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EFFECTS OF MOLECULAR WEIGHT ON MICROFLUIDIC SEPARATION

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Abstract. This paper examines how molecular weight affects the diffusion of molecules in the interface of laminar flow in a microfluidic channel. Two mixtures of PS with anisole and PEG were used to evaluate the effect of molecular weight on the microfluidic separation. Also, the separation of a low molecular weight substance of anisole from the mixture with a high molecular weight substance of PS is proved experimentally. The soft baking was conducted at 65 ^{o}C for three minutes and at 95 ^{o}C for nine minutes in a hot plate. The SU-8 photoresistant agent was exposed to a UV light of 365 nm for 30 seconds to form the pattern. However, it is still difficult to separate PEG from the mixture with PS. This study provides more information about diffusion in microfluidic channel and can be applied to polymer science and separation fields. The difficulty of separation of PEG from the mixture of PS and PEG was observed because of the same polymeric characteristics of PEG and PS. For future study, the separation experiment in the smaller microfluidic chip will be challenged for high resolution and efficiency and the study is expected to apply to other subjects such as the polymer science and separation of proteins and micro-nano particles.

Keywords: diffusion, laminar flow, separation, microfluidic.

Classification numbers: 2.2.1, 2.8.3, 2.10.2, 3.3.3

1. INTRODUCTION

The selective separation is a common process in the chemical and biochemical analysis. General separation methods include centrifugation, filtration, and chromatography and electrophoresis which are most prominent techniques [1]. In specific, the chromatography is a set of laboratory techniques used to separate the constituents from a chemical mixture. The liquid chromatography is also a common technique used in standard laboratory procedures such as size-exclusion chromatography [2], and high performance liquid chromatography (HPLC) [3]. Also, a popular technique on separation in a microfluidic device is field flow fractionation (FFF) [4]. However, chromatography methods are generally operated in a complex separation column and the FFF always needs a high external field for separation.

The numerical analysis of diffusion potential (e.g., the T-sensor) has been investigated previously. The T-sensor has been used to analyze molecular interaction based on changes in the diffusive transport of one of the reacting components [5], to quantitatively describe molecular interaction in a microchannel [6], to quantitatively measure the spatial distribution of diffusing analytes in a microfluidic pressure-driven device [7], to measure the diffusion coefficient of large and small molecules [8 - 9], and to provide a theoretical analysis of the scaling laws for analyte diffusion [10]. Due to the very low Reynolds numbers, the flow is strongly laminar and the transport between input streams occurs only via diffusion [7]. The diffusion species are usually molecules but may also be micro or nanoparticles. Binding events generate new species with molecular weights more significant than the original species and a corresponding diffusion coefficient reduction. This dependence is described by the Stokes-Einstein equation [11]

$$D = \frac{k_B T}{f} = \frac{k_B T}{6\pi\mu R_0}$$

where f is the friction coefficient of the solute, k_B the Boltzmann's constant, T the temperature, μ the viscosity of the solvent, and R_0 the solute radius.

In this paper, we examine how the molecular weight of substances effects their diffusion in a microfluidic channel. The two mixtures of polystyrene as the high Mw substance with anisole and PEG as the low Mw substances were used to test their diffusion which can result in the separation of the low molecular weight substances from the mixture.

Table 1. Table of abbreviations.

CCD	Charge-coupled device
DMF	N,N-dimethylformamide
FFF	Field Flow Fractionation
HPLC	High Performance Liquid Chromatography
Mw	Molecular Weight
PDMS	Polydimethylsiloxane
PEG	Polyethylene Glycol
PS	Polystyrene
UV	Ultraviolet

2. MATERIALS AND METHODS

2.1. Materials

Polystyrene (PS) (Mw: 48479 g/mol) was received from Department of Polymer Science & Engineering, Pusan National University, South Korea without further purification.

PEG (Mw: 200 g/mol) was purchased from Aldrich-Sigma.

Anisole and N,N-dimethylformamide (DMF) were purchased from Daejung Chemicals.

