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Uric Acid Concentration-Surface Tension Level Through Reflective Intensity of Optical Fibre Sensor

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ABSTRACT

Human body fluids are regarded as desirable sources for biological markers due to the fact the altered protein expression profiles reflect the change of physiological states and cell networks of the diseased tissue/organ. Owning to several advantages including low invasiveness, low cost and rapid sample collection and processing makes the evaluation of human body fluid has become one of the most promising approaches in disease diagnosis and prognosis to discover biomarkers or reveal pathophysiological mechanisms for human disease. Surface tension is a surface characteristic that related to the forces of molecules residing at the interface. The presence of surface-active substance in biological or body fluids which adsorb at interface influences the norm surface tension value. Such the changes indicate valuable signs in medical field particularly in pathological states. Thus, in this study we demonstrate the effect of concentration towards the surface tension by employing the concept of light reflective intensity modulation as a function of displacement since the meniscus formation is one of surface tension characteristics. A key reference parameter for examining 0 mg/dl – 10 mg/dl of uric acid was evaluated. It is found that the fingerprint of each sample has two maximum output voltages located at approximately two stable positions. The surface tension value decreases from 71.849 mN/m to 70.238 mN/m in the change of 0 ppm to 500 ppm with deviation of 2.6 V to 3.5 V.

1. Introduction

Surface tension, σ is a one of liquid parameter residing at surface or interface. It is cohesive force of molecules which is dependent on many variables for instance temperature, composition of the solution, the presence of impurities in fluid measurement time, materials of the apparatus and the viscosity of the fluid itself [1,2]. Previous researchers claimed that surface tension has its own potential interest in medical area. The changes in surface tension of human biological fluids might be a vital sign to pathological disorder which correlates to the development of diseases. Exploration on

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surface tension of human biological fluids began early nineteen whereby the changes in surface tension of several body fluids had reported some information on disease characteristics and abnormality such as in saliva, blood, urine and airways [3-7] which are able to distinguish caries, presence of bile salt, thermal body effect and respiratory disease of infant's airways. This creates a new level of knowledge to the concept of surface tension might be useful to be implemented as a diagnostic tool since this parameter's data are helpful in providing additional information in medical practice and its values could aid in differentiating health condition. To date, surface tension concept has been applied in many biological fields such as disease diagnosis and treatment, blood compatibility, biomaterial implant and even in biosensor [8,9]. Conventionally, surface tension measurement has been carried out by direct measurement by force sensor, the study of drop [10,11], the capillary force and pressure analysis [12,13].

Researchers had employed optical fibre as probe for surface tension measurement such as fibre-dipping capacitive drop method to analyse drop shape formation [14], low-coherence interferometer that formed from a spliced fibre for monitoring the phase shifting of hanging droplet [15] and the diffraction of light on capillary wave [16] that acts as reflective grating resulting the formation of interference patterns at which the surface tension is obtained by applying the dispersion equation. Besides, complicated dipping and splicing of fibre system like Fabry-Perot sensor required surface tension determination through monitoring the interference signals that implying the changes in drop height and wavelength spacing respectively [17,18]. All these integrated optical sensors had encountered problem like required sensor-liquid need to be contact as the fibre had to be dipped and spliced and they tend to damage the fibre's probe.

Previous fibre optic displacement sensor system that utilized transmission scheme [19,20] and reflectance scheme [21-23] towards Pb^{2+} [24], hydrogen peroxide in low fat and full cream milk [25] has made an interest into this study. Few studies regarding refractive index based optical fibre sensor have conducted [26,27]. However, some modifications have to be made in order to fit in the need for future surface tension application. In addition, the employment of optical method in technology nowadays facilitates the measurement of surface tension due to the role of optics has been widely used as a powerful catalyst for sensing application in understanding light behaviour and manipulation especially in revealing subtle changes in surface tension through several techniques for instances in capillary waves [16,28], interferometry [15,18,29] and drop formation [14,17].

Thus, in this paper a non-contact fibre optic sensor is demonstrated based on curve reflectivity concept verified by displacement to calibrate uric acid concentration-surface tension relationship in between 0 ppm to 500 ppm. A light source from laser diode is launched into the bundled fibre and directed to a region where the light interacts with the uric acid liquid surface in a cuvette. The meniscus surface behaves as a curved mirror as an evidence of surface tension. This interaction results in a modulation of optical intensity and change in the shape of response curve.

