New life for old soiled banknotes

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We are averse to handling soiled banknotes not only because they are dirty, but also they are breeding grounds for several bacteria which will be potentially harmful to our health. Though it is always more attractive and secure to employ fresh and crispy currency notes, it is practically difficult to use new banknotes for every transaction as the cost of producing currencies by Federal Banks will be high. Even as early as in 31 January 1964, the Government of India officially stated that members of the public sometime deface notes by scribbling on them and that such practice shortens the life of currency and banknotes[1]. This results in increased expenditure on the import of paper and on the printing of notes required for replacing the defaced ones[1]. Therefore, it is important to establish viable methods to provide a new life for soiled paper money keeping all the secret codes intact and without giving any loophole for counterfeiting. Federal Banks employ sorting machines equipped with a number of sensors to examine banknotes for their authenticity and for their fitness for recirculation.

It is amazing to know that nearly 150 billion notes are printed in Federal Banks of various countries around the world annually and around 10 billion notes (weighing about 150,000 tonnes) become unfit for circulation after the sensors in the processing machines reject them on the basis of soiling (works out to about 60–80% of notes processed around the world) and therefore they need to be replaced. The disposal of the unfit notes is another great challenge without polluting the environment, in addition to the involvement of a huge cost in printing new banknotes. It is appraised that replacement of the US$ 1 denomination costs $0.055/note, and for the US$ 100 denomination banknote it will cost US$ 0.126/note. Worldwide the cost of replacing soiled notes works out to nearly US$ 10 billion per year. The only desirable solution to curtail the huge expense to the exchequer is to clean the soiled notes by a cheap method and make them fit for recirculation. While the process chosen must be effective, it is imperative that the method should not damage the expensive security features and other printed features on the banknotes.

The pioneering work by Balke[2,3], reveals that a banknote is soiled mainly because of the fingerprint deposits of human sebum (skin oil from people's hand) on the note surface and its subsequent oxidation in air that results in a yellowish/brown colour. Sebum adheres to the elevated parts (crumble or fold lines) of the banknote. Also, the touch of the human finger causes relaxation of the cotton fibres. The crumbling and folding of the banknote also affects the stiffness, porosity, thickness, micro roughness and weight of the currency[2,3]. Though sebum can be removed by common solvents, most of the solvents damage security features and magnetic and fluorescent inks on the banknotes. Therefore, Federal Banks prefer to withdraw notes heavily encrusted with sebum from circulation.

It has been now established that a supercritical fluid like supercritical carbon dioxide (SCCO2) is a good solvent for cleaning[4–6]. A supercritical fluid is any substance, the temperature and pressure of which are higher than their critical values and which has a density close to or higher than its critical density. Among the various fluids, carbon dioxide and water are often employed in reactions at supercritical conditions. The critical temperature (T_c) and pressure (P_c) of carbon dioxide are 31°C and 73 atm respectively. Since T_c of SCCO2 is near ambient condition, it is often used in industries as a solvent for removing commonly encountered contaminants found in the precision cleaning of optical components, computer parts and electronic assemblies. Processing in SCCO2 also provides potentially attractive means of inactivating microorganisms in food and related materials[7].

Lawandy and Smuk[8] have recently reported the use of SCCO2 in cleaning soiled banknotes[8]. They confirmed by a simple experiment that the yellow coating on the banknotes is due to the oxidized sebum. They coated uncirculated banknotes with Bey sebum, which is a mixture of beef tallow, free fatty acids, lanoline, fatty acid triglycerides, cholesterol, hydrocarbon mixture and cutina. After allowing oxidation for eight days under conditions of 65% humidity and 90°C, the sebum coating developed yellow colour similar to soiled banknotes. The absorbance spectra of the oxidized sebum and the material extracted from banknotes in circulation shown in Figure 1 *a* indicate identical features, except a difference in the magnitude of absorbance. The appearance of US$ 1 banknote before and after coating with an oxidized sebum layer is shown in Figure 1 *b*.

In their method of SCCO2 cleaning, Lawandy and Smuk[8] employed laboratory-soiled banknotes. To establish the efficacy of their method, they used soiled banknotes of different countries. The currency notes were soiled with sebum as mentioned earlier. The cleaning process was carried out in a cell in the temperature range 20–60°C and at pressures up to 2000 psi. To accelerate the cleaning process, the cell was immersed in an ultrasonic bath. Diffuse reflection spectral measurements were used to comprehend the removal of sebum and its oxidized products. Figure 2 shows the £5 banknote images in circulation, sebum-soiled and SCCO2-cleaned along with their corresponding reflectance spectra.

