STUDY OF MIXING IN MINIATURIZED INTENSIFIED REACTOR (MIR)

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STUDY OF MIXING IN MINIATURIZED INTENSIFIED REACTOR (MIR)

by

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Gopinathan A/L Subramaniam.

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LIST OF ABBREVIATIONS

MIR	Miniaturized Intensified Reactor
CSTR	Continuous stirred tank
ID	Internal diameter
nm	Nano meter
Re	Reynold number

LIST OF SYMBOLS

Symbol	Descriptions	Units
X^2	The diffusion of a species in a surrounding fluid	m^2
D	length of complete mixing in a fluid	m^2/s
t	Time	s
I	Segregation intensity	
σ^2	mean square deviation of the concentration profile of the component i in a cross section	
$\sigma^2 max$	mean square deviation of the concentration profile of the component i in a cross section at maximum	
Re	Reynolds number	
ρ	density of fluid	Kg/m^3
u	velocity of fluid	m/s^1
h	height of the equipment	m
μ	dynamic viscosity	m^2/s
A	Absorbance	L/mol.m
I_0	Intensity of light before it enters the sample	
I	Intensity of light, that has passed a sample (transmitted light)	
OD	Optical density	L/mol
L	Thickness of sample	m

ABSTRAK

Percampuran dalam industri adalah satu proses biasa yang membantu proses pemindahan haba, tindak balas kimia dan proses pemindahan jisim. Proses pencampuran adalah satu proses yang sangat penting untuk memastikan kualiti produk akhir akan ditentukan oleh kualiti campuran. Proses pencampuran dalam bidang kejuruteraan kimia adalah berkembang dan digunakan secara meluas di mana penggunaan peranti mikrofluidic telah dinaik taraf kepada skala pengeluaran. Salah satu kaedah penting dalam teknologi mikroreaktor ialah pemindahan jisim yang menawarkan manfaat yang berpotensi untuk masa depan kejuruteraan kimia kerana mikrorektor meningkatkan kadar pemindahan, dan meningkatkan keselamatan. Berhubung dengan proses pembesaran mikroreaktor, ia juga menumpukan pada kinetik kimia dan pengangkutan dalam mikro-peranti yang lebih cepat daripada mixer konvensional. Untuk mengeksploitasi potensi yang dihasilkan, tingkah laku pencampuran mixers aliran mikro-skala perlu diteliti lebih lanjut. Dalam karya ini, eksperimen yang dijalankan untuk kadar aliran masuk yang berbeza dan pengukuran kuantiti terhadap kualiti pencampuran Keputusan memberi sedikit sokongan fenomena pengangkutan di pencampuran yang berlaku di saluran mikro itu. Keputusan menunjukkan bahawa geometri mikroaktor mempunyai kesan penting kepada prestasi pencampuran. Y-bentuk menggunakan halaju masuk yang rendah dan 0 mm panjang percampuran menyebabkan lebih cepat proses pencampuran. Mikrosaluran berbentuk Y menunjukkan kualiti pencampuran lebih baik daripada saluran mikro berbentuk T.

ABSTRACT

Mixing in industrial is a common process which helps the process of heat transfer, chemical reaction and mass transfer process. Mixing process is a very important process to make sure the quality of the final product will be derived by that quality of the mix. Application of mixing process intensification in chemical engineering area is growing and widely used where the use of microfluidic devices has already been upgraded to production scale. An essential method of process intensification which are microreactor technology, offers potential benefits to the future of chemical engineering due to the well-defined high specific interfacial area available for heat and mass transfer, which increases transfer rates, and enhances safety resulting from low hold-ups. In relation to the time-scale of chemical kinetics, diffusive transport in micro-devices is faster than in conventional mixers. To exploit the resulting potential, the mixing behavior of flow mixers on micro-scales needs to be further investigated. In this work, experiment conducted for different inlet flowrate and absorbance measurement towards the mixing quality The results provide some support of transport phenomena on mixing that occurred in the microchannel. The results demonstrated that inlet geometry has significance effects on the mixing performance. Y-shape uses low inlet velocity and 0 mm mixing length resulted in faster mixing process. Y-shaped microchannel shows better mixing quality than T-shaped microchannel.

CHAPTER ONE

INTRODUCTION

1.1 Research Background

Mixing in industry is a common process which helps the process of heat transfer, chemical reaction or separation process. Mixing process is a very important process to make sure the quality of the final product will be derived by that quality of the mix. It is known that product consistency depends on quality of mixing. There are different process of mixing and there are ever increasing industrial mixing processes. when it comes to industrial applications which need careful selection and design to make sure that there is effective and efficient mixing (Ottino, 1990). Mixing of complex liquids at low Reynolds number is basic for a wide scope of uses, including materials gathering, microfluidics and, biomedical gadgets. The yield stress of liquids represents the most critical difficulties, particularly when they must be mixed in low volumes over short timescales. New scaling connections between mixer measurements and operation conditions are determined and tentatively checked to make a structure for outlining dynamic microfluidic mixing that can proficiently homogenize (Ober et al, 2015).

In mixing, continuous and batch are two modes of mixing operation. In batch operation, all ingredients are loaded into the mixer together or in a pre-defined sequence, and mixed until a homogenous material is produced and discharged from the mixer in a single lot. The continuous mixer on the other hand is generally dedicated to a single high volume product. Ingredients are continuously charged into the mixer in accordance with the formulation.

The mixing takes place as the material travels from the charging port to the discharge nozzle, from where it is continuously discharged (Manas-Zloczower, 1994).

There are two type of mixing which is passive and active mixing. A simple and operate with no moving parts, but their mixing efficiency is strongly depending on flow rate and geometry is known as passive mixing. This active mixing is typically applied for low-viscosity fluids containing diffusive species, such as colloidal particles (Ober et.al, 2015). A simple and operate with moving parts, but their mixing efficiency is strongly depending on flow rate and geometry is known as active mixing. Typically for active mixing there will be a micromixer added for high viscous fluid for better mixing quality (Meijer et.al., 2009).

The modern technology leads to shrinking in tools which is known as micro technology. The micro reactor is a contribution of micro technology and used for micro mixing. Micro mixing is the last stage in the very complex process of turbulent mixing and concerned with those features of mixing that cause the attainment of homogeneity on the molecular level. It is well known that micro mixing plays a very crucial role in the chemical industry because complex chemical dynamics can be altered while the time scale of the chemical reaction involved is comparable with that of the mixing process. Micro reactor provides an optimum condition for accelerating mass transfer and heat transfer rates compared to large scale reactors (Gao et.al., 2015). The micro mixing is also dependent on the geometry and the operating condition of the micro reactor (Krupa et.al., 2012) .

