A CFD SIMULATION STUDY ON THE EFFECT OF OIL LEAKING RATE FROM DAMAGED SUBMARINE PIPELINE

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Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
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MAY 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).

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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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Dedication

To my supervisor, Miss Siti Noraishah Ismail for her unlimited support in making this research project successful and to all my family members especially my mom and dad, and my fellow friends and my team mates, million thank you for all your supports, encouragement and guidance. You are my inspiration in completing this project.

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ABSTRACT

This paper presents the simulation studies on the effect of oil leaking rate for oil leakage from damaged submarine pipelines. Oil spill are very serious issue that need to be taken care when construct and install the submarine pipeline. Due to the demand, transporting via pipeline with safety precaution is the best way to fulfil the demand. The objective of the present paper is to study the oil flows from damaged submarine pipelines with different oil leaking rate. CFD (computational fluid dynamic) simulations with GAMBIT and FLUENT software are carried out to investigate the process of oil spill from submarine pipeline to free surface. 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 damage submarine pipeline with the outside diameter (OD) of 0.6 m. The size of leakage hole (d) is a variable ranging from 0.01 m to 0.05 m with increment of 0.01 m, in order to examine the effect of leak size. GAMBIT 2.4.6 mesh-generator is employed to perform all geometry generation and meshing. From the study, the dimensionless longest horizontal distances the droplets migrate when they reach the sea surface were analysed and the fitting formulas are obtained and conduct rapid response the maximum horizontal migration distance of oil at certain time is predicted, and a forecasting model is proposed. These calculated results will provide useful guidance to place the oil containment boom. This helps to detect the leakage more accurate and precise while reduces the cost of handling.

Key words: Oil leaking rate, Oil spill, CFD (Computational fluid dynamic), leak size, GAMBIT 2.4.6 and FLUENT 6.3.26, Mesh

ABSTRAK

Kertas kerja ini membentangkan kajian simulasi kesan kadar minyak bocor untuk kebocoran minyak dari saluran paip yang rosak di dasar laut. Tumpahan minyak adalah isu yang amat serius yang perlu diambil berat apabila membina dan memasang paip di dasar laut. Oleh kerana permintaan minyak yang tinggi, penghantaran minyak melalui saluran paip dengan langkah-langkah keselamatan adalah satu cara yang terbaik bagi memenuhi permintaan pelanggan. Objektif kertas kerja ini adalah untuk mengkaji aliran minyak dari saluran paip dasar laut yang rosak dengan kadar minyak bocor yang berbeza-beza. CFD (*computational fluid dynamic*) simulasi dengan perisian *GAMBIT* dan *FLUENT* dijalankan bagi penyiasatan proses tumpahan minyak dari paip di dasar laut ke permukaan laut yang terbuka. Domain pengiraan keseluruhan ialah sebuah segiempat tepat dengan panjang 20 m dan ketinggian 15 m. Panjang pengiraan domain adalah besar berbanding jarak terpanjang pergerakan titisan minyak yg mendatar apabila tiba di permukaan laut yang terbuka. Air memenuhi kawasan bawah dengan ketinggian 14.5 m, sementara udara akan memenuhi kawasan atas. Saluran paip yang rosak mempunyai panjang diameter luar 0.6 m. Saiz lubang yang bocor adalah pembolehubah yang terdiri daripada 0.01 m kepada 0.05 m dengan pertambahan sebanyak 0.01 m, bagi mengkaji kesan saiz kebocoran. *GAMBIT 2.3* penjana mesh digunakan bagi melaksanakan segala generasi geometri dan *meshing.* Dari kajian tersebut, jarak mendatar terpanjang bagi pergerakan titisan apabila sampai ke permukaan laut dianalisis dan formula sesuai diperolehi dan tindak balas pantas jarak pergerakan mendatar minyak yang maksimum pada masa tertentu yang diramalkan dijalankan. Keputusan yang dikira akan memberikan panduan yang berguna bagi meletakkkan ledakan yang membendung minyak. Ini dapat membantu bagi mengesan kebocoran minyak dengan tepat dan boleh mengurangkan kos pengendalian.

