# Effect of physical properties on co-current gas-liquid stratified downflow

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## *Abstract*

An important multiphase flow regime, frequently encountered in long distance hydrocarbon pipelines, as well as in transfer lines in process plants, is the co-current stratified gas-liquid downflow. The work presented herein deals with the ***transition*** from smooth to wavy stratified flow for various pipe inclination angles, liquid physical properties and gas-liquid flow rates. To understand the mechanisms involved in the evolution of waves at the transition from smooth to wavy stratified flow regime, the accurate characterization of both the structure of the gas-liquid interface and the flow field inside the liquid layer for various liquid physical properties is essential. Local axial velocity measurements, in conjunction with the liquid layer characterization experiments are expected to elucidate the influence of the liquid flow field on the interfacial structure.

Experiments are conducted at ambient temperature and pressure in a flow rig comprised of a 24 mm i.d. Plexiglas® tube with a 7 m long straight section, capable to be inclined up to 8° with respect to the horizontal, for various gas ($U_{SG}$=0-15 m/s) and liquid ($U_{SL}$=0-0.1 m/s) superficial velocities. A schematic layout of the flow rig is presented in ***Figure 1***. Using a parallel-wire conductance technique liquid layer thickness time records are acquired from which the statistics of the layer thickness, power spectra of its fluctuations, as well as wave celerities are calculated. Laser Doppler Anemometry (*LDA*) is employed to investigate the flow structure in the thin liquid layer both with and without interfacial shear induced by a co-current gas flow. A differential pressure transducer is used for pressure drop measurements in the liquid phase.

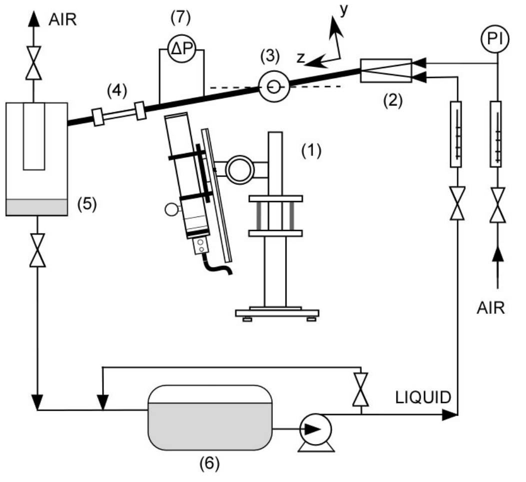

Figure 1. Experimental flow rig: (1) *LDA* setup; (2) entrance test section; (3) rotating support; (4) conductance probe; (5) phase separator; (6) liquid storage tank; (7) pressure transducer.

Table 1. Physical properties of the liquids tested.

| | *index* | *%*<br>*w/w* | ***ρ***<br>*kg/m³* | ***σ***<br>*mN/m* | ***μ***<br>*mPa.s* |
|---|---|---|---|---|---|
| water | w | - | 1000 | 72 | 1.00 |
| water-glycerin | *g* | 30.0 | 1090 | 70 | 2.50 |
| water -acetic acid | *a* | 30.0 | 1050 | 43 | 1.02 |
| water-Tween® | *T* | 0.15 | 1000 | 45 | 1.03 |

In order to study the influence of the liquid properties on the mechanisms promoting wave formation, several liquids are employed (i.e. water, aqueous glycerine and acetic acid solutions) covering a sufficiently broad range of viscosity (1.0-2.5 mPa.s) and surface tension (43-72 mN/m) values (***Table 1***). The effect of a surfactant on the gas-liquid stratified flow patterns is also studied employing a dilute aqueous solution of a non-ionic surfactant (*Tween®*), the use of which is expected to have a dramatic effect on two-phase flow [1]. The acetic acid solution, having a surface tension similar to that of the surfactant solution, is employed to confirm that the peculiar behavior of the surfactant solution (described in a previous work [2] conducted in this Lab), may be attributed to its special chemical structure and not to its low surface tension.

