CFD SIMULATION STUDY ON THE EFFECT OF WATER VELOCITY TOWARDS OIL LEAKAGE FROM SUBMARINE PIPELINES

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AMARASINGAM A/L SELVARAJAH

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering (Gas Technology)

Faculty of Chemical & Natural Resources Engineering
UNIVERSITI MALAYSIA PAHANG

JULY 2014

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering (Gas technology).

Signature	:
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Position	: SENIOR LECTURER
Date	: 3rd JULY 2014

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Date : 3rd JULY 2014

Dedication

To my supervisor, Miss Siti Noraishah Ismail for her unlimited support in making this research project successful.

ACKNOWLEDGEMENT

I would like to thank and dedicate my appreciation to;

My supervisor Miss Siti Noraishah Ismail

- For her unlimited guidance through an effective well-arranged weekly meetings.
- For helping me in accomplishing my tasks promptly.
- For helping me organize my literature study.

ABSTRACT

This paper presents Computational fluid dynamic (CFD) studies on water velocity effect towards the time taken for migration of oil droplets to reach free surface. Computational Fluid Dynamic (CFD) simulations with FLUENT software 6.3.26 were simulated to detect the leakage process of oil spill from submarine pipeline to free surface. GAMBIT 2.4.6 mesh-generator is employed to perform all geometry generation and meshing. The velocity inlet of water (vs.) was varied whereas density of oil (kerosene liquid) was constant at 780kg/m^3 .A computational rectangular domain with length of 20m and height of 15m was simulated in Gambit 2.4.6. The mesh was generated and exported to Fluent. In the Fluent 6.3.26, the time taken for the oil droplets to reach free surface was observed by varying water inlet velocity; v_{w1}=0.02m/s, v_{w2}=0.04m/s,v_{w3}=0.08m/s respectively. Kerosene droplets reached free surface faster as the velocity of water inlet increased. Results were observed at 1000 number of time steps (iterations) with a step size of 0.1seconds. The leak size was shown to be 0.1meter, which was fixed at the beginning of the simulation conditions. **Justifications** were shown where oil droplets released from a greater leak width are easier to collision and have greater chance of gathering into large droplets, (Zhu et al., 2013). This is because at a larger face of leakage, the shear stresses increases, causing a larger displacement in oil migration. From the study, the dimensionless longest horizontal distance the kerosene droplets migrate when they reach the sea surface are analysed and the fitting formulas are obtained. With this, the maximum horizontal migration distance of oil at certain time is predicted, and a forecasting model is proposed in order to place the oil containment boom. This helps to detect the leakage more accurately and reduces cost of handling.

Key words: Computational fluid dynamic (CFD), computational domain, Gambit 2.4.6 and Fluent 6.3.26, Water velocity

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

<u>Greek</u>

v_l	kinematic viscosity
µm	micrometre
m/s	Water velocity / oil leaking rate
m^3/s	Volume flux
wt %	moisture content
KJ/kg	Calorific Value
Kg/m3	oil density
Pa.s	Pascal .seconds
Diameters	(height, distance)
ρ	density
g	gravity

CFD	Computational Fluid Dynamics
RANS	(Reynolds-Averaged-Navier-Stokes) equations,
VOF	Volume of Fluid
FVM	(finite volume method)
MESH	2.4.6
FLUENT	6.3.26

1 INTRODUCTION

1.0 Brief introduction and problem statement

Oil had become one of the most important energy we have. Every day we will use hundreds of things that are made from oil. Therefore, the demand for this energy is quite large and increasing. This issue had led to the exploration of oil and then the construction of submarine pipeline system at the sea. The important issues related the submarine pipeline is the oil spill or leakage incident. These incidents usually present in pipelines due to several factors such as corrosion, flow erosion, or submarine landslide. This incident may lead to serious environmental issues especially to marine life and human health. As the largest accidental marine oil spills had occurred in Gulf of Mexico, around 4.9 million barrels of oil were released into the sea. Due to the months-long spill, along with adverse effects from the response and clean-up activities, extensive damage to marine and wildlife habitats, fishing and tourism industries, and human health problems have continued through 2014 (Tangley,2010).

Some research has forecasted the trajectory of submarine oil spill using radar galvanic current (Abascal et al., 2009), but the approach can only supply partial real-time information and may not support emergency behaviour for the influence of weather and night. Li and Yapa (2002), Øistein et al. (2003) and Dasanayaka and Yapa (2009) have also carried out the research on submarine oil ejecting, but they all aim at oil gas mixture and cannot contribute to forecasting oil spill greatly.

In this modern era, exploration is now extending into sensitive areas, in particular, offshore field. Washout and perforation failures are usually present in oil submarine pipelines due to corrosion or flow erosion. Then oil spills into marine environment from the leak, causing extensive damage to marine life, human health, and natural resources (Wang et al., 2013).

According to Xu and Wei (2013), oil spill accidents occurred at platform B and C of the Penglai 19-3 oilfield located in Bohai Sea It was estimated about 700 barrels of oil and 2500 barrels of mineral oil-based drilling mud were released at shallow water depths of 18m, causing a relatively high risk to the environment.

Once accidental oil leakages occur, a quick and adequate response in order to reduce the environmental consequences is required. (Biksey et al., 2010). Besides, laying oil containment boom, as a basic way to control oil dispersal, also depends on the rising velocity of oil droplets and the trend of spreading. Therefore, an exact prediction of oil spill process and dispersal could provide useful information for setting up oil containment boom and reducing the damage of future oil spills. (*Hongjun* et al., 2014)

An effective attempt has been made to observe the oil spill under the action of current and wave. However, the velocity of current in their study was uniform, which does not match with the actual shear velocity distribution under sea surface. And the actual hydrostatic pressure distribution was not used in their modelling. Moreover, the crucial parameter, the maximum horizontal migration distance of oil, was not considered in their research. (*Li* et al., 2013)

1.1 Motivation

The increasing oil spill accidents from submarine pipelines have caused severe damage to the aquatic life and health problems to mankind. A lot of research had been made manually and by simulation to study the effective measure in detecting a leakage. Because of the oil leakage from damaged submarine pipeline, the migration of oil flow along the depth direction is an important issue to address.

Hence, numerical simulation can provide detailed information on the hydrodynamics of oil flow, which is not easily obtained by physical experiments. CFD (computational fluid dynamic) model coupling with VOF (volume of fluid) method has been used to investigate the process of oil spill from submarine pipeline to free surface. The actual shear velocity distribution of current and the actual hydrostatic pressure distribution are considered in this study.

Detailed oil droplet and sea-surface in-formation could be obtained by the VOF model. By conducting a series of numerical simulations, effects of oil density, oil leaking rate, leak size and water velocity on the oil spill process are examined. Then, the dimensionless time required for oil droplets which have the longest horizontal migrate distance when they reach the sea surface and the dimensionless longest horizontal distance the droplets migrate when they reach the sea surface are analyzed and the fitting formulas are obtained.(Yadav et al.,2013 ; Arpino et al.,2009 ; Jalilinasrabady et al.,2013).

Summary

The topic was scoped from addressing the problem in the petroleum industry, way by identifying the problem of leakage in submarine pipelines.Then, an alternative solution using the CFD (computational fluid dynamic) model coupling with VOF (volume of fluid) method has been used to investigate the process of oil spill from submarine pipeline to free surface.

1.2 Objectives of Study

The main objective of this study is to investigate the time taken for oil droplets(s) to migrate along a horizontal distance up to free surface with varying water velocities (m/s) using the Gambit 2.4.6 and Fluent 6.3.26.

1.3 Scope of this research

The scopes of this study are to mainly study the effects of water velocity on the oil spill process. The method of study is by implementing computational fluid dynamics using the Gambit 2.4.6 and the Fluent Software. GAMBIT 2.4.6 mesh-generator is employed to perform all geometry generation and meshing. The whole computational domain is a rectangle with a length of 20 m and a height of 15 m. The length of computational domain is large enough, which is larger than the longest horizontal distance the oil droplets migrate when they reach the sea surface. Water occupies the lower region with height of 14.5 m, while air occupies the upper region. The damaged submarine pipe with the outer diameter (D) of 0.6 m at both sides. . In the Fluent 6.3.26, the time taken for the oil droplets to reach free surface was observed by varying water inlet velocity; v_{w1}=0.02m/s, v_{w2}=0.04m/s,v_{w3}=0.08m/s respectively. Kerosene droplets reached free surface faster as the velocity of water inlet increased. Results were observed at 1000 number of time steps (iterations) with a step size of 0.1s.

1.4 Hypothesis

As the water velocity inlet (m/s) increases, the time taken for the oil droplets to reach free surface is much shorter.

1.5 Main contribution of this work

The following is the contribution:

- Contribution was prior to our supervisor's guidance in helping us learn and venture into the CFD simulation of Gambit and Fluent Software.
- And from this simulation study, I can be able to understand the factor of water velocity which affects the time for oil droplets to reach free surface.

1.6 Organisation of thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides an overview of oil leakage in pipelines underneath the ocean. A general description on the Computational Fluid Dynamics (CFD) and the Volume of Fluid (VOF) approach. This chapter also provides a brief review on previous study made on oil leakage myths. A comparison made on all the factors which directly affect the time period for the spills to reach the free surface.

Chapter 3 gives a review of the procedure involved in the simulation process. The mesh is generated and exported to the Fluent Software to simulate results. Results generated for varying velocities are compared to its standard case.

Chapter 4 gives a clear understanding of the effect of water velocity on the time taken for oil to reach the sea-surface while leaving other parameters of oil density, oil leak rate and leak size constant. It is attributed to the increasing kinetic velocity of oil droplets. Hence, the larger the water velocity, the more obvious the trajectory of oil flow skewed to the downstream. The reason is that high-speed water exerts more shear stress on oil droplets and transfers more kinetic energy to oil droplets (kerosene liquid).

Chapter 5 draws together a summary of the thesis and outlines the future work which might be derived from the model developed in this work.

2 LITERATURE REVIEW

2.0 Screening Route

My literature study was on the oil leakage in submarine pipelines which endanger the environment and aquatic life. In addition, research was also completed on Computational Fluid Dynamics (CFD). The study conducted did not neglect the environmental aspects and economy imprecision. Finally, the literature centered on the effect of water velocity towards oil migration in a horizontal distance to the free surface.

2.1 Oil Leakage

Over the past few decades, several major U.S. oil spills have had lasting repercussions that transcended the local environmental and economic effects. The April 2010 oil spill in the Gulf of Mexico has intensified interest in many oil spill-related issues. Prior to the 2010 Gulf spill, the most notable example was the 1989 *Exxon Valdez* spill, which released approximately 11 million gallons (260,000 barrels) of crude oil into Prince William Sound, Alaska. The *Exxon Valdez* spill produced extensive consequences beyond Alaska. According to the National Academies of Science, the *Exxon Valdez* disaster caused “fundamental changes in the way the U.S. public thought about oil, the oil industry, and the transport of petroleum products by tankers ‘big oil’ was suddenly seen as a necessary evil, something to be feared and mistrusted; Jonathan L (2012)

Offshore production constitutes a major portion of the overall oil and gas production. Offshore oil and gas production is more challenging than land-based installations due to the remote and harsher environment. Other than the production challenges, environmental risks due to oil spills pose major challenges. An “oil spill” usually refers to an event that led to a release of liquid petroleum hydrocarbon into the environment due to human activity and is a form of pollution. Oil spills usually include releases of crude oil from tankers, offshore platforms, drilling rigs and wells, as well as spills of refined petroleum products (such as gasoline, diesel) and their by-products, and heavier fuels used by large ships such as bunker fuel, or the spill of any oily white substance refuse or waste oil. Spills may take months or even years to clean up. (*Agrawal* et al., *2011*)

There are several factors that may cause the oil spill from submarine pipeline.

