The Use of Microfluidics to Combat Fuel Crime (Catching Mr Big with the Small)

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ABSTRACT

Taxation on fuels is an incentive for crime syndicates to set up smuggling and laundering groups that extract billions of dollars from the global economy every year. This crime falls into three categories, adulteration, grade swapping and tax evasion e.g. smuggling. In order to combat these crimes Authentix has developed and installed advanced microfluidic systems to test the fuel. Our system allows efficient marker testing in-field and we have demonstrated consistent extractions under a variety of conditions. Although microfluidics drives the technical engine of the testing program, our multi-million dollar success in these areas is also related to our ability to bring about legal enforcement. This is done through wide-scale testing and control programs.

Keywords: fuel marking, microfluidics, revenue recovery laundering, smuggling

1 INTRODUCTION

The significant taxation on fuels is a big incentive for criminals and terrorist groups to set up smuggling and laundering syndicates that cost legitimate businesses and governments billions of dollars every year. In our experience this varies from between 7 to 30% of sales, depending on the measures in place within the country (or company). This can be reduced significantly with an effective marking program. In some cases these syndicates undermine the stability of the government and reduce a government's ability to attract investment. Moreover, the lost revenues can fund groups that have an active interest in destabilising and undermining governments. Although losses are large due to the volumes of fuel used, in fact this is a greater loss to the country than first appears. In addition to funding organised crime and thus taking physical resources in terms of policing etc., the company loses the immediate revenue that would have resulted from a sale and the government its tax. Furthermore, there is less legitimate money running through fuel stations and consequently distribution companies reduce their investment as they see very little return from these loss-making franchises. This ultimately leads to the loss of jobs and people turning out of necessity to the very crime syndicates that have reduced their income. From the government standpoint the income from personal taxation and company taxes is reduced. As GDP is reduced locally, it interferes with the ability to invest in infrastructure (which would ordinarily produce more income/GDP). Thus there is a crossover point where organised crime can become so profitable that the government becomes starved of finances and resources to such an extent that it can never gain effective control without taking extraordinary measures.

Authentix is heavily involved in a variety of nanotechnology programs in fuels management; the company has successfully used Nanotag™ in Malaysia and has used nano and microfluidic systems to combat many of these crimes. It has applied this in fuel systems from heavy crude through to Liquid Petroleum Gas (LPG).

Authentix has developed three signature systems for meeting the needs of different client groups such as:

1.1 Those wishing to identify even tiny quantities of adulterants in fuels (such as low tax kerosene, tax exempt diesel in road fuel or even LPG). For this system, we use markers that are recognised by antibody receptor molecules in a lock-and-key fashion. The exquisite selectivity and sensitivity of the antibodies renders them particularly useful for identifying and quantifying a few parts per billion of the adulterant marker. These markers must be resistant to extraction and attempts at laundering.

1.2 Those wishing to determine if the fuel has been tampered with or is below specification (grade swapping).
In these situations, each of the fuels is coded with a different marker. Any dilution with the wrong or cheaper grades will be flagged with a value of less than 100%. A different technology from that used in 1.1 needs to be employed, and preferably one that can read a marker for each grade

1.3 Those wishing to identify dilution of fuels with smuggled fuel from, for example, neighbouring states. In this case (as for 1.2) normally the fuel is marked and

results below 100% imply that smuggled fuel or an adulterant has been added; either way, this is illegal.

Although microfluidics provides the engine of the testing program, our success in these areas is also related to our ability to test the fuel and bring about legal enforcement. This is done through wide-scale testing and control programs. One drawback from field testing is the need to have highly skilled employees doing the testing and this can be time consuming, costly and produces some chemical waste that needs to be disposed of appropriately.

Authentix has been actively involved in developing microfluidic systems based on lab-on-a-chip technologies. The goal was to efficiently and quantitatively remove the marker from the fuels without the need of a full scale laboratory. The use of microfluidics lends itself to our needs. The ability to produce a lab-on-a-chip system that will perform chemical reactions and extractions in one device takes away much of the need for highly skilled staff. Samples can be introduced into a black box, a button is pressed and after a few minutes a reading is given. Very little waste is produced during the process and because the volumes are so very small, diffusion can usually take the place of mixers etc..

Most investments in microfluidics have supported development of uses with biological fluids – which are almost invariably water-based systems. It is much more difficult to do this work with two immiscible fluids. It is also a challenge to find pumps and materials that are compatible with the extremes of pH and the solvents we use. So initially glass was our preferred substrate.

