Trans. Phenom. Nano Micro Scales, 6(Special): 15-19
DOI: 10.22111/tpnms.2018.23940.1146

ORIGINAL RESEARCH PAPER

# Experimental Study of the Laser Induced Flow and Thermophoresis in Suspending Microparticles

***Sharzad Ebadati, Danial Zarbaf, Mohammad Zabetian Targhi*, Yaser Oghabneshin***

*Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran*

*Received 9 February 2018; accepted 10 March 2018; available online 6 May 2018*

**ABSTRACT:** The induced flow effect is the rotary motion generated in the fluid flow due to the temperature gradient. The phenomenon of thermophoresis is the movement of particles from the warmer side of the fluid to the cooler side. Laser is a very suitable device for creating a temperature gradient due to its unique features such as high power density, harmonic waves, single wavelength and very low divergence. Thermophoresis phenomenon and induced flow have many uses in the transfer of particles and in various fields such as medicine and industry. In the present work, the phenomena of laser thermal interactions and flows of microparticles were studied. Thermophoresis phenomenon and induced flow were investigated experimentally using laser. Scale analysis of the migration velocity caused by the laser thermal effects shows that the induced flow in the fluid has a larger scale in comparison with the thermophoresis phenomenon. Thus, the focus of the experimental study was on the laser induced flow by the local heat absorption of Rhodamine B solutions. Review of recent researches show that the idea of Rhodamine B topical absorption to create fluid motion has not been previously published. Therefore, it is considered as the most important novelty of the present work.

**KEYWORDS***: Induced flow; Laser; Rhodamine B solutions; Thermophoresis phenomenon*

## INTRODUCTION

The laser is used in many fields such as medicine, engineering, and science, due to its unique features such as high power, uniformity of waves, single wavelength and low divergence in comparison with other light sources (1). The effect of laser on the flows containing microparticles is divided into two sections of thermal effects and hydrodynamic effects. Thermal effects are divided into three catagories of thermophoresis, photophoresis and induced flow. The subject of this research is the studying effect of thermophoresis and induced flow on flows containing microparticles**.** As is shown in Figure 1 schematically, the thermophoretic phenomenon creates a temperature gradient in the fluid and particles motion under the applied temperature gradient (2).

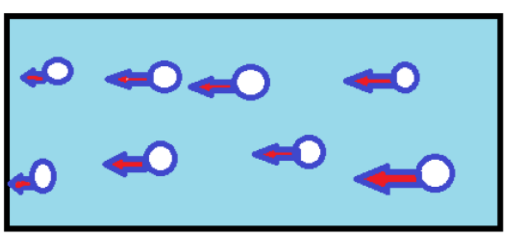


**Fig.1.** Schematic of thermophoresis phenomenon and suspending particles' movement from the hot zone of the liquid to the cool zone

Among researchers who studied the phenomenon of thromophoresis, Brenner et al. provided an appropriate model for analysis of temperature effect on the thromophoretic velocity (3). Mast et al. experimentally accelerated the polymerization process of RNA without changing the nature of these particle using laser and thermophoretic phenomenon (4). With regards to the invulnerability of DNA and RNA molecules due to the use of lasers and the effect of theromophoresis on the displacement of these particles, researchers such as Braun et al, used laser and thermophoretic phenomenon on medical diagnostics and blood cell separation (5). Regazzetti experimentally checked and calculated the velocity of thermophoresis for porous microparticles (6).

Eslamian et al. was among the researchers who developed McNab model for the thermophoretic velocity in the liquid environment, that is depending on the type of liquid, thermal expansion coefficient, thermal conductivity coefficient and liquid temperature. This study is a further model development of the correlation that was proposed by McNab, which calculated the velocity of thermophoresis in the environment of gases (7). Considering many applications of thermophoresis, photophoresis and induced flow phenomenon, and also due to the limited researches done in this field, especifially in the liquid environment, there is a need for a closer look at these three effects. Therefore, in this study, experiments have been designed and carried out to determine the effect of thermophoresis phenomenon and induced flow on suspended particles in liquid. Using the Particle Tracking Velocimetry (PTV) method, the velocity that created by these two effects has been investigated.