Table 2-1: The **factors** of how oil spill can occur from damaged submarine pipeline

Factor	Explanation	Author
Submarine landslide	This is happen due to high of sedimentation rates and usually occurs on steeper slopes. This landslide can be triggered by earthquakes in the sea. When the soil around the piping system is subjected to a slide, and give the result of displacement at high angle to the pipeline, the pipe will severe bending. This will cause tensile failure.	Palmer & King (2008)
Ice issues	This happen to submarine pipeline system in low temperature water especially in freezing waters. In this case, the floating ice features often drift into shallower water. Therefore their keel comes into contact with the seabed. When this condition happen, they will scoop the seabed and came hit the pipeline	Croasdale K. (2013)
	Stamukhi can also damage the submarine pipeline system. Stamukhi is a grounded accumulation of sea ice rubble that typically develops along the boundary between fast ice and the drifting pack ice. This stamukhi will exert high local stresses on the pipeline system to inducing the excessive bending.	Croasdale K. (2013)
Ship anchors	Ship anchors are a potential threat to submarine pipelines, especially near harbours. This anchor will give high damage to the pipeline due to their massive weight.	
Corrosion	For small size lines, additionally, failures due to external corrosion were more frequent compare than internal corrosion. However in medium and large-size lines, failures due to internal corrosion were more frequent than those due to external corrosion.	J. S. Mandke (1990)

Table 2-2: Oil Spills of 100,000 Tons (640,000 Barrels), or More (*International Tanker Owners Federation, 2001 New York Times Almanac*)

Date	**Cause**	**Location**	**Barrels Spilled**	**Rank, by spilled volume**
1942	German U-boats attacks on tankers after U.S enters World War 11	U.S. East Coast	590,000	4
1970	Tanker *Othello* collides with another ship	Tralhavet Bay, Sweden	60,000 to 100,000	15
1994	Pipeline bursts, oil enters rivers that flow into Arctic Ocean	Near Usinik, Russia	312,500	5

2.2 Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) provides a qualitative (and sometimes even quantitative) prediction of fluid flows by means of mathematical modeling (partial differential equations), software tools (solvers, pre- and post-processing utilities), and numerical methods (discretization and solution techniques). (*Wesseling* et al., 2001)

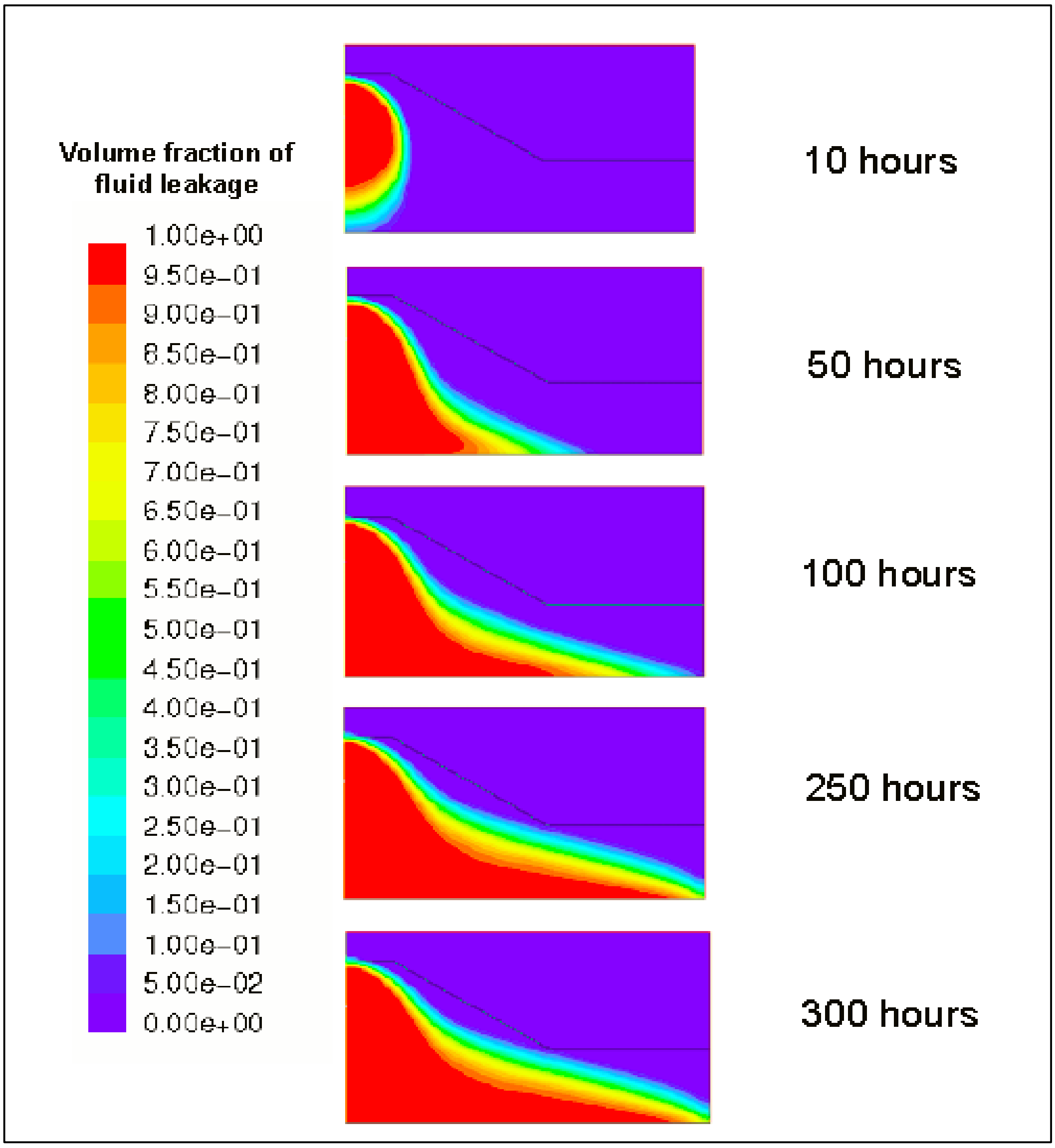
2.2.1 Oil Spillage

By definitions, Leakage is the accidental admission or escape of liquid or gas through a hole or crack from the pipeline. Spillage is an accidental release of oil /liquid petroleum hydrocarbon to the sea from tankers at larger amounts than a leak, which may end in Pollution. Both definitions were derived from the *Oxford Dictionary 2010*.Alexander, C. (2005) through Stress Engineering Service (SES) performed a more rigorous investigation to determine what conditions were required to produce daylighting, the significance of which involved quantifying the estimates of leak duration and the petroleum volumes at Houston, Texas. This effort integrated assumptions and data from prior analyses to assess the effects of time-dependency using computational fluid dynamics (CFD) modeling techniques.

Table 2-3: CFD Modeling Scenarios; Alexander, C. (2005)

Scenario	Description	Volume of product released	Daylight (YES or NO)
1	Continuous leaking (330 hours)	24685 gallons 240 ft^3/day-330 hours	YES
2	Leak rates based on tabulated existing data considering two different pressure levels a. Pipeline beginning pressure (***667 hours***) b. Static head end pressure (***667 hours***)	4,940 gallons (a) 6,212 gallons (b)	NO (a) NO(b)

Table 2-4: CFD contour plots with continuous leaking at 240 ft^3/dayAlexander, C. (2005)



According to another research from Shehadeh (2012), the research focused on studying the velocity magnitude (V), total pressure (P), and turbulence intensity (I) for the hole of 5 mm diameter in a pipe of 3.5 mm wall thickness at ambient temperature. The study is to put forward the relationship between these parameters and the leakage mass flow rate (m_{leak}).A new CFD model was applied to simulate leakage in water pipeline by means of turbulence.

All zones are solved by initializing the entire flow field using the k-epsilon realizable model, as shown in Figure2-1.

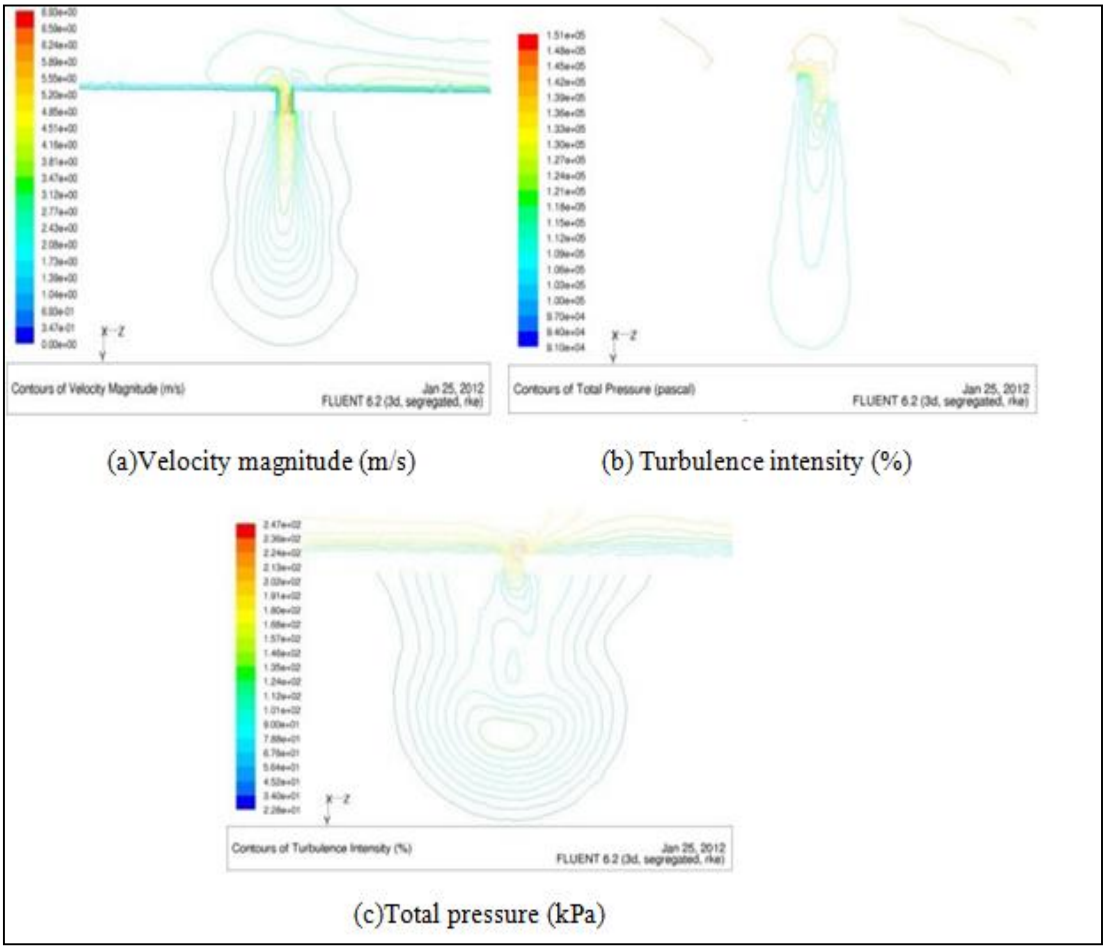


Figure 2-1: Fluent Simulation using k-epsilon turbulence model. (Shehadeh *et al.*, 2012)

Table 2-5 below depicts on the parameters used to run the fluent software in detecting water leakage.

Table 2-5: Parameters used in the Fluent Simulation (Shehadeh*et al.*, 2012).