Kata kunci: Kadar minyak bocor, CFD (*computational fluid dynamic),* saiz kebocoran, GAMBIT dan FLUENT, *Mesh*

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LIST OF ABBREVIATIONS

A_0	constant of eq.(3.6)
A_s	constant of eq.(3.6)
a	interfacial area per unit volume
$a(L_i)$	breakage kernel
$b(k, L_i)$	daughter bubble distribution function
B	nucleation kernel
C	impeller off-bottom clearance
C_o^*	oxygen solubility in water
C_D	drag coefficient
v_g	superficial gas velocity
VVM	volume per unit volume
w	weight for QMOM
W	impeller blade width
Y_v	turbulent destruction term for Spalart-Almaras model

Greek

v_l	kinematic viscosity
θ_{ie}	collision rate of bubbles with turbulent eddies
κ_i	break-up efficiency
$\Lambda(L_i, L_j)$	bubble collision eficiency

Subscripts

b	bubble
g	gas
l	liquid
eff	effective

LIST OF ABBREVIATIONS

CARPT	Computer-automated radioactive particle tracking
CFD	Computational fluid dynamics
CSP	Capillary suction probe
CT	Computer tomography
DAE	Differential algebraic equation
DES	Detached eddy simulation
DI	Digital imaging
EIT	Electric impedance tomography
ERT	Electric resistance tomography
FFT	Fast Fourier transform
GRT	Gamma ray tomography
IZ	Ishii-Zuber drag model
LDA	Laser doppler anemometry
LES	Large eddy simulation
LIF	Laser image fluorescence
PBE	Population balance equation
PBM	Population balance modelling
PDA	Phase doppler anemometer
PIV	Particle image velocimetry
PLIF	Planar laser induced fluorescence
MOC	Method of classes
MOCh	Method of characteristic
MOM	Method of moment
MRF	Multiple reference frame
PD	Product difference
QMOM	Quadrature method of moment
RDT	Rushron turbine
RANS	Reynolds averaged Navier-Stokes
RNG	Renormalised k-□
RSM	Reynolds stress model
SA	Spalart-Allmaras model
SGS	sub-grid scale
SMM	Sliding mesh method
SN	Schiller-Naumann drag model
SST	Shear stress transport model

1 INTRODUCTION

1.1 Motivation and statement of problem

Nowadays, in the globalisation 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).

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).

When this incident occurs, a quick and adequate response must be required in order to minimize the consequences especially to marine environmental. Therefore the accurate information related to the rise process of oil droplets and the dispersal path of oil spill is required. Through the exact information the oil containment boom can be set up immediately to reduce the damage of oil spills. A lot of researched and studied had been made to focus on the oil spill. At present, the modelling for forecasting oil spill behaviour and incidence is usually based on sea surface (Zhu and Dmitry, 2002; Xie et al., 2007) or offshore zones (Guo and Wang, 2009; Guo et al., 2009).

However, the numerical modelling for submarine oil spill is relatively lacking. 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.

However, for oil leakage from damaged submarine pipeline, the trajectories of oil spill that flow along the depth direction are important issue need to be considered. An effective attempt has been made to observe the oil spill under the action of current and wave (Li W,2013) .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. According to Yadav As, 2013, the information about hydrodynamics of oil flow, which are not easily obtained through the physical experiments can be obtained using numerical simulation. Therefore, in this researched, CFD (computational fluid dynamic) simulation with FLUENT software had been used to investigate the process of oil spill from submarine pipeline to free surface.

In this CFD simulation, the effect of oil leakage size is examined by using a several series of numerical simulation. 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 analysed and the fitting formulas are obtained. Using the formulas we can obtain when and where to see oil reaching the sea surface, and conduct rapid response. Finally, the maximum horizontal migration distance of oil at certain time is predicted, and a forecasting model is proposed. The results provide useful guidance to place the oil containment boom.

Summary

The topic was scoped from addressing the problem in the petroleum industry, way by indentifying the problem of leakage in submarine pipelines.Then, an alternative solution using the Computational Fluid Dynamic (CFD) simulations with FLUENT software to detect leakage process of oil spill from submarine pipeline to free surface was implemented. Then, an alternative solutionusing the computational fluid dynamics(CFD) simulation had been introduced . 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. Not forgetting that bio-oil are less toxic and environmental friendy compared to OBM.

1.2 Objectives

The main objective of this research is to study the oil flow from damaged submarine pipelines with the different oil leaking rate which are 1 m/s, 3 m/s and 5 m/s. In this research, a CFD (Computational Fluid Dynamic) simulation with FLUENT software are carried out in order to investigate the migration process and the trajectory of oil spill from submarine pipeline to free surface of the sea. Lastly, to compare the standard case of oil leakage dispersion with the effect of oil leaking rate for oil leakage dispersion from damaged submission pipeline.

