Miniatured Microfluidics Heuristics towards the detection of polluting molecules in the environment

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Abstract

Toxic substances (pesticides, heavy metals, and xenobiotics) in the environment pose a threat to all living organisms towards health issues. The existing bioremediation approaches exploit the usage of microbes to convert, accumulate, and breakdown into less hazardous compounds under optimized conditions. Despite the continuous effort made on bulk bioremediation studies, analytical tools available for assessing or validating the presence of toxic substances in the environment have cost-and labour intense. A multi-facet miniature microfluidic technology seems to be a viable option for detecting the pollutants in rapid successions. In this chapter, we will highlight the developments made towards the implementation of miniaturized platforms for fast and frugal analysis of pollutants present in the environment.

Keywords: Microfluidics; Pollutants Detection; Lab-on-chip; Calorimetric; Electrochemical.

1. Introduction to Polluting molecules and its effect on environmental and human health

The advent of the modern era has seen an exponential rise in polluting practices which degrade natural resources as a result of increased human activity. Mismanaged energy reservoirs, unsafe agricultural techniques and rapid industrialization have led to an increase in the concentration of pesticides, heavy metals, xenobiotic molecules, nuclear wastes, greenhouse gases and hydrocarbons in nature whose toxic effects pose a great risk and challenge to environmental and public health. Traditional methods for analysis of the same are time consuming and require expensive equipment and technical expertise to operate. Additionally, these methods are not viable for field usage due to bulky nature and power usage. Conventional methods also tend to be highly precise and specific. This level of accuracy is excessive for most monitoring applications which further calls into question their use considering their high costs. These methods cannot meet the growing demand to close the gap on the dearth of analytical data. Therefore, this pressing need calls for the use of Heuristic approaches towards data collection via miniaturization of traditional analysis that one is able to achieve via microfluidic devices for different and specialized applications. This Chapter will go through the pollutants of interest, the merits of adaption of traditional methods to microfluidic applications and the relevant innovative discoveries for the same.

1.1 Heavy metals

"Heavy metals" are considered as metals with densities ranges above 5 g/cm^3 (Yetisen et al., 2013). Though heavy metals such as magnesium (Mg), copper (Cu), molybdenum (Mb), zinc (Zn), chromium (Cr) and iron (Fe) are utilized as crucial factor in various aspects of biochemical and physiological functions. Over exposure of these metals due to meteoric increase in consumption of resources and the corresponding pollution have caused increased environmental concerns recently. Heavy metals are non-biodegradable and can pile up in ecological matrices as a result, they can be regarded as the most troublesome substances among other pollutants. Human utilization of heavy metals has considerably increased due their myriads of applications in medical, domestic and industry sector. This has led to chemical contamination in environment and is posing potential threat to public health. For example, high levels of arsenic and cadmium exposure to human's results in increased risks of systemic and carcinogenic effects (Lin et al., 2016). Among children, prolonged exposure of lead can result in growth retardation, delayed neurobehavioral development and

diminished intelligence. In case of adults, over exposure of lead can result in reduction of sperm count, spontaneous abortions, kidney and brain damage(Tchounwou et al., 2012).

1.2 Pesticides

Generally, the title “pesticide” offers broad spectrum of substances, which include herbicides, fungicides, insecticides etc. Though meant to target specific types of pests, abuse and over spraying of potent pesticides lead to the contamination of the environment with disastrous effects on not only the animal but also human population (Jaffrezic-Renault, 2001). Present in the soil, air and water, pesticides tend to be sparingly soluble, highly stable and extremely toxicity leading to their residues and metabolites being called persistent organic pollutants (POPs) (Fenner et al., 2013; Kudr et al., 2017).

1.3 Organophophorus compounds:

Among commercial grade pesticides, the worst offenders are organophosphorous compounds. They are used as pesticides, insecticides and chemical war agents. The lethality at extremely low doses credited to organophosphorus and its massive proliferation in the agricultural sector, has roused public concerns. This had led to inculcation, implementation of high-end techniques and development of frugal technologies to treat effluents at manufacturer or producer and consumer levels (Jaffrezic-Renault, 2001).