1.1 Theory

Theoretically, surface tension is measured in millinewtons (mN/m) or dynes per centimetre (dynes/cm). Interfaces has different characteristics of matter from that in the bulk of the media. The former is influenced by a net of downward force due to absence of molecules at the surface whereas the latter is attracted equally and the net force is balanced [30,31]. A simple equation relates surface tension, σ to the force, F acting perpendicular to the surface divided by the length, L of the surface can be given as in Eq. (1):

$$\sigma = \frac{F}{L} \quad (1)$$

In the case of composition dependency, surface tension is affected by composition of solutes which it depends on the nature of the surface and the solute. Gibbs isotherm explained the changes in concentration of a component in contact with a surface to the changes in surface tension can be expressed by Eq. (2):

$$\Gamma = -\left(\frac{d\sigma}{dC}\right)\left(\frac{C}{RT}\right) \tag{2}$$

Where σ is the surface tension of the solution, *Γ* is the excess concentration of the solute on the surface, *C* is the concentration of the solute in solution, *R* is the gas constant and *T* is the temperature in *K*. This equation shows that there is an exact relationship between change in surface tension of solvent due to presence of solute. Moreover, for a given temperature, the relationship between surface tension and acid concentration [32] can be related through Eq. (3):

$$\sigma^* = \frac{\sigma_2-\sigma}{\sigma_2-\sigma_1} = \left(1+\frac{ax_2}{1-bx_2}\right)x_1 \tag{3}$$

Where σ^*, $\sigma_2$and σ_1 are the dimensionless surface tension, surface tension of pure water and pure acid respectively, x_2 and x_1 are the mole fraction of water and acid and a and b are linear functions of temperature for each acid. Changes in surface tension from higher to lower is caused by the addition of acid concentration which influence the mole fraction of the solution; thus, surface tension is decreases with increase of mole fraction. Other than that, since the formation of meniscus is a surface tension characteristic, Young equation related the surface tension to the contact angle at which the value of contact angle determines the curvature of the meniscus. The equation indicates when θ=90°, the meniscus is flat; when θ<90°, the meniscus is curved upward; and when θ>90°, the meniscus is curved downwards [33]. Due to difference in contact angle, the curvature differed. Therefore, the formation of meniscus has a relationship with the surface tension and contact angle. Young equation is given as in Eq. (4):

$$\sigma_{lv}\ \cos\theta = \sigma_{sv} - \sigma_{sl} \tag{4}$$

Where σ_{lv}, σ_{sl} and σ_{sv} are the liquid–vapor contact line to the surface tension of the liquid, the solid–liquid and solid–vapor interfacial tension, respectively. Apart from influenced by the contact angle value, the meniscus liquid surface has a capability to reflect the light [34,35] through reflection principle. Hence, the application of optical method for the concentration-surface tension measurement is possible due to formation of meniscus is related to surface tension and the ability of curved liquid to reflect light can be used further to study surface tension.

1.2 Uric Acid

Uric acid is the final oxidation product of purine metabolism. Elevation in uric acid level causes deposition of monosodium urate (MSU) crystals [36]. Synthesis of uric acid occurs mainly in the liver, intestines and other tissues. Living and dying cells degrade their nucleic acids through deamination and dephosphorylation to form uric acid [37]. The most well know disease connected with uric acid is gout. Usually, a gout attack happens when there is a sudden rise in uric acid level. The gout becomes chronic when urate crystals deposit in various tissues such as joints, connective tissue and kidneys [38]. Clinically, gout undergoes four stages starting with asymptomatic hyperuricemia, acute gouty attack, intercritical period and chronic tophaceous gout. Meanwhile, diagnosis is done based on laboratory feature through identification of characteristic MSU crystals in the synovial fluid by using polarized light microscopy and radiological feature, non-invasive imaging scans to diagnose including conventional radiography, ultrasonography, conventional CT, Dual-Energy CT, Magnetic Resonance Imaging, nuclear scintigraphy and positron emission tomography [15]. It is known that the uric acid level can be controlled and treated by taking medication if the condition is still mild and acute. However, for a long term treatment, it is advisable to modify the life dietary for preventing further attacks including limit the consumption of purine-rich [39-41]. Normal concentration range of uric acid falls in between 0.15-0.45 mmol/L for blood cited by Uric Acid Level Charts Introduction [42] and 1.5 to 6.0 mg/dL in women and 2.5 to 7.0 mg/dL in men as mentioned by Maiuolo *et al.,* [36]. However, ranges could be varied from lab to lab due to overlapping among results from different health status since reference values are merely based on statistical and experimental data. Thus, the concentration level plays a crucial role in preliminary diagnosis because other parameter as well such as surface tension might be affected.

