ABSTRACT

The present dissertation explores the physics of natural planar hydraulic jumps formed solely by viscous shear without any geometric obstruction.

Four typical flow configurations namely (a) laminar flow in channels slightly inclined from the horizontal orientation, (b) co and countercurrent gas-liquid laminar flow, (c) laminar flow over obstacle and (d) turbulent flow in closed conduits at slight deviations from the horizontal are considered for the study.

In problem (a), the investigation is performed through shallow water theory, supplemented by numerical simulations and experimental observations. The experiments are conducted in an ingenuously designed test rig which ensures laminar flow even after the jump, thus enabling an extensive validation of the theoretical model and numerical simulation over the entire flow length. A modified expression for Froude number is proposed to predict viscous jumps in inclined channels. Beyond a critical upslope inclination, submerged jump results in subcritical flow right from the entry and below a critical downslope inclination, the flow remains supercritical throughout the channel. Both the theory and simulations reveal that the linear free surface profile upstream of jump is a function of Reynolds number only, while the downstream profiles can be tuned by changing both Reynolds number as well as the length and inclination of the channel. In concurrence with the experiments, the simulation results have also been used to elucidate the occurrence of submerged jump, wavy jump, smooth jump and no jump conditions.

A hitherto unexplored flow phenomenon, namely internal hydraulic jump in thin films during co-current and counter current two-layer flow between parallel plates has been studied through shallow water theory, numerical simulations and experimental results. The theory has been extensively validated with experimental data for coflow of the two phases and numerical simulations for both co and counter-current flow. In the limit of zero viscosity ratio, the theoretical results reduce to the expression for single-phase viscous jumps. Both the shallow water theory and computational simulations reveal recirculation zones even in co-current laminar flow. They also suggest the occurrence of different jump types namely wavy, smooth and submerged which can be represented in a phase diagram.

Shallow viscous flow over a two-dimensional obstacle placed in an otherwise horizontal channel has been studied using shallow water theory and numerical simulations. The results from theory and simulations unravel the simultaneous jump-drop-jump phenomena, hitherto unexplored for thin films. The theory with a customized solution identifies the myriad of free surface profiles for different flow and geometric parameters. The observations are consolidated as a phase diagram useful for understanding horizontal laminar flow over an obstacle. Specific energy changes accompanying the process and analytical expressions for jump efficiency and head loss are proposed for a viscous jump. Numerical simulations reveal recirculation regions close to the channel floor and at the free surface under certain flow conditions. The condition for its existence is further quantified from energy dissipation.

Turbulent jumps at small inclinations of a narrow rectangular conduit are investigated by means of extensive experiments and theoretical analysis. Several intricacies are noted when flow downstream of jump approaches the conduit ceiling. In particular, upslope flow exhibits unique instabilities and undergoes a hysteretic excursion to regain the initial stable state. The hydrodynamic states observed for different flow rate and conduit inclination are consolidated as a phase diagram that identifies natural jump regime bounded by supercritical flow, subcritical flow and full bore flow and also demonstrates the existence of multiple hydrodynamic states for certain range of operating conditions. Apart from experiments, the shallow water theory is reformulated by incorporating the effect of turbulent viscosity and lateral averaging along the conduit width to account for side wall effects. Additionally, mass and momentum balance across jump is used to identify domain of natural jump in horizontal conduits. The theoretical predictions are in close agreement to experimental results.