1.4 Xenobiotics

A xenobiotic is a chemical substance found in a biological system that is naturally non occurring within the system. It can also refer to compounds that are present in unusually raised concentrations than are usual. In an environmental context, they are mostly found in industrial runoffs mostly in terms of agro and industrial chemicals. Later, these substances reach the soil environment and are subjected to sorption, degradation and organism uptake. Though the case in most, recent advancements show that some substances fail to be broken down in a system due to their unique properties. Several xenobiotics such as trichloroethylene (TCE), polycyclic aromatic hydrocarbons (PAHs),polychlorinated biphenyls (PCBs) possess resistance to natural breakdown and results in bioaccumulation in various environmental levels. Due to their toxicity and artificial pervasiveness, this has become a serious environmental concern for researchers and public(Katayama et al., 2010). Presence and effects of xenobiotics can also be studied in tandem with phenol presence in nature as they tend to be linked. Furthermore, Phenolic compounds are used in widespread

areas including pharmaceutical, petroleum and chemical industries. In addition, the release of these untreated biocides like pentachlorophenol to water bodies can contaminate and eventually bio accumulate and affect the soil quality.

2. Existing detection strategies for environment pollutants and its drawbacks

2.1 Detection of Heavy metals

Detection and effects of heavy metals is already a part of the general dialogue due to its unique history in terms of societal health. Even though, the deleterious effects and the impact of heavy metals are already known. Increasing in their utilization and exposure as well as the quest to understand their toxicity is extending(Järup, 2003). Several traditional techniques have been developed and utilized for the detection of heavy metals. They include energy dispersive X-ray fluorescence (EDXRF),flame atomic absorption spectrometry (FAAS), inductively coupled plasma atomic/optical emission spectrometry (ICP-AES/OES), inductively coupled plasma mass spectrometry (ICP-MS), atomic absorption spectrophotometry (AAS) and electro thermal atomic adsorption spectrometry (ETAAS) (Lin et al., 2016).

The aforementioned conventional techniques are expensive, they possess advantages like high sensitivity and specificity. They require highly trained professionals and involves tedious operations. Hence, there is great demand for robust, simple and frugal analytical methods, especially for developing countries lacking prerequisites and operational conditions for traditional analytical techniques. Additionally, deploying such bulky and expensive instruments for *in situ* analysis is always challenging(Lin et al., 2016).

2.2 Detection of Xenobiotics

Due to the particular nature of most xenobiotics, multi-step solvent extraction is used to assess the total amount of extractable compound from the sample to be studied. Recently, Mass-Spectrometry (MS) based systems are used comprehensively for detecting xenobiotic metabolites. Several variants of MS-based detection systems like high resolution (HRMS), Orbitrap, Fourier Transform ion cyclotron resonance are used to detect and identify xenobiotic metabolites (Takahashi et al., 2018). It is also crucial to study the interactions of xenobiotic and also their mechanisms of uptake in biological systems thereby preventing the overestimation of their bioavailability. For example, butanol-shaking extraction and dichloromethane-Soxhlet extraction methods overestimated the phenanthrene bioavailability in soils (average of more than 60%). Consequently, there is a great need for the development

of less tedious and flow controlled techniques to analyse the bioavailable pool in soil (Reid et al., 2000).

Traditional methods of phenols separation and determination encompass high performance liquid chromatography (HPLC) with UV spectrometry and gas chromatography combined with mass spectrometry (GC-MS). Comparably, to understand its breakdown in nature, moderate extraction methods that mimic the chemical uptake of phenols by soil organisms. These methods often provide accurate estimation of phenol content and also represent a real value instead of a heightened bioavailability (Järup, 2003).