2.2. Diffusion mechanism and separation theory

Figure 1 shows the flows of the small and large molecules in a three-inlet and three-outlet microchannel. When a mixture of a high Mw substance and a low Mw substance is injected into the center inlet, this flow is focused by the sheath flow of solvents which are injected through the side inlets. A stable laminar flow is generated. Due to the difference in concentration of substances from the center flow to the channel wall along the channel width, molecular diffusion occurs via the flow interface. The molecules of the mixture tend to move to the channel wall by diffusion via the flow interface. And the small molecules of the low Mw substance move faster than that of the large molecules. By controlling the inlet flow rates, only the small molecules can be received at the side outlets while the large molecules remain at the center flow and move to the center outlet. This separation theory is obtained simply by the dynamic movement of molecules with different diffusion behavior along with the channel width perpendicular to the flow direction.

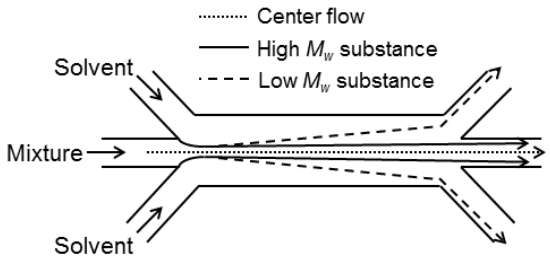

Figure 1. Illustration of flows along microchannel length.

2.3. Fabrication process of microfluidic channel

The microfluidic channels were fabricated by bonding a cast PDMS (polydimethylsiloxane) and a slide glass after the treatment of oxygen plasma. A 100 μm thick layer of the SU-8 photoresistant agent (SU-8 2050, MicroChem) was spin-coated onto a 4-inch layer of silicon. Next, soft baking was conducted at 65 ^{o}C for three minutes and at 95 ^{o}C for nine minutes in a hot plate. The SU-8 photoresistant agent was exposed to a UV light of 365 nm for 30 seconds to form the pattern. The patterned SU-8 mold was created by immersing in the developer solution for three minutes and then rinsing with isopropyl alcohol.

A mixture of the PDMS elastomer and the curing agent with a ratio of 10:1 was produced. After removing air bubbles in the mixture by vacuum, the mixture was poured onto the SU-8 mold and cured at 130 ^{o}C for 30 minutes. The patterned PDMS was then lifted off from the SU-8 mold. The patterned PDMS layer was bonded with a clean glass substrate to form the microfluidic channel after plasma treatment for two minutes by a Plasma cleaner (PDC-32G, Harrick Plasma). The dimensions of the microfluidic channel are given in Figure 2.

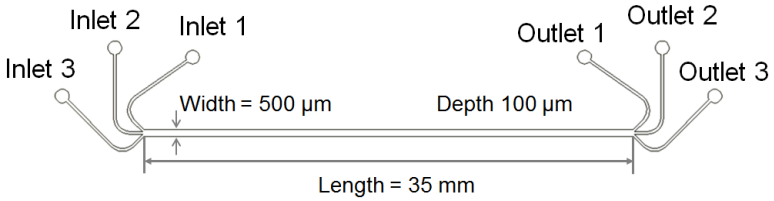

Figure 2. Design of the microfluidic channel.

2.4. Experiment of separation

The experimental setup is illustrated in Figure 3. The mixture of PS with anisole and PEG and the solvent are injected into the microfluidic chip from the respective inlets, and the outlet samples are collected by vials. The flow rates of the mixture and solvent were controlled by syringe pumps (Harvard Apparatus). The flow in the microchannel is captured by using a high-speed CCD camera. The mixture was injected into the inlet, positioned in the center and the solvent into the side inlets, placed symmetrically about the central inlet. The inflow rates of the mixture and the solvent were adjusted to be 5 μl/min ~ 50 μl/min and 15 μl/min ~ 150 μl/min, respectively.