*Corresponding Author Email: *zabetian@modares.ac.ir*
Tel.: +982182884985; Note. This manuscript was submitted on February 9, 2018; published online May 6, 2018.

| | **Nomenclature** | | |
|---|---|---|---|
| X | Ratio of the particle diameter to the inter-particle distance | D | particle diameter |
| L | the inter-particle distance | | **Subscripts** |
| u | velocity of particles $\times 10^{-4}$ (m/s) | freq | frequency |

By performing specific tests and changing parameters such as the diameter of the laser beam, the particle concentration and the concentration of Rhodamine B solutions, their effects has been observed on the velocity of suspended particles**.**

## EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The aim of the present study is to investigate the possibility of transfer of particles along the channel by laser thermal effects. Experiments have been designed, including studying the effect of laser beam diameter, Rhodamine B concentration, and particle concentration on the particulate velocity.

The experimental apparatus includes the following items: a mini-channel made of plexiglass, laser with wavelength of 532 nm (in order to create heat in the fluid), microscope for imaging, a CCD camera for recording Rhodamine B penetration in a water plug, distilled water (water without particles), non-absorptive particles, solid particles of Rhodamine B (fluorescent material) that having a high absorption coefficient in wavelength of 532 nm and solution of Rhodamine B in water make it a light absorber, and a computer for image processing, as depicted in Figure 2.

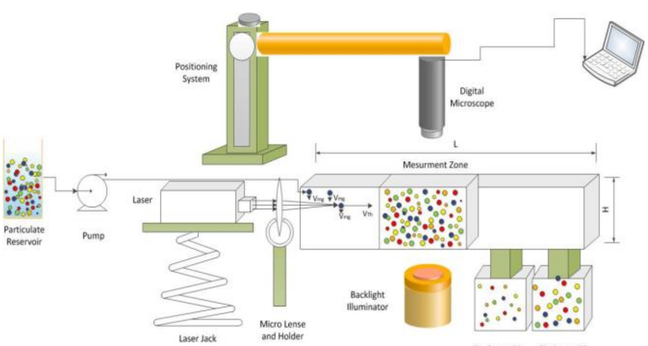


**Fig. 2.** Schematic of test components arrangement

To conduct the tests, the following steps are performed in sequence:

1) Distilled water plug is injected inside the channel.
2) The laser beam is adjusted into the channel as shown in Figure 3.
3) The microscope is set to a maximum magnification of 140 times.
4) Discharging 1cc of water inside the channel by opening the outlet valve.
5) One mili-liter of Rhodamine B fluorescent solution that containing particles of 10µm, with an insulin syringe was injected into the channel, as shown in Figure 4 (In order to stop the plug, the outlet valve is closed as soon as the plug has been formed). In this way, the light absorbent plug is formed at the beginning of the channel and the particle-free plug is formed at the ending of the channel.

**Fig. 3.** Laser light beam adjustment

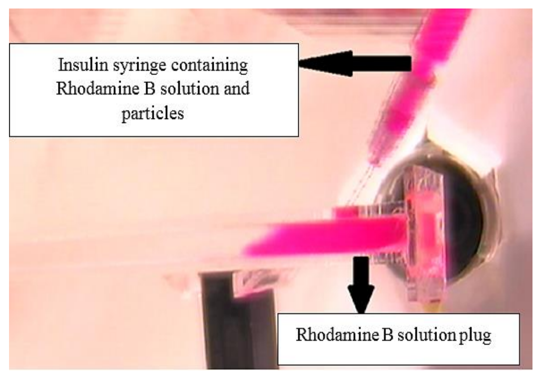


**Fig. 4.** Injection of 1cc Rhodamine B solution into the water-filled channel

6) The microscope was placed at the beginning of the channel in a way that laser light was at maximum intensity (in order to the effect of the temperature gradient can be observed on microparticles velocity).
7) The microscope is focused in the middle of the channel.
8) The background light is exposed directly on the microscope (bright background light for better particle look).
9) Grabbing pictures of how the particles move (in up and side directions of mini-channel).
10) Rhodamine B was removed from the channel with an insulin syringe.

