STABILITY ANALYSIS OF GAS SOLIDS SEPARATION IN SCALING-UP FLUIDIZED BED REACTORS

Fei Wei, Beijing Key Laboratory of Green Reaction Engineering and Technology ,Department of Chemical Engineering, Tsinghua University, China
Chenxi Zhang, Zhao Jia, Weizhong Qian, Beijing Key Laboratory of Green Reaction Engineering and Technology, Department of Chemical Engineering, Tsinghua University, China

In large industrial fluidized bed reactors with high gas solids flow rates, small cyclones working in parallel are often preferred to achieve higher efficiency in the case of uniform distribution of gas-solid two-phase flow across each inlet. However, there is mounting evidence[1-5] that gas-solid suspensions pass through identical paths in parallel can be significantly non-uniform, resulting in a dramatically drop in overall efficiency. In this study we used the direct Liapunov method by considering the interaction between gas and solids to detect the instability of uniformity. Owing to the special symmetry in this system, the criterion can be simplified into identifying the concavity (concave or convex) of pressure drop across a single cyclone with respect to operational parameter C_T. Then, based on the stability analysis of uniformity, a novel design principle is provided to prevent non-uniform distribution at high dust loading. The effect of geometrical factor, i.e. dimensionless vortex finder diameter d_r, on the stability of uniformity has been further investigated. The phase diagram of stability is calculated to give a clue of designing robust parallel cyclones system.

Hereon, we considered two identical and symmetrically parallel cyclones. The mass flow rate of gas stream and solids in steady state through a pair of parallel cyclones give:

$$m_{gT} = m_{g1} + m_{g2} = \gamma_1 m_{gT} + \gamma_2 m_{gT} \quad (1)$$

$$m_{sT} = m_{s1} + m_{s2} = \sigma_1 m_{sT} + \sigma_2 m_{sT} \quad (2)$$

where γ_i and σ_i are the mass fractions of gas and solids phase flows, respectively passing across cyclone i ($i=1,2$). For a given parallel system:

$$\gamma_1 + \gamma_2 = 1 \quad (3)$$

$$\sigma_1 + \sigma_2 = 1 \quad (4)$$

In order to present the multi-phase interaction, the ratio between total mass flow rate of solids and gas is introduced here:

$$C_T = \frac{m_{sT}}{m_{gT}} = \frac{\gamma_i m_{si}}{\sigma_i m_{gi}} \quad (5)$$

The total energy dissipation at uniform distribution can be expressed as:

$$\varepsilon_{T,Uniform} = f(C_T, \sigma_1 = \sigma_2 = \frac{1}{2}) \quad (6)$$

The non-uniform distribution of two-phase flow through two identical cyclones can be written as:

$$\varepsilon_{T,Nonunifrom} = f(C_T, \sigma_1 \neq \sigma_2) \quad (7)$$

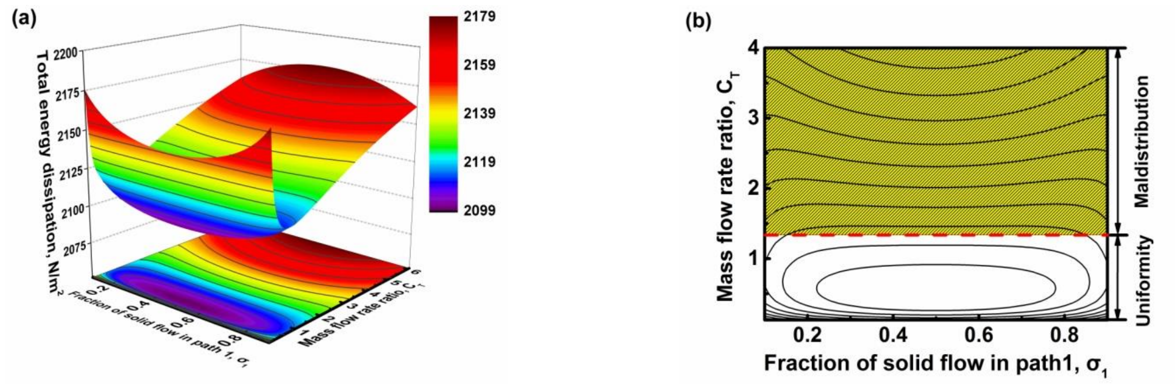

Figure 1. (a) The effect of flow distribution of solids phase on total energy dissipation for different mass flow rate ratio (C_T); (b) The phase diagram of stability of uniformity

Due to the special symmetry in this system, the criterion for predicting mal-distribution across parallel cyclones can be simplified into determining the characteristics (concave or convex) of multivariate surface on which total energy dissipation (ε_T) lies.

Figure 2 provides a phase diagram of stability. Since the criterion of uniformity can be simplified as the 'one-dimension' concavity of pressure drop with respect of C_T, the 'two-dimension' phase diagram will illustrate the effects of both operational parameter (mass flow rate ratio C_T) and geometrical parameter (dimensionless vortex finder diameter d_r) on stability of uniform distribution.

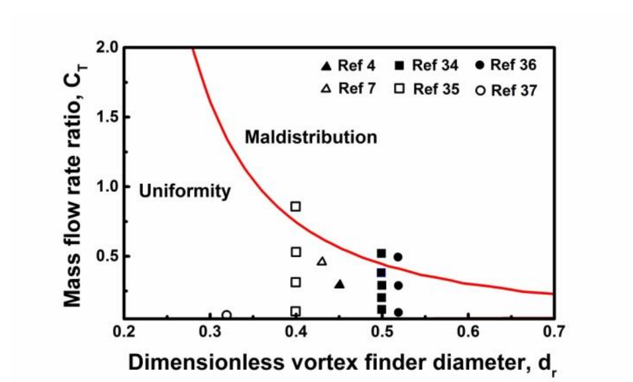

Figure 2. A phase diagram of relationship between stability of uniform distribution with dimensionless vortex finder diameter d_r and mass flow rate ratio C_T

Literature Cited

1. Hoffmann AC, Stein LE. Gas cyclones and swirl tubes-principles, design and operation (2nd edition). London: Springer, 2008.
2. Broodryk NJ, Shingles T. Aspects of cyclone operation in industrial chemical reactors. Preprints for Fluidization VIII Conference, Tours, France. May 14–19 1995:1083
3. Kim TW, Choi JH, Shun DW, Kim SS, Kim SD, Grace JR. Wear of water walls in a commercial circulating fluidized bed combustor with two gas exits. Powder Tech. 2007; 178: 143-150.
4. Jiang Y, Qiu GZ, Wang HG. Modelling and experimental investigation of the full-loop gas-solid flow in a circulating fluidized bed with six cyclone separators. Chem Eng Sci, 2014; 109: 85-97.
5. Guo Q, Zhang XS, Zhou Q, Nie L, Liu TS, Hu XK. Operation experience and performance of the first 300 MWe CFB boiler developed by DBC in China. Proceedings of the 20th international conference on fluidized bed combustion. Xian: Springer.