New Developments in Sustainable Petroleum Engineering

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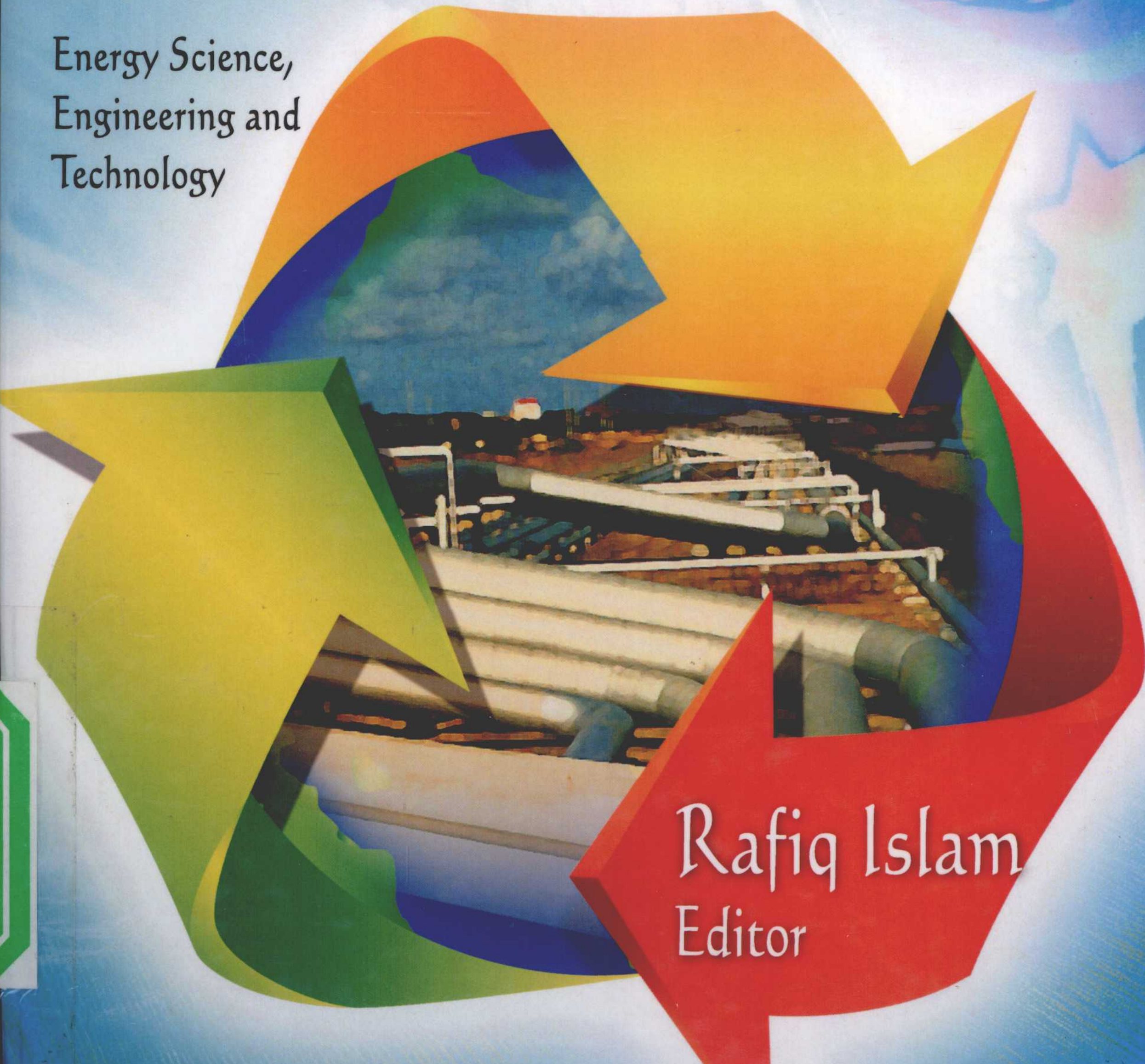

Rafiq Islam
Editor

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ENERGY SCIENCE, ENGINEERING AND TECHNOLOGY

NEW DEVELOPMENTS IN SUSTAINABLE PETROLEUM ENGINEERING

RAFIQ ISLAM
EDITOR

NOVA

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ENERGY SCIENCE, ENGINEERING AND TECHNOLOGY

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PREFACE

Petroleum engineering is an engineering discipline concerned with the activities related to the production of hydrocarbons, which can be either crude oil or natural gas. Subsurface activities are deemed to fall within the upstream sector of the oil and gas industry, which are the activities of finding and producing hydrocarbons. This new book presents current research in the study of sustainable petroleum engineering including topics such as optimization techniques in groundwater monitoring network design for petroleum contaminant detection; a relation-analysis-based approach for assessing risks of petroleum-contaminated sites and an improved model for predicting formation damage induced by oilfield scales.