11) The channel was washed with successive water plugs until the channel is suitable to repeat the test.

To conduct experiments at uniform conditions, a solution was made that has the same concentration in all experiments**.** Also, the particle concentration is low such that the particle interactions force can be ignored**.**

Hence, for making the liquid containing microparticles that the average ratio of the particle diameter to the inter-particle distance are 10, the necessary calculations were carried out with the formula presented by Zabetian et al. (8), which is given by equation1.

$$X = \frac{L}{D} \tag{1}$$

If this ratio is greater than 10, the particle interaction can be neglected and the particles are considered independent of each other.

As shown in Figure 5, D is the particle diameter and L is the inter-particle distance**.**

To make the fluid with this feature, 0.0699 gr of particles were suspended in 15cc of water. To dilute it, and with attention to the impossibility of observing the fluid due to the high density of particles, For the ratio mentioned to reach from 10 to 15, each 1cc of this solutions is mixed with 2.357 cc of water.

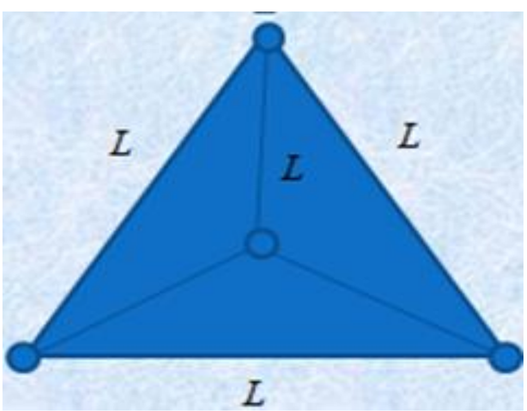


**Fig. 5.** Suspended particles in fluid with spacing of L

To make a Rhodamine B solution with concentration of $5\times10^{-4}$ M, the amount of 0.059 gr of Rhodamine B is dissolved in 250 cc of water. Various amounts of these solutions can be combined with particle suspension to perform different experiments.

## RESULTS AND DISCUSSION

A test was repeated four times with a basic test settings to ensure the accuracy of the results**.** In order to prove the theory and that the laser radiation can accelerate particles, each experiment is done in two stage**.** The first stage, by turning on the laser that results in accelerating particles, and the second stage, by turning off the laser that results in decelerating particles**.** As the first data, velocity vectors are indicated in Figure 6. It can be inferred that the particles have a rotating motion inside the channel.

By comparing Figure 6 and Figure 7 which shows the motion of particles in both laser modes (laser-on and laser-off), It can be deduced that the particle velocity is reduced due to laser-off condition.

