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RESEARCH ARTICLE

The Effect of Velocity Ratio Study on Microchannel Hydrodynamics Focused of Mixing Glycerol Nitration Reaction

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Abstract

The paper describes the effect of velocity ratio for mixing glycerol nitration in microchannel hydrodynamic that focused on the stream width. The method used are experimental and theory modeling of hydrodynamic fluid flow focused on predicting behavior stream width glycerol nitration.

The research uses microchannel hydrodynamics focused on consisting of three channels inlet (one core and two sheaths). The core glycerol the beginning of the sheath distributed nitric acid with sulphuric acid as a catalyst. The length channel dimension of inlet and outlet of L_1, L_2, L_3 = *1000 µm,* L_4 = *4000 µm with the width of* D_1, D_2, D_3, D_4= *300 µm, and the depth of w =200 µm. using transparent material that is acrylic with thickness (*T_1 *and* T_2*) as 5 mm arranged accumulated. Fluid volume glycerol of the core of 2 ml, and volume nitric acid of 1.05 ml (+ aquades 0.75 ml) and sulphuric acid 0.1 ml (+ aquades 0.1 ml). The independent variable namely variation the velocity ratio (*v_2 / v_1*) 0.5,1,2,3,4,5,6,7,8,9,10, and 11. It is Added a slight coloring yellow to fluid glycerol and red to a fluid mixture of nitric acid and sulphuric acid, to understand the mixing process of fluid at the reaction of glycerol nitration. The mixing of the measurement of stream width performed on the ratio of the length (*$\alpha = L_4 / L_1$*) of 1 , 2 and 3.*

The result shows that diffusion of regional differences takes place in the velocity ratio shown by color changing of data on the picture. The width of focus stream is smaller as increasing the velocity ratio. This is caused by the pressure of a fluid channel sheath against core channel fluid is greater than diffusion reaction, as well as the energy required that is used to form a molecular bond.

Keywords

nitration, glycerol, nitric acid, nitroglycerin, velocity ratio, ratio of the length, mixing

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1 Introduction

Nitroglycerin is a compound derived from nitration reaction of a nitric acid, sulphuric acid with glycerol, as shown in Fig. 1.

$$C_3H_5(OH)_3 + 3HNO_3 \xrightarrow{H_2SO_4} C_3H_5(ONO_2)_3 + 3H_2O$$

Fig. 1 Chemistry equation of nitroglycerin formed

Nitroglycerin is commonly used as explosives due to its explosive properties. In addition, nitroglycerin can also be used in medical especially as a cardiovascular disease coronary heart, in mining and other businesses, other cloth as the main ingredient and additional material.

Nitroglycerin production process has long been developed starting with the production process using batch reactor and continuous stirred tanks reactor (CSTR). In which Nitration nitroglycerin process took place in hele-shaw cell methods [1]. Previous studies showed that the Atwood number can influence the nitration nitroglycerin reaction and hydrodynamic conditions extremely affect the process of fingering nitration nitroglycerin product. While the uses of microreactor in nitration process have been done by some researchers, such as the toluene nitration using microreactor at a constant reactor temperature, and nitric acid as nitration agent which yielded more reaction product compared with batch reactor system [2]. The use of microreactor in the nitration process by employing iso-octanol HNO_3-H_2SO_4 mixture. Nitration reaction of iso-octanol with HNO_3-H_2SO_4 is fast and strong caused by acid composition, the ratio of mass , the temperature of the mixture and dissolved reaction. This reaction is safe and stable on a 25°C–40°C degree in microreactor [3].

Micro fluids technology in nitration process has been developing very rapidly, thus, that technology can be applied in various fields such as; medical, biology, chemical, and others. The use of micro fluids is more profitable than macro fluids from the performance, and cost perspective [4, 5]. Because nitroglycerin is explosive, needs to be developed methods safe in the mix fluid nitric acid with glycerol. For it needs to be done research on the production of nitroglycerin by using microchannel.