Scenario	V_{in} (m/s)	P_{out}(kPa)	M_{in} kg/s	M_{leak} in kg/s	M_{out} in kg/s	$V_{m/s}$		P(kPa)	I(%)
1	2.7	100	5.96	0.1	5.86	Min	0	91.3	22.8
						Max	6.93	150.92	246.8
2	3.2	130	7.13	0.17	6.96	Min	0	81.62	26.9
						Max	11.23	249.01	369.7
3	3.7	155	8.24	0.22	8.02	Min	0	75.12	31.3

						Max	14.2	340.09	462.0

Hence, the turbulence intensity has a great effect on monitoring of pipeline, for instance leakage using novel technique such as acoustic emission [15] and ultrasonic techniques [16].The study has predicted correlations between the mass flow rate of the leakage and the various parameters of the pipeline system.

2.2.2 Experiments versus Simulations

Table 2-6: Comparison of experimental and simulation runs (*Wesselling et al., 2001*)

Experiments	**Simulations**
Quantitative description of flow phenomena using measurements • For one quantity at a time • At a limited number of points and time instants • For a laboratory-scale model • For a limited range of problems and operating conditions Error sources: measurement errors, flow disturbances by the probes	Quantitative prediction of flow phenomena using CFD software • For all desired quantities • With high resolution in space and time • For the actual flow domain • For virtually any problem and realistic operating conditions Error sources: modeling, discretization, iteration, implementation

2.2.3 The Finite Volume Method

A method for discretizing the transport equations commonly implemented in CFD codes are the finite volume method (FVM). In a FVM, the computational domain is divided in control volumes and conservation principles are applied to each control volume. This ensures conservation, both in each cell and globally in the domain, which is a great advantage of the FVM? Using FVM also allows for the use of unstructured grids which decreases the computational time. (*Stenmark et al., 2013)*

2.3 Multiphase Flow Theory

Multiphase flow is flow with simultaneous presence of different phases, where phase refers to solid, liquid or vapor state of matter. There are four main categories of multiphase flows; gas-liquid, gas-solid, liquid-solid and three-phase flows.
(*Thome, (2004))*

2.3.1 VOF Model Approach

A third modeling approach is the volume of fluid (VOF) method. VOF belongs to the Euler-Euler framework where all phases are treated as continuous, but in contrary to the previous presented models the VOF model does not allow the phases to be interpenetrating. The VOF method uses a phase indicator function, sometimes also called a colour function, to track the interface between two or more phases. The indicator function has value one or zero when a control volume is entirely filled with one of the phases and a value between one and zero if an interface is present in the control volume. Hence, the phase indicator function has the properties of volume fraction. The transport equations are solved for mixture properties without slip velocity, meaning that all field variables are assumed to be shared between the phases. To track the interface, an advection equation for the indicator function is solved. In order to obtain a sharp interface the discretization of the indicator function equation is crucial. (*Stenmark et al., 2013*)

2.4 Software

For geometry and mesh generation the ANSYS software ICEM CFD was used.

2.4.1 ICEM CFD

ICEM CFD is meshing software. It allows for the use of CAD geometries or to build the geometry using a number of geometry tools. In ICEM CFD a block-structured meshing approach is employed, allowing for hexahedral meshes also in rather complex geometries. Both structured and unstructured meshes can be created using ICEM CFD. (*Stenmark et al., 2013*)

2.4.2 Fluent

The Fluent solver is based on the centre node FVM discretization technique and offers both segregated and coupled solution methods. Three Euler-Euler multiphase models are available; the Eulerian model, the mixture model and the VOF model. In addition, one particle tracking model is available.

As mentioned in Section 2.3.1, the discretization of the volume fraction equation is crucial in a VOF method to keep the interface sharp. The choice of discretization method can have a great influence on the results in other multiphase models as well. To resolve this issue, Fluent has a number of discretization techniques implemented specifically for the volume fraction equation. Several methods are also available for spatial discretization of the other transport equations.

To model interphase transfer there is both a number of drag models available along with other transfer mechanisms such as lift forces and turbulent dispersion Fluent offers three main approaches to model dispersed phases with a two-fluid formulation. With the default settings it is assumed that the dispersed phase has a constant diameter or a diameter defined by a user-defined function. With this setting, phenomena such as coalescence and breakage are not considered. (*Stenmark et al., 2013*)

2.5 Computational Domain and Mesh

A sketch of the geometry (a) and numerical grid for computational domain (b) investigated in this study. GAMBIT 2.4 mesh-generator is employed to perform all geometry generation and meshing. The whole computational domain is a rectangle with a length of 20 m and a height of 15 m. The length of computational domain is large enough, which is larger than the longest horizontal distance the oil droplets migrate when they reach the sea surface. Water occupies the lower region with height of 14.5 m, while air occupies the upper region. In the computational domain, the damaged submarine pipe with the outer diameter (D) of 0.6 m on both sides, the most common diameter of submarine pipe used in Bohai oilfield, is located in the sea bed. The speed of the water velocity (m/s) is a variable ranging from 0.01 m/s to 0.09 m/s, in order to examine the effect of water velocity. (*Zhu et al., 2013*)

Table 2-7:Simulation cases, in which variables of oil density, oil leaking rate, diameter of leak, and maximum water velocity are varied (*Zhu et al., 2013*)

Case	Oil density(kg/m^3)	The maximum water velocity(m/s)	Oil leaking rate(m/s)	Diameter of leak(m)	Volume flux of leaking oil(m^3/s)	Flux multiple(comparing with case 12)
1	780	0.1	2	0.05	0.003925	25
2	810	0.1	2	0.05	0.003925	25
3	840	0.1	2	0.05	0.003925	25
4	870	0.1	2	0.05	0.003925	25
5	900	0.1	2	0.05	0.003925	25
6	930	0.1	2	0.05	0.003925	25
7	960	0.1	2	0.05	0.003925	25
8	870	0.1	1	0.05	0.0019625	12.5
9	870	0.1	3	0.05	0.0058875	37.5
10	870	0.1	4	0.05	0.00785	50
11	870	0.1	5	0.01	0.0098125	62.5
12	870	0.1	2	0.02	0.000157	1
13	870	0.1	2	0.03	0.000628	4
14	870	0.1	2	0.04	0.001413	9
15	870	0.1	2	0.05	0.002512	16
16	870	0.04	2	0.05	0.003925	25
17	870	0.07	2	0.05	0.003925	25

2.6 Effect of oil density on Oil spills

As the density of oil and seawater is almost the same, when current velocity rises continuously with the same operating pressure, the influence of sea current is strengthened. Meanwhile, the influence of buoyancy is relatively weakened. When the current velocity is low (u = 0.1m/s), as shown in Fig. 2-2, the influence of buoyancy becomes dominant to the rising spilled oil. When the current velocity is u = 0.3, u = 0.5 and u = 0.8 m/s, respectively as shown in Fig. 2-3 to 2-5, the influence of sea current dominates obviously and oil particles move with sea current after spilled immediately. Therefore, the higher current velocity is, the longer submarine drift distance is with its respective densities. (Li *et al.*, 2013)

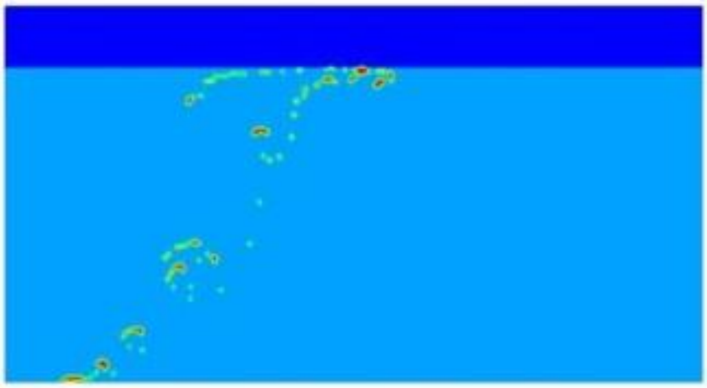


Figure 2-2: Distribution of oil-water-gas (t = 56s, u = 0.1m/s, P = 101000pa) (Li *et al.*, 2013)

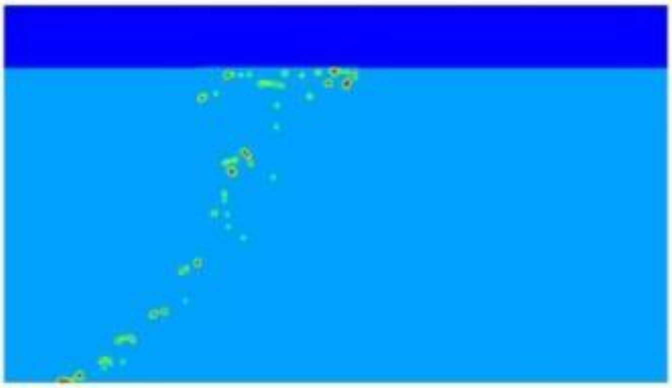


Figure 2-3: Distribution of oil-water-gas (t = 60s, u = 0.1m/s, P = 100800pa) (Li *et al.*, 2013)

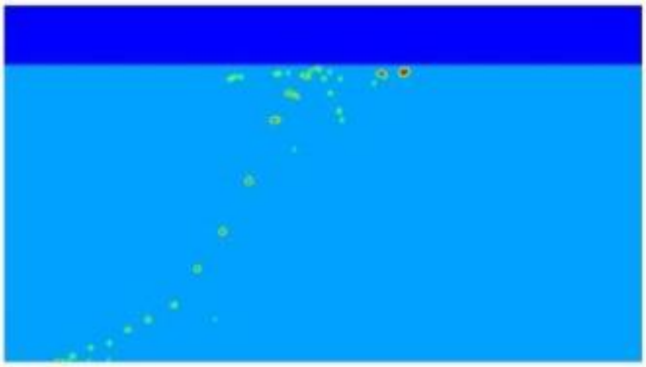


Figure 2-4: Distribution of oil-water-gas (t = 80s, u = 0.1m/s, P = 100600pa) (Li *et al.*, 2013)

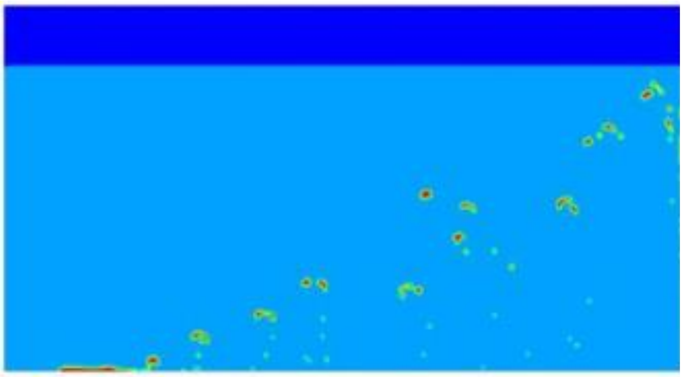


Figure 2-5: Distribution of oil-water-gas (t = 80s, u = 0.3m/s, P = 101000pa) (Li *et al.*, 2013)

3 MATERIALS AND METHODS

3.1 Overview

This paper is about to study the oil flows from damaged submarine pipelines with different water velocities. First and foremost, CFD (computational fluid dynamic) model coupling with VOF (volume of fluid) method has been used to investigate the process of oil spill from submarine pipeline to free surface. The actual shear velocity distribution of current and the actual hydrostatic pressure distribution are considered in this study. Detailed oil droplet and sea-surface in-formation could be obtained by the VOF model. Effects of oil density, oil leaking rate, leak size and water velocity on the oil spill process are examined.