2.3 Detection of Pesticides

Chromatographic methods such as gas chromatography, liquid chromatography and thin film chromatography when clubbed with specialized detectors have been the industry standard for the analysis of pesticides due to their consistent and efficient results. Yet, they are time-consuming and labour intensive, and training in costly instrumentation to be applied (Khairy et al., 2018). The nature of the analysis also rules out collecting dynamic real time data. A simple colorimetric method which relies on the inhibition of cholinesterase activity is commonly used detection of determination of organophosphorus compounds. Immunoassays tend to have extended times for analysis and laborious and often tedious handling. These teqniques require multiple costly plastic kits and fail to collect real time data as well (Jaffrezic-Renault, 2001).

Additionally, regarding non microfluidic biosensor use for detection of pesticides, from a sheer economic point of view biosensors suffer from many disadvantages. Mainly, the enzymes are expensive and their chemical/physical stability in time is an issue. Also due to the inherit contamination of environmental samples, enzyme activity might get affected by the presence of certain heavy metals leading to skewed results (Aktar et al., 2009). Moreover, lower concentrations of compounds of interest in the sample will signal the lead to perform pre-concentration practices which are time consuming and expensive (Chorti et al., 2014).

Table 1. Existing detection technologies for environmental pollutants and it's drawbacks

Pollutants	Detection method	Drawbacks
Heavy metals	Inductively coupled plasma mass spectrometry (ICP-MS)	Demands complex equipment, trained personnel, and tedious operations.
	Inductively coupled plasma atomic/optical emission spectrometry (ICP-AES/OES),	High Accuracy tends to be redundant
	Energy dispersive X-ray fluorescence (EDXRF)	
	Electro thermal atomic adsorption spectrometry (ETAAS)	
	Flame atomic absorption spectrometry (FAAS)	
	Atomic absorption spectrophotometry (AAS).	
Xenobiotics	Exhaustive solvent extraction	Leads to overestimation of Bioavailability
	High performance liquid chromatography (HPLC) with UV spectrometry	Not accurate for modelling breakdown of xenobiotics in nature
	Gas chromatography coupled with mass spectrometry (GC-MS)	Demands complex equipment, trained personnel, and tedious operations
		High Accuracy tends to be redundant
Pesticides	Chromatographic methods coupled to selective detectors	Time-consuming and laborious
	Immunoassays	

	Non- microfluidic biosensors	Expensive equipment's and highly trained technicians. Long analysis time (one to two hours) - numerous washing steps. Stocking equipment inconvenient
		Expensive, less throughput
		Unstable and expensive enzymes
		Can't handle contaminated sample, Pre-treatment needed

3. Positive attributes of microfluidics towards better detection of environmental pollutants

Microfluidic systems operate using scale down ideologies and capabilities to develop platforms which are aimed at controlling and manipulating fluidic samples at very low volumes and Reynolds numbers. Using this technique, we can modularize multiple laboratory grade analytical techniques onto a single system or Lab-On-A-Chip (LOC). The volumes of fluidic samples often range from as large as nano-litres (10-9) to as small as atto-litres (10-18). A fluidic input in this range is highly favourable (Maguire et al., 2018).Last two decades has seen a renewed importance in leveraging microfluidics for myriads of applications. Owing to its advantages like high throughput, enhanced sensitivity, possibility of miniaturization and parallelization, requirement of less reagent volume, reduction in instrumental requirements and ease of handling, microfluidics has revolutionized the approaches used by analytical chemists for detecting biomarkers and analytes (Stanley et al., 2016).

High analytical throughput: The ability to control flow of analyte and reagents autonomously, several tests and experiments of chemical, genetic, or pharmacological nature can be conducted on a single unit. Through this process, we can design systems that can rapidly identify compounds of interest in relatively low amounts of time. This also increases the amount of data that is procured(Sierra-Rodero et al., 2014).

