A study of the near-field characteristics of round turbulent jets discharged into waves

Wastewater is often discharged into near-shore coastal waters in the form of a round turbulent jet. Due to the interaction between the jet and the ambient fluid motions, an intensive mixing is achieved early in the near-field region. As a result, dilution of the evolving jet is determined by both the characteristics of the ambient fluid flow and the nature of the exit conditions. In the present study, the near-field characteristics of a jet discharged into waves are studied both theoretically and experimentally.

Two series of experiments have been conducted within the present project. The first concerns a jet discharged into a variety of steady ambients involving a stagnant ambient, crossflows, co-flows and counterflows. In contrast, the second series of experiments concerns a jet-in-waves, and considers a wide variety of discharge orientations (relative to the wave motion) which includes a vertical jet-in-waves, a horizontal jet-in-opposing-waves and a horizontal jet-in cross-waves. The present study contrasts the behaviour of jets discharged into a stagnant ambient, a variety of steady currents, and a range of wave conditions. In this wave, the present thesis will provide quantitative results from which the action of the waves on a jet can be clearly deduced. In particular, the importance of the wave motion relative to the effects of a steady or quasi-steady current are fully explored. The present results reveal that the jet-axial temperature of a jet-in-waves at a particular phase of a wave cycle is correlated with the strength of the corresponding quasi-steady current. In addition, the experimental results also indicate that when the jet is subjected to a quasi-steady crossflow, ambient fluid may intrude into the jet through the forced entrainment mechanism. Moreover, the observed turbulence properties of a jet-in-waves are very similar to that obtained in the case of a jet-in-crossflow.

A novel integral-based model has been developed to predict the time-averaged and phased averaged characteristics of a jet-in-waves. In this model, a jet trajectory is regarded to consist of a series of non-interfering jet-elements. The elemental mass increment is assumed to be generated through the shear and the forced entrainment mechanisms, with the amount of entrainment calculated using the corresponding quasi-steady currents. The derivation of this model together with detailed comparisons with the experimental results are presented. From these comparisons, it is seen that the model is capable of describing the near-field characteristics of a jet-in-waves.

A series of numerical simulations has also been conducted using a $\kappa-\varepsilon$ turbulence model. A CFD package, FLUENT, was employed for both grid generation and equation solving. Simulations concern both a range of jet-in-waves and a jet-in-crossflow. In the case of a jet-in-crossflow, it has been demonstrated that the simulation describes the measured data well. In addition, a distinct vortex-structure, which was first mentioned by Platten & Keffer (1968) and is believed to be closely related to the forced entrainment mechanism, has been observed in a simulated jet-in-crossflow. With reference to the description of a jet-in-waves, the numerical calculations provided detailed velocity-fields which illustrate the jet-wave interactions extremely well. In particular, a vortex-structure, similar to that found in a jet-in-crossflow, has also been observed within a jet-in-waves when the jet-in-waves is subjected to a quasi-steady crossflow. Since this vortex-structure is associated with the forced entrainment mechanism, the numerical simulations also suggest that the forced entrainment is an important source of entrainment for a jet-in-waves. A relationship between the strength of the simulated vortex-structure and the Keulegan Carpenter number based on the corresponding flow field was also studied. It is shown that the larger the Keulegan Carpenter number the stronger the simulated vortex-structure.