In microfluidic system, the designation refers to characteristics length that are in the range of micrometre. A substantial impact of this little measurement is that liquid properties turn out to be progressively controlled by viscous force rather than inertia. In other context, the decreased measurements of the microfluidic system lead to a large surface-to-volume proportion which lead to an increase heat and mass transfer efficiencies (Mansur et.al., 2008).

Mixing in microfluidic systems begins solely from standard periodical concentration profiles with steep gradient, which is administered by sub-atomic diffusion proceeding in deformed fluid elements. Disfigurement diminishes segregation scales in a blend, produces contact surface between blended materials and maintains high local concentration gradient (Mansur et.al., 2008).

Furthermore, the technique of absorbance is as old as the first alchemists. They sought to identify and understand their elixirs by looking at the colour and opacity of solutions as different reagents were mixed, heated, and stirred. Today it remains the most widely used spectroscopic technique for studying liquids and gases due to its simplicity, accuracy, and ease of use. An absorbance spectrum can be used as a qualitative tool to identify or "fingerprint" substances, or as a quantitative tool to measure the concentration of a molecule in solution.

The most common image of an absorbance measurement is a solution in a cuvette, measured in transmission with a dual-beam spectrometer – the classic introductory chemistry lab experiment(D.L.TIMMA, 1952). In practice, however, absorbance measurements can take many forms. They work equally well for gases as for liquids, and have found their way into consumer products and industrial applications alike. Samples no longer need to fit into the standard 1 cm path length cuvette, as Z-flow cells allow the sampling optic to be measure the absorbance of sample. Spectra suite spectrometer software is an absorbance measurement in Z-flow cell.(Ornet, 2015)

1.2 Problem statement

Conventionally the common type of reactor used for mixing is continuous stirred reactor (CSTR) and continuous flow reactor. The mixing in CSTR normally homogenous mixing and always assumed as well mixed. Commonly the mixing in conventional CSTR

is not well mixed which will give impact on product quality. A good mixing is needed to obtain the desired product. Microreactors are small reactors which have higher mass transfer rate than conventional reactors, and have tendency of better mixing performance. Since microreactors are smaller the visualization of mixing performance is easier. The usage of transparent microreactor is to visualize the mixing quality of two different minor colours to obtain a primary colour. Inlet angle also plays a major role in mixing performance. A better inlet angle need to be identified to minimise the use of energy and maximize the mixing quality. In this experiment, the mixing quality of microreactor is studied by using different type of inlet geometry which are T- and Y-shaped inlet. For both type of inlet, the flowrate is varied to study mixing quality and mixing length. Two different colours of food dye which are used for mixing are blue and yellow. Mixing of the blue and yellow colour will result green colour. The well mixed green colour will have a constant absorbance or concentration. To justify the mixing quality of measured length, the spectra suite spectrometer analysis can be conducted to measure absorbance or concentration .

1.3 Research objectives

i. To study the effect of inlet geometry for better mixing.

ii. To investigate the effect of varying inlet flowrate towards mixing quality in a microfluidic channel.

iii. To investigate and visualize accurately the mixing performance of MIR using spectra suite spectrometer absorbance measurement.

CHAPTER TWO

LITERATURE REVIEW

This chapter encompasses reviews on previous work done on mixing principles in MIR, mixing characteristics, mixing behaviour in MIR and absorbance measurement via spectra suite spectrometer analysis.

2.1 Mixing Principles in miniaturized intensified reactor(MIR).

Micro or miniaturized reactors is basically small in size where the process, reaction or separation happens in its microfluidic streams. This small size channels permits heat and mass transfers within short length. The shorter length provides higher transfer rate which is known as diffusive mass transfer with the mean transport length from the equation (Mayinger, 2007).

$$x^2 = 2\,Dt \qquad (2.1)$$

Where,

x^2 =The diffusion of a species in a surrounding fluid, m^2

D = length of complete mixing in a fluid, m^2/s

t = time, s

For transport length by diffusive mixing in gases the range of D values are from 10^{-5} to 10^{-6} m^2/s and for liquids with low viscosity the given range of D values are from 10^{-9} to10^{-10} m^2/s is displayed over the corresponding time in Figure 2.1. Conventional equipment has typical geometries in the range of centimeters and produces fluid structures in the range from 100 μm to 1 mm. The corresponding diffusion time is in gases slower than approximation. 1 ms and in liquids in the range of 1 s. Microstructured devices with typical length scales from 100 μm to 1 mm provide fluid structures with length scales of

approximation. 1 µm. These small fluid structures lead to mixing times shorter than 100 µs in gases and approximation. 1 ms in liquids. This is the main reason for the enhanced selectivity and high yield of chemical reactions in microreactors

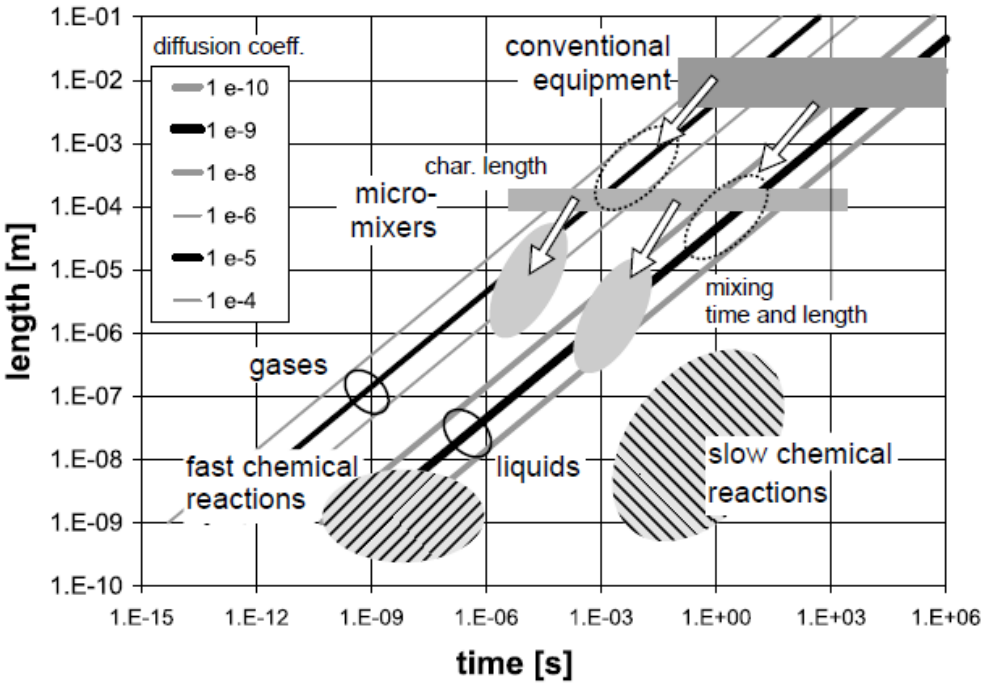


Figure 2.1: Characteristic length and time scales for mixing in microstructure devices together with chemical reactions

