EXECUTIVE SUMMARY

A number of Gas leaks from subsea pipelines have been recorded in recent years. These occurrences highlight the need for better understanding of the way Gas leaks (plume) behave under water and the risks they present. The effects of subsea hydrocarbon release depend on a number of factors, including whether the release is liquid or gas.

a. For a liquid release, the buoyancy will result in the leaked material spreading on the surface to form either a polluting slick, or an expanding pool fire.

b. For a gas release, although the buoyancy is rather greater, significant drag forces will cause the plume to break up and rise to the surface as a series of bubbles. On breaking surface, ignition of the gas plume would result in a sea surface fire with different characteristics to those incorporated into the usual pool and jet fire models.

c. Alternatively, and more likely, the plume will begin to disperse in the atmosphere, and may be diluted to a concentration below the lower flammable limit before there is any possibility of encountering an ignition source.

d. A further effect of a gas bubble plume is the reduction in the stability of floating vessels, due to either the loss of buoyancy, or, more likely, due to the radial outflow of water which has been entrained into the plume.

Consequence models are used to predict the physical behaviour of hazardous incidents mainly flammable and toxic releases. Some models only calculate the effect of a limited number of physical processes, like discharge or radiation effects. More complex models interlink the various steps in consequence modelling into one package. The field of consequence modelling for hydrocarbon releases in open atmospheric conditions is highly developed. Whereas, the understanding about the behaviour of a subsea gas release up through the water column (plume raise) is very limited from risk assessment point of view. The hydrodynamic basis for bubble-plume flows is reasonably well understood, but the solutions of the associated equations, depend on a large number of parameters that can only be evaluated by experimentation.

In the recent years some research works were carried out in UK and Norway to study the subsea gas leaks plume behaviour for North Sea and Norwegian Sea conditions.

The discharge of the gas from the release point to the surface is considered in three zones.
Zone of Flow Establishment (ZOFE): The region between the release point and the height at which the dispersion appears to adopt a plume-like structure. At this height the effects of initial release momentum are considered to be secondary to the momentum induced by buoyancy.

Zone of Established Flow (ZOEF): The plume-like region of dispersion which extends from the ZOFE to a depth beneath the free surface which is of the order of one plume diameter.

Zone of Surface Flow (ZOSF): The region above the ZOEF where the plume interacts with the surface causing widening of the bubble plume and radial flow of water at the surface.

Three approaches, of varying complexity, have been used in modelling the discharge of subsea releases in North Sea and Norwegian Sea:

a. Empirical/ Cone model
b. Integral Model
c. Computational Fluid Dynamic (CFD) model

The simplest are empirical models which consist of those that assume the plume radius to be proportional to the release depth or correlations that have been produced to fit the available experimental data.

Integral models are based on local similarity i.e. the radial profiles of velocity and density defect are assumed to have a similar form at different heights within the plume. The plume properties can be represented, using for example Gaussian profiles, by their plume centreline values. Entrainment of water into the plume is described using a correlation relating the rate of increase of water flow to the plume centreline properties through the use of an entrainment coefficient, as is used in single phase plume modelling. Gas continuity, and equating the increase in momentum to the buoyancy forces, allows the plume properties to be calculated in a step-by-step manner as the height above the release is incremented. Separate models have been produced for the ZOEF and the ZOSF as described in integral models for initial release and integral models for the region of established flow respectively.

The most complex models are represented by Computational Fluid Dynamics (CFD) or field codes which solve the Navier Stokes equations of fluid flow. Their advantage over integral models is that effects such as entrainment and turbulent transport of momentum are modelled directly and do not require the use of empirical constants. However, they still involve some
modelling assumptions, as described in CFD models, and are more resource-intensive to run than integral or empirical models.

Striking a right balance between accuracy, uncertainty, cost effectiveness and user-friendliness, clearly, the simple empirical ‘model’ remains most favoured for use in risk assessments.

The objectives of this thesis are:

a. To identify various sub-sea gas discharge models that are currently being used in North Sea and Norwegian Sea with respect to plume discharge (initial release of plume to the sea surface from the point of leak);

b. To study and analyse the accuracy and uncertainty levels of various discharge models used in North Sea and Norwegian Sea based on the feedback received from lab scale experimentation and limited filed trials carried out so far;

c. Identify the most optimal discharge model suitable for Arabian Sea conditions striking a right balance between i) accuracy, ii) uncertainty, iii) cost-effectiveness and iv) user-friendliness;

d. Validate the chosen model for Arabian Sea Conditions based on lab-scale experimentation and CFD Modelling.

In this study the available information on the bubble plumes, both theory and experiments was reviewed for the purpose of improving our prediction capabilities of small to medium releases which are common.

Lab-scale experimentation was held at Department of Ocean Engineering, Indian Institute of Technology (IIT), Madras for validating the Empirical/ Cone gas discharge plume models established in North Sea & Norwegian Sea for Arabian Sea conditions. The main parameters considered for experimentation were release rate, gas density, and depth of release, sea temperature and salinity. The results of IIT experimentation were corroborated using CFD modelling.

In conclusion, the plume model established through IIT experimentation for Arabian Sea conditions very well matches with the Plume model established by Fanneløp and Sjøen (1980) [7] and the plume measurements published by Milgram (1983) [17] for North Sea and Norwegian Sea conditions.