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Effect of surfactant on the linear stability of a shear-imposed fluid flowing down a compliant substrate. (English) [Zbl 07388698]


Summary: We study the linear stability of a surfactant-laden shear-imposed fluid flowing down a compliant substrate. The aim is to extend the earlier and recent studies [P. W. Carpenter and A. D. Garrud, ibid. 155, 465–510 (1985; Zbl 0596.76053); J. P. Alexander et al., ibid. 900, Paper No. A40, 33 p. (2020; Zbl 1460.76035)] in the presence of insoluble surfactant when an external streamwise imposed shear stress acts at the fluid surface. In other words, the current study expands the earlier study [H.-H. Wei, Phys. Fluids 17, No. 1, Paper No. 012103, 5 p. (2005; Zbl 1187.76555)] in the presence of a flexible substrate. The Orr-Sommerfeld-type boundary value problem is derived and solved by using the long-wave series expansion as well as the Chebyshev spectral collocation method for disturbances of arbitrary wavenumbers. The long-wave result reveals the existence of two dominant temporal modes, the so-called surface mode and surfactant mode, where the surface mode propagates faster than the surfactant mode. It is found that the surface mode can be stabilized by introducing an insoluble surfactant at the fluid surface even though the spring stiffness $C_K$ keeps a lower value than its critical value $C_K^*$. But the imposed shear stress exhibits a dual role in the surface mode in two different regimes of spring stiffness $C_K$, i.e. a stabilizing effect when $C_K < C_K^*$ and a destabilizing effect when $C_K > C_K^*$. Further, the surfactant mode becomes more unstable with the increasing values of spring stiffness $C_K$ and damping coefficient $C_D$. On the other hand, the numerical result in the arbitrary wavenumber regime reveals the existence of subcritical instability induced by the surface mode. Furthermore, a different temporal mode, the so-called wall mode, appears in the finite wavenumber regime for special values of $C_K$ and $C_D$, which becomes weaker with increasing values of the wall parameters $C_K$, $C_D$, $C_B$ and $C_T$, but becomes stronger with increasing values of the inclination angle $\theta$ and wall parameter $C_I$. Moreover, the temporal growth rate associated with the wall mode enhances with the increasing value of the Marangoni number but attenuates with the increasing value of imposed shear stress. In addition, another temporal mode, the so-called shear mode, emerges in the finite wavenumber regime when the Reynolds number is high and the inclination angle is small. The unstable region generated by the shear mode magnifies with the increasing value of the imposed shear stress but decays with the increasing value of Marangoni number. Further, the shear mode becomes more unstable as soon as the spring stiffness $C_K$ and damping coefficient $C_D$ increase.

MSC:
76-XX Fluid mechanics

Keywords:
flow-structure interactions; shear-flow instability; thin films

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References:

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