Enhanced sensitivity: since operated at lower volumes, a heuristic output for particular substance of interest is easier to obtain as an observable or quantifiable change resulting from an interaction from the reagent is much more clear due to less interference with side reactions in solution and built in systems for analysis(Battersby and Trau, 2002).

Facile parallelisation: due to small size of structure, it is easier to form channels and barriers on the same device for parallel reactions and operations as the reagent and space required for analysis is significantly reduced. If allowed by the media, foldable and 3D absorptions and analysis can also be done(Rusconi et al., 2014).

Ease of use: Multiplexing the sample pre-treatment and chemical or bioassay in a same device. User-friendly designs and ability to perform multiple analysis by just modifying the patterns (Stanley et al., 2016).

Reagent consumption: With a reduced input sample size, there is a corresponding reduction in reagent consumption and required detection time. This range also increases the systematic detection resolution and sensitivity, whilst also lowering the material quantity required to conduct an experiment(Maguire et al., 2018).

Last decade, micro-fluidic paper based analytical devices (µPADs) have been deployed due to major benefits like they do not require pumps and valves to drive fluid. Instead fluid is driven via capillary action due to the porous nature of the paper being used. These devices are increasingly cheap and reproducible. This particular attributes also make them perfect for field and point of care applications for detection and medical diagnosis in combination with smart-phone based imaging (Jokerst et al., 2012).

4. Designs for detection

This part will highlight the applications, where researchers have leveraged microfluidic and miniaturization concepts for detecting aforementioned pollutants. Considering the relevance of these concepts to environmental monitoring, the research output in this field is very fast paced and active. Although there is an exhaustive list encompassing myriad of applications

this field has given rise to. This section is divided into three major sections based on the detection method used. Firstly, we will explain the qualitative colorimetric detection methods employed for detecting pollutants. Secondly, we will highlight quantitative detection of analytes using electrochemical method. Finally, we will emphasize the importance of other optical-based detection methods.

4.1 Colorimetric approach

Colorimetric detection ranks first when it comes todetection of heavy metals in waste-water and is commonly preferred over other techniques (especially in laboratorial and industrial set-up)(Mwegoha and Lema, 2018). This method offers provides analytical readouts with the assistance of a reference or calibration chart. In these kind of paper devices, detection or working zone encompasses multi-analyte detection systems. Once the sample is loaded and accumulated over different reaction or experimental zones, chemical reaction between reagents (imbibed on paper devices) and target analytes will occur, thereby enabling the user to observe a colour change. Typical colorimetric approach provides a sudden colour change or change in the colour intensity, which is visible to naked eye. This kind of colour indication is easy to analyse and manual interpretation doesn't necessitate an additional equipment. (Lin et al., 2016).

Using simple microfluidic paper-based analytical device (μPADs), Chaiyo et al., 2015 developed silver nano-plates to trace or detect the Cu^{2+} ions. This method is highly robust and shown high selectivity towards Cu^{2+} ions, despite the presence of more than ten heavy metal ions (Chaiyo et al., 2015). Recently, simultaneous detection or capturing of other heavy metals like Hg^{2+} and Cr^{3+} ions in acetonitrile has been achieved by (Patidar et al., 2015). The authors developed or synthesized two kinds of ionophores (derived from rhodamine). They exhibit great potential for specific detection of Hg^{2+} and Cr^{3+} ions, just relying on a simple and sharp colour change (colourless to pink, colourless to reddish-pink for Hg^{2+} ions, and Cr3+ ions respectively). In an interesting attempt in converting a simple filter paper into a versatile tool for colorimetric detection of different types of ions, intercalation of $Fe(CN)_6$4and S^{2-} into the inter layers of layered double hydroxides (LDH) was performed. Later, the respective colour change, indicating the presence of $Cu^{2+}$and Fe^{3+} were measured (Huo et al., 2019).

Inkjet- Printing techniques give much more precision and accuracy for printing scripts or making channels. They also enable the ability to create complex multi-layered structures.