The residence time is another factor which also known as period of process occur or time taken to complete a process. The shorter length of process indicates the good or faster characteristic of transport of fluid in a system.

Moreover, Figure 2.2 depicts main mixing principles for microfluidic devices. Repeated folding and stretching in a mixing length is a distributive mixing and dependent on lamellae width. Decrease in lamella width in a fluid mixing length is an accelerated and stretched fluid flow. Figure 2.2 also discussed on some mixer types and applications however, the amount investigated is much larger. (Hessel, Hardt and Löwe, 2004). The typical length scale for mixing depends on the repetition rate of folding or stretching.

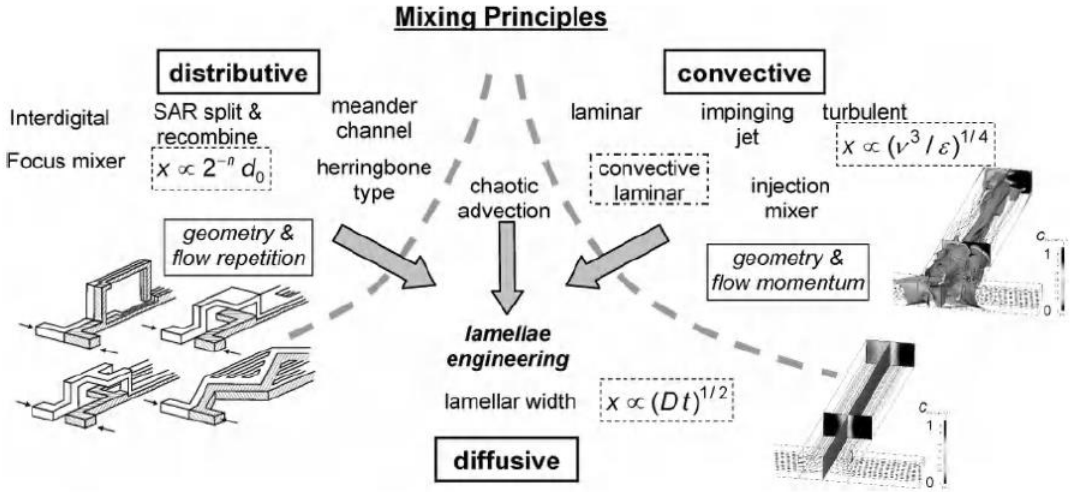


Figure 2.2: Mixing principles for microfluidic devices.

As stated (Mayinger, 2007), convective mixing is study of fluid dynamics of convective fluid motion where the flow velocities are relatively high and lead to *Re* numbers from approx. 10 to 1 000. For liquid and gas the w range from approx. $0.1 < w < 10$ m/s and $1 < w < 50$ m/s respectively. Momentum forces plays an important role at this range of velocity where vortices appear in curved flow, and transient flow regimes may arise, but in long straight channels, the flow relaminarizes again and leads to straight, undisturbed streamlines. The channel geometry is determined by the micro fabrication process which produces vertical walls and rectangular cross sections. In most cases, a two-dimensional channel layout is extruded into the third dimension of the silicon substrate, hence, all channels have similar depth due to the given stretching time (Hessel et.al, 2004).

2.2 Mixing Characteristics.

There are some fundamental definitions are helpful to study the various mixing states and mixing equipment. The Danckwerts segregation intensity is defined with the mean square deviation of the concentration profile of the component i in a cross section (Kraume, 2006).

$$I = \sigma^2 / \sigma_{max}^2 \quad (2.2)$$

Where,

I = Segregation intensity

σ^2 = mean square deviation of the concentration profile of the component i in a cross section

σ_{max}^2 = mean square deviation of the concentration profile of the component i in a cross section at maximum

The value of I can be in between 0 to 1 where 0 indicates completely segregated and 1is completely mixed. So that we call mixing quality as α_m.

Therefore,

$$\alpha_m = 1 - \sqrt{\sigma^2/\sigma_{max}^2} \quad (2.3)$$

As stated by (Rührtechnik, 1999) the standard deviation can be derived from a concentration distribution or from a temperature profile in a cross section and can be modified as below.

