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## Fluidic delivery system for in-situ naphtha detection



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### ABSTRACT

A fluidic delivery system that operates, as processing unit for naphtha sensor, has been developed to detect naphtha. It is a mixture of varied hydrocarbons, which constitute less than 1% seepage in the tailings waste that further incorporates into Mature Fine Tailings. Presently, a sample of mature fine tailings is collected and analyzed using Gas Chromatography Mass Spectrometry every 6 h to monitor its naphtha content. This conventional method of detecting naphtha is time consuming, expensive and requires trained personnel. Furthermore, it does not allow for real-time detection. To meet the demand of real-time naphtha detection in mature fine tailings, efforts were made to design and develop fluidic delivery line as processing unit for naphtha sensor. This paper presents a portable monitoring system, which would facilitate in-situ naphtha detection, and reduced manual labor, cost, among others. This prototype combines filtration unit, pumping system, heating unit and vapor storage for a compact and portable delivery system of the feed obtained from Oil Sands Tailings. The device runs in continuous mode and bears inlet tubing that can be used to draw feed into the system at any source where naphtha is to be detected.

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### Nomenclature

$D$	Hydraulic diameter of pipe
$b$	Path length of cuvette containing sample
$Re$	Reynolds number
$H_p$	Pressure head in a pump
$L$	Length of pipe
$c$	Concentration of the sample
$P$	Pressure of the pump
S.G.	Specific gravity of the sample
$H$	Hydraulic head of the sample
$z$	Elevation of the pump
$\Delta P$	Pressure loss in the pipe

### 1. Introduction

Naphtha is a mixture of low molecular weight aliphatic and aromatics, having compounds with 7–14 carbon atoms, and other low molecular

weight hydrocarbons, viz., iso-paraffins and naphthenes. It is used as a diluent in processing bitumen from oil sands. During oil sands processing, almost all of the naphtha is recovered, although a small fraction (<1%) is lost in the tailings. Since it cannot be recovered, it remains part of the mature fine tailings (MFT) (Siddique et al., 2007), where it needs to be periodically monitored to mostly check its possible leaching and subsequent environmental pollution. A significant amount of energy is lost in this process (Camp, 1976).

A regular protocol for environmental monitoring involves the manual collection of tailing samples, and analysis in an off-site laboratory. This strategy does not provide real-time data, and incurs heavy expenses in transportation, storage and installation of the sophisticated instrumentation (Ramirez-Garcia et al., 2008; Diamond et al., 2008). Periodical analysis of naphtha is important as it is expensive and a much valued component in oil industry.

Environmental monitoring has become increasingly important in recent years due to increasing concerns over industrial and urban contamination with chemical and biochemical agents. Naphtha lost to the tailings could lead to significant volumes of methane production from the MFT zones in oil sands settling basins, which could contribute to green house gas emission (Siddique et al., 2007). The microbial masses in the tailings tend to become active in a hydrocarbon-contaminated

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soil. Schneider et al. observed that a mixture of hydrocarbons—namely naphtha, diesel oil, gasoline, condensate, and fuel oil—catalyzed the microbial activity in degradation of hydrocarbon-laden soil (Schneider et al., 2006). Extensive research has been done in microbial degradation of tailings, which is elaborated elsewhere (Henrikshen et al., 2008; Rajasekar et al., 2005; Phelps and Young, 1999; Nölvak et al., 2016; Siddique et al., 2011; Penner et al., 2010; Huang et al., 2008; Wong et al., 2015). Aforementioned disadvantages of naphtha seepage into tailings demand for precise monitoring of naphtha on a real time basis.

A miniaturized analysis system allows us to perform quick analysis of samples while reducing its amount, waste storage and power requirement (Bowden et al., 2002a). The arrangement offers reliable information on the state of sample during its deployment period (Bowden et al., 2002b). The total cost of a single field analysis event was found to be approximately 18% of the total cost of sending that sample to a commercial analytical laboratory. Cost differences were correlated to variations in performance capabilities (Bagheri et al., 2014). To draw the benefits offered by a miniaturized analysis system, one such system could also be devised in detecting naphtha concentration in oil sands tailings.

Global concerns like eutrophication demands for phosphate analysis in water bodies to monitor its concentration (Manuel, 2014). Conventional way of water quality monitoring samples involved sampling, transport, storage and observation of protocols (Jordan et al., 2005). To overcome significant manpower needed and high cost associated with the conventional techniques, Cleary et al. (2010a) developed a portable sensor for the analysis of phosphate in aqueous samples that incorporated microfluidic technology, wireless communication and calorimetric detection in a compact and portable device. Fluid handling was facilitated by a sample port to collect water, and an array of solenoid pumps were used to pump the water into the microfluidic chip wherein it is allowed to mix with a reagent before delivering to the photodiode and LED for detection purpose.

McGraw et al. made a similar approach for real-time phosphate detection in natural waters using microfluidic system based on yellow vanadomolybdophosphoric acid method for detecting phosphate. The current device also incorporated filtration of the natural water, prior to phosphate detection, within the analysis system. Peristaltic pump was used to control the fluid flow into the microfluidic chip having serpentine channel that facilitated solution and reagent flow designed in such a way that it covered all the active area of photodiode detector. Wireless communication allowed for real-time data to be downloaded and saved in a remote land (McGraw et al., 2007a). Miniaturized systems were also developed to monitor other chemicals. Unlike commercially available detectors to monitor nitrite, work conducted by Beaton et al. devised a miniaturized portable system to monitor nitrite, which worked on low power and generated high-integrated performance. Syringe pumps were used to drive the liquid through the delivery tubing into Polymethylmethacrylate microfluidic chips for mixing with the reagent. The fluidic manifold incorporated a polyethersulfone filter membrane to prevent the particulate matter from entering the system. Photodiodes were housed in customized electronic package that detected nitrite in the sample (Beaton et al., 2011). Czugała et al. (2013) designed a wireless and portable microfluidic analysis system for quantitative measurements of nitrite in freshwater using Griess reagent.