Chapter 1 – Ocean waves can generally increase the initial dilution of produced water and subsequently affect the ecological risk. To study the wave effects on ecological risk, a probabilistic based buoyant jet dispersion model has been integrated with risk analysis software, @ RISK, to assess ecological risk for a case corresponding to published parameters for the White Rose field, off east coast of Canada. The ecological risks on sheepshead minnows were evaluated by conducting Monte Carlo simulation for four different discharge scenarios. The Hazard Quotients (HQs) method was used to characterize the risk. Contour plots of probability distributions of HQs from those four discharge configurations were compared and discussed. The wave effects were identified by comparison of the wave and no wave simulations.

Chapter 2 – With the advent of fast computational techniques, it is time to include all salient features of the material balance equation (MBE). The inclusion of time dependent porosity and permeability can enhance the quality of oil recovery predictions to a great extent. This alteration occurs due to change of pressure and temperature of the reservoir which causes a continuous change of rock-fluid properties with time. However, few studies report such alterations and their consequences. This study investigates the effects of permeability, pore volume, and porosity with time during the production of oil. Moreover, a comprehensive MBE is presented. The equation contains a stress-strain formulation that is applicable to both rock and fluid. In addition, this formulation includes memory effect of fluids in terms of a continuous time function. Similar time dependence is also invoked to the rock strain-stress relationship. This formulation results in a highly nonlinear MBE, with a number of coefficients that are inherently nonlinear (mainly due to continuous dependence on time). This enhances the applicability of the model to fractured formations with dynamic features. Such formulation is different from previous approach that added a transient term to a steady state equation. For selected cases, the MBE is solved numerically with a newly developed nonlinear solver. A comparative study is presented using field data. Results are compared with conventional MBE approach. This comparison highlights the improvement in the recovery factor (RF) as much as 5%. This new version of MBE is applicable in the cases where rock/fluid compressibilities are available as a function of pressure from laboratory measurements or correlations. It is also applicable where non-pay zones are active as connate water and solid rock expansions are strong enough with pressure depletion. Finally, suitability of the new formulation is shown for a wide range of applications in petroleum reservoir engineering.

Chapter 3 – Effective reflection of and coping with uncertainties are essential for generating reliable risk assessment outcomes. In this study, an integrated risk assessment approach was proposed for assessing environmental risks associated with contamination of multi-component petroleum hydrocarbons. The approach consists of (a) predicting contaminant flow and transport through a multiphase multi-component numerical modelling system; (b) using interval-anlaysis approach to analyze effects of uncertainties associated with subsurface conditions; and (c) applying fuzzy relation analysis to quantify the general risks based on the interval-analysis results. The application of the proposed approach to a petroleum-contaminated site in western Canada indicated that system uncertainties would have significant impact on the risk assessment results. Implementation of risk assessment under more deterministic conditions generates clearer risk assessment outcomes, but leads to missing of more valuable information; conversely, risk assessment under more uncertain circumstances offers more comprehensive information, but leads to higher vagueness of risk descriptions. Application of the proposed approach in risk assessment of groundwater contamination represents a new contribution to the area of petroleum waste management under uncertainty. It is not only useful for evaluating risks of a system containing multiple factors with complicated interrelationships, but also advantageous in situations when probabilistic information is unavailable for performing a conventional stochastic risk assessment.

Chapter 4 – This study presents a two-step modeling method to the recovery of leaked petroleum product in groundwater system. Specifically, an oil volume estimation method is developed to calculate the total volume of LNAPL residing in both saturated and unsaturated zones under concern. With the information of LNAPL distribution in the groundwater system, porous media multiphase simulation technique is then used to examine the remediation alternative of vacuum-enhanced multiphase extraction (i.e., VER). VER modeling results can be also verified by the oil estimation analysis through comparing recovered and estimated LNAPL volumes. At the study site, the soil and groundwater are contaminated by leaked condensate from perforated underground storage tanks. The VER system designed for the separation and recovery of condensate from subsurface consists of one extraction well. Good results have been obtained with the recovered amount of LNAPL close to the estimated volume. It indicates the developed method is effective in simulating the recovery process of LNAPL from the contaminated site, and thus provides optimal parameters for the remediation program.