Researchers leveraged wax printing and demonstrated the multiplexed devices for simultaneous estimation of Fe, Ni and Cu within 40 mins. The reagents were printing using custom modified inkjet printing. Later the sample was drop-casted onto the reaction zone. The colorimetric reagents 4,7-diphenyl-1-1,10-phenanthroline, dimethylglyoxime and dithiooxamide specific for Fe, Ni and Cu, respectively have shown a coloured precipitate (Cate et al., 2015). This allows for high throughput analysis of multiple molecules, which if done traditionally would take a magnitude of more time.

On the other hand, researchers developed a foldable paper-based device for detecting large and more complex molecule i.e., dimethyl methyl phosphonate (DMMP), therebyaiding the detection of organophosphates in a heuristic manner using a colorimetric technique. The device exhibited yellow colour, indicating the presence of DMMP. The concentration of the analyte was quantified with the aid of angle-based readout. The linear response in the angle was observed for the concentration 1 – 4 M (Lee et al., 2018) (Fig.1).

To determine the nitrite ion in environment, disposable microfluidic paper devices were developed using Griess reaction. The device contains 8 star-shaped channels, out of which 3 were used as controls and 5 were used as detection zones for standard and working samples. Upon addition of the sample, a colour change (from colourless to strong pink) attributed to the presence of nitrile. This allows for multiple independent tests to be done. This also ensures that a few of the paths to be used as controls. This method proved to be an powerful and economical way to determine the substrates for on-field based detection of environmental samples (Cardoso et al., 2015).

4.2 Electrochemical approach

Environmental samples are composed of a multitude of components leading to the existence of a complex matrix, which in itself makes analysis very difficult due to risk of false results. Henceforth multicomponent analysis demands separation step. The ideal way to do separation step is by integration within the chip itself. The common and popular way of performing separation step is by utilizing electrophoresis technique, where migration of ions occurs based on the electric field. Electrophoretic separation majorly relies on factors like molecule size and charge (Marle and Greenway, 2005).

Conventional electrochemical technique usually deploys three-electrode system for quantification of analytes. This encompasses a counter electrode, a reference electrode and a working electrode.Few researchers also reduced the utility of electrodes to two and proven

that electrochemical measurement can be carried out (Newman and Thomas-Alyea, 2004). Significant measures have been addressed by researchers to combine electrochemical detection with paper-based microfluidics. As of now, screen printing is the holy grail for printing conductive electrodes on a paper substrate. On contrary, simple methods including free-hand drawing and lithography were also shown to be effective (Dossi et al., 2013).A single-step assay combining filter paper strips and electrochemical detection was used for the determining Pb^{2+} and Cd^{2+} ions in aqueous medium. This method proven to detect the analyte at low concentration and also offered high selectivity. Additionally, a handheld reader for quantifying the colorimetric signal was also used (Zhao et al., 2014). Lee et al., 2014 exploitedgold nanoparticles in a composite of polypyrrole/cellulose and detected heavy metal ions (Hg^{2+}, Ag^{+}, Cr^{3+})in ground water. The authors proposed that polypyrrole offers favourable electrochemical properties while the cellulose provides enough mechanical strength (Lee et al., 2014).

The effects xenobiotic molecules like nitro-aromatic compounds (NACs) on human health are far reaching and have been shown to be toxic and carcinogenic to humans.Towards the detection of nitroaromatic compounds (NACs), several methods were developed for determining2,4-dinitrotoluene (DNT), 1,3-dinitrobenzene (DNB), 1,3,5-trinitrobenzene (TNB), and2,4,6-trinitrotoluene (TNT) in river, tap and cooking water (Nie et al., 2010).Yew et. al., (2019) demonstrated that mesoporous material of carbon (CMK-3) can be used as carbon disk electrode. The authors believe that CMK-3 coating offers high electrical conductivity as well as improved sensitivity. This approach was utilized for the detection of trace NACs from 3.0 to 4.7 μL/g (Yew et al., 2019).