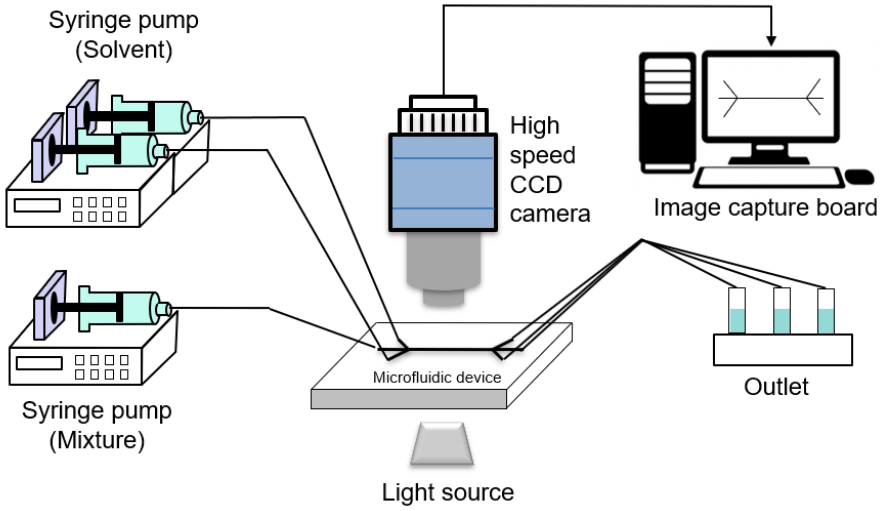

Figure 3. Schematic of the experimental setup for separation.

The flows of mixture and solvent in the microfluidic chip are transparent. So, we use the 1 μm fluorescent microparticles to visualize the laminar flow formed in the microchannel. Figure 4 clearly shows the laminar flow of 1 μm fluorescent microparticles with a mixture flow rate of 10 μl/min at inlet 2. The DI water as a solvent is injected into the microchannel through inlet 1 and inlet 3 at a flow rate of 30 μl/min.

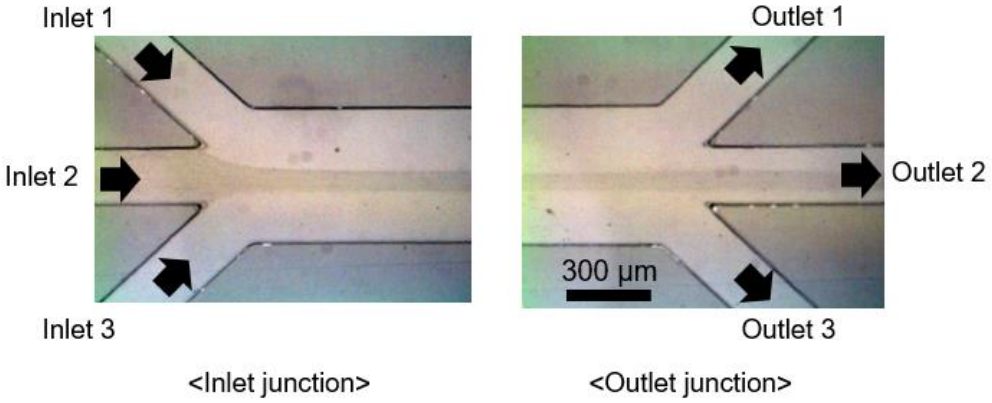

Figure 4. Flow visualization in the microfluidic channel
(Flow rates at inlet 1, 2, 3 are 10, 30, 10 μl/min, respectively).

In this paper, two mixtures of PS with Anisole and PEG were examined for the effect of molecular weight on the separation ability. The mixture 1 was prepared by dissolving completely 16.67 mg of PS and 0.083 ml of anisole in 1 ml of N,N-dimethylformamide (DMF). The same way was used to prepare the mixture 2 (5 mg of PS and 0.05 ml of PEG in 1 ml DMF). The inflow rates of the mixture and the solvent varied at a ratio of 1:3 for each experiment. The outlet samples were collected in vials, while the inlet flow rates were kept stable. After the experiments, all outlet samples were analyzed using the gel permeation chromatography.