2 MICROFLUIDICS DEVELOPMENT

2.1 The Reactor

This consists of a 2 layer glass microchip. A D shaped groove is etched into the first layer at 35 micrometers deep and 60 micrometers wide. The channel is sealed with the second glass layer. Both glass surfaces are optically polished before sealing. (See Figure 1)

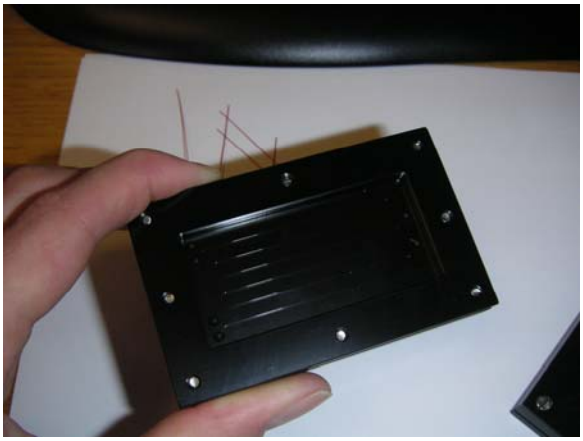

Figure 1. Picture of the re-usable fuel chip prior to connection into a reader.

2.2 Extraction

This is done using marked diesel and an aqueous extractant. The two fluids flow side by side for a few seconds (channel is ~11 cm long). The two flows are then split such that 100% of the fuel and some 10-20% of the extractant moves down one capillary whilst the remaining 80-90% extractant is passed to the detector

2.3 Detection

Detection of the fluorescent markers was done by epifluorescence using a sapphire ball lens and suitable beam splitting mirrors, a blue LED light source and a silicon photodiode as a sensor (see Figure 2). This has the benefit of making the detector very robust, small and simple to situate at the extractant outlet of the chip. Synchronous detection using a laboratory lock-in-amplifier is used in order to keep the electronic and light bleed noise to a minimum. With this setup, the noise level is not limited by the detector as the chemical background of the system' is higher than the noise of the detector.

Figure 2. The epifluorescent detector – note the capllary running along the front edge of the device beside the sapphire ball lens.

3 RESULTS

Figure 3 shows the effect of running fuel and extractant together, producing stable laminar flow. It was necessary to vary the flow rate to achieve stable laminar flow as this is dependent upon the viscosities of the fuel and the extractants, which in turn are dependent upon temperature. Under the right conditions, it was possible to get 100 ± 3% extraction of the marker. Figure 4 shows the eluates from the separation system. In order to prevent any fuel contamination it was found that it was best to have a ratio of 1.1–1.2 : 1 of extractant to fuel volume flow rates, resulting in pure extractant at the other outlet (is my reword correct?). The system was optimised for consistency and speed rather than purely extraction efficiency. At flow rates of 4 µl min^{-1}, extractions of 88 - 90% efficiency were generally achieved using diesel fuel. These results could be generated within 30 seconds of starting the test. More importantly, much less than 500 µl of fuel and reagent were used in the test, so that there was very little disposable waste.

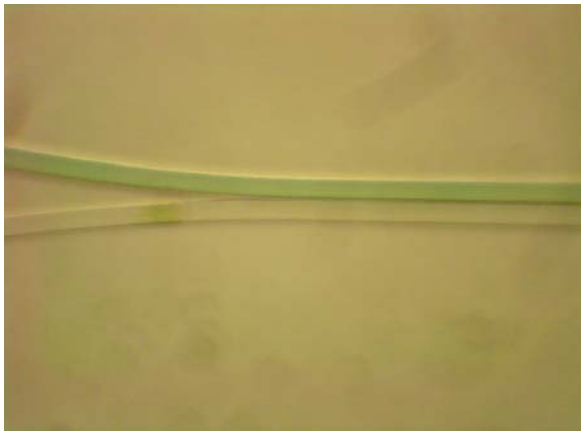

Figure 3. Laminar flow of two phase systems containing diesel and an aqueous extractant

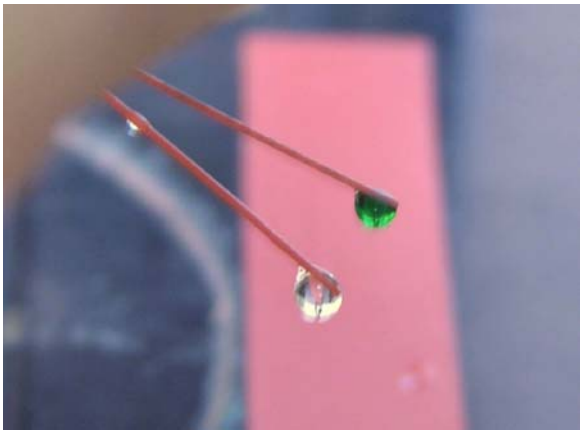

Figure 4. Excellent separation of markers from fuel and aqueous extractant.

4 DISCUSSION

The results of this study have shown that Authentix can produce a simple lab-on-a-chip device capable of doing the normal extractions required for a typical laboratory-based system in a fraction of the time required to do the same work at a macro scale (30 seconds *vs* 10 – 20 minutes). It also gives us the concurrent benefit of using minute quantities of reagents and producing a fraction of the waste. The system is almost solid state with few moving parts and can be easily reduced to a small hand-held device. Automating the process has reduced the possibilities of user error and initial field tests on the system have demonstrated good reliability. However, we have seen problems of 'tube flow' under certain conditions where the extractant coats the walls of the glass, with the fuel flowing as a tube within the extractant. Some levels of temperature control and a redesign of the chip to reduce the chance of this happening are under investigation.

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