1.3 Scope of this research

The scopes of this study are to mainly study the effects of oil leaking rate on the oil spill process. The method of the study is by implementing computational fluid dynamics (CFD) using the GAMBIT 2.4.6 and the FLUENT Software. 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 that the longest horizontal distance the oil droplets migrate when they reach the sea free 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. The size of the leakage hole (d) is a variable ranging from 0.01 m to 0.05 m with increment of 0.01 m, in order to examine the effect of leak size. GAMBIT 2.3 mesh-generator is employed to perform all geometry generation and meshing. The scope also widens to compare the horizontal distance the droplets migrate in the given period of time. Finally, the leakage can be detected more accurately and cost-effectively. The 2-D simulations will be used to show the oil leakage dispersion varies based on the oil leaking rate. Secondly, the study was conducted by using Computational Fluid Dynamic, CFD. The submission pipeline is assumed to be underground. The study was performed based on different oil leaking rate which are V_o = 1m/s, 3m/s, 5m/s, 7m/s.

1.4 Hypothesis

Computational fluid dynamic (CFD) using Gambit Mesh and Fluent Software is a much reliable, accurate and cost effective measure method in detecting leakage in submarine pipelines compared to manual maintenance method. The time taken to reach the sea surface for small leaking rate is longer compared to higher leaking rate.

1.5 Main contribution of this work

i. Is it feasible method to detect any leakage in submarine pipeline when oil pipeline leak. Thus, it is possible to reduce the oil leakage in pipeline and early stage precaution of oil transportation through pipeline. Pipeline is the best way of oil transportation and has been used as an alternative and more economical method.

ii. Higher rate of dispersion of oil leakage could result in damage our submarine life. This incident will totally effect the environment and also people. Hence, using this software many damage and pollution can be avoided.

iii. Malaysia can commercialize oil production in large scale and transport it via pipeline if and only if oil leakage is less dangerous to the people and the environment.

1.6 Organisation of this 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 computational domain and Mesh generator were simulated. Results were further generated for different cases comparing to its standard case.

Chapter 4 gives a clearer understanding of the effect of oil density on the length of time for oil to reach the sea-surface and the distance for oil moving downstream, simulations are conducted by changing the oil density while leaving other parameters same.. 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.

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

2.1 Overview of Oil Spill Incident

An oil spill is the release of a liquid petroleum hydrocarbon into the environment, especially marine areas, due to human activity, and is a form of pollution. The term is usually applied to marine oil spills, where oil is released into the ocean or coastal waters, but spills may also occur on land. Oil spills may be due to releases of crude oil from tankers, offshore platforms, drilling rigs and submarine pipeline (Marybeth, 2004). The oil spill incident can caused numerous problems within the ocean ecosystem and has continued to cause problems even after some time has passed. Issues such as genetic damage, liver disease, and cancer can occur within the wildlife among other aquatic life defects. When the aquatic environment became toxic this affected humans too. As omnivorous consumers, fish are important to humans because of the important nutritious resources they provide. If these species become dangerous to eat, human health can be affected and may lead to abnormal disease or sickness.

2.2 Oil Leakage

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 10 biggest oil spills in history which catch a global attention.

2.2.1 Gulf War, 1991

The location was in Kuwait. The oil spill is about 240 to 336 million gallons. The incident happened as Iraqi forces retreated from Kuwait during the first Gulf War, they opened the valves of oil wells and pipelines in a bid to slow the onslaught of American troops. The result was the largest oil spill history has seen. Some 240 million gallons of crude oil flowed into the Persian Gulf. The resulting oil slick spanned an area just larger than the size of the island of Hawaii. After the event, the clean-up process was taken by coalition forces which managed to seal off some of the open pipelines using smart bombs, but most recovery efforts had to wait until after the war. At that point 25 miles of booms (orange rope like products that contain the oil that is floating on top of the water) and 21 skimmers (machines that separate oil from water) were deployed in the gulf, mostly to protect the water intakes of desalinization, industry and power plants. Together with vacuum trucks, about 58.8 million gallons of oil was recovered from the gulf. The largest oil spill the world has seen exacted little permanent damage on coral ecosystems and local fisheries, according to a report by the Intergovernmental Oceanographic Commission at Unesco. The study concluded that about half the oil evaporated, one-eighth of it was recovered and another quarter washed ashore, mostly in Saudi Arabia.

