Elastic Instability of Hyaluronate Solution in Micro Abrupt Contraction-Expansion Channels

Ruri Hidema[1], Hiroshi Suzuki[2], Yoshiyuki Komoda[2]
[1]Organization of Advanced Science and Technology, Kobe University, Kobe, Japan
[2]Department of Chemical Science and Engineering, Kobe University, Kobe, Japan

Abstract

High deformations of fluids in an abrupt contraction or expansion channel induce unstable behaviors of the fluids. This happens especially in a micro scale, which order is 50 microns or less, even when Reynolds number is low. The aqueous solutions of high molecular weight of polymers at low concentrations are likely to enhance the instability of the fluidity. This is because, the high molecular weight of polymers are comparably large to the scales of the micro channels when the polymers are in elongated state. Although such a non-Newtonian fluid is important to the micro-fluidic instability, not enough studies have mentioned about non-Newtonian fluids during the last decades [1-3]. In these studies, dimensionless numbers, such as, the Reynolds number, Re, and the Weissenberg number, Wi, are used to characterize the behaviors of viscoelastic flows. In addition, the ratio of Wi/Re called the Elastic number that related to elasticity and inertia of the fluids is important to characterize the flows. Therefore, the unstable flow of the now-Newtonian fluids in a micro-channel is also called elastic instability. In terms of applications, techniques of inkjet printing and lab-on-a-chip are relevant to the micro-fluidic instability. Recently, a unique study related to a non-Newtonian behavior in a micro-channel has been made, which measures the rheological properties of fluids [4]. Therefore, the flow instability in a micro-channel has full of potential and interests in fundamental and applied studies.

Here, we focus on elastic instability of hyaluronate solution in a micro-channel. Hyaluronan is essential biopolymers for human body. For example, normal synovial fluids in human joints contain hyaluronan at the concentration of 3-4mg/ml. Lack of hyaluronan in the synovial fluids induces joint pain. Indeed, more than 1/3 of over 60 years old senior citizens suffer from the disease. Therefore, a quantitative diagnostic method with a little amount of the sample is needed, which is still difficult. The problems of diagnostics are now that the test is not really

quantitative. Besides, the test needs 1ml synovial fluids in spite of the fact that all amount of the synovial fluid is 3ml.

Elastic turbulence of hyaluronate solution in a micro abrupt contraction-expansion channel can be used to determine the concentration of hyaluronan in solution. In this study, flow behavior of the hyaluronate solution and its concentrations were characterized. Water and phosphate buffered saline (PBS) solution of sodium hyaluronate (HA-Na) at the concentration of 1.5 to 4.5 mg/ml were prepared as a hyaluronate solution. Solutions at the concentration of 3.5 mg/ml HA-Na are quasi-normal synovial fluids, while the solutions 1.5 mg/ml HA-Na are quasi-sick synovial fluids. Viscoelastic characteristics of these solutions were measured by a rheometer. HA-Na water solution showed higher viscosity than that of HA-Na PBS solution at each concentration. Elasticity of HA-Na water solution was decreased considerably with decreasing the concentration of HA-Na. On the other hand, elasticity of HA-Na PBS solution was slightly decreased with decreasing the concentration of HA-Na. A micro abrupt contraction-expansion channel was used to visualize elastic turbulences of HA-Na water/PBS solutions. For visualization, polystyrene particles were dissolved in the solutions. The micro channel closely follows a design proposed by Rodd et al [1, 2]. Width of the main channel was 400 microns, and the depth of the channel was 50 microns. Contraction ratios of a width of main channel to a width of the contraction channel and the length of the contraction parts are varied. These variations affect extensional stress to the flow in a micro channel. Therefore, the flow behavior was affected. At low Reynolds numbers, the flow of hyaluronate solution was stable. By increasing the Reynolds numbers, sizes of vortices at corners in main channel were increasing. At a critical Reynolds numbers, the vortices fluctuated and disappeared. Once the vortices disappeared, it is difficult to be regenerated. This condition is determined as an elastic turbulence. The critical Reynolds numbers were changed by the concentration of HA-Na in each solution. In addition, the critical Reynolds numbers were affected by the solvents, which may correspond to elasticity of HA-Na water solution and HA-Na PBS solution. Tendency of the critical Reynolds numbers in a micro-channel having different contraction ratio can be different.

Since the elastic turbulence of Ha-Na solution is related to its concentration, this technique is a promising application method for a diagnostic of bio fluids such as

synovial fluids with a small amount.

[1] L. E. Rodd, T. P. Scott, D. V. Boger, J. J. Cooper-White, G. H. McKinley, J. Non-Newtonian Fluid Mech, **129**, 1 (2005)
[2] L.E. Rodd, J.J. Cooper-White, D.V. Boger, G.H. McKinley, J. Non-Newtonian Fluid Mech, **143**, 170 (2007)
[3] A. Lanzaro, X. –F. Yuan, J. Non-Newtonian Fluid Mech, **166**, 1064 (2011)
[4] K. Kang, L. J. Lee, K. W. Koelling, Exp. in Fluids, **38**, 222 (2005)