3. RESULTS AND DISCUSSION

Figure 5 shows the relative intensities of the mixture of anisole and PS measured by gel permeation chromatography. Then, the relative intensities were collected at three outlets. As shown in Figure 6, through outlets 1 and 3, only anisole was observed while both anisole and polystyrene remained. Also, at an increased inflow rate, the intensity of anisole collected at outlets 1 and 3 decreased due to short diffusion time. The results also confirmed that no peak of PS was detected at outlets 1 and 3. The PS peaks are observed only at outlet 2. It proves that anisole can be isolated from the mixture with PS.

However, it is difficult to separate PEG from the mixture 2 with PS. The peaks of PS and PEG are not detected at outlets 1 and 3 as shown in Figure 8, when the flow rate of mixture is 10 µl/min. It means that no separation occurs at this or higher flow rate. Also, if the mixture flow rate is 5 µl/min or lower as shown in Figure 7, both PS peak and PEG peak appear at side outlets 1 and 3, confirming that there is no separation. These are caused by the difference of the size of PS molecules having long polymer chain length compared to anisole having the common molecular size of solvent. Although the difference in molecular weight of PS with anisole and PEG is almost the same, PEG has the same polymeric characteristics of PS, so it is difficult to separate from the mixture with PS.

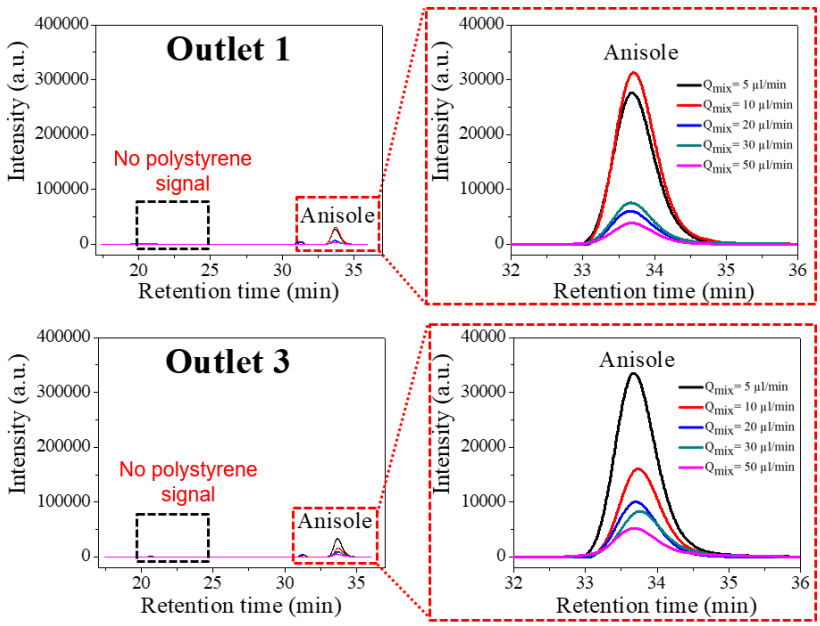

Figure 5. Analytical results at outlets 1 and 3 for various inlet flow rates.