In a comparative study conducted by Ziolkowski et al. on first and second generation of fluidic based chemical analyzers for monitoring nitrite, phosphate, pH, among others, it was found that the cost of first generation analyzers were almost 7 times more than the cost involved in second generation analyzers. 50% of the total cost of analyzers was that of fluid handling systems. In first generation analyzer, fluidic handling, electronics package and housing accounted for 84%, 11% and 5% respectively, whilst, it was 63%, 11% and 26% in second-generation analyzer (Ziolkowski et al., 2012).

Micropumps are indispensable in a miniaturized set-up for monitoring analyte. They help in flow controlled delivery of the samples that may range from flow rate as low as in microliters per minute to deciliters per minute. Woias et al. and Santiago et al. classified the pumps based on their pressure and flow rate of the sample. There are two types of pumps, viz., displacement micro pumps that worked

on discrete volume of fluid and continuous flow micro pumps that allowed fluid to flow continuously from the source (Woias, 2005). Based on the working principle of the pumps, Nguyen and Wereley classified the pumps as mechanical and non-mechanical micro pumps. Non-mechanical pumps devoid use of any moving parts to provide momentum to the fluid. It converts any form of energy either in kinetic energy or pressure that facilitates flow of the fluid. On the contrary, mechanical pumps use moving parts to allow fluid flow. For instance, peristaltic pumps, viscous pumps, membrane pumps, among others are mechanical pumps (Nguyen and Wereley, 2002). Mechanical pumps can be used in applications that demand high volumes of fluids, such as those used in microelectronic systems in cooling of laptops (Ma et al., 2009). On the other hand, non-mechanical pumps work well in most biochemical analyzers that require low volumes of fluid (Nguyen and Wereley, 2002).

Peristaltic pumps can be exclusively used for fluid handling. Peristaltic movement occurs when there is a contractile wave-like motion of the walls of a tube through which the liquid is flowing. This concept is used in both macro- and microenvironment. In macro peristaltic pumps, rollers are used that press flexible tube containing the fluid against them. A continuous peristaltic transport of the fluid is obtained from these pumps. On the contrary, peristaltic transport of fluid in micro environment, viz. microfluidic chip, is conveyed by incorporating actuators or more likely known as pumping steps (Berg et al., 2003).

For a sample fluid to traverse through the miniaturized analysis system, it is inevitable to make the sample devoid of particulates that can likely clog the system. Microfilters are versatile to use, however, there are many bottlenecks that one faces overtime. Depending on the feed stream, fluid components, relative filter membrane pore size and high flux of the fluid passing through the membrane, there is a possibility of large particles or aggregates to clog the pores of the membrane that leads to the formation of filter cake. Overall characteristics of filtration are, thus, governed by the formation of filter cake and their properties (Merin and Daufin, 1990). Researchers have found that most of the rejection of membranes is mainly due to size exclusion and electrostatic interactions of the fluid particles and the membrane (Yaroshchuk, 2008). Several challenges that one faces while using membranes are formation of cake; commonly called fouling, transport description of the fluid containing complex mixtures and maintenance of large pressure gradients to pump the fluid across the membrane. Membrane technology has upgraded materials used in membranes to make them flexible, resistant to fouling and more cost effective (Zhang et al., 2014). Fouling of membrane can be either internal or external in nature. External fouling is largely due to particulates settling on the filter cake while internal fouling occurs when particulates get trapped in the pores or gets adsorbed in a way to partially clog the pores. Therefore, pore size of the membrane and particle sizes in feed is important in deciding the extent and nature of fouling of the membrane (Aslam et al., 2015). Most of the miniaturized analytical system developed for monitoring chemical and biochemical analytes used membranes with pore sizes ranging from 0.25  $\mu\text{m}$  to 0.45  $\mu\text{m}$  (Glasgow et al., 2004; Cleary et al., 2010b; McGraw et al., 2007b).

Films are ubiquitous and play a crucial role in everyday processes. The study of dynamics and heat and mass exchanges in fluid films is necessary to understand these processes in a better way. Study of fluid films finds wide application in chemical industries, heat exchangers, and refrigeration, among others. Several researches have been made on the study of fluid films in heated environments. The interaction of mechanism that affects the dynamics and stability of non-uniformly heated fluid films is detailed both numerically and experimentally (Kabov, 2010). Surtaev and Pavlenko made study on transient heat transfer in a falling liquid film. They showed stepwise generation of heat within the liquid film. At the place of vapor bubble formation on the heater surface, there is a decrease in temperature in the area above which nucleation occurs. A local increase in heat transfer intensity was shown in the same area. So-called temperature waves were formed at the free surface of the liquid film at the same time (Surtaev and Pavlenko, 2014). Petkovsek et al. extensively studied temperature variation underneath the areas of growing bubble. They recorded the transient wall temperature using high-speed infrared camera and video

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