One of microchannel is focused in hydrodynamic, which shape is rectangle [6]. It can be used in various fields such as; cytometer [7, 8, 9, 10], patterning cells [11], and diffusion-based mixers [12, 13]. The mixing process between core stream and a sheath stream in the interface area is fully affected by diffusion. The configuration of focused hydrodynamic generally uses 3 inlet channels and 1 outlet channel. It causes early mixing between the core and the sheath fluid. The core fluid stream lies between two sheath fluid streams. So that, the width of core stream will lessen and two areas of mixing diffusion in the exit will be hybridized. This will make the mixture that contains biology agent like the cell of virus blends into sheath stream. The pattern of behavior can be adjusted to control the stream water in the channel [14].

Focused Hydrodynamic can be used to tackle the problems of the fluid dynamics, as an example; the mixing process of two fluids, this process depends on the diffusion of inter-fluid, which is affected by mixing time and the characteristic of channel output length determined from the width of stream focus. Hence, the researcher wants to study the effect of velocity ratio stream on microchannel hydrodynamic focused on glycerol nitration reaction on the process mixing fluid.

In various research on mixing two fluid use microchannel, there has never been subjecting discuss mixing fluid reactive pertaining to ratio speed fluid .One factor that good effect on mixing fluid is characteristic inlet fluid , terms of speed water flow and density fluid .The objective of this research article is to investigate the influence of ratio the velocity of fluid flow in microchannel hydrodynamic focusing on mixing nitric acid, sulphuric acid (catalyst) with glycerol to produce nitroglycerin, which has indicated by width stream focus on the in the experiment.

2 Materials and Methods

This research work intended to investigate the parameters of the flow of the action of nitric acid and sulphuric acid with glycerol in microchannel hydrodynamic focusing by experiment .This report is written with a variety a velocity ratio a stream against its width stream focus to know the mixing fluid. So that the process of mixing between glycerol, nitric acid, and sulphuric acid can be identified inform a product nitroglycerin .

Microchannel hydrodynamic focusing consists of three a channel in which glycerol fluid is distributed on a track of the core and a mixture fluid of nitric acid distributed of the sheath with sulphuric acid as a catalyst .

The length of the inlet and outlet microchannel (Table 1) used in this study were L_1 , L_2 , L_3 = 1000 µm , L_4 = 4000 µm with the width of D_1, D_2, D_3, D_4 = 300 µm , and the depth of 200 µm, as shown in Fig. 2, and the focus width was measured as length ratio ($\alpha = L_4 / L_1$) ranging from 1, 2, and 3. To make it easy to get data visually acrylic is used because transparency. The arrangement of microchannel material in size 10 x 10 centimeters with thickness (T_1 and T_2) on 5 mm arranged accumulated. One of the forms of the furrow in accordance with microchannel dimensions while the others as a cover.

Table 1 The specification of microchannel inlet fluid

No.	Fluid	Molekul weight (gr/mol)	Density Kg/liter	Fluid volume (ml)	Aquades Volume (ml)	Channel
1	Glycerol	98.08	1.26	2	0	Core
2	Nitrit acid	62.98	1.41	1.05	0.75	sheath
3	Sulfat acid	98.08	1.84	0.1	0.1	

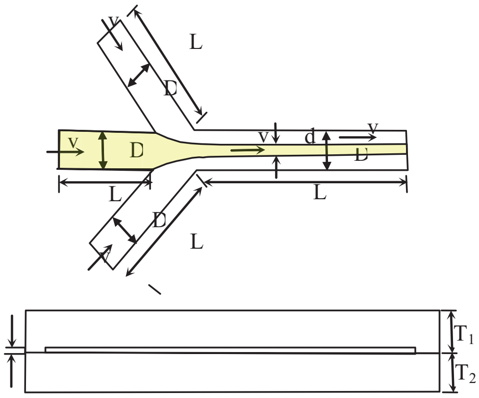

Fig. 2 Scheme of the hydrodynamic flow focusing

The research was performed with the ratio sheath and the core velocity stream (v_1 / v_2) variations of 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11. To check if mixing nitration reaction occurs in a microchannel, a slightly yellow color, and the red color was added for glycerol and nitric acid fluid, respectively.