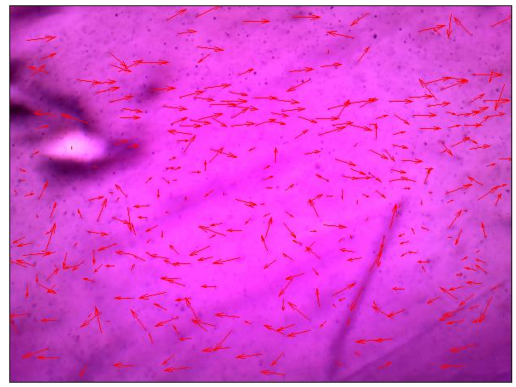

**Fig. 6.** Particle motion vectors, in laser-on mode at the beginning of the channel

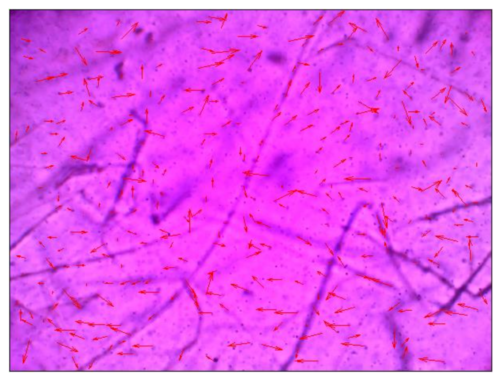

**Fig. 7.** Particle motion vectors, in laser-off mode at the beginning of the channel

In Figure 8 and Figure 9, the horizontal velocity contours of the particles are observed in both laser modes (laser-on and laser-off).

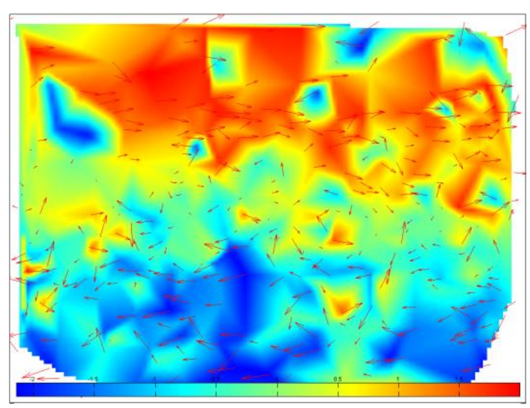

**Fig. 8.** Horizontal velocity contour in laser-on mode at the beginning of the channel

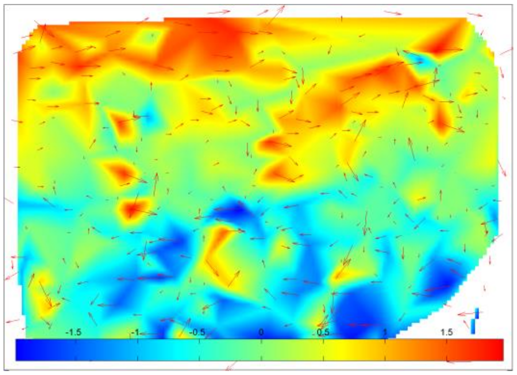

**Fig. 9.** Horizontal velocity contour in laser-off mode at the beginning of the channel

As are illustrated by Figure 8 and Figure 9, the horizontal velocity in laser-on mode is more than laser-off mode and the upper regions of the channel have higher velocity magnitudes than the lower regions of the channels. As these figures show, the clockwise circular motion has been created in the fluid which this movement prevented the particles from being deposited and also in laser-on mode, almost all regions have high speed particles**.** Figure 10 and Figure 11, show the frequency of particles versus velocity magnitude. As can be seen, the number of particles at the same velocity in laser-on mode is more than laser-off mode (e.g. About 150 particles have velocity of 100μm per second in laser-on mode, while in laser-off mode, this number has decreased to 70 particles).

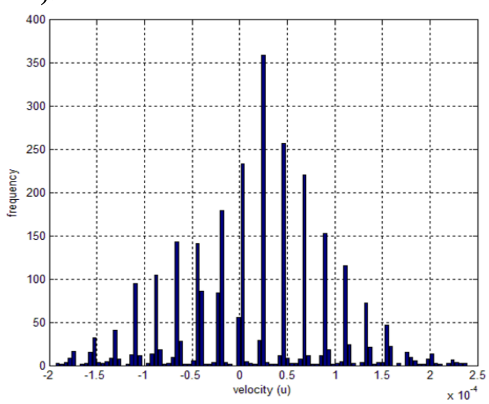


**Fig. 10.** Frequency of data in laser-on mode

In order to compare the thermal effect of the laser on the particles velocity, at three different channel positions (as depicted in Figure 12, the mean velocity for particles are presented in Table 1, that are processed from 10 images in a second of the experiment.