The new experimental data reveal a strong interplay between the wave evolution at the interface and the flow field development inside the liquid layer (***Figure 2***). A critical Reynolds number, $Re_{LC}$, is related to the emergence of the first large-amplitude solitary wave, which appears to be associated with changes of the liquid flow field structure. In particular, the new liquid axial velocity data and the liquid layer characteristics suggest that the ***onset*** of the solitary waves is strongly affected by the laminar to turbulent transition within the layer for all liquids employed [2, 3]. It is observed that these solitary waves emerge in a narrow range of $Re_{LC}$ ~2100-2300 for ***all*** liquids (with the exception of the surfactant solution) and gas flow rates tested. When the surfactant solution is used, the experimental results show that the transition to wavy stratified flow shifts to lower $Re_L$ ($Re_L$~1600-2100) as the gas flow rate increases (***Figure 3***). Furthermore, a significant pressure drop reduction (up to 35%) is observed when the surfactant is added in the water during gas-liquid stratified flow. This behavior, which is attributed to the attenuation of the turbulent ejection and sweep events within the liquid layer, as well as the eddy dissipation originating from the gas shearing motion, results in higher layer thickness values and damping of the interfacial waves.

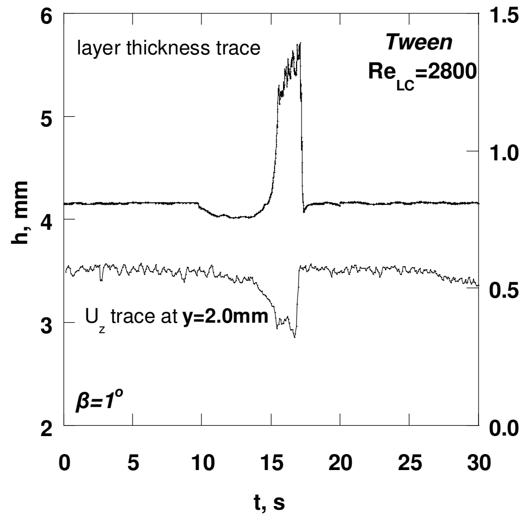

Figure 2. Simultaneous layer thickness and $U_z$ traces for Tween® solution (at $y$=2mm from pipe wall), $\beta=1^o$.

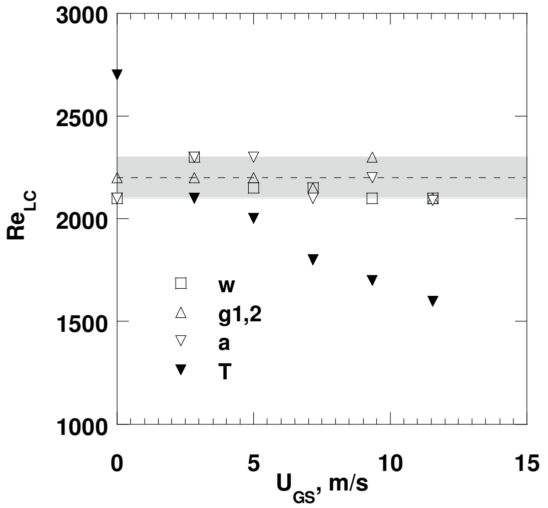

Figure 3. Onset of the solitary waves for various gas flow rates; $\beta=1^o$.

## References

[1] Manfield, P.D., Lawrence, C.J. and Hewitt, G.F, 1999 Drag reduction with additives in multiphase flow: a literature survey. *Multiphase Science and Technology*, **11**, 197-221.

[2] Lioumbas, J.S., Mouza, A.A. and Paras, S.V. 2006 Effect of surfactant additives on co-current gas-liquid downflow, *Chem. Eng. Sci., **61**,* 14, 4605– 4616.

[3] Lioumbas, J.S., Paras, S.V. and Karabelas, A.J. 2005 Co-current stratified gas-liquid downflow – Influence of the liquid flow field on interfacial structure. *Int. J. Multiphase Flow*, **31**, 8, 869-896.