3.2 Simulation Methodology

3.2.1 Governing equations

The VOF approach is based on the solution of one momentum equation for the mixture of the phases, and one equation for the volume fraction of fluid. In this study, volume of fluid functions F_w and F_o are introduced to define the water region and the oil region, respectively. The physical meaning of the F function is the fractional volume of a cell occupied by the liquid phase. For example, a unit vale of F_w corresponds to a cell full of water, while a zero value indicates that the cell contains no water. The fraction functions F_w and F_o are described as follows:

$$\boldsymbol{F_w}=\frac{\boldsymbol{V_w}}{\boldsymbol{V_c}} \qquad \textbf{Equation 3.2(a)}$$

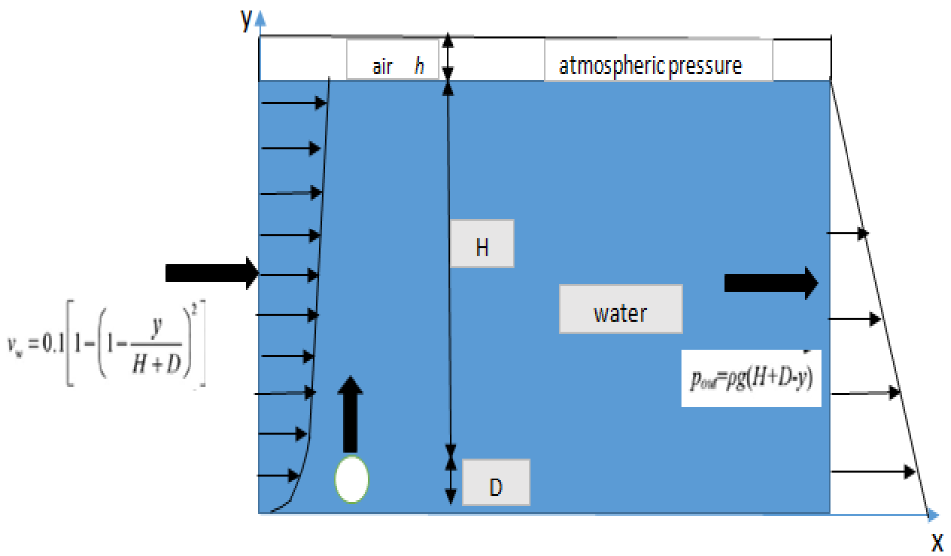
$$\boldsymbol{F_o}=\frac{\boldsymbol{V_o}}{\boldsymbol{V_c}} \qquad \textbf{Equation 3.2(b)}$$

where F_o and F_w are oil and water fractional function, respectively, V_c, V_o and V_w represent volume of a cell, volume of oil inside the cell and volume of water inside the cell, respectively.

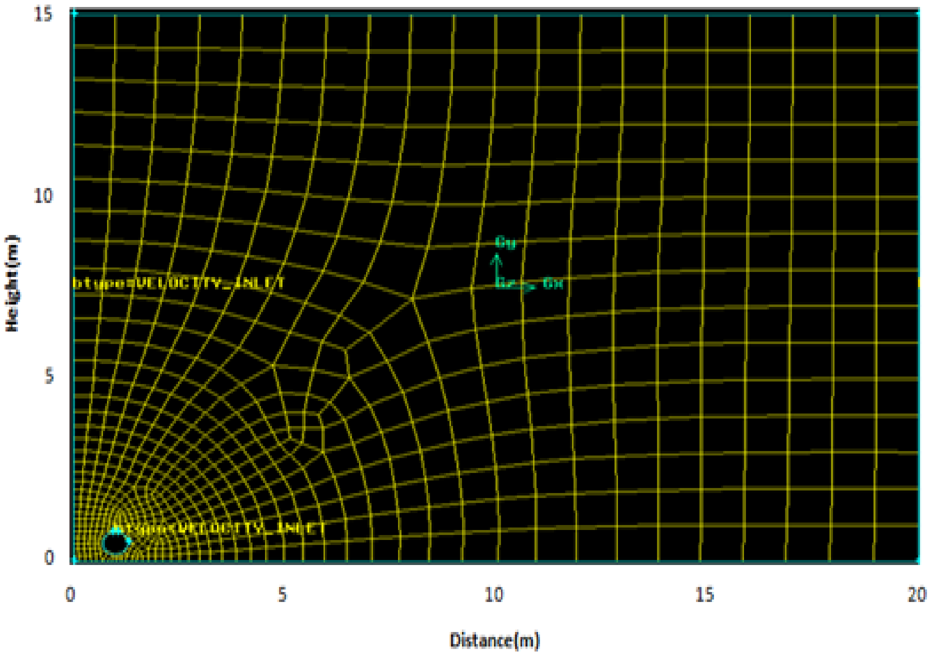
3.2.2 Computational Domain and Mesh

(a) Gambit 2.4

A two-dimensional flow simulation is accurate enough to capture the maximum horizontal migration distance. Using Gambit 2.4, a rectangular computational domain was created with a length of 20 m and height of 15 m. Water occupies the lower region with height of 14.5 m, while air occupies the upper region. In the computational domain, the damaged submarine pipe with the outer diameter (D) of 0.6 m was displayed and transformed to a coordinate of (-9,-7, 0). There is a leakage hole on the top of pipe, opening upwards. The size of the leakage hole (d) is fixed at 0.1m. Then, a paved quadratic mesh with 0.5 spacing was generated for the leak and domain at one time. Progressive mesh is used to capture the near-leak flow properties. A suitable grid density is reached by repeating computations until a satisfactory independent grid is found. The mesh is then exported to be used to generate results in the Fluent 6.3.26. Figure 3-1 below shows (a) sketch of the geometry and (b) numerical grid for computational domain investigated in this study.



(a)



(b)

Figure 3-1: Sketch of the geometry and numerical grid for computational domain: (a) overall view of the computational domain and boundary conditions; (b) grid distribution of computational domain. *(Zhu et al. 2013)*

(b) Fluent 6.3.26

The mesh document is then read in the fluent software with a 2d, double precision (d.p.) unsteady simulator**.** Then, grid was checked and a multiphase theory was approached. Turbulence of k-epsilon was chosen to test its viscosity of kerosene liquid. The next procedure was to select materials in the multiphase category. The three phase materials chosen were water liquid, kerosene liquid and air at their fixed densities respectively.

The parameter of inlet water velocity (vs.) was varied in Fluent with trials of v_{w1}=0.02m/s, v_{w2}=0.04m/s,v_{w3}=0.08m/s respectively. Phase 2 which consists of kerosene liquid was set with a volume fraction of 100%. The leak size was shown to be 0.1meter, which was fixed at the beginning of the simulation conditions. **Justifications** were shown where oil droplets released from a greater leak width are easier to collision and have greater chance of gathering into large droplets, (Zhu et al., 2013). This is because at a larger face of leakage, the shear stresses increases, causing a larger displacement in oil migration. Under the operating conditions, gravity of 9.81ms^{-2} was chosen acting in the vertical direction. The grid was displayed and initialization was begun.

To generate results, the animation was run based on time step. Sequence was chosen and the contour was set to phases. All ranges were ticked to enable visual interpretation of results. Finally, case input of data was checked and iteration step was chosen. A time step size of 0.1sec with 1000 number of time iterations was set. The simulation was run at 20 max iterations per time step.

3.3 Effects of variables on the Oil Spill Process

3.3.1 Effects of oil density

It can be seen that the larger the oil density, the longer the time required for oil to reach free surface. For ρ_0=960 kg/m^3, the required time for the maximum horizontal migration is about 1.84 times as long as that when oil density is 780 kg/m3. It is attributed to the increasing gravity of oil droplets. In the vertical direction, an oil droplet is mainly subject to the force of gravity and buoyancy. For two droplets of the same size, the upward buoyant forces are the same, while the droplet of larger density has a larger gravity. Therefore, the final vertical upward force is small for high density droplet, resulting in a slow rising rate. (*H. Zhu et al. 2013)*

At the same time (t_0=15 s), the maximum horizontal migration distance of light oil droplet (ρ_0= 780 kg/m^3) is 7 m (8.8 m minus 1.8m), about one time longer than that with density of 960 kg/m^3.Before the leaking oil reaching the sea-surface, the horizontal migration of oil flow under the sea-surface cannot be easily observed without monitoring instruments. In addition, oil containment boom is laid floating on the sea-surface. So the maximum horizontal migration distance when the oil droplet reaches the free surface is a very vital parameter. This horizontal migration distance for ρ_0= 960kg/m^3 is 17.1m(18.9m-1.8m), a little shorter than that when oil density is 780 kg/m^3 which is 18 m(19.8m-1.8 m). The main cause of this result is that low density oil droplets rise faster and enter into high-speed water zone earlier, leading to shearing action of current acting on oil earlier. However, the difference in the maximum horizontal migration distance is little.

Therefore, light oil can reach surface quickly, requiring short response times, while the location be laid with oil containment boom to control oil dispersal is basically the same for different-density oil flow. (*H. Zhu et al. 2014)*

3.3.2 Effect of oil leaking rate

At small leaking rate (v_o=1 m/s), 79 s is required for oil flow to reach the maximum horizontal migrate distance when it reaches the free surface, and the maximum horizontal migration distance is arrived at 16.4 m (18.2 m minus 1.8 m).

However, for higher leaking rate (v_o=5 m/s), just 15 s is needed for oil to reach the maximum horizontal migrate distance when it reaches the free surface. It can be explained that high-speed leaking oil has more ascending kinetic energy. The reason is that the total amount of released oil is larger as the mass rate of oil is larger (For incompressible fluid, mass flow rate in-creases as the increase in velocity). Thus, in order to reduce the environmental consequences, a relatively fast response is required for high-speed leaking oil, and an adequate response should be considered to solve a large number of oil spills.

3.3.3 Effect of oil leak size

The results indicate that the effect of the diameter of leakage hole plays a significant role in the spread of oil spill. With increasing leakage size, the time required for oil to reach the maximum horizontal migrate distance when it reaches the free surface is shortened. As leakage size reduces from 0.05m to 0.01m, the required time decreased by 23.53 percent. It can be explained that at the same leaking rate, the bigger the diameter of leak, the larger the amount of released oil and the greater the upward momentum. Due to the large mass flow rate, oil droplets released from the leak with d = 0.05 easier to collision and have greater chance of gathering into large droplets. Though the water velocities are the same, large active faces of big oil droplets lead to great shear stress. Under the action of shear stress, the maximum horizontal migrate distance,16.7m (18.5m minus 1.8 m), presents in the case of d=0.05 m. This distance is about 1.5 times than the maximum horizontal migrate distance for d =0.01m. Therefore, big-hole leaks may lead to more serious consequences.

3.3.4 Effect of water velocity

In order to study the effect of water velocity on the migration of oil droplets to free surface, boundary conditions of the water velocity were altered while leaving other parameters same as those in the standard case. In conclusion, The larger the water velocity, the more obvious the trajectory of oil flow skewed to the downstream. The reason is that high-speed water exerts more shear stress on oil droplets and transfers more kinetic energy to oil droplets.

Table 3-1: Simulation cases, in which parameters are varied in recent findings.

Parameters	**Visual**	**Multi phase**	**Viscosity**	**Materials**	**Phases**	**Oil leak rate (m/s)**
Conditions	2d, dp (double Precision)	VOF	k-epsilon	1) Water liquid 2) Air 3) Kerosene Liquid (Density=780kg/m^3)	1)Water liquid 2)Kerosene liquid	0.1

3.4 Summary

The mesh generated from the Gambit Software, is exported to the Fluent 6.3.26 software in order to generate results of oil spill from submarine pipelines in 2D visual. Nevertheless, the longest horizontal oil migrate distance was observed upon the effect of varying the water velocities.

4 RESULTS & DISCUSSIONS

4.1 Overview

In this section, it is to study the effect of water velocity on the time taken for oil droplets to reach free surface upon leakage. The other parameters of oil density, oil leak rate and leak size were set constant at 780kg/m^3, 0.1m/s, 0.1m respectively. Results obtained were as follows with comparison of water velocities at 0.02m/s, 0.04m/s and 0.08m/s respectively.