The spectra of the note before and after application and oxidation treatment with Bey sebum clearly reveal that SCCO2 removes the sebum and oxidized products. Mineral oil-coated notes were also cleaned by SCCO2 and confirmed by diffuse reflectance spectral studies. This also demonstrates the efficacy of SCCO2 cleaning. When conventional straps of 100 banknotes are cleaned with SCCO2, there is a decrease of 4% initial strap weight pointing out that the contaminants in the soiled notes have been removed.

In order to make counterfeiting difficult, emissive features like security threads, inks, planchettes, holograms and fibres are introduced by the Federal Banks in the banknotes. Almost all banknotes bear an important public security feature which displays fluorescence and phosphorescence on excitation with UV light. The observation that the emission spectra of US dollars and Indian rupees before and after SCCO2 treatment are identical

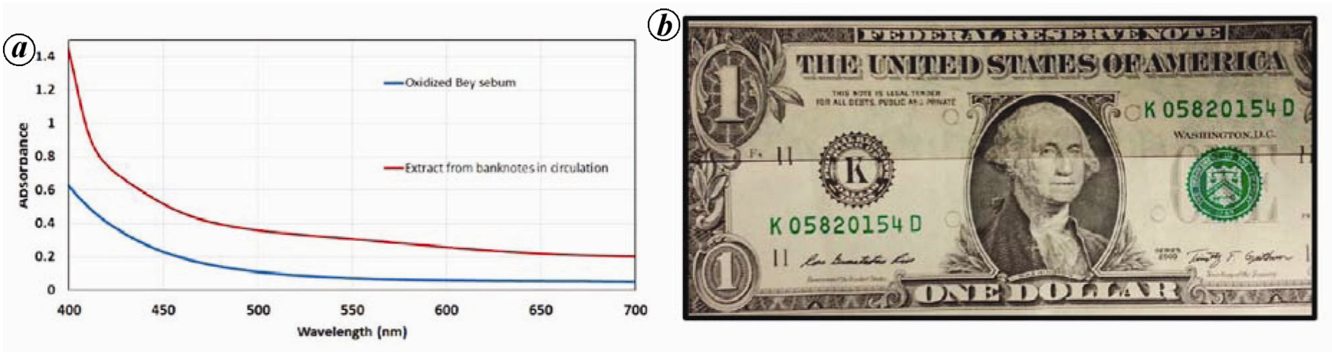

Figure 1. *a*, Absorbance spectra of 1 mm thick samples of oxidized Bey sebum and the material extracted from circulated banknote. *b*, Comparison of a US$ 1 banknote before and after coating with an oxidized sebum layer. The top half of the note is coated with sebum and oxidized. Reprinted with ACS permission from Lawandy and Smuk[8]. Copyright (2014) from the American Chemical Society.

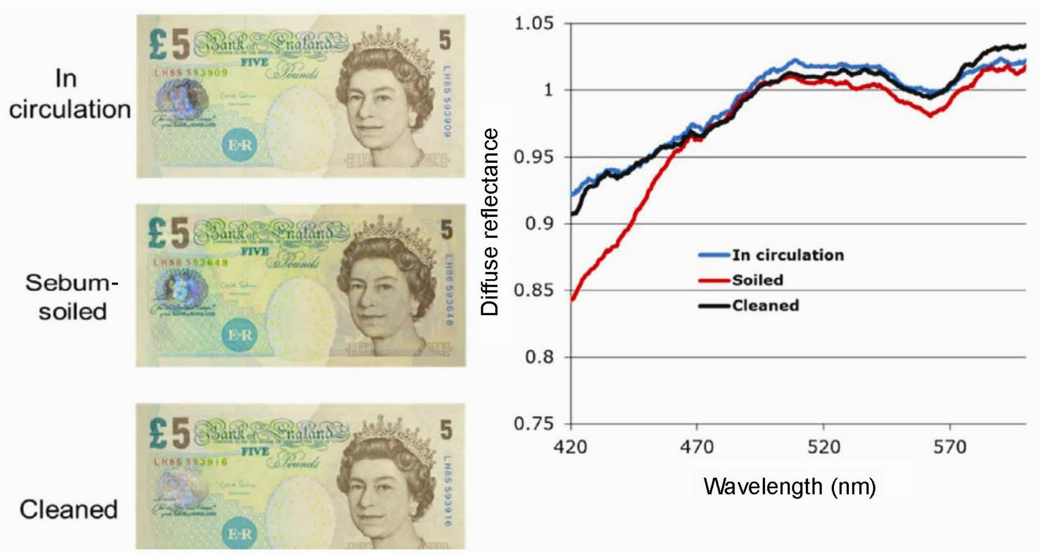

Figure 2. Images and diffuse reflectance spectra of £5 banknotes treated with sebum and SCCO2-cleaned. Reprinted with ACS permission from Lawandy and Smuk[8]. Copyright (2014) from the American Chemical Society.