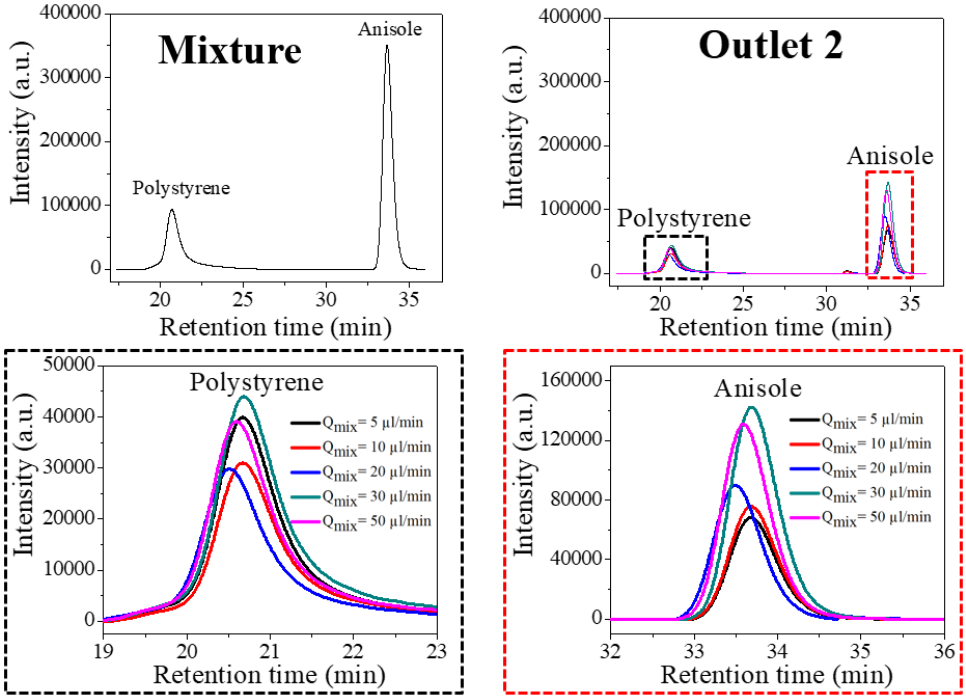

Figure 6. Analytical results at outlet 2 for various inlet flow rates.

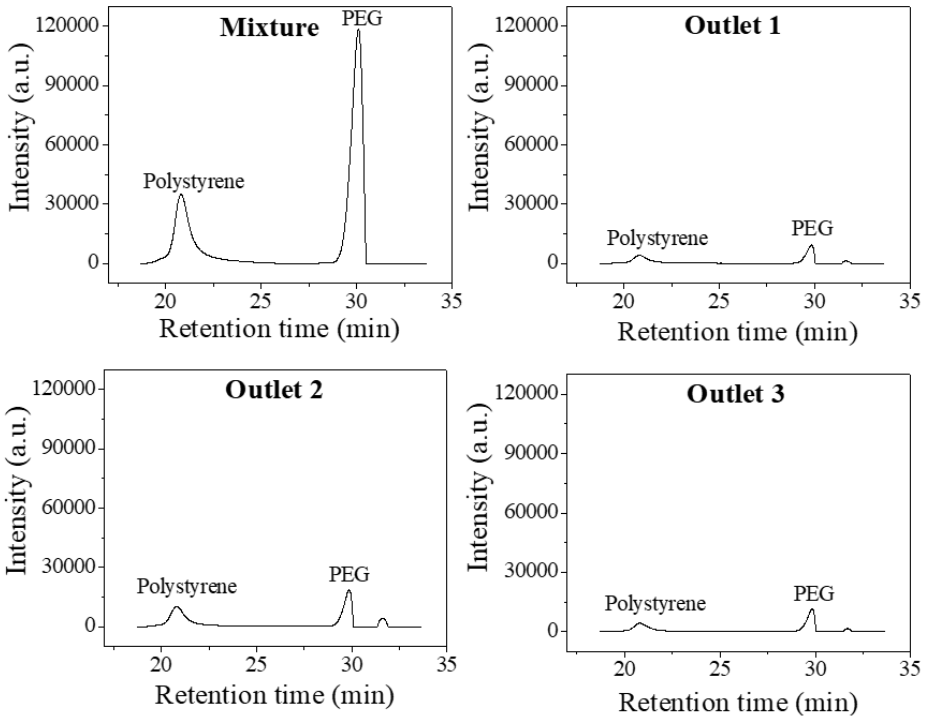

Figure 7. Analytical results for the separation of PS and PEG
(Flow rate PS:PEG of 5:15 µl/min).