4.2 Results and Discussions

The results below were discussed based on their respective velocities and time intervals. **Figure 4-1** Process of oil spill to free surface from damaged submarine pipelines at water velocity of 0.08m/s. **Figure 4-2** Process of oil spill to free surface from damaged submarine pipelines at water velocity of 0.04m/s.**Figure 4-3** Process of oil spill to free surface from damaged submarine pipelines at water velocity of 0.02m/s.

Figure 4-4 Comparison of water velocity (m/s) towards time(s) of leakage from pipeline. **Figure 4-5** Comparison of effect of water velocity towards time of oil leakage from pipeline.**Figure 4-6**Comparison of effect of water velocity (m/s) towards time (s) of oil leakage from pipeline. **Figure 4-7**Comparison of water velocity; 0.04 m/s for both from results and journal at specific time period(s)

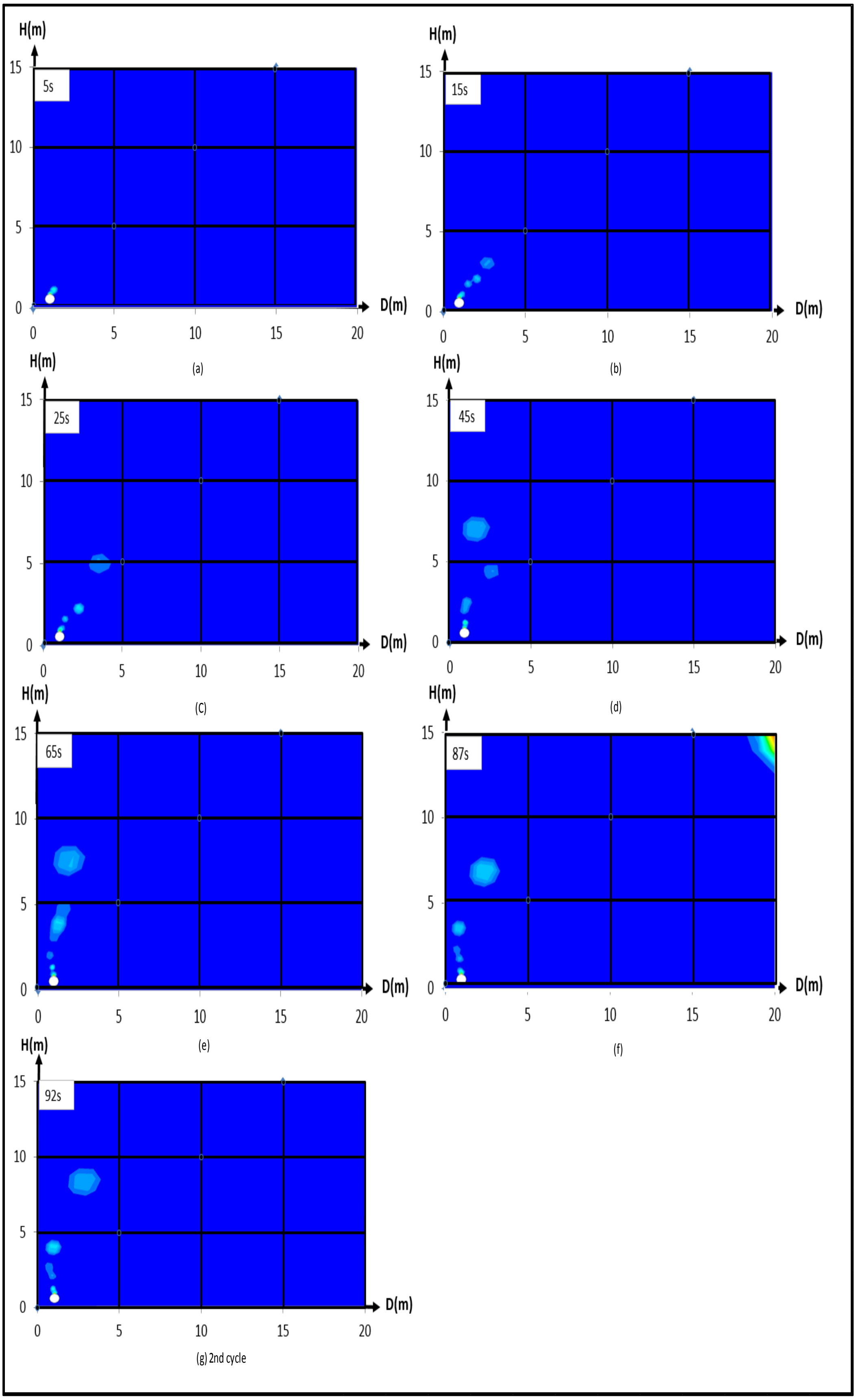


Figure 4-1: Process of oil spill to free surface from damaged submarine pipelines at water velocity of 0.08m/s.

DISCUSSIONS

The study was based on a 15m height by 20m domain scale reading. From figure 4-1 (V_w=0.08 m/s), process of oil spill to free surface was simulated at different time intervals. The oil leak rate and oil density was fixed at 0.1m/s and 780 kg/m^3 for this research.

For the first **5 seconds**, a small cloud of light blue contour started to form on the domain of the first quadrant indicating the leak. As the time proceeds, the distance and height of the oil droplet starts to increase in the first quadrant (15seconds)

At **25 seconds**, the clouds of droplets start to form in larger sizes and higher from its initial position. At **45 seconds**, the droplets of oil start to smear in large sizes to the above quadrant but at the maintained oil leak rate of 0.1m/s. At **65 seconds**, the clouds start to intimate with on another closely and separate in clots as to proclaim emulsion process of oil and water. At **87s**, the migration of oil succeeds to its surface end of the domain forming a contour. The contour actually indicated the volume fraction of the kerosene liquid (oil) which is considered 100% before the iteration stage. At **92 seconds**, the oil droplets began a new cycle process of migration to free surface.

From the observations above, we can deduce that the cloud appearance of oil droplets were more visually seen at 45 seconds and reached free surface at 87 seconds. Water velocity of 0.08 m/s was used as to replace the previous research with 0.1 m/s (Zhu *et al.*, 2013).

Hence, the research supports the hypothesis that when water velocity increases, the time taken to reach free surface is much faster at constant oil leak rate.

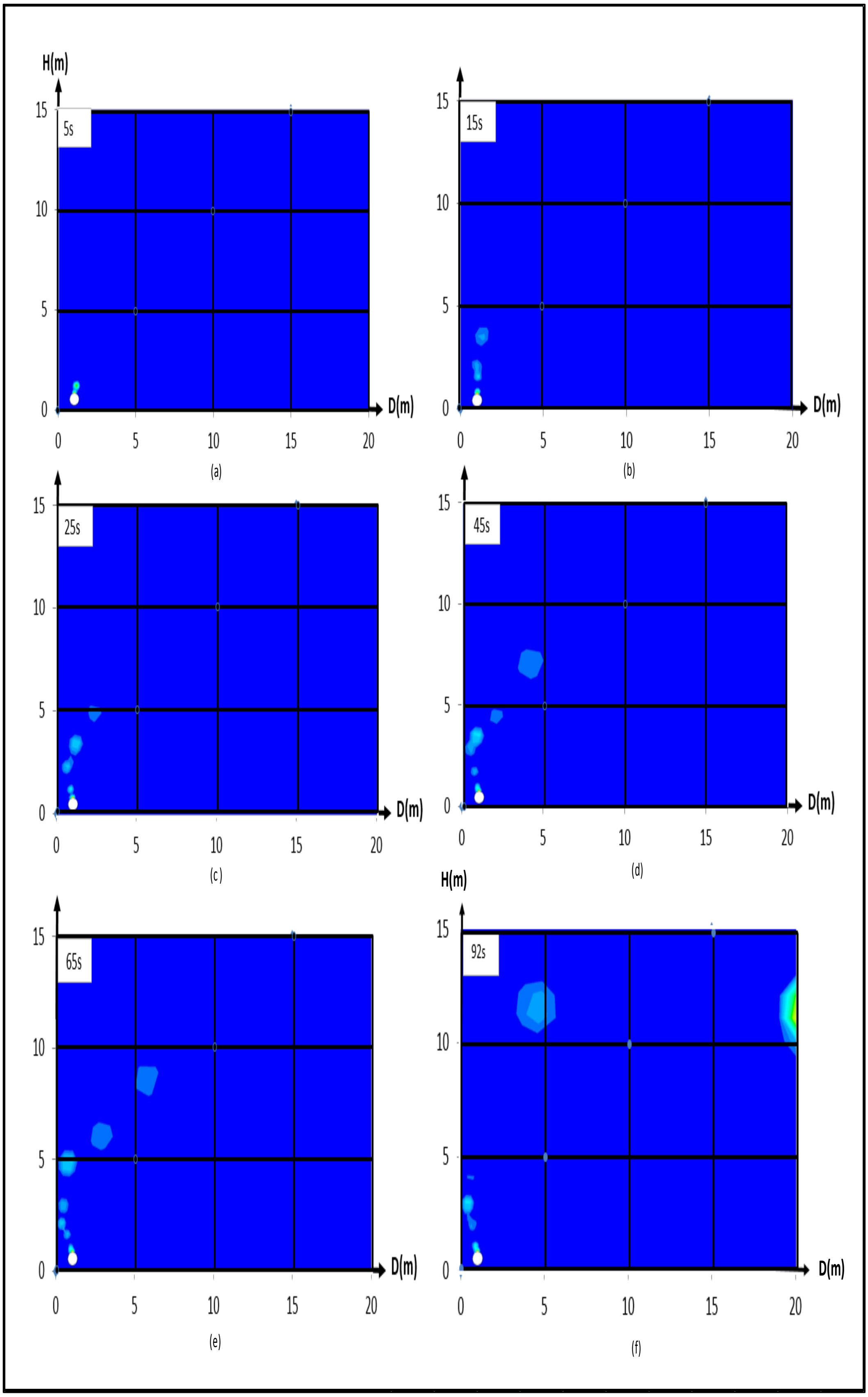


Figure 4-2: Process of oil spill to free surface from damaged submarine pipelines at water velocity of 0.04m/s.

DISCUSSIONS

The study was based on a 15m height by 20m domain scale reading. From the Figure 4-2 above, the process of oil spillage was observed again at water velocity of 0.04m/s. The oil leak rate and oil density was fixed at 0.1m/s and 780 kg/m^3 for this research.
At the exposure of **5 seconds**, the oil droplets formed a small light blue cloud indicating the leakage on the surface of pipeline. At **15 seconds**, the clouds of oil droplets started to rise a distance around three metres from the point source of leakage based on the domain illustrated, At **25 seconds**, the oil droplet slowly started to deviate to its right position of the domain. At **45 seconds**, the oil droplets started to break into separate clouds and started to smear further into the second quadrant of the domain. The distance between the clouds were much further apart compared to that in 25 seconds interval. At **65 seconds**, it was observed that the oil droplets formed a curved plot of clouds at a height of almost 10 metres from seabed with a distance above 5 metres from the leakage point. At **92 seconds**, the oil droplet managed to reach the free surface of the blue sea just slightly below surface and with a contour display. The contour was observed to be of green, yellow, and turquoise paved colour indicating a volume fraction of only 0.75 achieved by the kerosene liquid compared to results seen at 0.08m/s.

From the scenario above, we can deduce that the kinetic energy was lower to force the oil droplets up to free surface.

Hence, the research supports the hypothesis that when water velocity increases, the time taken to reach free surface is much faster at constant oil leak rate.