In this present work, fibre optic sensor through reflective intensity modulation system is employed to study the effect of different level concentration on surface tension in uric acid. Light intensity modulation technique can be effectively employed as a diagnostic tool by providing the calibration curve of the surface tension parameter. The light-path of optical fibre-based displacement sensor runs directly with almost no air obstruction through the surface of the sample liquid. The optical characteristics earns by the sensor system are therefore contingent upon the various types of the sample surface (uric acid), which may be flat or curved, depending on meniscus present at the air–liquid interface. The study of surface tension can be used not only for understanding the biological nature of the disease, but also for the diagnosis purpose in biological fluids depending on their concentration level.

2. Methodology

Uric acid solution was prepared by dissolving uric acid solute powder into distilled water for 0 ppm to 500 ppm. Figure 1 illustrates the optimized fibre sensor system [43] to study the potential role of uric acid surface tension based on its medical concentration level. Laser diode with 650 nm wavelength was coupled to concentric bundled fibre probe. The meniscus formed in cuvette was an evidence of surface tension effect. The surface tension value for each uric acid concentration was measured at a resolution of 0.001 mN/m tensiometer. The reflected light from the meniscus then collected by 16 receiving fibres that maximize the amount of light collected due to its concentric arrangement surrounding the transmitting fibre. Silicon detector (DET100A2, Thorlabs) was chosen to detect the light collected based on its high-speed detection and also optical response extends from 320 nm to 1100 nm for optimum transmission.

By using automated displacement controller which monitored by a computer, a precise displacement of 40 mm for fibre probe was taken and the probe was shifted away from the meniscus yielding a response of light behaviour. There were two reference points of the probe shift; the position of the fibre probe must be as close as to the meniscus and precisely located in the middle on the main axis. The captured light response was evaluated by an oscilloscope in order to obtain the important data from each concentration.

