more test data becomes publicly available, APR Technical Committees and work groups can use these results to improve the Design Guidance and test methods presented above. Further, where there is supporting data, there can be opportunities to simplify testing and reduce the number of cases where labels require testing.

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DOCUMENT VERSION HISTORY

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1	July 20, 2018	Original
2	August 30, 2024	Changed name of testing from RES-SORT-02 to RES-SORT-01 and added hyperlink to SORT-S-01; Updated hyperlink to match new website
3	October 23, 2024	Added information on new Early Evaluation Protocol SORT-EE-02 for packaging that contains high coverage labels