Chapter 5 – The process of formation damage due to oilfield scale precipitation and accumulation has been quantitatively modelled based on existing thermodynamics and deposition kinetic model. A variety of models on formation damage due to solid precipitation in porous media during water flooding have been reported in the literatures. Early models were based on chemical reaction involving dissolution/precipitation while neglecting the effect of operational and reservoir/brine parameters. This paper presents modified models for predicting permeability damage due to oilfield scale precipitation. The key operational and reservoir parameters which influence the magnitude of flow impairment by scale deposition were identified through the modification.

Chapter 6 – In order to detect petroleum contaminants in groundwater, it is paramount to design a proper monitoring network. Groundwater monitoring network design has advanced in recent years with the Genetic Algorithms optimisation techniques to address and achieve the optimal management strategy. This paper presents and describes various optimisation techniques, especially the state of the art robust Genetic Algorithms and their application in groundwater management focused on groundwater monitoring network. This review describes the Optimisation of groundwater management has become an active area of research in the last several years because of its ability to reduce cost substantially. It is the purpose of this paper to provide a comparison of a variety of optimisation methods on a groundwater problem due to petroleum contamination.

Chapter 7 – The precipitation and deposition of scale pose serious injectivity and productivity problems. Several models have been developed for predicting oilfield scales formation and their effect on deliverability of the reservoir to aid in planning appropriate injection water programme. In this study an analytical model has been developed for predicting productivity index of reservoir with incidence of scale deposition in the vicinity of the well bore.

Chapter 8 – In North America, numerous aquifers as fresh drinking water supply sources have been contaminated from various sources such as septic systems, leaking underground storage tanks, spills or improper disposal of industrial chemicals, and leachate from solid and hazardous waste landfills. A major task associated with the contamination of aquifers is to develop effective tools to assess and determine the health risks to individuals potentially consuming the water from these aquifers. This poses many obstacles due to the complexity of the environment that the contaminant is spilled in and the population consuming the water. This paper presents a Monte Carlo simulation based methodology which is capable of considering many variations present in the natural environment and human populations. The methodology is tested using a hypothetical aquifer and population case. Downgradient contaminant concentrations resulting from a leaking underground storage tank, containing petroleum, are calculated using an analytical solution to the two-dimensional advection-dispersion transport model. Contaminants under consideration include benzene, toluene, and ethylbenzene (BTE) which can cause deleterious health effects. Parameters and variables in the model are considered as random numbers. Contaminant ingestion dose is calculated using the stochastic exposure-dose model. Random population variables are used to give a distribution for contaminant ingestion dose for each contaminant. The chronic non-cancer hazard index is used to determine the risk associated with the ingestion of non-carcinogenic contaminants. The cancer risk is calculated using the slope factor, given by the USEPA, for the carcinogenic contaminants. Results of the case study indicate that environmental health risks can be effectively analyzed through the developed methodology. They are useful for supporting the related risk-management and remediation decisions.

Chapter 9 – In this paper, author introduce a new version of homotopy perturbation method to obtain exact solutions of systems of linear integro-differential equations. Theoretical considerations are discussed. Some examples are presented, to illustrating the efficiently and simplicity of the method.