$$\sqrt{S} = \sigma/\bar{c} \quad (2.4)$$

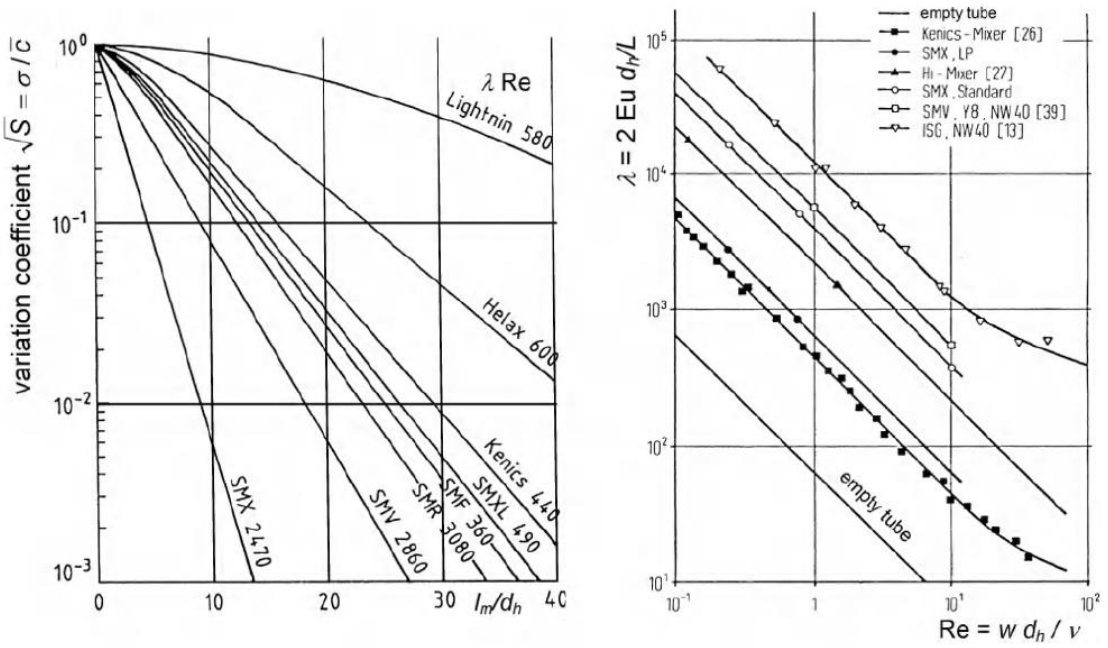


Figure 2.3: Mixing characteristics and pressure loss with static mixer as stated by (Rührtechnik , 1999)

The mixing intensity is measured with colour dispersion experiments along the pipe length and decreases linearly with increasing tube length for all in-line mixers. This curve is also called the operating line of a static mixer. The incline of the mixer's operating line depends on the pressure loss within the static mixer Cf. Re, where a high pressure loss causes intensive mixing. The Re is Reynolds number and can be express in equation.(Li et .al., 2016).

$$Re = \frac{\rho u h}{\mu} \tag{2.5}$$

Where,

Re= Reynolds number

ρ= density of fluid

u= velocity of fluid

h=height of the equipment

μ=dynamic viscosity

2.3 Mixing behaviour in MIR

Stated by (Lee et.al., 2011) that convection in microchannels plays a major role for micromixers with high mass flow rates. Bent or curve in a designing an equipment are the cause of convection. The secondary flow structures which is known as advection flow are normally added with elements, such as posts or grooves in microchannels, however, the main channel remains straight. In Figure 2.4 from (Kockmann N et.al.,2004), equal fraction of (1:1 mixture) of two mixing components are calculated with numerically for a channel with square cross section (100×100 μm2) and a 90° bend. The mixing quality αm, can be determined for a constant mixing channel length of 1 000 μm.

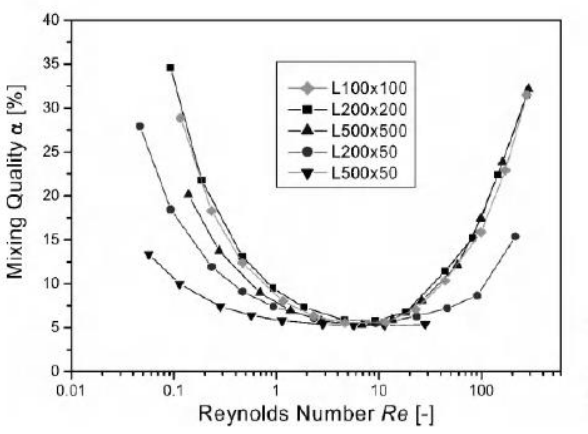


Figure 2.4: Mixing quality am after the 90° bend of five various mixers (L-shaped, channel width × depth) over the Re number; Right

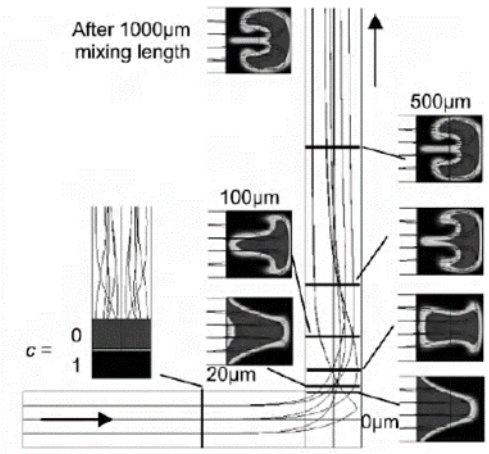


Figure 2.5: Mixer geometry (cross section 100×100 µm2) and concentration profiles at various channel locations, Re = 99, w = 0.85 m/s, (Kockmann N, Engler M, Haller D 2005).

Moreover, compared to diffusion two components mix by convective effects will have higher *Re* approximately 10. For straight laminar flow the *Re* numbers is lower which allows only diffusive mixing. The mixing quality α_m at constant mixing channel length is proportional to the inverse of the *Re* number due to the residence time of the fluid. Smaller channels produce higher mixing quality due to their short diffusion length, Figure 2.4 Due to a convective enlargement of the interface between the components, the mixing quality am increases with the *Re* number for *Re* > 10.

The centrifugal force from the curved flow forces faster fluid parts from the middle of the channel to the outer wall of the bend and elongates the component interface. The mushroom-like interface structure is clearly visible in Figure 2.5. The *Re* number and the aspect ratio of the channel is important for the mixing quality. The channel width is now included in the *Re* number. This shows that the convection in microchannels is scale-invariant. The mixing in curved microchannels displays similar behaviour , as shown by (Jiang et al., 2004) .

The mixing quality in the single 90° bend (L-mixer) increases from 0.1 for low Re numbers up to 0.45 for a *Re* number larger than 270, Figure 2.6. The combination of two 90° bends (S-mixer) increases the mixer performance, a *Re* number of approximately 270 results in a mixing quality close to 0.65. The combination of four bends or U-mixer raises the mixing quality above 0.7 for high Re numbers. At these flow rates the difference between the S- and the U-mixer decreases and will vanish at higher flow rates.