2.2.2 Ixtoc 1 Oil Well, 1979

The incident occurred at the Bay of Campeche, Mexico and involved 140 million gallons of oil spill. In June 1979, an oil well in the Bay of Campeche collapsed after a pressure build up sparked an accidental explosion. Over the next 10 months about 140 million gallons of crude spouted into the Gulf of Mexico from the damaged oil well. In order to slow down the flow of oil from the damaged well, mud and later steel, iron and lead balls were dropped down its shaft. According to PEMEX (Mexican Petroleum), half the oil burned when it reached the surface and a third evaporated. PEMEX also hired a company to spray dispersants over 1100 square miles of oil slick. Dispersants effectively act like dish soap, breaking up oil so that more of it can mix into the water. That way, they can reduce the effect of the oil slick on shorelines. On the Texas side of the gulf, skimmers and boomers were placed in the water to protect the bays and lagoons of the Barrier Islands.

2.2.3 Atlantic Empress, 1979

One stormy evening in July 1979 at Trinidad and Tobago, West Indies, two full super tankers collided off the coast of Tobago in the Caribbean Sea, precipitating the largest ship-sourced oil spill in history which is 88.3 million gallons of oil spill. Crippled by the accident, both vessels began to leak their crude and caught fire. The fire on one of the vessels, the *Aegean Captain,* was soon controlled, and the damaged vessel was towed to Curacao, where its remaining cargo was recovered. The other tanker, the *Atlantic Empress,* stubbornly ablaze, was towed farther out to sea until it exploded 300 nautical miles offshore. All told, 26 crews were killed in the disaster and nearly 90 million gallons of crude was dumped into the sea. The response to the incident included fire fighting efforts and the use of dispersants to treat the oil that spilled over the course of the accident and then while the *Atlantic Empress* was towed away. Luckily, only minor shore pollution was reported on nearby islands.

2.2.4 Fergana Valley, 1992

The event location was in Uzbekistan. Nearly 88 million gallons of oil spilled from an oil well in Fergana Valley, one of Uzbekistans's most active energy- and oil-refining areas. While the spill didn't get much press at the time, it is the largest inland spill ever reported. The ground absorbed this spill, leaving nothing for cleaning crews to tackle.

2.2.5 Nowruz Oil Field, 1983

Smack in the middle of the Iran-Iraq War, an oil tanker crashed into the Nowruz Field Platform in the Persian Gulf and knocked it askew, damaging the well underneath. The oil well then leaked about 1500 barrels a day, but because it was in the centre of a war zone, seven months went by which is 80 million gallons was spilled before it was fixed. Norpol, a Norwegian company, used booms and skimmers to stem the spread of oil.

2.2.6 ABT Summer, 1991

At Off the coast of Angola, while en route to Rotterdam, the fully loaded tanker *ABT Summer* experienced an explosion on board and caught fire while it was 900 miles off the coast of Angola, leaking its payload into the ocean. Surrounded by a growing oil slick that spanned 80 square miles, the tanker burned for three days and spill 80 million gallons before sinking. While no one can say how much of the oil sank or burned off, most of the oil is thought to have been broken up by high seas at little environmental cost, thanks to the incident's offshore location.

2.2.7 Castillo de Bellver, 1983

Another torcher, the *Castillo de Bellver* caught fire about 70 miles northwest of Capetown, South Africa, on August 6, 1983. The blazing tanker was abandoned and drifted offshore until it eventually broke in half. The stern capsized and sank into the deep ocean, with some 110,000 ton of oil remaining in its tanks. The bow section was towed away and sunk in a controlled explosion. The vessel was carrying nearly 79 million gallons of crude at the time of the accident. Clean-up was minimal. There was some dispersant spraying, but by and large the environmental consequences were small. About 1500 gannets that happened to be gathered on a nearby island, gearing up for their breeding season, were oiled, but the impact on local fish stocks was minimal.

2.2.8 Amoco Cadiz, 1978

The tanker *Amoco Cadiz* ran aground off the coast of Brittany after its steering failed in a severe storm. Its entire cargo of 246,000 tons of light crude oil was dumped into the roiling waters of the English Channel, with the grim consequence of killing off more marine life than any other oil spill to date at the time. Clean-up efforts were foiled by strong winds and heavy seas and less than 3300 tons of dispersants were used. Within a month of the spill, 200 miles of the French shoreline was contaminated with oil. Vacuum trucks and agricultural vacuum units were used to suck up some of the oil, although a lot of it was simply removed by hand.

2.2.9 Odyssey Oil Spill, 1988

In November 1988 the Liberian tanker *Odyssey,* virtually full to the brim with North Sea 43 million gallons of crude oil, broke in two and sunk in the North Atlantic 700 miles off the coast of Nova Scotia. It also caught fire as it sunk. Because the incident took place so far from the coastline, the oil was expected to dissipate naturally, ergo no clean up at all.