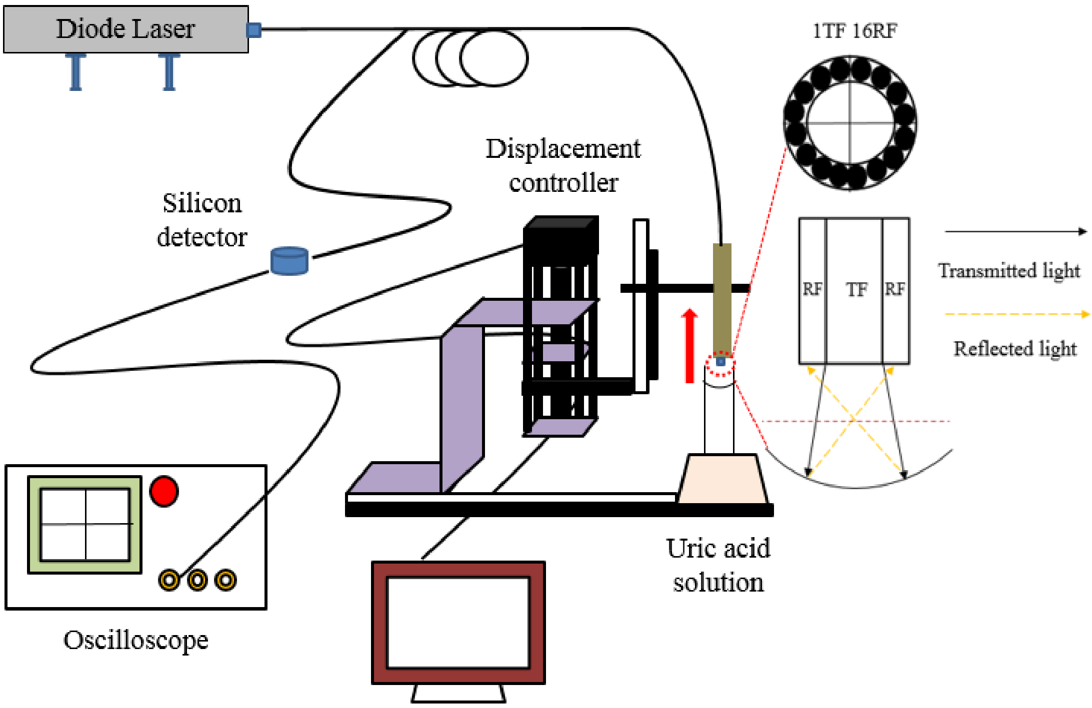

Fig. 1. Experimental setup

3. Results

Each response factor plotted in Figure 2 indicates the relationship between concentration and surface tension of uric acid. There is an inverse relationship with linearity more than 99% suggesting the dependency is quite strong between them. The value of surface tension keeps on decreasing as the concentration increases probably due to the increasing number of moles in each concentration. High percentage of mole bring about a change in surface energy of the uric acid solution, hence lowering its surface tension by minimizing its surface energy as represented in Eq. (2) and Eq. (3). It can be concluded that the different concentration level of uric acid influences the curvature of surface tension. Moreover, it is noteworthy to denote the focused square region in Figure 2 as it implies indirect trendline between concentration-surface tension for uric acid calibration curve to be utilized by any sensor instrument as their diagnostics tool.

The diagnosis level is divided into four states in accordance to the amount of uric acid in human body as shown in Table 1 and the range is taken based on statistical data [42].

Table 1
General medical range of uric acid in human body

Diagnosis	Concentration (mg/dl)	Concentration (ppm)
Danger	Over 7	Over 70
Warning	6 – 7	60 - 70
Good	5 – 6	50 - 60
Safe	5 or less	50 or less

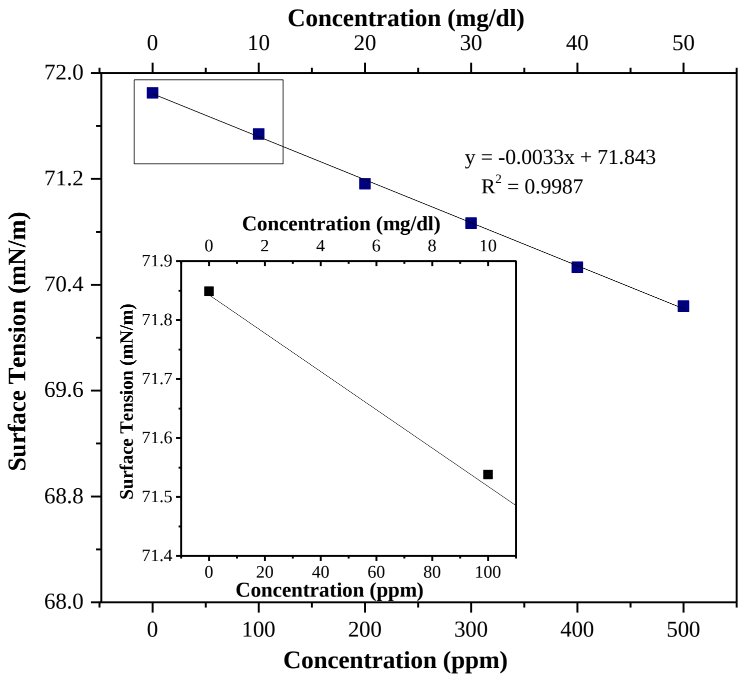

Fig. 2. Relationship between concentration and surface tension of uric acid

Figure 3 depicts the response curve of output voltage against displacement for the study of various uric acid surface tension. The displacement curve exhibits a dip like-shaped along 40 mm with two maximum output voltages located at different position. The shape of the curve is regarded as an indicator for meniscus characteristics and it has a similar response as concave based displacement sensor [44]. It could be inferred that the meniscus is in concave-shaped when it is experiencing the phenomenon of surface tension. From the graph, the output voltage is low when the displacement is small due to the close position between the probe and the meniscus allowing only a small amount of light entering the receiving fibre. When the displacement increases, the output voltage increases rapidly due to the light cone from transmitting fibre overlaps with the receiving fibre's core subsequently leading to a first peak voltage when the overlapping becomes maximum. However, the output voltage drops after further increment in displacement as it obeys the inverse square law and comes to a dip space called local minima. This is probably due location of the virtual point source makes a distance with the probe. After passing through that point, the second peak voltage is reached because the output voltage is rises up again and eventually declines obeying the law as the displacement is getting far from the meniscus. The light source becomes weak and far resulting a collection of less power detected.