Chapter 10 – Alkali and alkali/polymer solutions are well known techniques for the chemical flooding application. For this scheme, synthetic high-pH alkaline solutions are commonly used. These solutions are not environment friendly and are expensive. As a result, alkaline flooding has lost its appeal in last few decades. However, low-cost, environment-friendly alkaline solutions hold promises. This paper demonstrates how wood ash can be used as a source of low-cost alkali that is also environment friendly. The feasibility of using high pH alkaline solution, extracted from wood ash was conducted in the laboratory. From the experimental studies, it was found that the resulting solution was transparent and had high alkalinity. It was also found that the pH value of 6% wood ash-extracted solution was very close to the pH value of 0.5% synthetic sodium hydroxide or of 0.75% synthetic sodium meta silicate solution. A preliminary microscopic study of oil/oil droplets interaction in natural alkaline solution was carried out in order to understand the oil/water interface changes with time and its effect on oil/oil droplet coalescence. The microscopic study showed that two oil droplets were coalesced after 3.5 minute in 6% wood ash extracted solution. The interaction of the alkali in floodwater and the acids in reservoir crude oil result in the in-situ formation of surfactants that causes the lowering of interfacial tension (IFT) in caustic flooding that assist in the oil recovery process by mobilizing oil. In this study, the interfacial tension was measured using the Du Nouy ring method and it was observed that this environment friendly alkaline solution effectively reduced the interfacial tension with the acidic crude oil. Characterization of maple wood ashes has been was investigated using a variety of techniques, including, SEM-EDX, XRD, NMR. The SEM micrographs of the maple wood ash samples showed that the ash samples consisted of some porous and amorphous particles of carbon and several inorganic particles of irregular shape. The X-ray analysis on maple wood ash revealed that the predominant elements in the wood ash samples were oxygen, calcium, potassium, silicon. Lesser amounts of the elements were sodium, magnesium, titanium and aluminum also observed in maple wood ashes. The XRD analysis revealed that the major components of maple wood ashes were calcium oxide, potassium oxide, manganese oxide, silica oxide and magnesium oxide which were alkaline in nature. The ^{13}C CP/MAS NMR spectrum of maple wood ashes showed a very pronounced intense peak around 168.36 ppm was revealed that was assigned for the carbonate, $[(O)_2\text{-}C{=}O]$. It was revealed that nutrient elements status in fresh and treated maple wood ashes is almost same. Therefore, after alkaline extraction for EOR application, the same maple wood ashes has potential to use as a source of nutrient to soil and plants.

Chapter 11 – Chemical demulsification is most widely applied in petroleum industries, painting and wastewater treatment technology and involves the use of chemical additives to accelerate the emulsion breaking process. The stability of the emulsion has been characterized and it is observed that the stability depend on oil-water contact time, turbulence and amount of oil in contact with the water. A series of experiments have been carried out with different demulsifiers for separation of oil from oil-in-water emulsion. More than 90% separations are obtained with some demulsifiers under specific operating conditions.

Versions of these chapters were also published in *Advances in Sustainable Petroleum Engineering Science*, Volume 1, Numbers 1-4, edited by Rafiq Islam, published by Nova Science Publishers, Inc. They were submitted for appropriate modifications in an effort to encourage wider dissemination of research.

CONTENTS

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Chapter 1

ASSESSING ECOLOGICAL RISKS OF PRODUCED WATER DISCHARGE IN WAVES

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ABSTRACT

Ocean waves can generally increase the initial dilution of produced water and subsequently affect the ecological risk. To study the wave effects on ecological risk, a probabilistic based buoyant jet dispersion model has been integrated with risk analysis software, @ RISK, to assess ecological risk for a case corresponding to published parameters for the White Rose field, off east coast of Canada. The ecological risks on sheepshead minnows were evaluated by conducting Monte Carlo simulation for four different discharge scenarios. The Hazard Quotients (HQs) method was used to characterize the risk. Contour plots of probability distributions of HQs from those four discharge configurations were compared and discussed. The wave effects were identified by comparison of the wave and no wave simulations.

Keywords: produced water; hydrodynamic model; ecological risk; hazard quotients; waves.

1. INTRODUCTION

The recent increase in offshore oil and gas development off the east coast of Canada has created concern regarding the capacity of the marine environment as an intermediate buffer

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zone for receiving the produced water and the subsequent mixing of the waste materials with offshore waters. Produced water, which is normally comprised of formation water and injected seawater, is the largest waste stream associated with offshore petroleum production and its composition is strongly site dependent. The risks associated with the offshore discharge of produced waters depend on the composition of contaminants in the water and their distribution in the receiving environment. The distribution of produced waters in the receiving environment depends upon the discharge and ambient parameters, such as discharge depth, pipe orientation, relative density, current speeds, the presence of stratified density layers and the wave conditions. For discharge at given ambient conditions, the environmental concentration and therefore ecological risks may be reduced with optimally designed outfalls.