2.2.10 M/T Haven Tanker, 1991

An apparently shoddily maintained tanker exploded and later sunk off the coast of Italy. The accident killed six people. Immediately after the incident, an effort by the Italians to tow the *Haven* to shore failed, and the 820-foot-long (250 meter) vessel sank off the coast of Genoa. Today it is believed to be the largest shipwreck in the world and is a popular tourist destination for divers. Fortunately, after the incident Italian authorities scrambled to fight the fire and control the spread of the spillage using six miles of inflatable barriers that were submerged below the water surface around the vessel. The rest of the surface oil was sucked up using vacuums.

2.3 *Factor of Oil Spill from Submarine Pipeline*

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

Table 2-1: Factors that may cause the Oil Spill from Submarine Pipeline (Wesselling et al., 2001).

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. Stamukhiis 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)

2.4 Effect of Oil Spill from Submarine Pipeline

A serious environmental issue can be a rise from this oil spill incidents. It is very unlikely to occur, however if this incident happen, it would be likely to have serious consequences such as the incident in Gulf of Mexico. This consequences can be serious depends on many factors including the size of leak of oil spill, its location, the leak rate, and the weather. All this effects must be considered in the submarine pipeline spill consequence analysis. Table 2.2 below show the several effects of oil spill from damaged submarine pipeline (Jusoh, 1999).

Table 2-2: The effect of oil spill from damaged submarine pipeline (Wesselling et al., 2001).

No	Effect of Oil Spill
1.	The depth of submarine pipeline as referred to it location on the seabed will affect the rate at which the oil reaches the surface. The oil will become oil in water emulsion that will increase the persistence of the oil slick.
2.	An open sea activities such as fishing activities will be prevent because the clean-up operations are underway. Besides that, the equipment would be fouled and fishing would have to be temporarily suspended while oil slicks persist. The impact on fish stocks will normally be restricted to eggs and larvae.
3.	In the event of oil spill near to the shoreline the tourism, the recreational activities will be directly affected. Oil slicks would reach the beach and prevent activities such as swimming, sailing, diving, etc. In short oil pollution would disrupt water sport and cause acrimony among both tourists and local

	populace, with associated loss of tourist income.
4	When an oil slick from a large oil spill reaches the beach, the oil coats and clings to every rock and grain of sand. If the oil washes into coastal marshes, mangrove forests or other wetlands, fibrous plants and grasses absorb the oil, which can damage the plants and make the whole area unsuitable as wildlife habitat.
5.	The major effect of this oil spill is toward marine life. The oil sometimes clogs the blow holes of whales and dolphins, making it impossible for the animals to breathe properly and disrupting their ability to communicate. Besides that, the shrimp and oyster fisheries along the Louisiana coast were among the first casualties of the 2010 BP Deep water Horizon offshore oil spill.

As the previous research, there several methods used to identify the possible oil spill which present on Synthetic Aperture Radar (SAR) satellite images based on the artificial intelligence fuzzy logic which has been developed. The oil spills are recognized by expert as dark patterns of characteristic shape, in particular context. The system analyses the satellite images and assigns the probability of a dark image shape to be an oil spill. The case study area was the Aegean Sea in Greece. The complete algorithmic procedure was coded in MS Visual C++ 6.0 in a stand-alone dynamic link library (dll) to be linked with any sort of application under any variant of MS Windows operating system. (Keramitsoglou *et al., 2006)*

Table 2-3: The name of some satellites carrying SAR instruments. (Camilla & Anne, 2005)

Satellite (sensor)	Operative	Owner	Characteristics
SEASAT	1978 – off same year	NASA	L-band, HH-pol
ALMAZ-1	1991 - 1992	Russian Space Agency	S-band, HH-pol
ERS-1	1991 - 1996	ESA	C-band, VV-pol

ERS-2	1995 - operating	ESA	C-band, VV-pol
RADARSAT-1	1995 - operating	CSA	C-band, HH-pol
ENVISAT (ASAR)	2002 - operating	ESA	VV, alt. pol., and crosspol, modes

C-band 4-8 GHz, λ 3.75-7.5 cm, L-band 1-2 GHz, λ 15-30 cm and S-band 2-4 GHz, λ 7.5-15 cm.