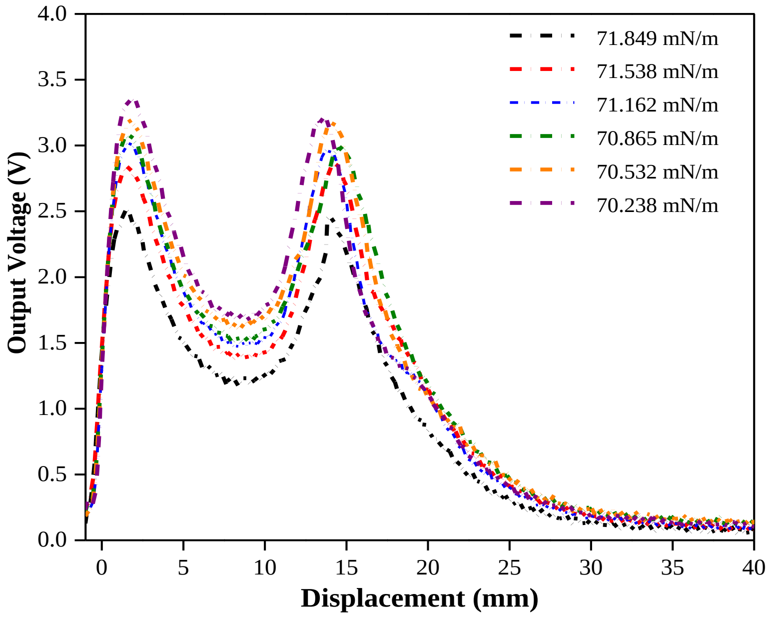

Fig. 3. Output voltage against displacement for various uric acid surface tension

The peak voltage from each response curve of uric acid solution is plotted against its respective surface tension as shown in Figure 4.

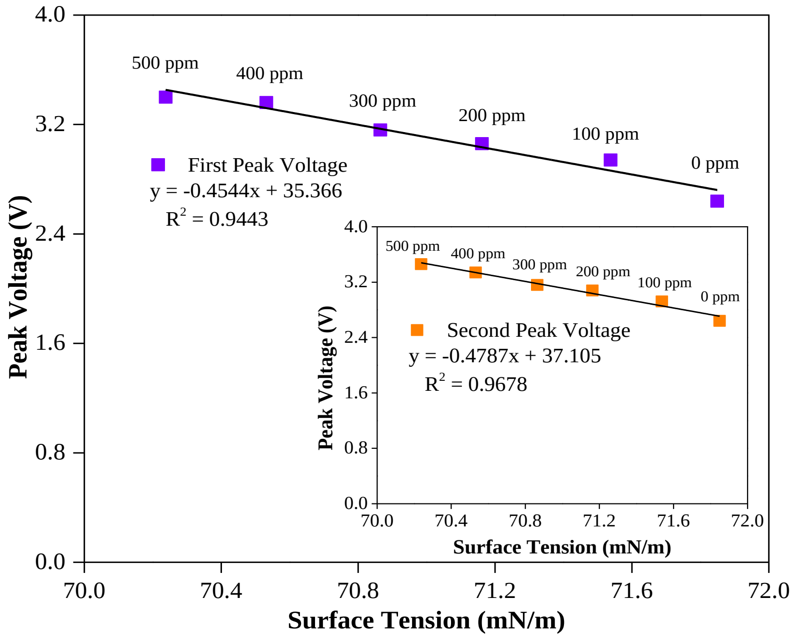

Fig. 4. Variation of peak voltage with concentration-surface tension information

Meanwhile the reaction for different level concentration of uric acid according to the peak voltages of displacement response curve are shown in Table 2. It can be seen that sensitivity of 0.4544 V/mN/m and 0.4787 V/mN/m with linearity more than 97% and 95% is achieved for first and second peak voltage respectively which are determined by the slopes. The close in sensitivity for first peak to second peak denotes that both peak voltages are implication of curve reflection. This infers that both peak voltages are beneficial indicator for the sensor calibration curve whereby they are stable and located at a nearly fixed position with a good linearity. Moreover, the sensor exhibits a low detection limit of 0.055 mN/m and 0.053 mN/m indicating that it could works efficiently in detecting uric acid level in human body and applicable to be a potential sensor for medical application concerning the issue of uric acid related diseases.

Table 2
Information of the uric acid and the peak voltages of displacement curve

Part per million (ppm)	Concentration of uric acid (mg/dl)	Surface tension (mN/m)	Peak voltage (V)	
			First	Second
0	0	71.849	2.64	2.64
100	10	71.538	2.94	2.92
200	20	71.162	3.06	3.08
300	30	70.865	3.16	3.16
400	40	70.532	3.36	3.34
500	50	70.238	3.40	3.46

In addition, sensor performance of uric acid based on surface tension is tabulated in Table 3.