Syringe pumps were used to flow the fluid from the three inlets. These pumps were controlled by a generator function so that the fluid streams will become steady and simultaneous as shown in Fig. 3.

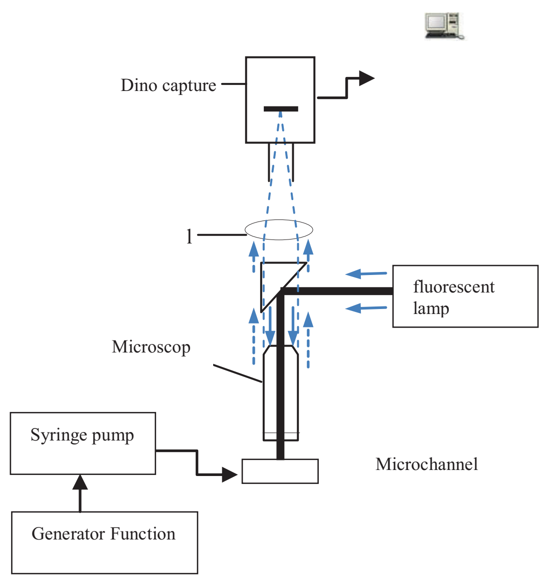

Fig. 3 Experimental setup

2.1 Theoretical Background of the model

Some assumptions were used in estimating the time required for fluid to flow from inlet and outlet of the channels. They are:

1. The fluid stream inside of microchannels are stable and laminar.
2. Fluid is categorized as a Newtonian fluid.
3. The dimensions for inlet and outlet are similar.

According to the law of mass conservation the amount of fluid through an inlet is equal with the amount of fluid passing to the mixing area, shown by Eq. (1)–(4):

$$Q_2 = Q_a \tag{1}$$

$$A_2 v_2 = A_a v_a \tag{2}$$

$$D_2 h v_2 = d h v_a \tag{3}$$

$$D_2 v_2 = d v_a \quad \text{or} \quad \frac{D_2 v_2}{v_a} = d \tag{4}$$

Where D_2 is a channel width, focusing d, and v_2 is the velocity of core fluid and v_a is the velocity of the stream. If it is assumed as a laminar stream, and diffusion process in core fluid is ignored, the total mass of fluid according to the law of mass conservation can be expressed in Eq. (5)

$$v_4 = \frac{\left(\rho_1 v_1 D_1 + \rho_2 v_2 D_2 + \rho_3 v_3 D_3\right)}{\rho_4 D_4} \tag{5}$$

If it is assumed that outlet flow is fully-developed laminar core, then the width of focus stream can be written as Eq. (6):

$$d = \frac{\rho_4 D_4}{X\left(\rho_1\left(\frac{v_1}{v_1}\right)\left(\frac{D_2}{D_1}\right) + \rho_2 + \rho_3\left(\frac{v_3}{v_1}\right)\left(\frac{D_3}{D_1}\right)\right)} \tag{6}$$

where D_1, D_2, D_3 and D_4 are the width of the channel and v_1, v_2 and v_3 are the average velocity of the inlet channel, whereas v_4 is the average velocity of the outlet channel. ρ_1 is glycerol density, ρ_2 and ρ_3 are nitric acid and sulphuric acid, respectively, while ρ_4 is average density of nitroglycerin, the value of X is 1.5 as recommended by [15], Eq. (6) then will become:

$$d/D_4 = \frac{\rho_4 D_4}{1.5\left(\rho_1\left(\frac{v_1}{v_1}\right)\left(\frac{D_2}{D_1}\right) + \rho_2 + \rho_3\left(v_3/v_1\right)\left(D_3/D_1\right)\right)} \tag{7}$$

Equation (7) shows that focus width of the stream is inversely proportional to the increase of the core velocity ratio and the stream of the sheath.