Nerve agents in soil can have lasting effects on the life. Therefore, a biochemical sensor for the same has been developed by researchers. The device relies on double electrochemical measurement of butyrylcholinesterase (BchE) enzyme activity in presence of nerve agent.An intriguing approach of using carbon black and Prussian blue nanocomposites as working electrodes for detecting paraoxon (nerve agent simulant), exhibited a linear response with detection limit of 3 μg/L (Cinti et al., 2017; Kung et al., 2019).

In specific reference to electrochemically detect pesticides, a 3-D origami based paper device involving various enzymatic activity was developed. The authors used a portable potentiostat and chrono-amperometrically detected the paraoxon and atrazine at very low concentration (ppb levels) in river water samples. Interestingly, Arduini *et. al*., used screen-printed

electrodes (SPE) on office paper and developed origami based paper device. The authors observed two linear responses for the control solutions and river water samples. This method exhibited 2 ppb as the limit of detection (Arduini et al., 2019).

Using three electrode system made of gold anodic stripping, Manuel *et. al.,* demonstrated a multi-component analysis by studying the oxidation of catechol along with copper and parathion (OPP) in a simple microfluidic device. The analytes were detected using different chronoamperometric methods (Gutiérrez-Capitán et al., 2014).

4.3 Other optical methods

Optical detection encompasses the overseeing and uncovering the light properties including fluorescence, luminescence and absorbance emitted from samples. These methods usually have either an analyser attached to the chip or the chip is used in tandem to an external apparatus.

Nitrite levels in potable water can swell by the contamination of a fertilizer or some sort of animal faecal matter in it and can cause serious harm to the consumer. Therefore, it is imperative to monitor the nitrite level in these water sources at a regular basis. Therefore by analysing the UV absorption of nitrite sample as well as the simple colorimetric method (Griess reaction), nitrite quantification can be easily achieved (Sieben et al., 2010). In addition to this, in another study the property of fluorescence of sulfite and nitrite when reacted with fluorescing agents is used as an analytical tool to find their corresponding levels. It has been further demonstrated that the dual detection of these ions in an aqueous solution with aid of fluorescent agents N-(9-acridynyl) maleimide (NAM) and 2,3-diaminonaphthalene (DAN) can be achieved fluorometrically in a microfluidic device (Fujii et al., 2004).

Like water, air can also be subject to a varied amount of contaminants which can have an adverse effect on humans. As an effort for monitoring air quality, luminol solution was held between two convex structures. Then, chemi-luminescence approach was used to detect chlorine gas in microdevice. This method yielded detection limit of 0.2 ppm for standard chlorine gas (Gao et al., 2008).

The systems described above rely on a carefully fabricated chip with materials that are relatively harder to scale economically due to complexity in form and multiple active parts. This problem has started to have been addressed by the development of paper based devices.

Conventional micro-fludic devices are mostly constructed or fabricated using glass and PDMS generally require external pump for injecting the samples. Whereas, paper-based analytical devices (PADs) doesn't require external driving pump and also gained major attention due to ease of use and simple fabrication methods (Lisowski and Zarzycki, 2013). By integrating PADs with other detection methods, we can achieve faster results and the detection sensitivity of analytes can be greatly enhanced. For instance, PADs were used to scale down the existing chemiluminescence detection system for Cr(III) ions in water samples (Alahmad et al., 2016; Yew et al., 2019).

Furthermore, Bell *et. al.*,demonstrated a simple microfluidic device which is an amalgamation of droplet-based system and gated indicator for detecting Hg^{2+} . Using polyethylene glycosylated boron dipyrromethene (indicator) and silica nanoparticles as scaffolds, the authors designed a gated indicator. They were able to estimate the Hg^{2+} ions in water with a limit of detection of 20 ppt, 50 times lower than the maximum permitted concentration in drinking water (Fig.2) (Bell et al., 2016).

