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Nonlinearity and bifurcation of particle-fluid systems

Particle-fluid systems are characterized by not only its dynamic and heterogeneous two-phase structure in both time and space but also its critical behavior with changing operating conditions. There is no single and general variation theorem for nonlinear steady-state dissipative systems; therefore, it is essential to define the stability condition and to understand its dependence on various factors in quantifying a nonlinear particle-fluid system.

With the increasing dominance of the fluid over particles, a vertical concurrent-up particle-fluid system can operate in particle-dominating (PD) regime of fixed bed, particle-fluid-compromising (PFC) regime of fluidization and fluid-dominating (FD) regime of dilute transport, each of which is characterized by its individual stability condition and distinct flow structure[1]. Especially, the two-phase structure prevails in the PFC regime. A so-called energy-minimization multi-scale (EMMS) model has been established to define stability conditions in these three regimes and to identify transitions between them by our research group.

Recent research results have indicated that the transition from the PD regime to the PFC regime corresponds to a nonequilibrium phase transition or bifurcation occurring in particle-fluid systems. Under certain conditions ($Re<2$), the PD regime can operate in a linear nonequilibrium state; however, particles start to move as long as the minimum fluidization velocity is reached, leading to the nonlinear behavior in the system. With increasing nonlinearity, a sudden change of flow structure occurs at a critical point called the minimum bubbling point, beyond which the self-organization of particles and the fluid prevails due to their compromising between each other, resulting in a dissipative two-phase structure. This phenomenon corresponds to the first bifurcation in thermodynamics. Such a dissipative structure becomes stable at the maximum energy dissipation corresponding to a maximum entropy production rate. With further increasing fluid velocity, the second bifurcation can occur at local scale; therefore, the bubbling regime with a relatively regular structure is replaced by the turbulent regime with obvious chaotic behavior. In this PFC regime, the ordered two-phase structure requesting the minimum suspending and the transporting energy is accompanied by the disordered dissipative behavior calling for the maximum dissipation, and the complicated time- and space-dynamic structure is attributed to the coupling of such two different processes. As long as the fluid can completely dominate particles, the second bifurcation occurs in the whole system, leading to the replacement of the heterogeneous dissipative structure by a uniform structure. Then, the system operates in the FD regime of dilute transport characterized by the minimum energy dissipation corresponding to the minimum entropy production rate.

Currently, our research is devoted to the nonlinear time- and space-dynamic structure of particle-fluid systems, especially to the disordered dissipative process and its coupling with the ordered two-phase structure. It is considered that multiple resolutions of the system should be explored to understand such a complicated system. That is, the movement can be divided into extreme and dynamic aspects, energy consumption into reversible and irreversible components, processes into disordered and ordered branches and structure into different scales. Such resolutions make it possible to extract deterministic aspects from the global process, then, simplifying the analysis of non-deterministic aspects.

References

1 Li Jinghai, Kwauk, M., *Particle-Fluid Two-Phase Flow —— the Energy-Minimization Multi-Scale Method*, Beijing: Metallurgical Industry Press, 1994.

2 Li Jinghai, Kwauk, M., Reh, L., The energy-minimization multi-scale model of circulating fluidized beds, *Science in China* (in Chinese), Ser. B, 1992, 11: 1127.

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