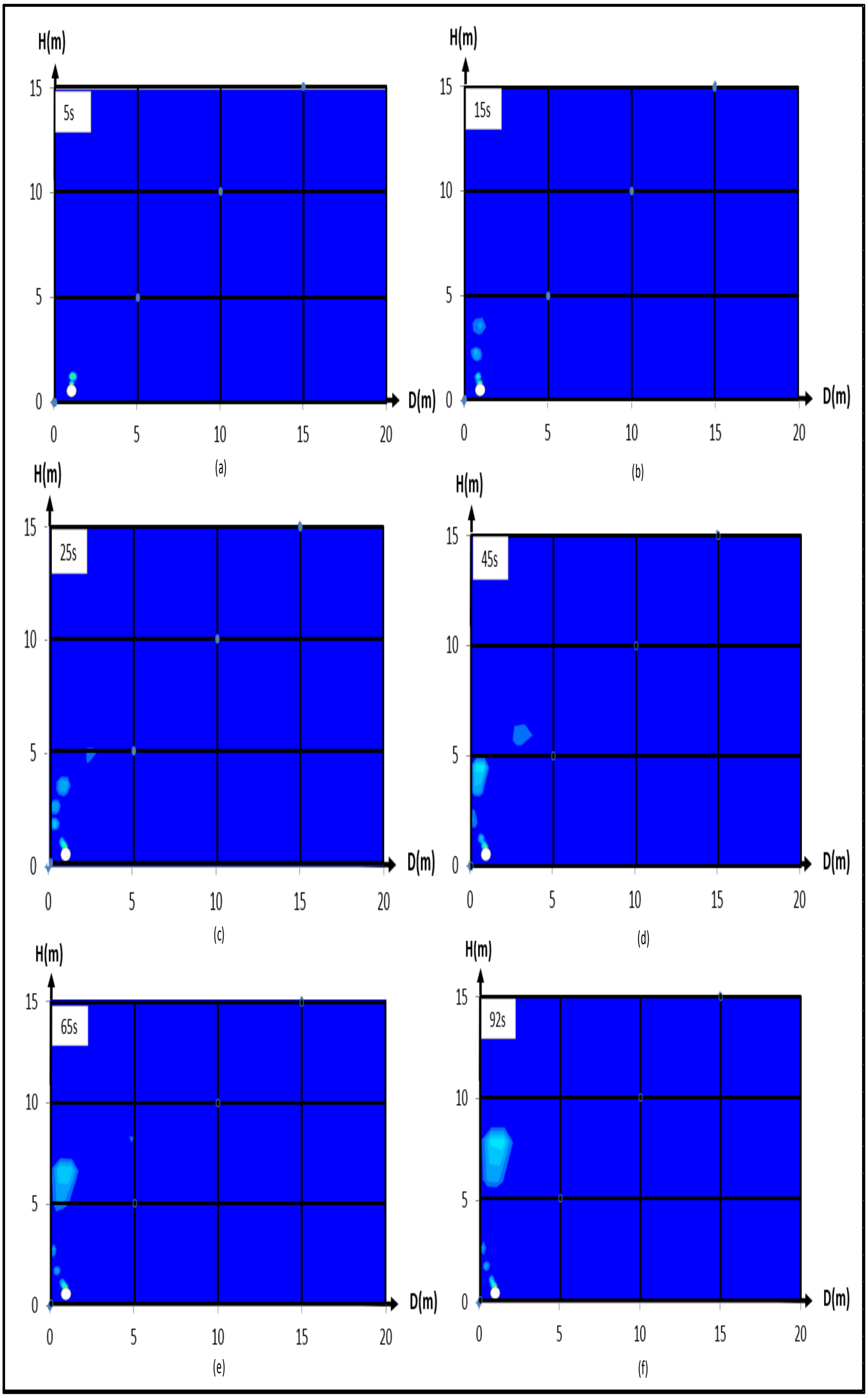


Figure 4-3: Process of oil spill to free surface from damaged submarine pipelines at water velocity of 0.02m/s.

DISCUSSIONS

The study was based on a 15m height by 20m domain scale reading. From the Figure 4-3 above, a water velocity of V_w=0.02 m/s was selected to investigate the process of leakage as compared to the previous research which was at 0.07 m/s (Zhu *et al*., 2013). The oil leak rate and oil density was fixed at 0.1m/s and 780 kg/m^3 for this research.

At **5 seconds**, for V_w=0.02m/s, the oil droplet was observed to begin exposure from pipe surface with a light blue contour. It was observed with a small area cloud above the pipe surface.

At **15 seconds**, for V_w=0.02m/s, the oil droplets were observed to have rose a height of almost 4metres with negligent distance of migration. With this, we can deduce that the movement above the seabed at 15 seconds was hardly aided by effect of water velocity.

At **25 seconds**, for Vs=0.02m/s, the oil droplets slowly begin to smear and deviate in a paved path towards a distance of almost 4 meters away from point source of leak.

It can be deduced that the oil droplets are slightly pushed by the 0.02m/s kinetic source in the right side direction.

At **45 seconds**, the oil droplets start to disperse from initial cloud formation into bigger clouds and away from the initial quadrant.

Unlikely, at **65 seconds** the clouds start to smear bigger in upward direction but without disintegrating from one another. The previous observation was prolonged until 92 seconds. In the whole, the clouds of oil droplets failed to migrate up to free surface due to the insufficient kinetic energy of water; 0.02m/s.

Hence, the research supports the hypothesis that when water velocity increases, the time taken to reach free surface is much faster at constant oil leak rate.

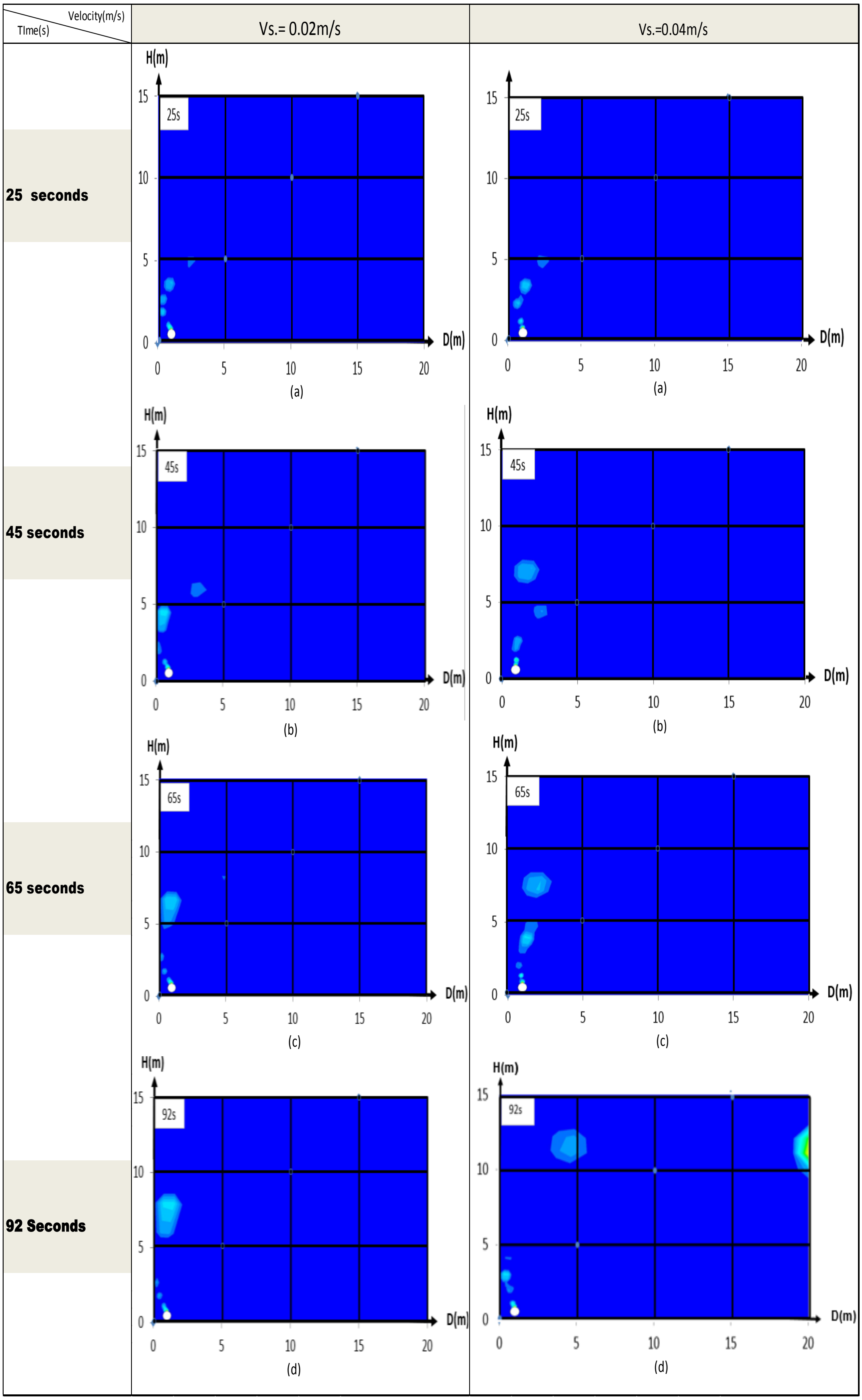


Figure 4-4: Comparison of water velocity (m/s) towards time(s) of leakage from pipeline.

DISCUSSIONS

From the Figure4-4 above, a comparison study was done between water velocities of 0.02m/s and 0.04m/s for 25, 45, 65, 92 seconds respectively. The study was based on a 15m height by 20m domain scale reading.
At **25 seconds**, for V_w=0.02m/s, the oil droplets were observed to still haven't reach the 5m height scale and migration was less than 3 metres . At 0.04m/s, the oil reached the 5 metres axis with an oil migration of more than 2 metres. We can deduce that the time for oil migration was faster at a higher water velocity.

At **45 seconds**, for V_w=0.02m/s, the oil droplets were observed to have smeared a distance of almost 4metres and a height above 5 metres. At 0.04m/s, the oil droplets are observed in clear and large clouds at a height around 7 metres from seabed. From the explanation above, we can deduce that the cloud appearance of oil droplets at 0.04m/s were more visually seen and further apart from the source of leakage compared to that of 0.02m/s. However, the scroll of deviation was still not too drastic due to its low water velocity inlet.

At **65 seconds**, for V_w=0.02m/s, the oil droplets begin to combine and become larger clouds. At 0.04m/s, the oil droplets combined to larger clouds as well but managed to disintegrate for a further distance apart.

At **92 seconds,** for V_w=0.02m/s, the oil droplets still remain in large clogs, whereas at 0.04 m/s the oil droplets succeeded to the free surface of water with a visual contour. The contour was of green, turquoise and yellow colour indicating the volume fraction of oil (kerosene droplets) still not a 100% fraction. In conclusion, we can deduce that the higher water velocity inlet helps to force the oil droplets up to free surface much easily.