5. Future scope

Microfluidic methods need costly liquid analyte and reagent in some cases, even when their alternates are available. The traditional PDMS based microfluidic devices have a considerable number of advantages, but still making these devices with precision is a costly affair. The design of LOC devices needs to be modelled well before fabrication (Kudr et al., 2017).Colorimetry-based paper assays suffer from problems like reagent evaporation and change of colour shades due to long storage. It is mandatory to improve the shelf life of paper devices. Smartphone-based colorimetry detector still depends upon the type of camera. Reference curve and calibration are needed for colorimetry approach (Lafleur et al., 2016).Creating hydrophobic surfaces with precise contact angle is a challenge associated with paper microfluidic devices. Wax printer based paper devices solve the issue of hydrophobic surfaces, but it is costly equipment. For paper-based Researcher planning to pursue paper-based microfluidic approach must remember that for Paper-colorimetry device to work well control region is needed (Yew et al., 2019).For electrochemical based device, there is always a chance of false result due to contamination. Gold nanoparticles approach can get rid of false results. Synthesis of gold nanoparticle for a particular electrochemical reaction is still a task. The sensitivity of the electrochemical reaction is dependant of the type of electrodes used. Carbon printed electrodes are easy to make but not as efficient as gold anodic ones. The

Origami paper devices have a proper scope in the future provided that they maintain existing LOD (Pol et al., 2017).Absorption and fluorescence-based methods are currently suffering due to the need for costly fluorescent microscope and also affecting their portability. External controlled environment e.g., the gas source is also a major hurdle needs to be crossed when we talk about on-field testing. Droplet-based devices have excellent LOD but non-uniformity of droplet sizes and costly oil environment to maintain droplet is an issue (Rusconi et al., 2014). Fluorescent luminance produced after reaction last for few minutes and hence fast and accurate reader for such systems in the field is a task especially when sunlight is present. Despite all these future improvements possible in microfluidic devices, the authors of the chapter will still recommend it over traditional methods (Sierra-rodero et al., 2014).

6. Conclusion

The modern era has seen an enormous increase in polluting practices that degrade natural resources. Rapid industrialization has led to a rise in the concentration of pesticides, heavy metals, and xenobiotic molecules. The toxic effects of these substances represent a significant risk and challenge to the environment and health. Traditional methods for their analysis take time, require expensive equipment and technical expertise. Traditional methods needed complicated operations, and many times, their very high precision tends to be redundant and may lead to overestimation. Conventional methods also found out to be needed many washing phases with proper storage equipment for intermediate stages.In this chapter, different microfluidic devices, which are being used for the detection of the pollutant, are reviewed. Microfluidic measurement offers a distinct advantage of handling very low liquid volumes. Microfluidics proved to be a better detection system for environmental pollutants. Multiple laboratory analytical techniques are done on single Lab-On-A-Chip (LOC).

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Figures:

