



Abstract

# Cleaning Assurance for Reusable Plastic Packaging using Ultraviolet Induced Fluorescence <sup>†</sup>

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**Abstract:** Implementing reusable packaging systems is one approach that could reduce the global consumption of single use plastics. Clearly, it is important to ensure that reusable packaging undergoes a process of cleanliness assurance before it is refilled. This research seeks to demonstrate the feasibility of an optical sensing technique to provide this assurance for polymer drinks bottles. An ultraviolet illumination source is used to induce fluorescence in both common polymer and fouling samples. The responses, captured by digital imaging, are processed to determine features that can be used to differentiate the packaging and fouling substances. Variation in signal intensity and differences in responses in the red, green and blue channels are identified as suitable features to enable detection of fouling.

**Keywords:** single use plastics; circular economy; optical sensors; reusable plastic packaging; ultraviolet fluorescence; image processing.

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## 1. Introduction

The global evidence for the need to reduce single use plastics is compelling. One of the approaches to reduce the quantity of end-of-life packaging that needs to be recycled or landfilled, is to increase the amount of packaging that is reused [1]. For food and drink applications (as well as pharmaceuticals, cosmetics and personal care products) contamination control and prevention of product crossover is extremely important when considering reusable packaging solutions. Essentially, before packaging is reused it must be cleaned and some degree of assurance of its cleanliness must be ascertained.

In this research a fluorosensing technique is assessed in terms of its ability to detect fouling (residual substances) within polymer drinks bottles. The technique has been utilized elsewhere for the detection of particular fluorophores in food manufacturing [2], powder processing [3] and plant biology [4]. The application of ultraviolet light (UV) of a suitable wavelength has the ability to induce fluorescence in a sample which may then be detected and utilized to confirm its presence (or absence) [5]. The technique has the potential to provide a low cost, real time, non-invasive detection system for the cleanliness of refillable drinks bottles and similar containers.

It is hoped that the method of assessing cleaning quality using UV fluorescence, as proposed in this research, will aid the development of a rapid and effective packaging reuse systems. Validating the cleaning quality not only reduces the risk to the public, but also enhances customer confidence and their perception of packaging reuse.

In this document the experimental design and procedure is described and the approach taken for image processing presented. Results from a number of different fouling media and polymer samples are compared and the implications for the approach as an industrial tool are discussed.

## 2. Materials and Methods

A laboratory scale setup is described that enables the assessment of various fouling media and polymer packaging samples in isolation from each other. The presence of the different substances are assessed by observing ultraviolet induced fluorescence. In this current work, the ability to detect the presence of contamination was the primary concern, rather than a measurement of the amount of remaining fouling.

### 2.1 Sample preparation

A purpose made stainless steel sample holder was intensively cleaned to remove any residual contamination. Small samples (< 1 ml) of fluids were deposited on the sample holder. The following fouling samples were investigated and are considered representative of some of the typical media that may need to be detected: Fanta®, Aldi® Vive Cola, Robinsons® Squash Fruit & Barley, Semi-skimmed pasteurised cow's milk, Banana and peanut butter smoothie (homemade), Captain Morgan's® Spiced Gold (rum), Vimto® Fizzy (Nichols plc), The Juice Company® Orange Juice with Juicy Bits, Sainsbury's® Blue Bolt (energy drink), and Olivio® olive oil.

Polymer samples (nominally 20 mm x 20 mm) were cut from a range of bottles, utilising the flattest sections available to limit the variation in signal obtained from complex geometries (see figure 1). Four different polyethylene terephthalate (PET) bottles and two different high-density polyethylene (HDPE) bottles were investigated. The samples were cleaned using detergent and their cleanliness checked using an industry standard Hygiena adenosine triphosphate (ATP) swab. The polymer samples were placed on a non-fluorescing stainless steel background.



**Figure 1.** Side image of a drinks bottle with residual fouling under UV illumination. Note the variation in signal intensity at regions of geometric complexity.

### 2.2. Image acquisition

A stainless steel optically isolated box (darkbox) was used capture images of fluorescing substances without contamination from external light sources. The UV illumination was provided by dual 18 W 370 nm (nominal) fluorescent lamps. Images were acquired using a Nikon D330 DSLR and a 10-20mm wide angle Sigma zoom. Multiple images for each sample were recorded to ensure repeatability of results.