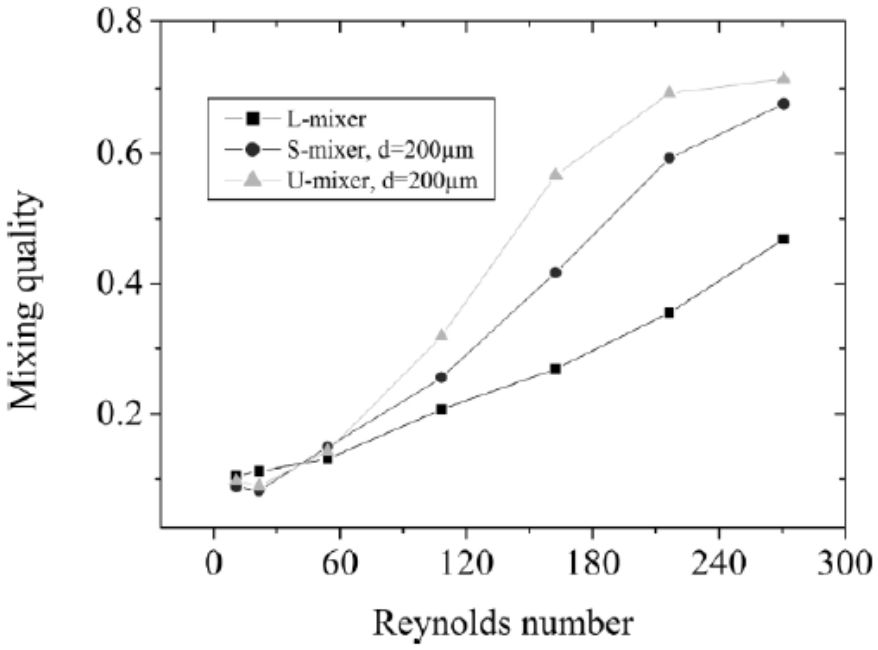


Figure 2.6: Simulated mixing quality at the outlet of the 90° bend mixer (4 800 µm mixing channel length) with three combinations over the Re number, L-mixer has one 90° bend, S-mixer has two 90° bends with a distance of d = 200 µm, U-mixer has four 90° bends

The mixing quality is determined at the channel outlet and can be directly compared, due to the relaminarized flow in the mixing channel with a measured length . The convective mixing process is completed at this point and the effect of diffusive mixing is comparable for all arrangements.

2.4 Absorbance measurement via spectra suite spectrometer analysis.

Absorbance measurement is also known as concentration measurement of a sample(Gray et.al , 2009). Absorbance measurement takes place when a monochromatic radiation which is intensity of before entering sample *(I_0)* and intensity of leaving sample *(I)* in cuvette and Z-flow cells.

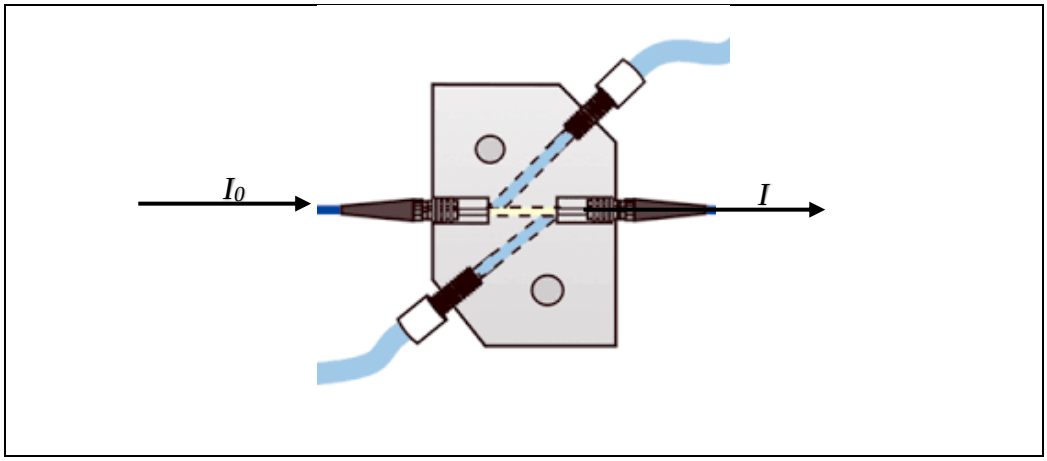


Figure 2.7: Intensity in (I_0) and out(I) in Z-flow cell.

It is familiarly known the absorbance measurement is related to Beer's Law. Beer's law state the linear relationship between absorbance and concentration of an absorbing species. This absorbance measurement represented by equation 2.6 and 2.7.(Biotronix, 2016)

Measuring the optical density of growing cultures is a common method to quantify various important culture parameters like cell concentration, biomass production or changes in the cell morphology. Online photometry allows continuous real time analysis of those parameters without any laborious work. Continuous measuring of optical density is the most basic and powerful tool for providing optimal yields and controlling reproducibility in many fermentation strategies. (Biotronix, 2016)

$$A = - log (I / Io) \quad (2.6)$$

Where,

A = the absorbance

Io = Intensity of light before it enters the sample

I = Intensity of light, that has passed a sample (transmitted light)

$$OD = A / L \quad (2.7)$$

Where,

OD = optical density

A = the absorbance

L = thickness of sample

Moreover, absorbance measurement basically measured using spectrometer which measures UV light and visible light spectrophotometers. This visible light spectrophotometer are fall in wavelength in between 400-700 nanometers (nm). The human eye is not capable of "seeing" radiation with wavelengths outside the visible spectrum. The visible colours from shortest to longest wavelength are violet, blue, green, yellow, orange, and red. Ultraviolet radiation has a shorter wavelength than the visible violet light (Jay Madigan, 2017). An absorbance versus wavelength for green food colouring measured and discussed.