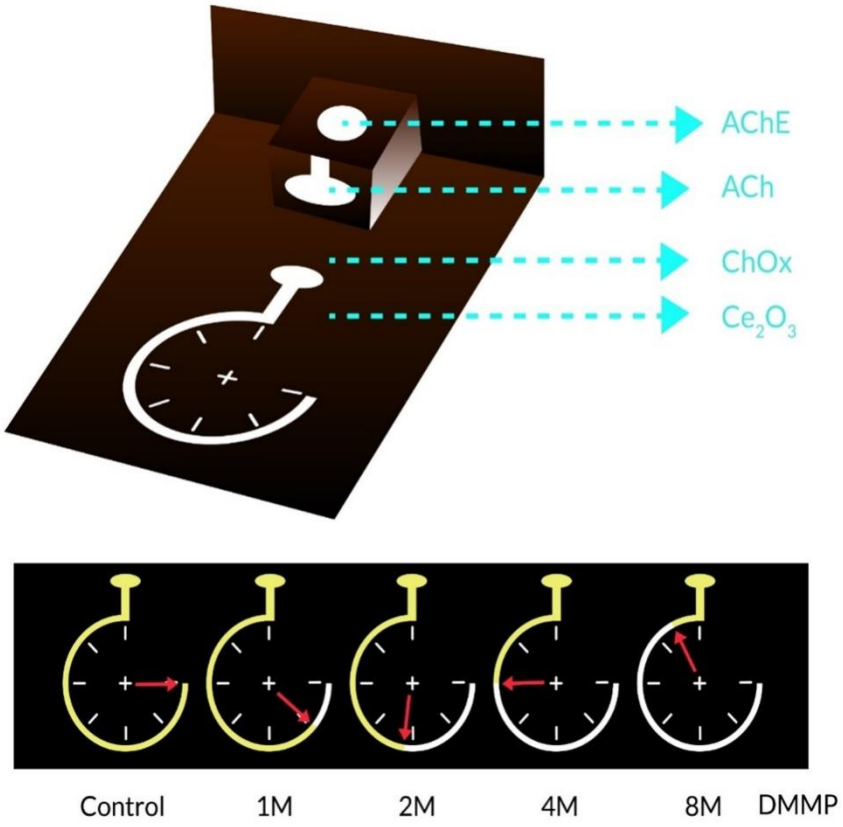

Figure 1. Colorimetric Reading of DMMP (Organophosphate) in a foldable Paper based analytical device. Different concentrations of organophosphate determined by angle at which yellow band stops.(Adapted and modified from Lee et al., 2018).

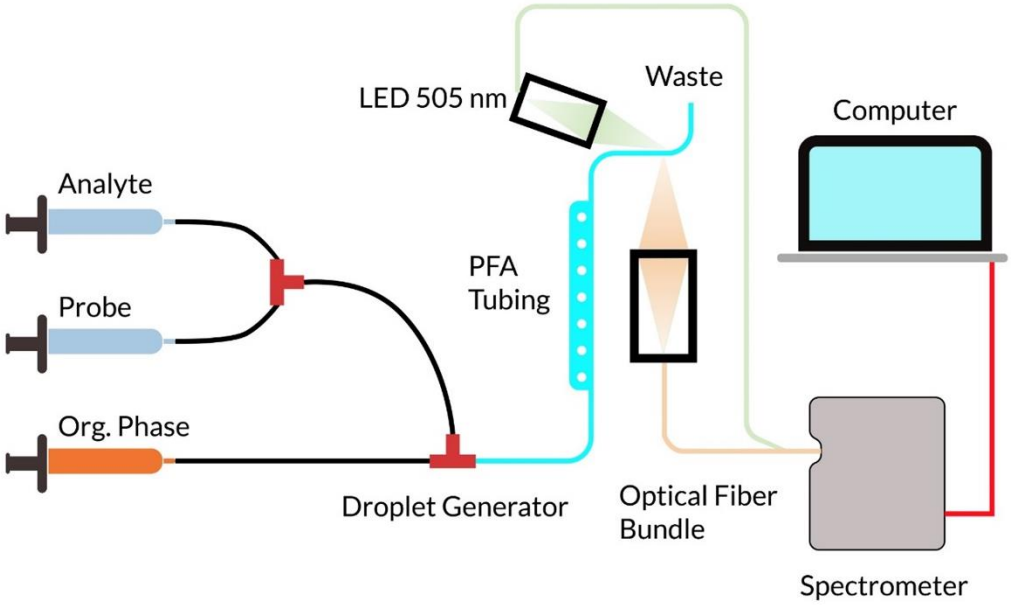

Figure 2. Droplet based Microfluidic Setup using a biphasic approach to find the presence of Hg^{2+} ions. After gated indicator is triggered by Hg^{2+}, ions in flow excited by light from LED and obtained light is fed into the Spectrograph for further analysis.(Modified and adapted from Bell et. al 2016).