The effects of ocean outfall design on the ecological risks of produced water have been studied by Mukhtasor (2001), who introduced a framework of ecological risk-based design and conducted a case study based on the Terra Nova oil field, about 350 km off the east coast of Canada. The framework of ecological risk-based design requires the integration of hydrodynamic modeling and ecological risk assessment. The limitation of Mukhtasor's (2001) work is the weakness in the hydrodynamic model. The model can only simulate vertical discharges with positive buoyancy, which means the direction of the buoyancy must be the same as the discharge direction. In practice, many produced water discharges involve negative buoyancy, which means the direction of the buoyancy is different from the discharge direction. Therefore, in order to evaluate the ecological risks resulting from negatively buoyant discharges, the hydrodynamic model of Mukhtasor (2001) must be improved.

Previous studies of negatively buoyant jets (Zeitoun *et al.*, 1970; Robert and Toms, 1987; Roberts *et al.*, 1997) have proved that the discharge angle is a key parameter which has a significant impact on the initial dilution. As a result, the discharge angle may have significant effects on ecological risks.

It has been shown by previous studies (Chin, 1987; Hwung *et al.*, 1994; Chyan *et al.*, 2002) that surface waves can significantly increase the dilution achieved by ocean outfalls. Using data obtained from an experiment conducted off Sydney, Australia, Tate (2002) also concluded that high frequency internal waves can increase the initial dilution of buoyant jets by a factor exceeding two. Because of this effect, the wave is expected to reduce the ecological risk of produced water.

In this study, the effects of wave on the ecological risk of a negatively buoyant produced water discharge will be investigated by conducting a case study.

2. Study Area

White Rose is an oil field located 350 km off the east coast of Newfoundland. The estimated maximum flowrate of produced water is 30,000 m^3/day (0.35 m^3/s), and the estimated density and temperature of the produced water are 25 ppt and 60 °C (Hodgins and Hodgins, 2000). Water depths in the study area range from about 120 m to 130 m. Currents in the vicinity of White Rose are dominated by wind and tide, with a mean flow to the south. The salinity of sea water is around 32.2 ppt and the water temperatures vary from 14.6 °C in summer to 0.25 °C in winter.

The density of the produced water is less than that of the ambient seawater. Once it is discharged, ecological entities, particularly those in the water column in the vicinity of the discharge, are potentially exposed to it. The potential risks include inhibition of growth and survival of fish (e.g. capelin, mackerel, cod and tuna) and shellfish (e.g. northern shrimp and snow crab) species.

Hodgins and Hodgins (2000) have calculated the exposure concentration for this site by assuming discharge of the water downward from a 0.356 m diameter pipe at 3 meter depth. In the following sections, ecological risks resulting from this discharge configuration will be calculated first. The effects of discharge configuration variations and wave effects on ecological risks will then be evaluated.

3. METHODOLOGY

3.1. Dispersion Model

To assess the risk, a hydrodynamic model is needed to calculate the exposure concentration. The model employed in this study has five sub-modules: (1) initial dilution model, (2) wave effect model, (3) boil location model, (4) intermediate model, and (5) far field mixing model.

The initial dilution model is an inclined (or declined) dense jet model as described by Roberts and Toms (1987) and Roberts *et al.* (1997). As shown in Figure. 1, a nozzle is declined downward to the horizontal at an angle of θ and discharge is through a round nozzle of diameter D at velocity U_j. The y_t is the maximum rise (or descent height), the y_L is the thickness of surface layer, S_i is the dilution at the boil point, x_i is distance from discharge point to boil point, x_m is the length of initial mixing zone, and S_m is the dilution at the end of initial mixing zone.