Based on the concept of stream ratio as explained above, this study discussed theoretically and experimentally the width of focused hydrodynamic on glycerol nitration reaction.

3 Result and Discussion

Some pictures of glycerol nitration reaction process were captured and obtained with a dinocapture camera combined with an optical microscope, which was undertaken at an equal distance. It was then processed using image processing program. The behavior of stream and mixing process of the fluid can be observed which was characterized by diffusion growth between two fluids, as shown in Fig. 4.

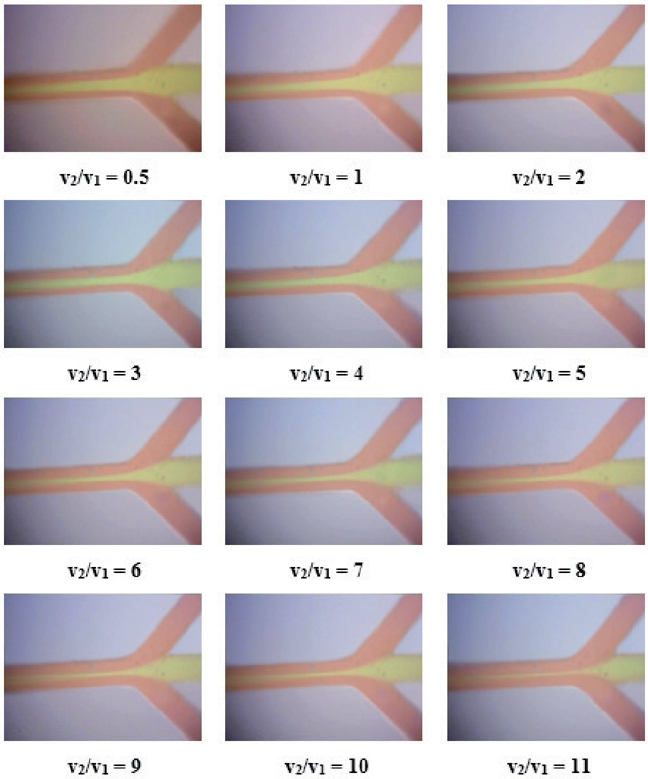

Fig. 4 The effect velocity ratio (v_1 / v_2) of glycerol nitration reaction

Figure 4 shows that there are regional differences in fluid mixing with velocity variation that can be seen with colors changing (dispersion in fluid). This mixing process was measured based on the distance from the meeting point of fluid inside microchannel.

Figure 5 presents focus width profile as measured in the same position (α = 1), It can be seen that the greater of the core-sheath channel rate ratio (v_2 / v_1), the smaller focus width. It because the bigger rate of the sheath stream will result in size diminishing of more channel core while the mixing diffusion process of glycerol and nitric acid is still relatively small. Moreover, Fig. 5 indicates that focus width displays the same behavior with the analytical model. Besides that, both experimental data and a theoretical model are almost similar.

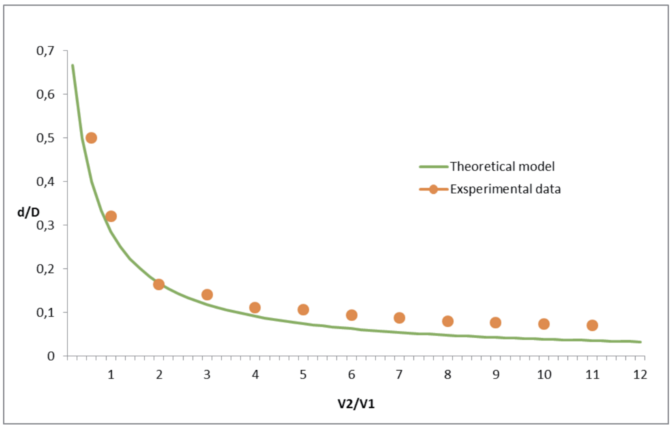

Fig. 5 The effect of velocity ratio (v_1 / v_2)
on glycerol nitration reaction with the length ratio (a) = 1.