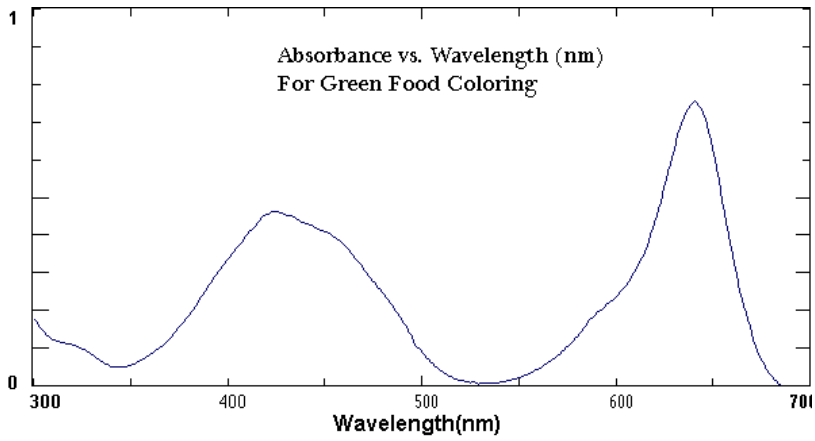
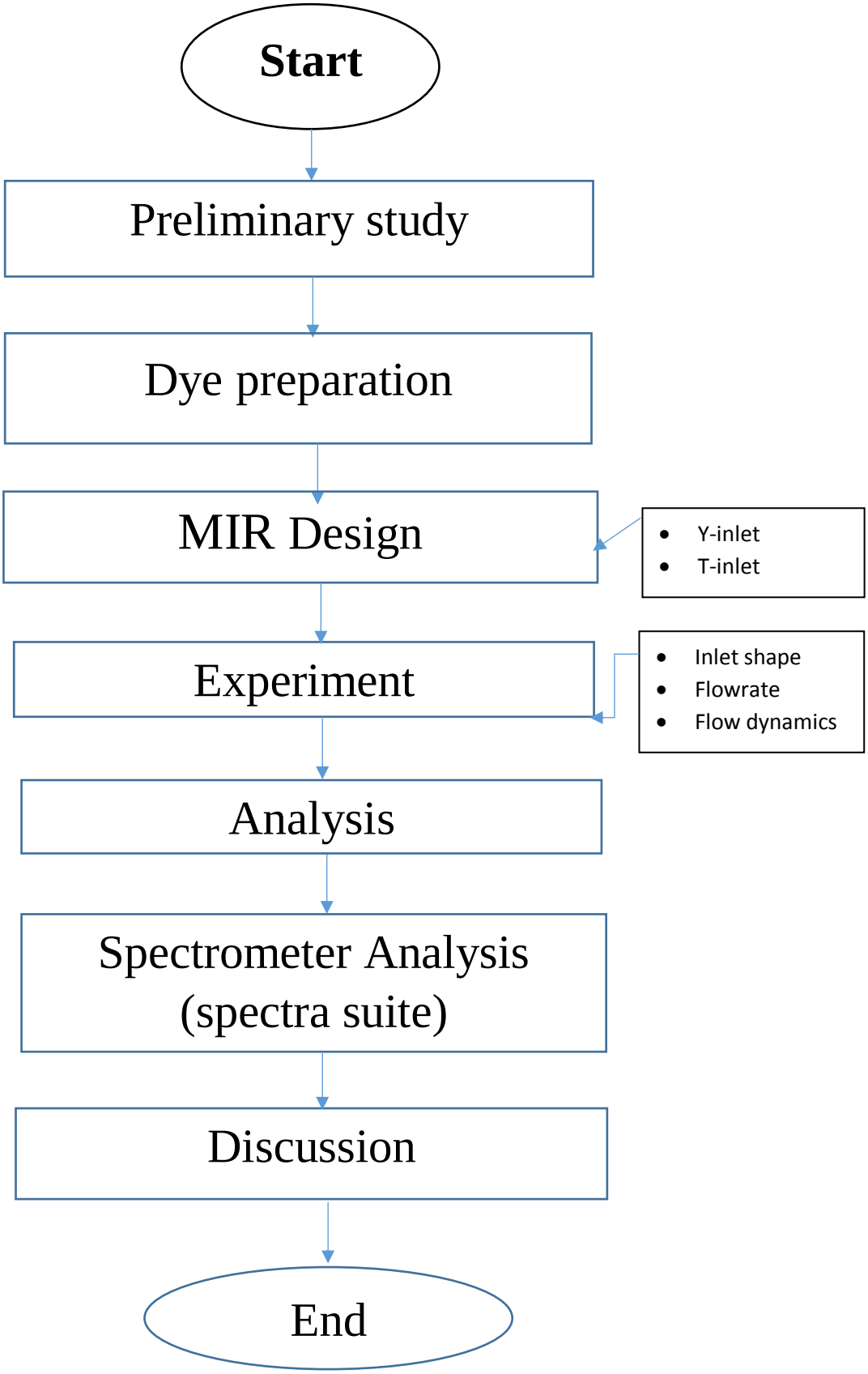


Figure 2.8: Plot absorbance versus wavelength.

The above graph shows green food colouring have two different absorbance at maximum peak is at approximately 420 nm with an absorbance of 0.45 while the other is at 640 NM with an absorbance of 0.80. The shape of the spectrum and the wavelength of maximum absorbance are characteristic of the chemical compound. The absorbance of compounds is also directly related to the concentration of the sample.(Gray et.al, 2009)

CHAPTER THREE

MATERIALS AND METHOD



3.1 MATERIALS.

3.1.1. Characteristics of food dye.

In this study, food colouring was used for easy observation and investigated mixing quality in MIR. Blue and yellow colour food dye were chosen as the individual reactant colour. Green colour is the result of well mixed of blue and yellow colours. This food dye has characteristics of fully mix, non-sticky and non-separable after mixing for long duration. The above shown food dyes are very cheap and can be purchase from nearest shopping mall or grocery shops.

Yellow

Blue

Figure 3.1: Yellow and Blue food colourings

3.2 EQUIPMENT AND INSTRUMENTATIONS

3.2.1 Type of pump.

Two type of syringe pump are used for pumping purpose.They are NE-1000 Series of Programmable Syringe Pumps and LAMBDA VIT-FIT (HP) Syringe Pump.

NE-1000 Series of Programmable Syringe Pumps

LAMBDA VIT-FIT (HP) Syringe Pump

Figure 3.2: Types of pump

3.2.2 Calibration of LAMBDA VIT-FIT (HP) Syringe Pump

The pump was switched on and set with speed of 200. The pump was set into withdraw mode. The pump and stopwatch were started simultaneously. The pump was allowed to withdraw 60 ml of water and time was recorded. The step above mentioned is repeated for speed of 400, 600, 800 and 999. Refer to appendices.

3.2.3 Dye concentration.

100 ml of water in 2 beakers were prepared. Two type of food dye colours were used which are blue and yellow for this mixing experiment. The micropipette was used to transfer the 150 microlitre of food dye from container into 100 ml of water in beakers. Then, the mixture in beakers is stirred and observed for 5 minutes to make sure no sedimentation of food dye occurred. Two syringe pump were used to withdraw the food dyes. The syringe pump was connected to Y- inlet and start to pumped with constant flowrate. The green colour was observed throughout the connected straight tube to Y-inlet. The experiment is repeated for 50,100 and 150 microlitres of food dyes. The observable amount of green colour were determined .

3.2.4 Designing of MIR

There are two type of inlet shape designed for MIR. They are Y-shape and T-shape. The Sizing or dimension of each reactor inlet shape are shown in table 3.1. The length of tube also manipulated as shown in Table 3.1.