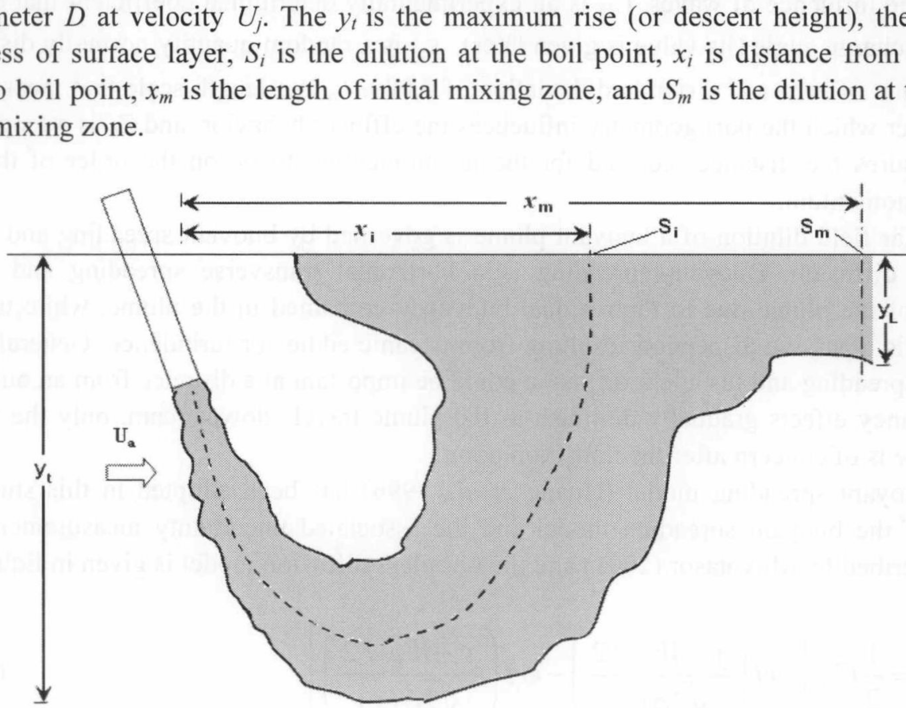

Figure 1. Definition Sketch for the Discharge.

The equations to determine above parameters are given by Robert *et al.* (1997) as

$$S_i = C_i F_i \tag{1}$$

$$S_m = C_m F_r \tag{2}$$

$$y_t = C_t D F_r \tag{3}$$

$$y_L = C_L D F_r \tag{4}$$

where the C_i, C_m, C_t, and C_L are experimentally determined constants. F_r is the densimetric Froude number.

Although the wave effect on ecological risk has not been has not been studied, the effects of waves on initial dilution has been investigated (Chin, 1987; Hwung *et al.*, 1994; Chyan *et al.*, 2002). The wave effects on initial dilution can be characterized by

$$\frac{S_{wave}}{S_{nowave}} = 1 + C_W \frac{L_q}{Z_m} + \varepsilon_2 \tag{5}$$

where S_{wave} is the initial dilution with the influence of waves, S_{nowave} is the initial dilution without the influence of waves, C_W is an experimentally determined coefficient that depends on the discharge angle (its value is given later), ε_2 is a random quantity normally distributed with a mean of zero and a standard deviation of 0.089, L_q is a length scale that measures the length over which the port geometry influences the effluent behavior, and Z_m is a length scale that measures the distance required for the jet momentum to be on the order of the wave induced momentum.

The far field dilution of a buoyant plume is governed by buoyant spreading and oceanic turbulent diffusion. Buoyant spreading is a horizontal transverse spreading and vertical collapse of the plume due to the residual buoyancy contained in the plume, while turbulent diffusion is a passive dispersion resulting from oceanic eddies or turbulence. Generally, both buoyant spreading and turbulent diffusion could be important at a distance from an outfall. As the buoyancy effects gradually diminish as the plume travels downstream, only the ambient turbulence is of concern after the transition point.

A buoyant spreading model (Huang *et al.*, 1996) has been adopted in this study. The details of the buoyant spreading model and the associated uncertainty measurements have been described by Mukhtasor (2001) and the turbulent diffusion model is given in Equation 6:

$$C(x,y) = \frac{1}{2} C_{BS} \left[erf\left(\frac{y + W_{BS}/2}{\sqrt{2}\sigma(x)} \right) - erf\left(\frac{y - W_{BS}/2}{\sqrt{2}\sigma(x)} \right) \right] \tag{6}$$

where $C(x,y)$ is the concentration at a point x, y downstream, C_{BS} is the centerline concentration at the end of buoyant spreading, W_{BS} is the plume width at the end of buoyant spreading, $\sigma^2(x)$ is the variance of the concentration distribution which can be related to the diffusion length scale L_y by $L_y = 2(3)^{1/2}\sigma(x)$. To estimate the concentration, the $\sigma(x)$ can be obtained through field dye diffusion experiments, or be estimated from empirical ocean diffusion diagrams in the case of lack of experimental data. Three diffusion laws (Fickian, Linear, and Inertial sub-range) are normally used to describe the turbulent processes. However, empirical results from large lakes and oceans show that natural turbulent processes cannot always be described by any one single diffusion law. Therefore, an empirical diffusion law (Equation 7), which was developed based on extensive oceanic diffusion studies (Okubo, 1971), is used in this work.

$$\sigma(x) = kT^f \tag{7}$$

where T is the effective diffusion time approximated by x/U_a , k and f are regression coefficients that depend on the time scale (day, week, or month) or length scale of dispersion. For the acute effects of produced water in the vicinity of the platform, a time scale of one day is important because the produced water can travel several kilometres during one day and become well diluted. It is assumed that there is no vertical variation of concentration and only the horizontal diffusivity was considered in this work. The limitation of this assumption is that it will underestimate the dilution in the buoyant spreading layer and ignore the presence of contaminants at other depths of water column.