In this Figure, point No. 1, is located at the position of full absorption of the laser light**.** The higher mean velocity for particles at this point compared with points No. 2 and No. 3, is due to the effect of thermophoresis**.**

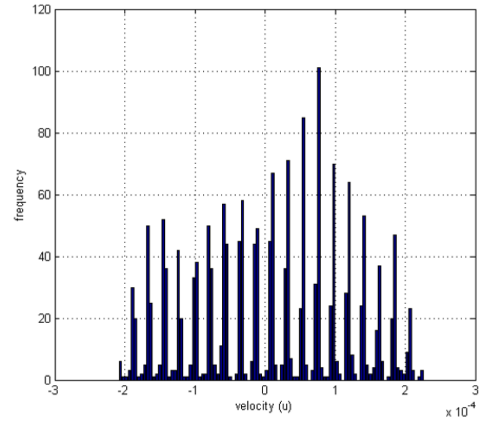


**Fig. 11.** Frequency of data in laser-off mode

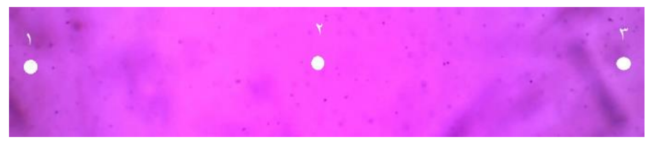

**Fig. 12.**The three points are the beginning, the middle and the end of channel

**Table 1**
Mean velocity for particles at 3 points at the beginning, middle and end of the channel

| Points | Mean velocity (μm/s) |
|---|---|
| 1 | 66.9 |
| 2 | 37.9 |
| 3 | 35.6 |

## CONCLUSION

In the present work, the induced flow and thermophoresis phenomenon was investigated in microparticles by using laser and it was observed that when the laser light is on, the horizontal velocity of particles that are moving right is greater than those which are moving to the left. In laser-on mode, particles had clockwise circular motion which this movement prevented the particles from being deposited while in laser-off mode the particles deposited quickly. Also, it was found that the number of particles in laser-on mode and at the same velocity, are significantly higher than the number of particles in laser-off mode**.** Finally, in this study, by comparing the velocity in different position of the channel, it was concluded that at the beginning of the channel, the velocity of particles was more than other points due to the effect of thermophoresis**.**

## REFERENCES

[1] Cobb CM. Lasers in periodontics: a review of the literature. Journal of periodontology. 2006;77(4):545-64.

[2] Jerabek-Willemsen M, André T, Wanner R, Roth HM, Duhr S, Baaske P, et al. MicroScale Thermophoresis: Interaction analysis and beyond. Journal of Molecular Structure. 2014;1077:101-13.

[3] Schermer RT, Olson CC, Coleman JP, Bucholtz F. Laser-induced thermophoresis of individual particles in a viscous liquid. Optics express. 2011;19(11):10571-86.

[4] Mast CB, Schink S, Gerland U, Braun D. Escalation of polymerization in a thermal gradient. Proceedings of the National Academy of Sciences. 2013;110(20):8030-5.

[5] Braun D, Libchaber A. Trapping of DNA by thermophoretic depletion and convection. Physical review letters. 2002;89(18):188103.

[6] Regazzetti A, Hoyos M, Martin M. Experimental evidence of thermophoresis of non-Brownian particles in pure liquids and estimation of their thermophoretic mobility. The Journal of Physical Chemistry B. 2004;108(39):15285-92.

[7] Eslamian M, Saghir MZ. On thermophoresis modeling in inert nanofluids. International Journal of Thermal Sciences. 2014;80:58-64.

[8] Zabetian M, Saidi MS, Shafii MB, Saidi MH. Sepa - ration of microparticles suspended in a minichannel using laser radiation pressure. Applied optics. 2013;52(20):4950-8.