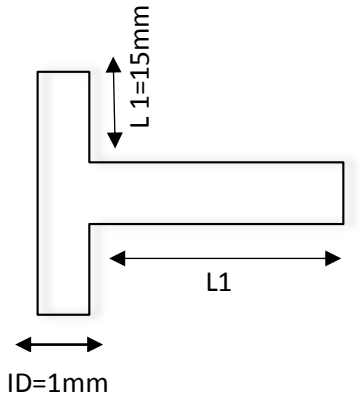
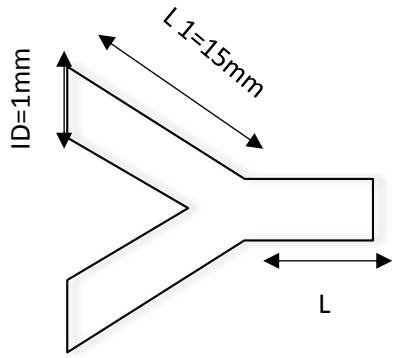
Inlet Shape	Angle	Length Of tube
	90 º	L=300mm
	45 º	

Table 3.1: Inlet shape and length of tube

3.3 Experimental procedure

3.3.1 Flow dynamics.

60 ml of blue dye was withdrawn into syringe pump 1 and 60 ml of yellow was withdrawn into syringe pump 2. 100 mm of tube with 1 mm ID was connected from pump 1 to one end of T-shape inlet. Another 100 mm of tubes with 1 mm ID was connected from pump 1 to one end of T-shape inlet. Connecting point of T-shape was with 100 mm of tube. The flowrate of pump was set at 6 ml/min. At the end of T-shape outlet, the time taken using stopwatch and sample of 120 ml collected in a beaker simultaneously. The procedure above repeated by increasing flowrate 8 ml/min, 10ml/min and 12 ml/min. The time taken for each flowrate was tabulated to calculate outlet flowrate. The calculated flowrate was used to calculate *Re*. The flow type was determined. The procedure above repeated for Y-shape inlet.

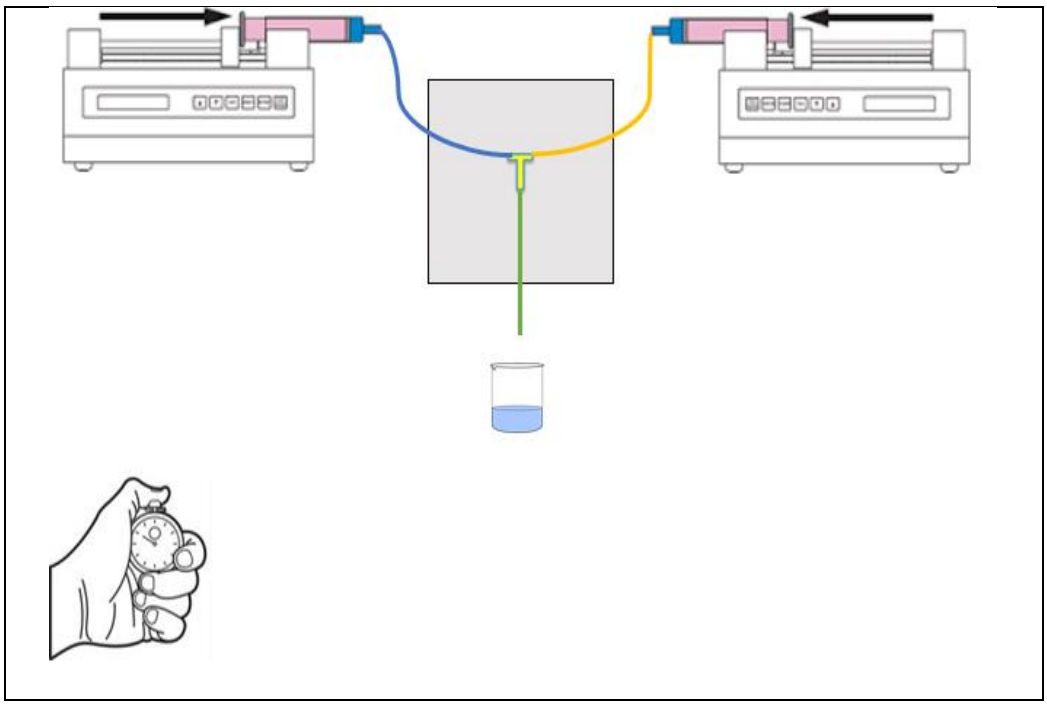


Figure 3.3: Schematic diagram for experiment on flow dynamics

3.3.2 Determination of mixing length for T and Y by varying flowrates

60 ml of blue dye was withdrawn into syringe pump 1 and 60 ml of yellow was withdrawn into syringe pump 2. 150 mm of tubes with 1 mm ID was connected from pump 1 to one end of T-shape inlet. Another 150 mm of tube with 1 mm ID was connected from pump 2 to another end of T-shape inlet. Connecting point of T-shape was connected to 300 mm of tube with 1 mm ID. The flowrate of pump was set at 6 ml/ min. Mixing length of green colour was observed and recorded through 300 mm tube which is connected at connecting point and picture is captured . The procedure above repeated by increasing the flowrate 8 ml/ min, 10 ml/min and 12 ml/min. This experimental procedure is repeated for Y- shape inlet.