3.2. Probabilistic-Based Modeling and Ecological Risk Assessment

For computation of exposure concentration using dispersion models, two approaches can be used: worst-case approach and probabilistic based approach.

The worst case approach calculates a single value exposure concentration by considering the combination of parameters at worst case conditions. The advantage of the worst-case approach is its simplicity. However, the results derived from this approach may be more stringent than necessary because the approach is conservative.

Unlike the worst-case approach, which recognizes the uncertainties but does not model it explicitly, a probabilistic approach considers parameter variability, which is often described in terms of time series or probability distributions. This approach is often implemented using a Monte Carlo simulation method and the result is a probabilistic description of concentrations. Several applications of probabilistic based assessment of effluent discharges into rivers have been reported (Bumgardner et al., 1993; Donigian and Waggy, 1974). Huang et al. (1996) used this approach to model a sewage ocean outfall. More recently, this approach was adopted by Mukhtasor (2001) to model the dispersion of produced water in marine environment.

To calculate the probabilistic distribution of exposure concentration, the method of Mukhtasor (2001) was employed in this study. The probability distributions of parameters in equations (1) to (7) were first defined. Monte Carlo simulations were then performed to generate a random number for each parameter from its associated distribution. An exposure concentration can be obtained using the generated values. After this procedure is repeated a sufficient number of times (for example, 1000 times), the probabilistic distribution of exposure concentration can be calculated.

With the computed exposure concentration, ecological risks can then be characterized. Ecological risks may be described qualitatively or quantitatively. For a quantitative approach, basically, there are two methods available: quotient method and continuous exposure-response method. The quotient method has proved to be an effective method in the analysis of risks from produced water discharges (Mukhtasor, 2001) and was adopted in this study.

The quotient or hazard quotient (HQ) method is based on chronic benchmark concentrations of the whole effluent toxicity to individual species. The HQ can be expressed as:

$$\text{Quotient} = \frac{\text{EC}}{\text{BC}} \tag{8}$$

where EC stands for the exposure concentration, and BC is the benchmark concentration.

Similar to the parameters in equations (1) to (7), the variability of BC in equation (8) can also be considered by defining a probability distribution (for example, lognormal) in the probabilistic analysis. The output of equation (8) is a probabilistic distribution of ecological risk.

3.3. Simulation of Ecological Risks

As described in the previous section, the exposure concentration for this study site has previously been studied by Hodgins and Hodgins (2000). The discharge of Hodgins and Hodgins (2000) is 90° from horizontal. In this study, a discharge angle of 60° rather than 90° was used to maximize the initial dilution as suggested by Roberts *et al.* (1997). To evaluate the effects of waves on ecological risk, the existing discharge scenario (D = 0.356 m) at the maximum flowrate (0.35 m^3/s) was evaluated first. To get more conclusive results on wave effects, discharges from different sizes of pipes at different flow rates were also evaluated. The estimated early stage discharge rate is 0.11m^3/s. Four different discharge scenarios were used by combining the maximum and early stage flow rates with two possible pipe sizes, 0.356m and 0.3m in diameter.

An influence area of 200 m × 200 m around the FPSO was studied. The coordinate system was defined using the same method as Huang *et al.* (1996). The Monte Carlo Simulation (MCS) method with a Latin Hypercube Sampling (LHS) was used in this work to consider the uncertainty associated with the variability of model inputs. The uncertainty measures associated with the models are listed in Table 1. The ambient water data for this area were analyzed and it was found that the ambient current speed can be fitted by a Gamma distribution and their directions can be approximated by a Beta distribution (see Table 1). For a given simulation, a sample is randomly drawn from each distribution and the value is assigned to the model input. The concentrations for the grid points within the study area were then calculated using the model described above. After repeating the simulation a given