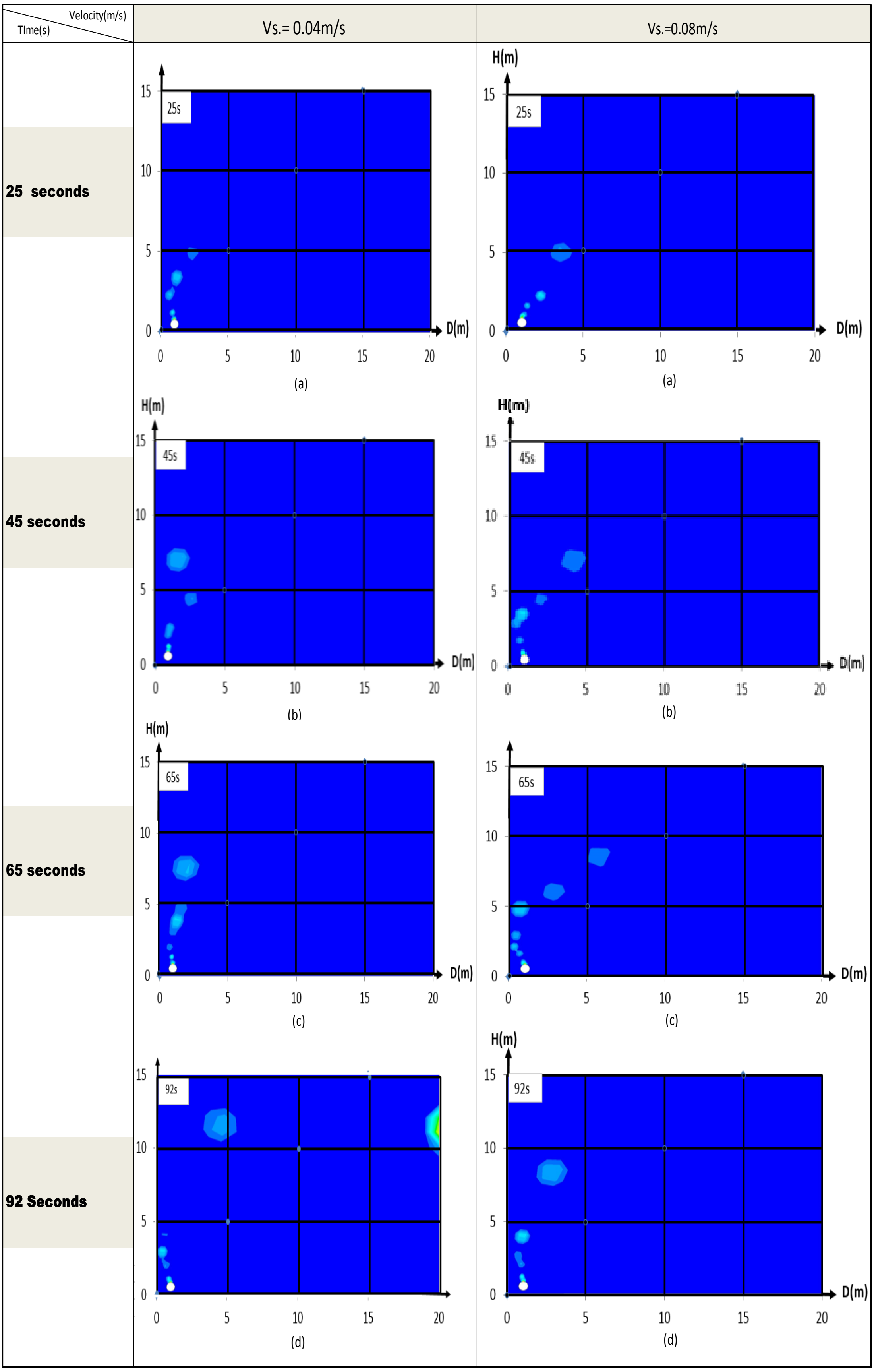


Figure 4-5: Comparison of water velocity (m/s) towards time(s) of leakage from pipeline.

DISCUSSIONS

From the **figure 4-5** above, a comparison study was done between water velocities of 0.04m/s and 0.08m/s for 25, 45, 65, 92 seconds respectively. The study was based on a 15m height by 20m domain scale reading.

At **25 seconds**, 0.04m/s, the oil reached the 5 metres axis with an oil migration of more than 2 metres. At 0.08m/s, the oil migration was above 5 metres from seabed with a distance of almost 4 metres from the inlet water velocity.

With accordance to this, we can deduce that the time for oil migration was faster at a higher water velocity.

At **45 seconds**, 0.04m/s, the oil droplets are observed in clear clouds at a height around 7 metres from seabed. At 0.08m/s, the oil migration has reached almost 5metres from the inlet water velocity with higher displacement.

The cloud appearance of oil droplets were more visually seen and further apart from the source of leakage compared to that of 0.04m/s.

At **65 seconds**, 0.04m/s, the oil droplets split and smear to a higher distance of 8metres but still in the same quadrant. At 0.08m/s, the oil migration has passed through the beside quadrant to a migration of almost 7m from the inlet velocity. Nevertheless, the distance from each oil droplets was further than at 0.04m/s.

From the information gathered, it can be deduced that the oil droplets spread further apart at 65 seconds and with clearer appearance of oil droplets.

At 92 seconds, for the 0.04 m/s, the oil droplets had reached free surface with a contour display. The display was of green, turquoise and yellow color indicating not a 100% volume fraction of kerosene liquid. On the other hand, as discussed earlier in Figure 4-1, for V_w=0.08 m/s, the oil droplets reached free surface much earlier at 87 seconds.

The results of display on diagram (d), **Figure 4-5** show a second cycle of oil spillage process. Hence, it can be seen that the higher kinetic property of water inlet influenced the time taken for oil droplets reach free surface.

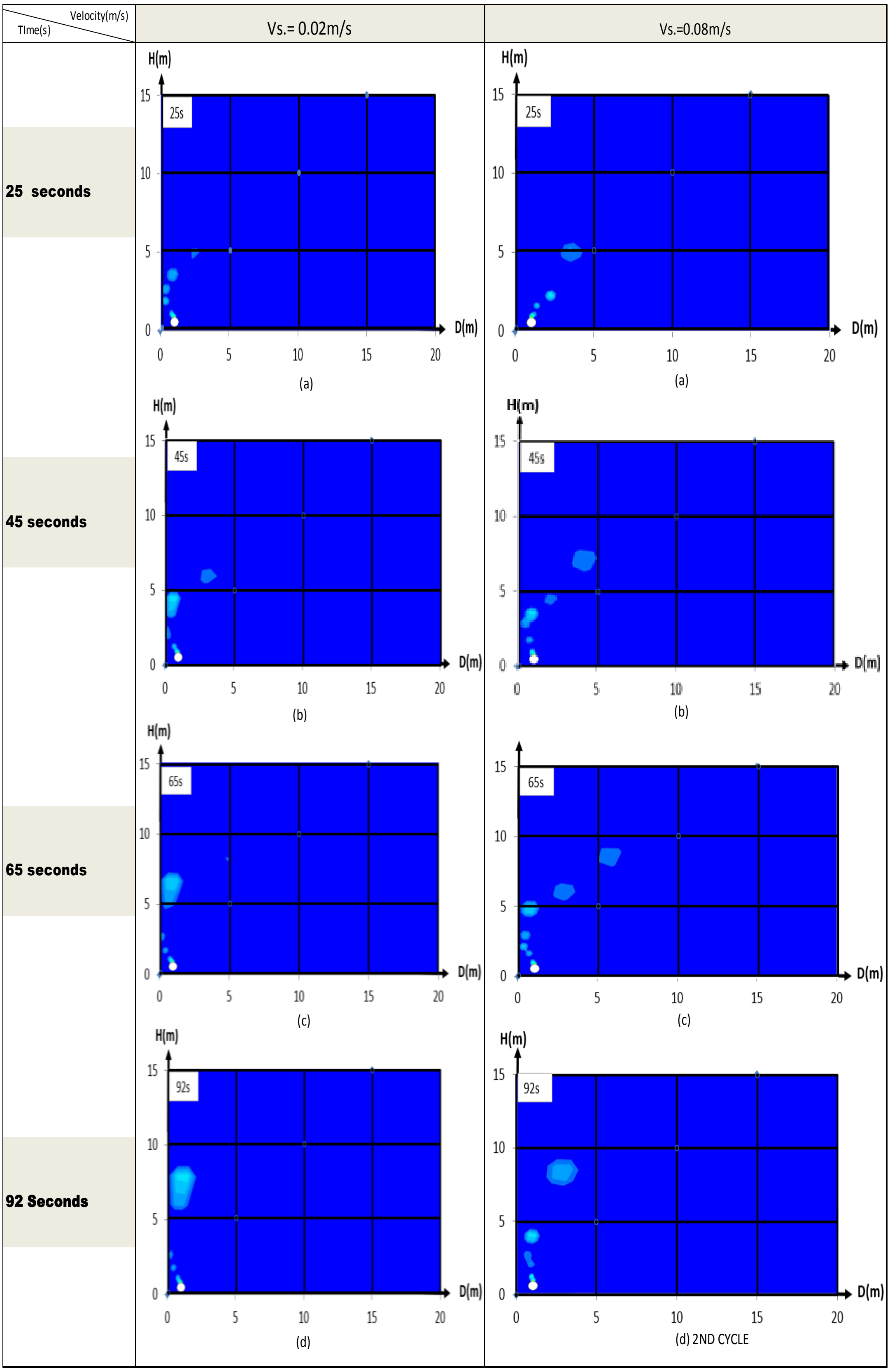


Figure 4-6: Process of oil spill to free surface from damaged submarine pipelines at water velocity of 0.08m/s.

DISCUSSIONS

From the Figure 4-6 above, a comparison study was done between water velocities of 0.02m/s, and 0.08m/s for 25, 45 ,65 and 92 seconds respectively. The study was based on a 15m height by 20m domain scale reading.

At **25 seconds**, for V_w=0.02m/s, the oil droplets were observed to still haven't reach the 5m height scale and migration was less than 2 metres . At 0.08m/s, the oil migration was above 5 metres from seabed with a distance of almost 4 metres from the inlet water velocity. The results observed deduce that the time for oil migration was faster at a higher water velocity.

At **45 seconds**, for V_w=0.02m/s, the oil droplets were observed to have smeared a distance of almost 4metres and a height above 5 metres. At 0.08m/s, the oil migration has reached 5metres from the inlet water velocity.

Cloud appearance of oil droplets in 0.04 m/s was more visually seen and further apart from the source of leakage compared to that of 0.02m/s.

At **65 seconds**, for V_w=0.02m/s, the oil droplets begin to combine and become larger. At 0.08m/s, the oil migration has passed through the beside quadrant to a migration of almost 7m from the inlet velocity.

It can be concluded that the oil droplets spread further apart at 65 seconds and with clearer appearance of oil droplets at 0.08m/s.

At **92 seconds**, for V_w=0.02m/s, the clouds move higher from leak source but without disintegration from its shape. However, in V_w=0.08m/s, as discussed earlier in **Figure 4-2**, the oil droplets had reached free surface at 87 seconds. So, the diagram illustration of (d) in Figure 4-6, repeats a cycle of oil spillage process again from its leak source.

From the observations gathered, it can be seen that the higher kinetic property of water inlet influenced the time taken for oil droplets reach free surface.