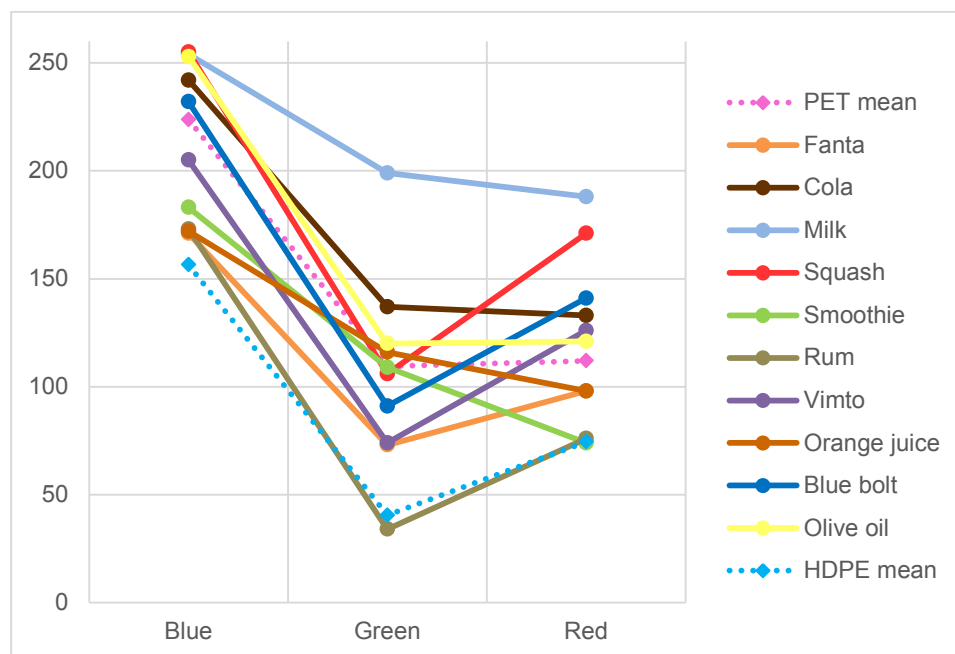
### 2.3. Image processing

Because both the fouling media and the polymer samples were found to fluoresce, it is difficult by using the naked eye to differentiate between fouling and packaging in the obtained images (other than by cognitive object recognition) as can be seen in figure 1.

The acquired red-green-blue (RGB) images appear as a 6000 x 4000 x 3 elements matrix, where the first two dimensions represent the image resolution (24Mp), and the third dimension represents the three color channels red, green and blue respectively. Matlab® was used to perform image processing, in order to try to establish fluorescent features of the liquid sample signals and differentiate them from the polymer sample signals. The method for obtaining the an RGB triplet for each sample involved manual selection of the region of interest before determining an average for that region via a Matlab® function. The result for each sample (fouling or packaging) is three component integers (RGB) in the range 0 to 255. The process was corroborated by manually selecting 10 semi-random pixels across each sample and taking an average.

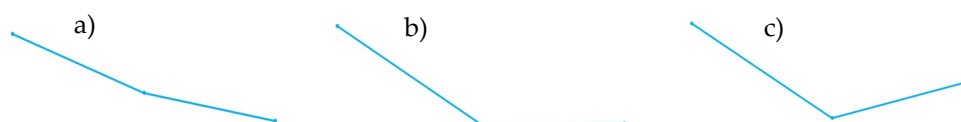
### 3. Results

For the smoothie sample, the average RGB value was [73.7: 108.6: 183.4]. This process was repeated for the other polymer and liquid samples, with the results plotted in figure 2.



**Figure 2.** RGB responses for the investigated liquid and polymer samples.

In all cases, the signal from the blue channel yields a higher intensity than those for the green and red channels, with often the green channel providing the lowest response. This is interesting given the published approaches for fluorosensing (e.g. [2] [3]) often favour the green channel for intensity assessment. In general the plots indicate some difficulty in separating the fluorescence of the packaging materials from the fouling media either via intensity of light (all samples were investigated using the same experimental conditions) or the shape of the graph. For example, perhaps unsurprisingly, olive oil and PET yield very similar responses when using this technique. However, in this research, it is possible to define three different line shapes (exemplified in figure 3) when comparing the intensities of the RGB channels: a) Decreasing (exhibited by the orange juice and smoothie), b) Levelling (exhibited by milk, cola, olive oil and PET), and, c) Inflection (exhibited by the squash, Blue Bolt, Vimto, Fanta, rum and HDPE). These line shapes imply the potential to use the ratios between the different channel responses to categorize the source of the signal.



**Figure 3.** Observed RGB responses: a) Decreasing, b) Levelling, and c) Inflection.

The milk and mean HDPE sample lie at the two extremes of the light intensities received by the camera and exhibit different line shapes (RGB ratios) which suggest that the presented technique is suitable for the detection of cleanliness of this particular packaging material. Indeed milk fluoresces strongly whilst HDPE emits lower signals under UV excitation. It is therefore deduced that the detection of milk residue in HDPE bottles would be more feasible than detecting other liquids in

PET. However, there is still the potential to apply the technique for the analysis of cleaning within PET bottles, although the process may not be suitable for all types of fouling.

#### 4. Conclusions

Ultraviolet induced fluorescence is a versatile technique and has been utilised in a range of reported applications. In this work, the technique was assessed for its suitability to differentiate between polymer bottle materials and common fouling media. The intention that it may be useful for cleaning assurance of reusable plastic packaging and hence provide part of a solution which leads to a reduction in single use plastics.

It has been established that the investigated common drinks bottle plastics and common drinks and liquid contents fluoresce in the visible spectrum under UV excitation (at 370 nm). It has also been shown that it is possible to differentiate between packaging materials and fouling media by considering both the intensity of fluorescence and also the variation in response in the red, green and blue colour channels of a digital imaging device. In particular, due to their marked differences in fluorescence response, the presence of milk fouling on HDPE bottles appears to be a highly suitable application.

Future work will focus on the differentiation of fouling on polymer substrates, an investigation into sensitivity of the detection process and the design of sensing equipment for the detection of fouling on complex packaging geometries.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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