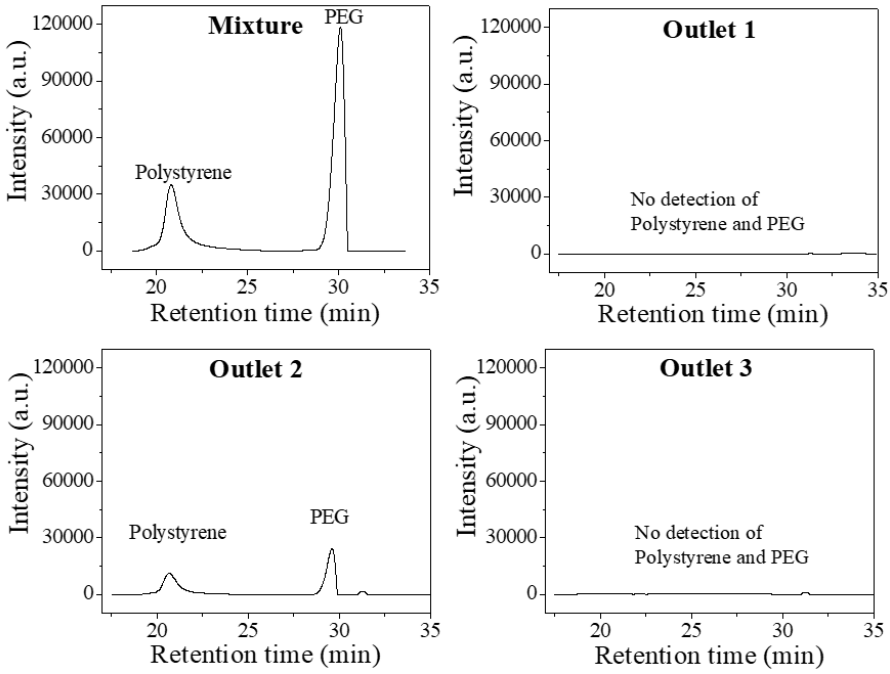

Figure 8. Analytical results for the separation of PS and PEG (Flow rate PS:PEG of 10:30 µl/min).

4. CONCLUSIONS

In this paper, we showed that a low Mw substance can be separated selectively from the mixture of a low Mw substance and a high Mw substance by using diffusion; anisole from the mixture of anisole and PS dissolved in the DMF solvent. The difficulty of separation of PEG from the mixture of PS and PEG was observed because of the same polymeric characteristics of PEG and PS. For future study, the separation experiment in the smaller microfluidic chip will be challenged for high resolution and efficiency and the study is expected to apply to other subjects such as the polymer science and separation of proteins and micro-nano particles.

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Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Pamme N. - Continuous flow separations in microfluidic devices, Lab. Chip. **7** (12) (2007) 1644-1659.

2. Peterman M. and Noolandi J. - Method of separation of polymers, US8070956B2, 06-Dec-2011.
3. Pavia D. L. - Introduction to organic laboratory techniques: a microscale approach, 4th edition, CA: Thomson Brooks/Cole, Belmont, New York, USA, 2007.
4. Giddings J., Yang F., and Myers M. - Flow-field-flow fractionation: a versatile new separation method, Science **193** (4259) (1976) 1244-1245.
5. Hatch A., Garcia E., and Yager P. - Diffusion-Based Analysis of Molecular Interactions in Microfluidic Devices, Proc. IEEE **92** (1) (2004) 126-139.
6. Kamholz A. E., Weigl B. H., Finlayson B. A., and Yager P. - Quantitative Analysis of Molecular Interaction in a Microfluidic Channel: The T-Sensor, Anal. Chem. **71** (23) (1999) 5340-5347.
7. Kamholz A. E. and Yager P. - Theoretical analysis of molecular diffusion in pressure-driven laminar flow in microfluidic channels, Biophys. J. **80** (1) (2001) 155-160.
8. Kamholz A. E., Schilling E. A., and Yager P. - Optical measurement of transverse molecular diffusion in a microchannel, Biophys. J. **80** (4) (2001) 1967-1972.
9. Munson M. S., Hawkins K. R., Hasenbank M. S., and Yager P. - Diffusion based analysis in a sheath flow microchannel: the sheath flow T-sensor, Lab. Chip. **5** (8) (2005) 856-862.
10. Kamholz A. E. and Yager P. - Molecular diffusive scaling laws in pressure-driven microfluidic channels: deviation from one-dimensional Einstein approximations, Sens. Actuators B Chem. **82** (1) (2002) 117-121.
11. Cussler E. L. - Diffusion mass transfer in fluid systems, Cambridge University Press, Cambridge, New York, USA, 2009.