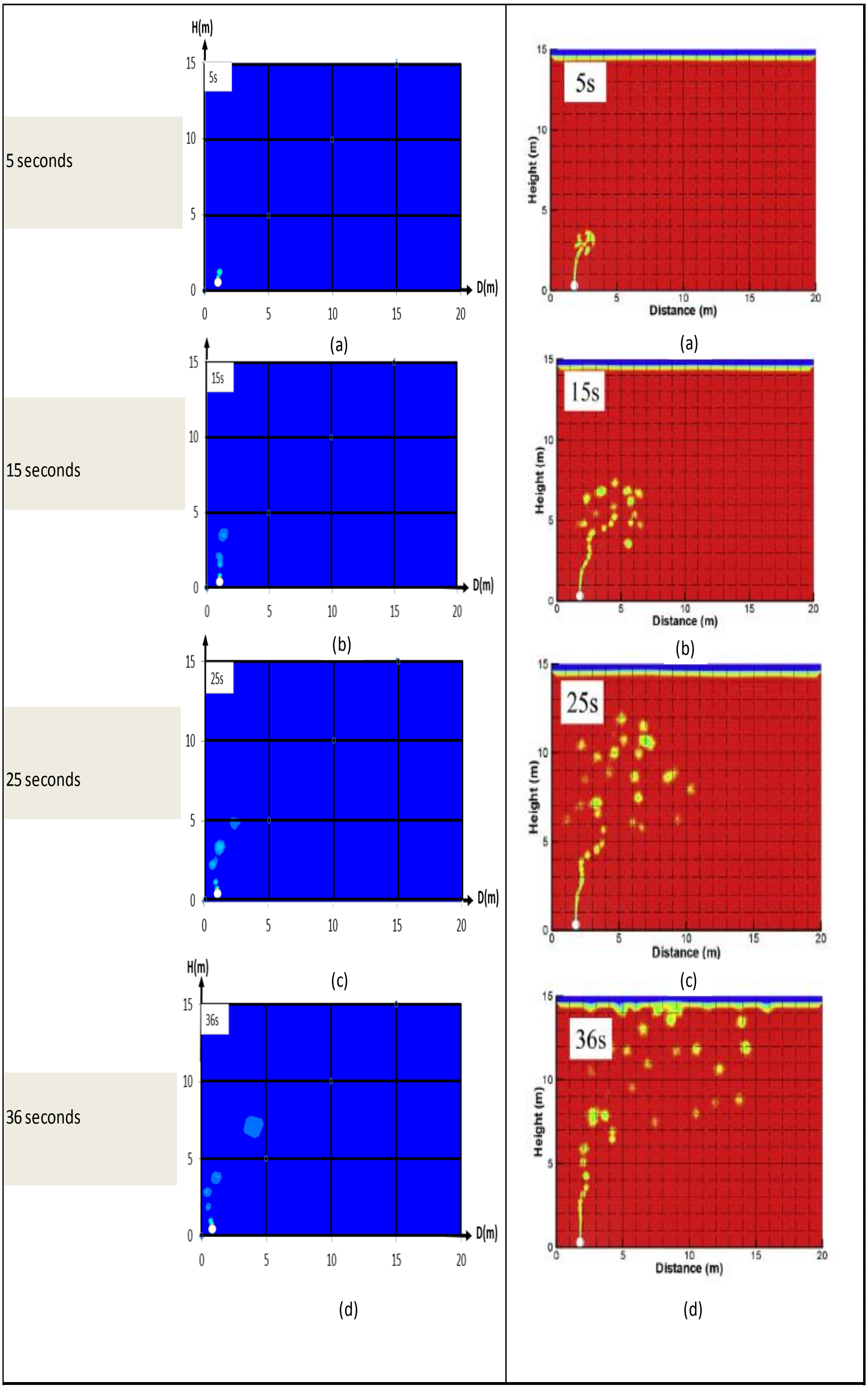


Figure 4-7Comparison of water velocity; 0.04 m/s for both from results and Journal (Zhu *et al*., 2013) at specific time period(s)

DISCUSSIONS

From the **Figure 4-7** above, a comparison study was done between water velocity of **0.04m/s** for 5, 15, 25, 36 seconds respectively. The study was based on a 15m height by 20m domain scale reading. The study was done to compare results simulated from previous journal (Zhu *et al*., 2013) with current research.

At **5 seconds**, research 2014, the oil droplets were observed with small exposure from the surface of the pipeline. The exposure was in the form of light blue cloud display. However, the previous research observed a shoot of oil droplet up to the first quadrant but at a continuous flow and in a red domain appearance.
We can deduce that the display of the previous researcher was without a global range parameter and with a higher turbulence.

At **15 seconds**, research 2014, the oil droplets were observed to have rose a height of almost 4metres above seabed but with the least migration. However, the oil smear in previous research was much disintegrated and not following a paved migration.
From the comparison above, we can deduce that the cloud appearance of oil droplets were more disintegrated in the previous researcher due to growth of the mesh used in the Gambit 2.4.6. The growth size used could have varied which caused disintegration in this display.

At **25 seconds**, research 2014, the oil droplets were observed to have rose a height of almost 5 metres above seabed but with migration to the right of the quadrant due to its velocity inlet. However, the oil smear in previous research was much disintegrated and was almost reaching a 13 metre height from seabed.
Framework appearance above deduces that the cloud appearance of oil droplets were more disintegrated in the previous researcher due to growth of the mesh used in the Gambit 2.4.6. The growth size used could have varied which caused disintegration in this display.

At **36 seconds**, research 2014, the oil droplets were observed to have rose a height of almost 7 metres above seabed but with migration to the right of the quadrant due to its velocity inlet. However, the oil smear in previous research was much disintegrated and reached free surface earlier than in current research.

According to ***Li, W., Y., Pang, Y., Lin, J., & Liang, X. (2013)***, research discussed on varying current velocities altered to observe the oil migrant to free surface. Upon fixed operating pressure, the sea current velocity dominates obviously and oil particles move with sea current after spilled immediately. Hence, the current velocity could not be too high as it will cause the oil to attach to the sea floor and increases problem of oil control and recovery.

Another research from Shehadeh (2012) also supports that the turbulence intensity has a great effect on monitoring of pipeline in CFD, for instance leakage using novel technique such as acoustic emission [15] and ultrasonic techniques [16].

Finally, we can deduce that the turbulence factor of the previous researcher was more intense in Fluent Approach compared to current research. The current research was just using the parameter on k-epsilon of 2 equations.

4.3 Statistical analysis

Each framework analysed above is derived from the Hardcopy Frame under animation tool of Fluent 6.3.26 with respective time slots. The analyses between both figures 4-1 and 4-2 were proven correct based on its time of framework obtained.

Table 4-1: Time taken(s) for oil to reach free surface with varying water velocities (m/s)

Case	Water velocities(m/s)	The oil density(kg/m3)	Oil leaking rate(m/s)	Diameter of leak(m)	Time taken to reach free surface(s)
1	0.02	780	0.1	0.05	-
2	0.04	780	0.1	0.05	92
3	0.08	780	0.1	0.05	87

4.4 Summary

Table above was tabulated based on the framework analysis obtained from the simulation process in Figure 2 and 3 respectively. Based on the time step iteration graph, it was observed that the fluctuation settled at 8500 iterations for (vs=0.08m/s) compared to that of v_w=0.04m/s which settled at 11500 iterations. Hence, it showed that for a slower speed of water, the fluctuation time is longer. For water velocity (v_w=0.08m/s), the time taken for kerosene droplets to reach free surface was 87s. On the other hand, when v_w=0.04m/s; time taken to reach free surface was at 92s. Hence, the larger the water velocity, the more obvious the trajectory of oil flow skewed to the downstream. The reason is that high-speed water exerts more shear stress on oil droplets and transfers more kinetic energy to oil droplets (kerosene liquid).

5.0 CONCLUSION & RECCOMENDATION

5.1 Conclusion

An approach, for predicting the process of oil spill under the action of current with shear velocity distribution, by finite volume simulation combined with VOF method is applicable under the Fluent 6.3.26.The dimensionless longest horizontal distance increases with the increase in water velocity. This will directly shorten the time taken for kerosene liquid to reach free surface. The method of study was by implementing computational fluid dynamics using the Gambit 2.4.6 and the Fluent Software. In this way, the method of approach will be environmental friendly and also capable to cost-effective globally. Nevertheless, this will reduce human error in detecting leakage in pipelines especially when the condition of inconsistent water velocity occurs. In recommendation, Fluent Software can be enhanced further with consideration towards the drag coefficient (C_d) and virtual mass of oil droplets.

5.2 Future work

The research carried in this simulation (CFD) is currently being expanded by Miss Siti Noraishah Ismail. Focus for this new work will be on finite volume method (FVM) on detecting the leakage of oil in submarine pipelines.

6.0 REFERENCES

1. Abascal, A.J., S. Castanedo and R. Medina, 2009. Application of HF radar currents to oil spill modeling. Mar. Pollut. Bull., 58: 238-248.

2. Alexander, C. (2005). MODELING LEAKAGE IN A FUEL TRANSFER PIPELINE USING COMPUTATIONAL FLUID DYNAMICS TECHNIQUES, (July 2001), 1–11.
3. Arpino F, Massarotti N. Numerical simulation of mass and energy transport phenomena in solid oxide fuel cells. Energy 2009;34:2033e41.
4. Biksey TM, Schultz AC, Bernhardt AM, Marion B, Peterson C. Ecological and human health risk assessment. Water Environ Res 2010;83:2067e94.
5. Dasanayaka, L.K. and P.D. Yapa, 2009. Role of plume dynamics phase in a deepwater oil and gas release model. J. Hydro-Environ. Res., 2: 243-253
6. E. Stenmark, "On Multiphase Flow Models in ANSYS CFD Software," 2013.

7. H. Zhu, Lin, P., & Pan, Q. (2014). A CFD (computational fluid dynamic) simulation for oil leakage from damaged submarine pipeline. *Energy*, *64*, 887–899. doi:10.1016/j.energy.2013.10.037
8. Jalilinasrabady S, Palsson H, Saevarsdottir G, Itoi R, Valdimarsson P. Experi-mental and CFD simulation of heat efficiency improvement in geothermal spas. Energy 2013;56:124e34.
9. J. S. Mandke Southwest Research Institute San Antonio,1990
10. Li, Z. and P.D. Yapa, 2002. Modeling gas dissolution in deepwater oil/gas spills. J. Mar. Syst., 31: 299-309.
11. LiW,PangYJ, Lin JG, Liang X. Computationalmodelingofsubmarineoil spillwith current and wave by FLUENT. Res J Appl Sci Eng Technol 2013;21:5077e82
12. Øistein, J., H. Rye and C. Cooper, 2003. Deep spill-field study of a simulated oil and gas blowout in deep water. Spill Sci. Technol. Bull., 8(5): 433-443.
13. R. Pitt, "M7 : Petroleum Spills Movement of Oil in 1999 Oil Production Between 1960 and 1998," 2003.
14. Shehadeh, M., Sharara, A., &Khamis, M. (2012). A Study of Pipeline Leakage pattern Using CFD, *3*(3), 98–101

15. Shifeng Liu, Luming Li, Jian Cui, Tie Li, "*Acoustic Emission Detection of Underground Pipeline Leakage*", 15th World Conference on Non-Destructive Testing (WCNDT), Roma, Italy, 2000.

16. Shuh-Haw Sheen, Hual-TeChien, Apostolos C. Raptis.“*Ultrasonic techniques for detecting helium leaks*”, Sensors and Actuators B 71, pp.197-202, 2000.

17. Tangley, Laura (30 April 2010). "Bird Habitats Threatened by Oil Spill".*National Wildlife* (National Wildlife Federation). Retrieved 3 May 2010.

18. Terashima HS, Koshi M. Approach for simulating gaseliquid-like flows under supercritical pressures using a high-order central differencing scheme.

J Comput Phys 2012;231:6907e23.

19. Thome, J.R. (2004): Engineering Data Book III, Wolverine Tube Inc., Decatur, Alabama, USA

20. Wang CY, Chen B, Zhang BY, He SJ, Zhao MM. Fingerprint and weathering characteristics of crude oils after Dalian oil spill, China. Mar Pollut Bull 2013;71:64e8.

21. W. Li, Y. Pang, J. Lin, and X. Liang, “Computational Modeling of Submarine Oil Spill with Current and Wave by FLUENT 1,” vol. 5, no. 21, pp. 5077–5082, 2013.noa

22. Xie, H., P.D. Yapa and K. Nakata, 2007. Modeling emulsification after an oil spill in the sea. Mar. Pollut. Bull., 68: 489-506.

23. Xu Q, Li XF, Wei YL, Tang ZY, Cheng YC, Pichel WG. Satellite observations and
modeling of oil spill trajectories in the Bohai Sea. Mar Pollut Bull 2013;71: 107e16.

24. Yadav AS, Bhagoria JL. A CFD (computational fluid dynamics) based heat transfer and fluid flow analysis of a solar air heater provided with circular transverse wire rib roughness on the absorber plate. Energy 2013;55: 1127e42.

25. Zhu, S. and S. Dmitry, 2002. A numerical model for the confinement of oil spill with floating booms. Spill Sci. Technol. Bull., 7(5): 249-255.