The width of focus stream channel does not depend on the size of the inlet and the stream rate volumetric channel part, but depends on the ratio of inlet channel and stream rate channel part as illustrated in Fig. 6.

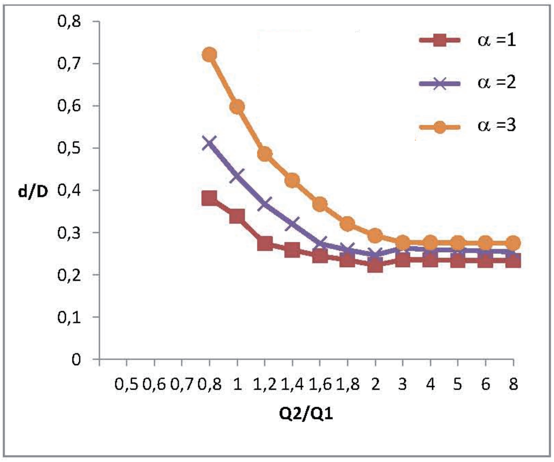

Fig. 6 The effect of stream rate ratio (Q_1 / Q_2)
on glycerol nitration reaction with various length ratio (α)

In the mixing process with velocity variations, it can be observed that the higher velocity of core channel stream-sheath (v_2 / v_1) stream focus width will become smaller as indicated in Fig. 7. It is caused by the channel pressure of sheath channel fluid against core channel fluid is larger than diffusion reaction, so the energy required to establish bigger nitroglycerin molecule bond is higher as well. In the end, it can lead to slow forming of nitroglycerin products formation.

A reaction which occurs between this surface can produce heat that can change the density of reactant and reaction products. This change causes hydrodynamics motion on the boundary layer solution that will lead to faster reaction process.

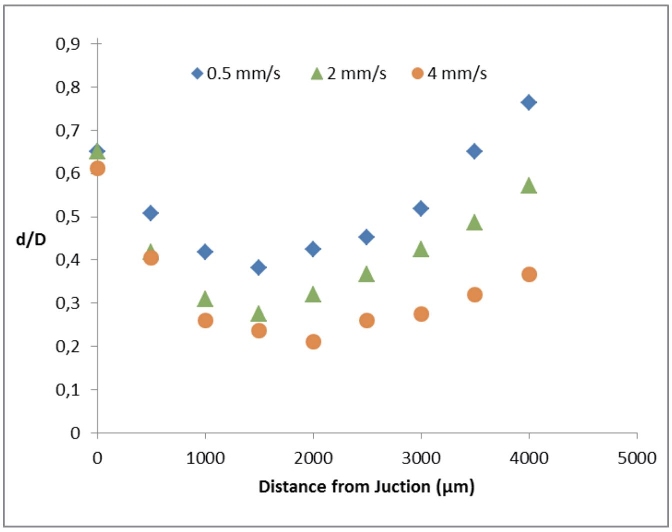

Fig. 7 The velocity variations of core channel stream
and sheath to focus width based on a range of the intersection.

4 Conclusion

This study has successfully examined the glycerol nitration reaction in microchannel hydrodynamic focused by stream focus width by confirming with a theoretical model of focused hydrodynamic and different stream velocities.where the ratio of velocity determines the focus stream width. The results show that the higher ratio of core channel stream and sheath-core channel focus width becomes smaller.

This study has also demonstrated when the velocity of glycerol fluid and nitric acid is higher in mixing process with velocity variations, the mixing time of this process will be longer. The heat that is produced on a surface from nitration reaction process can change the density of reactant. It will cause hydrodynamic motion that makes reaction runs faster.

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