Table 3
Sensor performance of uric acid based on surface tension

Parameter	Peak Voltage (V)	
	First Peak Voltage	Second Peak Voltage
Sensitivity (V/mN/m)	0.4544	0.4787
Range (mN/m)	71.849 -70.238	
Linearity (%)	> 97	> 98
Limit of detection (mN/m)	0.055	0.053

Figure 5 represent the variation of first and second peak voltage response towards surface tension, while the close-up region pertaining information of uric acid medical range in between 0 ppm (0 mg/dl) - 100 ppm (10 mg/dl) respectively. Both first and second peak voltage is declining in trend with every increment of surface tension. It decreases from 71.849 mN/m to 71.538 mN/m in the change of 0 ppm to 100 ppm shows that when there even have small changes in the concentration, the surface tension in that range capable to be evaluated. The intention focusing in the region is to emphasize that there is a probability to develop a sensor that able to different diagnosis level by merely looking at its concentration-surface tension relationship through meniscus characteristics and to obtain a better understanding of pathological diseases behaviour from surface tension approach. Therefore, it is possible for even slightest difference in concentration to have their own surface value and it can be concluded that surface tension has a good potential role in determining the level of diagnosis based on medical reference.

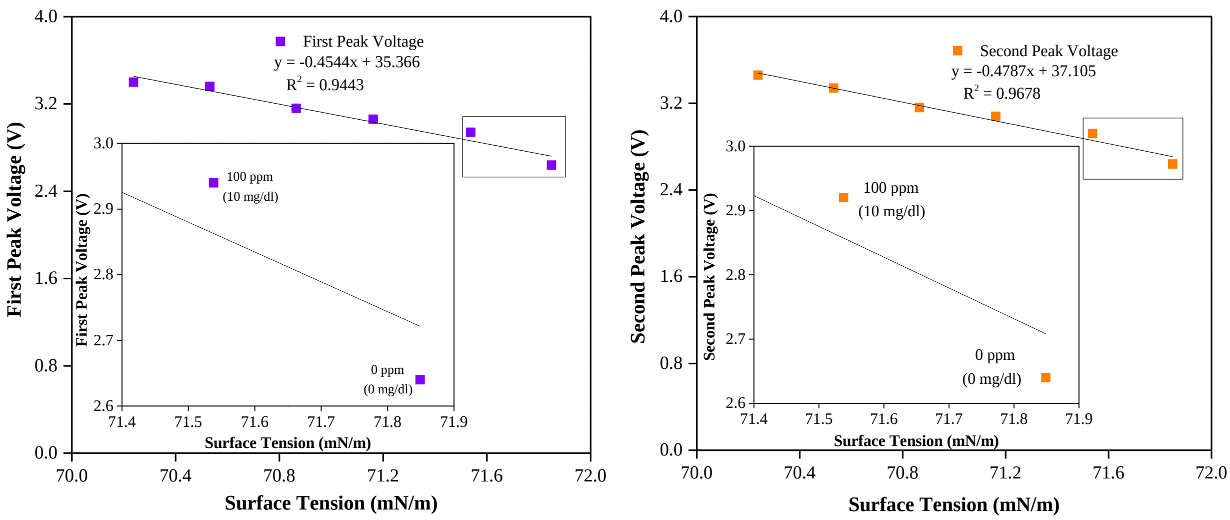

Fig. 5. Standard curve voltage with surface tension-concentration information for (a) First peak (b) Second peak

4. Conclusions

A simple intensity modulated displacement sensor is demonstrated as a device to study the potential of surface tension parameter for medical application. The displacement curves exhibit two maximum peaks and the experimental results show that the peak voltages are increases linearly with the concentration, but inversely in surface tension value. The sensitivity is measured to be around 0.4544 V/mN/m and 0.4787 V/mN/m respectively when the uric acid concentration is varied from 0 ppm to 500 ppm at which the region of 0 ppm to 100 ppm has a change in surface tension value of 71.849 mN/m to 71.538 mN/m. The experiment envisions those studies on the surface tension behaviour of human biological fluids has its added values in medical practice. This finding might be beneficial for many applications especially in biomedical sensor such as detecting uric acid level in biological fluids.

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