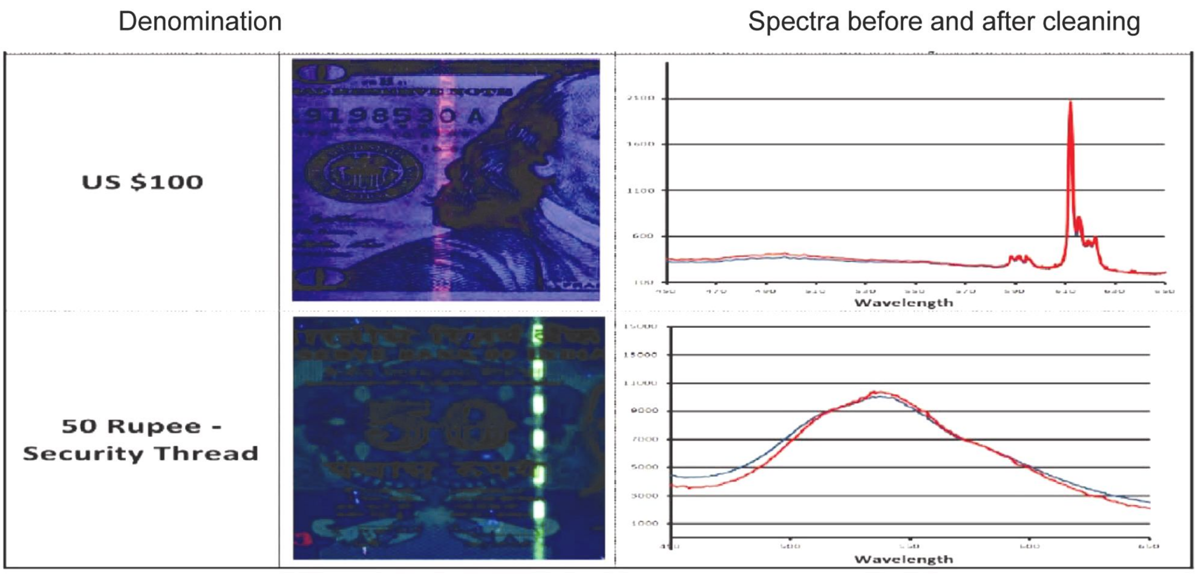

Figure 3. Chart showing data on UV-excited emission of security threads in the US dollars and Indian rupee. The emission spectra before (blue lines) and after (red lines) cleaning are also shown. Reprinted with ACS permission from Lawandy and Smuk[8]. Copyright (2014) from the American Chemical Society.

(Figure 3), clearly demonstrates the robustness of these UV-excited emissive features against the harsh conditions of cleaning process (16 h of cleaning at 60°C and 2000 psi). Apart from the emissive security threads, banknotes of several nations possess embedded polymeric security threads which are not affected by the SCCO2 cleaning method. To prevent counterfeiting, machine-readable security features are also included in the banknotes. These security features depend on magnetic susceptibility and capacitance. The magnetic inks employed in US dollars and Euros are not affected by this cleaning process. It has also been established that capacitive machine-readable features used in security threads based on metallization also survived after SCCO2 cleaning.

Some secret features, the signatures of which will be known only to Federal Banks and a select few, are also incorporated in the banknotes. One such secret security feature is Enigma supplied by De La Rue plc. These secret security features are also found to be intact and not affected during the cleaning process.

Since the paper currency is handled by several people during circulation, common organism colonies like *Micrococcus luteus* and yeast are found on the US$ 1 bills. Cleaning of the note by SCCO2 offers a bonus – the complete removal of both organisms from the banknotes.

The laundering of soiled notes by SCCO2 not only effectively removes oxidized sebum and other contaminants, but also maintains the integrity of the important and costly public and machine-readable security features without causing any damage to the printed features on the banknotes. This method of dry-cleaning of the soiled notes is likely to save billions of dollars and minimize the environmental impact of unusable banknote disposal.

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