

# Chapter 1

## Analysis of Hydrodynamics and Mass Transfer of Gas– Liquid and Liquid–Liquid Taylor Flows in Microchannels: Theoretical Approach and Experimental Proofs

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### **ABSTRACT**

*Analysis of hydrodynamics and mass transfer Taylor flows in micro channels of both gas-liquid and liquid-liquid systems on the basis of classical theoretical approach with some simplifying assumptions was performed. Results of theoretical analysis for description of hydrodynamic parameters and mass transfer characteristics were confirmed by comparison with the author's own and available in literature experimental data. It was shown that the main parameters of two-phase Taylor flows could be quite precisely described theoretically: mean bubble/droplet velocity, liquid film thickness, real gas holdup (which is always smaller than so-called dynamic holdup), pressure drop. Peculiarities of liquid-liquid flows compared to gas-liquid Taylor flows in capillaries are discussed. Wettability effect on hydrodynamics was examined. Tools of mass transfer intensification of gas-liquid and liquid-liquid Taylor flow in micro channels are analyzed. Three-layer model for heat and mass transfer has been proposed and implemented for the case of solid-liquid mass transfer for gas-liquid Taylor flows; optimal process conditions for this process are found theoretically and discussed from physical point of view.*

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## INTRODUCTION

In the past decades micro and minireactors are actively investigated for their use instead of conventional devices as well as for new processes which are crucially increased due to smaller transversal sizes of the micro and minichannels (capillaries in other word). One understands under the micro channels usually the channels with hydraulic diameter roughly smaller than 1 mm (often 100–200  $\mu\text{m}$  or even smaller, down to 10  $\mu\text{m}$ ). The mini channels have larger diameters, approximately up to 2 mm (see Background section for details). The advantages of micro and mini channels are:

1. Smaller diffusional path, e.g. for typical diffusivity in the liquid  $D = 10^{-9} \text{ m}^2/\text{s}$  the characteristic time of diffusion could be assessed as  $t_{\text{dif}} \approx d^2/D$ , i.e. for  $d = 100 \text{ mm}$   $t_{\text{dif}} \approx 10^7 \text{ s} = 2778 \text{ hours}$ , for  $d = 10 \text{ mm}$   $t_{\text{dif}} \approx 10^5 \text{ s} = 28 \text{ hours}$ , for  $d = 1.0 \text{ mm}$   $t_{\text{dif}} \approx 10^3 \text{ s} = 16.7 \text{ min}$ , for  $d = 0.1 \text{ mm}$   $t_{\text{dif}} \approx 10 \text{ s}$ . Hence, the decrease of the channel diameter results in much shorter time necessary to perform mass transfer due to diffusion alone.
2. The flow in micro and minichannels is close to the plug flow due to absence of turbulent mixing, especially for so-called Taylor (or slug, or chain) flow (Figure 1), where the bubbles/droplets of dispersed phase have the length larger than diameter of the channel.
3. The smaller volume of micro and minireactors is easier to control due to less inertia of hydrodynamics, heat and mass transfer parameters.
4. For explosive chemicals produced in micro and minireactors there is no risk of explosion because of their diameter is smaller than the critical value of diameter.
5. Excellent mixing in each element of Taylor flow structure due to inner local vortices (so-called Taylor vortices), allowing to increase mass transfer several times compared to one-phase laminar flow.

The application of micro and mini technologies can not only improve the quality of end products, reducing energy and resource consumption, but also increase the manufacturing mobility and the possibility of its rapid reset to produce other products. Micro- and minireactors can reduce the space occupied by the plant, making it safer and more environmental friendly.

Micro and minireactors are widely studied attracting significant interest of both researcher and industry. Nonetheless, many of published results have either experimental or numerical nature, and some theoretical approach is needed to provide more sophisticated understanding of phenomena and processes taking place in this promising type of chemical equipment.

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