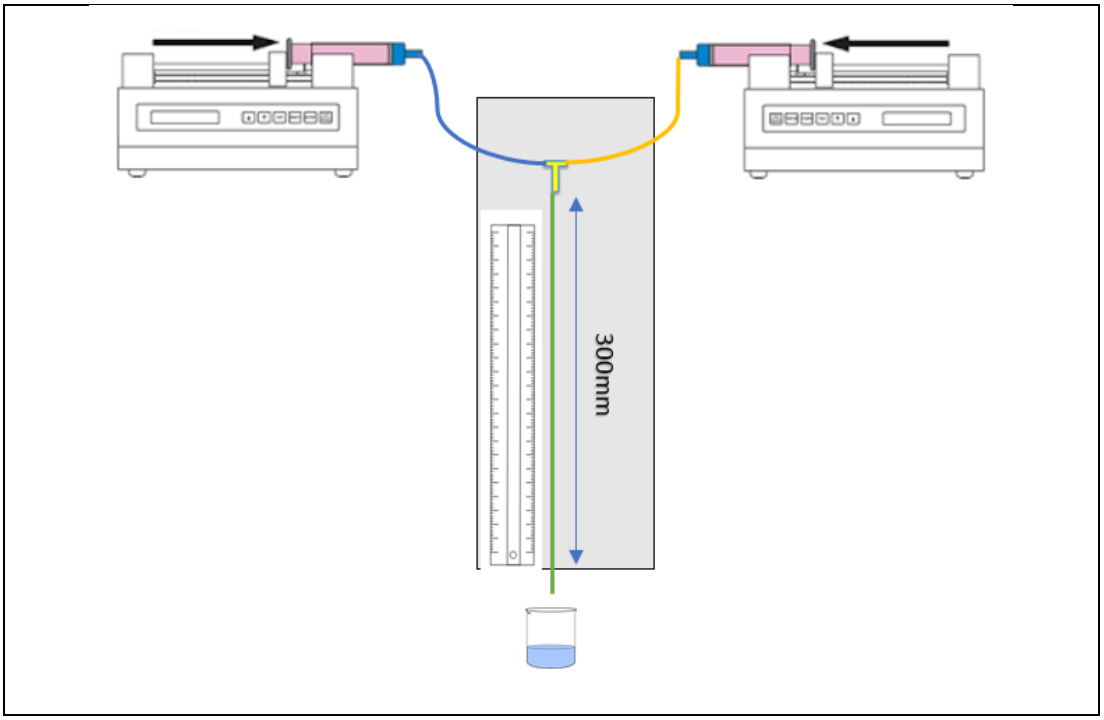


Figure 3.4: Diagram of experiment on determining mixing length

3.3.3 Spectra suite absorbance and intensity measurement

Both pumps are connected at the each of T-shape inlets. The end of connecting tube connected to Z-flow cell. The light source connected to one end of Z-flow cell with optic fibre connector. Another end of the Z-flow cell was connected by optic fibre connector to USB2000 ocean optic device which convert spectrometer analysis into absorbance measurement. Then, the optic fibre connector connected to laptop with spectra suite software. Calibration of spectra suite analysis was conducted. (refer to APPENDICES E).

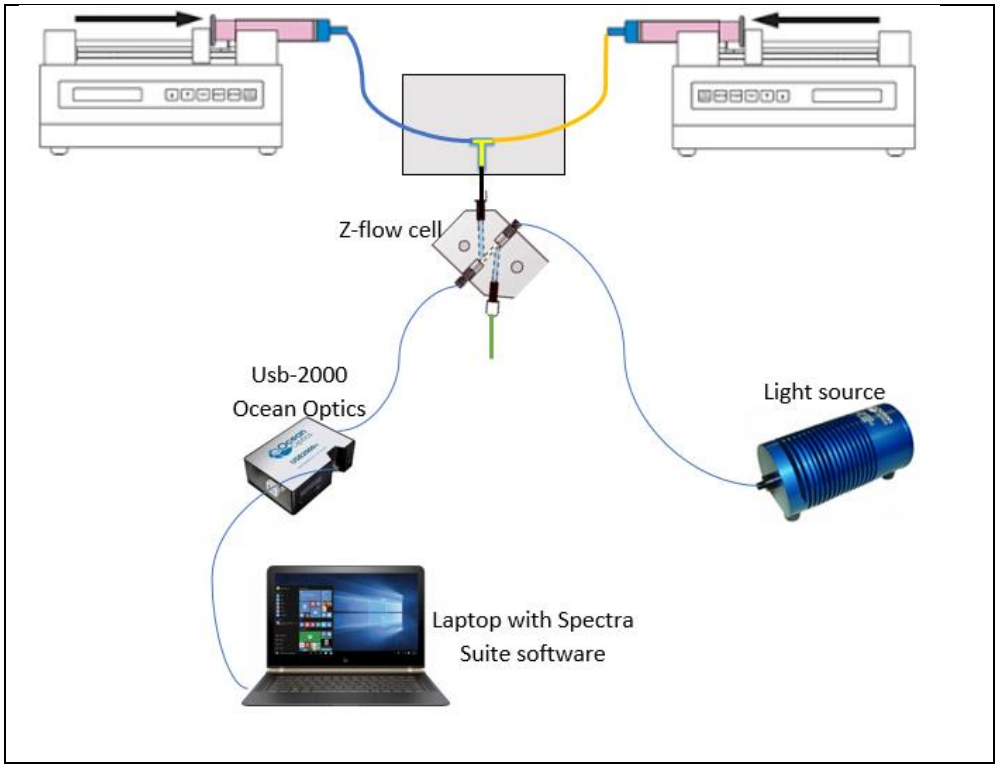


Figure 3.5: Arrangement for absorbance measurement experiment.

60 ml of blue dye was withdrawn into syringe pump 1 and 60 ml of yellow was withdrawn into syringe pump 2. 150 mm of tubes with ID 1 mm was connected from pump 1 to one end of T-shape inlet. Another 150 mm of tubes with 1 mm ID was connected from pump 2 to another end of T-shape inlet. Connecting point of T-shape

connected to 1mm ID tube and the tube length used was observed mixing length from experiment 3.3.2. The flowrate of pump was set according to measured mixing length as per Section 3.3.2. A plot of absorbance(OD) at Y-axis and wavelength (nm) at X-axis obtained from spectra suite software. The data obtained was summarized.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents experimental pictures, data and computational data by spectra suite of T-and Y- shaped MIR. This chapter divide into four section. The first section is the flow dynamics that will discuss on Reynold number. Second the mixing quality of both T- and Y-shaped with varying flowrate. Lastly, discuss and compare results of spectra suite absorbance measurement.

4.0Flow dynamics.

4.1 Reynold number.

The magnitude of inlet velocity for the T and Y-shaped MIR are tabulated in Table 4.1. The magnitude of outlet velocity for the T and Y-shaped MIR are tabulated in Table 4.2. It is shown that, the Y-shaped MIR gives higher outlet velocity than T-shaped MIR. The higher outlet velocity in Y-shaped microchannel was due to difference in angle of the inlet shape geometry which is 45º and smaller than T-shaped MIR by 135º that leaded to higher pressure drop than T-shaped microchannel which stated by (Rudyak and Minakov, 2014) that shows symmetric mixers are more efficient at minimum angles of opening of the inlet channels.

Table 4.1: Inlet velocity of T-and Y- shaped MIR

Inlet velocity		
Q(ml/min)	Q (m^3/s)	V(m/s)
6	1.002×10^{-7}	0.0001276
8	1.336×10^{-7}	0.0001701
10	1.67×10^{-7}	0.0002126
12	2.004×10^{-7}	0.0002551