CHAPTER VI

6. CONCLUSION AND FUTURESCOPE

This thesis reports a method to calculate the viscosity of test samples using a simple y-shaped microfluidic device. Both the test fluid and the reference fluid are made to flow in a rectangular micro-channel under the influence of a fixed flow rate. The concentration dependent viscosity of the sample can be found out based on the increase or decrease of width occupancy inside the microfluidic channel. The viscosity of the fluid is then estimated using the modified Hagen Poiseuille’s law which needs the width occupied by the fluids flowing in the channel as an input. This method has been shown to do real-time detection and monitoring of adulteration in several fluids like milk, diesel, petrol, etc.

The experimental analysis was performed for three different applications. The test samples were run in the optofluidic microviscometer and a more conventional Anton Parr rheometer to determine the accuracy and precision of the 3D printed device. A method was devised to determine the biodiesel blend based on the percentage of micro-channel occupancy by each of the biodiesel blends ranging from B20 to B100. The device was then used to test the variation in the viscosity of milk upon the addition of four typically used adulterants namely water, flour, starch and urea. Ratios ranging from 5% to 95% was tested in the case of water. Ratios ranging from 0.5% to 10% was tested for the solid adulterants. The percentage of adulteration was derived based on the inputs from local milk producers in the city of Dehradun. The linear equations obtained during the testing could be used to determine the ratio of adulteration in milk based on the width occupancy in the channel. Further, the device was also used to test the dynamic variation of the viscosity in fuels. Petrol, diesel and kerosene was tested in varying combinations namely diesel in petrol, kerosene in petrol, kerosene in
diesel and a mixture of all the three. There were minute but marked variations in the viscosity of the fuel samples upon addition of an adulterant. The device was effective in determining the viscosity of all the test samples in close correspondence to the results obtained using a standard rheometer. Regression analysis was performed to the data obtained from all the three types of experiments. In case of miscible fluids, regression analysis showed parabolic behavior, whereas in case of immiscible fluids, the behavior was found to be linear as derived in the theoretical model.

This lab-on-a-chip (LOC) device was initially fabricated using the conventional micromachining technique wherein limitations like tool size, leakage, need of an experienced operator and complicated designing was encountered. With the advent of the rapid prototyping techniques, the fabrication of the device became cost-effective and simple. The microviscometer was then fabricated by the stereolithography based 3D printing technique using an UV curable acrylic polymer. Once the device design was ready, the entire process of fabrication took less than ten minutes. The 3D printing method of fabrication gave a device which was durable, strong with accurate dimensions and leakage free operation. The embedded microchannels removed the necessity of an extra sheet of acrylic as in the case of micromachining. The device was found to be re-usable, could be re-calibrated and further made into a plug-n-play scheme for its use in different applications.

3D printed microfluidics could be the next step towards flawless bio-medical devices with numerous application ranging from blood coagulation, blood sampling to PT-INR measurement. In the future scope, an electronic version of the microviscometer will be explored which will work on the similar principle i.e. for any fluid, time required to travel a unit distance in a micro-channel, of a given cross-section, is inversely proportional to its viscosity. There will be no reference fluid required for such a device and its electrical output can have higher
possibilities of integration with other integrated control systems. This electronic version of the microviscometer can also be modified for other applications like food adulteration and hemoglobin detection in blood.

The device design for such a prototype would have a straight channel with a side-channel for flushing (to be closed during operation) as shown in figure 6.1 (a). In the main channel, electrodes could be placed along the y-axis at pre-determined locations with known distances of separation. A counter electrode along the main channel will generate a signal upon fluid flow. This will be due to the flow of fluid between the counter electrode and the various y-axis electrodes. A microcontroller and data acquisition system could be incorporated to record the signal generated by the passing of fluid at various positions of the y-axis electrodes in real-time mode. A 3D printed design of the electronic version has been done as shown in figure 6.1 (b) and the electronic circuitry will be the subsequent step forward.

![Figure 6.1 (a) Electronic Microviscometer Concept (b) 3D Printed Device](image)

Therefore, the viscosity of the fluid flowing in the main channel can be determined by the Hagen-Poiseuille flow equation, considering ‘L’ as length between two y-axis electrodes.
\[ \mu = \frac{w^2 \Delta P}{2v_m L} = \frac{w^2 \Delta P \Delta t}{2L^2} \quad (26) \]

As we know 'w' (width of the channel in mm), ‘ΔP’ (difference in pressure between the inlet and outlet channels in Pascals), and ‘Δt’ (time difference to cover the distance ‘L’), we can measure the viscosity.