Another research can be highlighted is machine learning for the detection of oil spills in satellite radar image. During a project examining the use of machine learning techniques for oil spill detection, they encountered several essential questions that they believe deserve the attention of the research of the research community. They use their particular case study to illustrate such issues as problem formulation, selection of evaluation measures, and data preparation. They relate these issues to properties of the oil spill application, such as its imbalanced class distribution, that are shown to be common to many applications. Their solutions to these issues are implemented in the Canadian Environmental Hazards Detection System (CEHDS), which is about to undergo field testing. (Robert, Miroslay, & Stan, 1998)

The third previous research is a case study for accidents with oil spill in the sea. The selection of the best combat response to oil spill in the sea when several alternatives have to be evaluated with different weight for each criterion consist of a multi-criteria decision making (MCDM) problem. In this work, firstly the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is described. Secondly, its expansion known as fuzzy TOPSIS to handle uncertain data is presented. Next, based on fuzzy TOPSIS, they propose a fuzzy TOPSIS for group decision making, which is applied to evaluate the ratings of response alternatives to a simulated oil spill. The case study was carried out for one of the Largest Brazilian oil reservoirs. The results show the feasibility of the fuzzy TOPSIS framework to find out the combat response in cas of accidents with oil spill in the sea. (Renato & Vinicius, 2011)

2.5 *Overview of CFD (Computational Fluid Dynamic)*

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)

2.5.1 Experiments versus Simulations

Table 2-4: 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

2.5.2 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)

2.5.3 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. *(Thom., 2004)*

2.5.4 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 inter-penetrating. The VOF method uses a phase indicator function, sometimes also called a color 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. Different techniques have been proposed for this. The equations solved in the VOF methods are shown below (Stenmark et al., 2013).

2.6 Computational Domain and Mesh

The average depth of water (14.5 m) in Kenli oilfield located in Bohai Sea is taken as the model depth in order to facilitate the comparison. 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, the most common diameter of submarine pipe used in Bohai oilfield, is located in the sea bed, 1.8 m (3D) downstream of the inlet. There is a leakage hole on the top of pipe, opening upwards.

The size of the leakage hole (d) is a variable ranging from 0.01 m to 0.05 m with increment of 0.01 m, in order to examine the effect of leak size (Zhu *et al*., 2014).

GAMBIT 2.3 mesh-generator is employed to perform all geometry generation and meshing. The water occupying region is discretized with triangular cells, while the upper region is discretized with quadrilateral cells. Progressive mesh is used to capture the near-leak flow properties.

Table 2-5: Simulation cases , in which variables of oil density, oil leaking rate, diameter of leak, and maximum water velocity are varied (Zhu *et al*., 2014).

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

2.7 Effect of Variables on the Oil Spill Process

2.7.1 Effect of Oil Leak Size

Fig. 2.6.3 shows the process of oil spill from submarine pipeline to free surface at different oil leakage sizes. 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 percents. 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 mare easier to collision and have greater chance of gathering into large droplets, as shown in Fig. 2.6.3. 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.

2.7.2 Effect of Oil Density

In this section, to study the effect of oil density on the length of time for oil to reach the sea-surface and the distance for oil moving downstream, simulations are conducted by changing the oil density while leaving other parameters same as those in the standard case. Fig. 4.2 illustrates the process of oil spill from submarine pipeline to free surface at three different oil densities. 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 ismainly 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. 2014)*

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.(*Zhu et al. 2014)*

3 MATERIALS AND METHODS

3.1 *Overview*

This paper presents a computational fluid dynamics (CFD) of the gas-liquid flow in a bubble column. Multiphase simulations were performed using an Eulerian-Eulerian two-fluid model besides considering the drag coefficient model suitable for spherical and distorted bubbles. The interfacial force modeling also considered the effect of the void fractions on the drag coefficient. The CFD predictions were compared to the experimental measurement adopted from literature. The CFD predicts the turbulent kinetic energy, gas hold-up and the liquid axial velocity fairly well, although the results seem to suggest that further improvement to both the interfacial force model and two-fluid modeling approaches is necessary. It is clear from the modeling exercise performed in this work that CFD is a promising method for modeling the performance of bubble column. Furthermore, the CFD method is certainly less expensive than the experimental characterization studies.

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:

$$\boldsymbol{F_w}=\frac{\boldsymbol{V_w}}{\boldsymbol{V_c}} \qquad \text{Eq. 1}$$

$$\boldsymbol{F_o}=\frac{\boldsymbol{V_o}}{\boldsymbol{V_c}} \qquad \text{Eq. 2}$$

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 Numerical Method

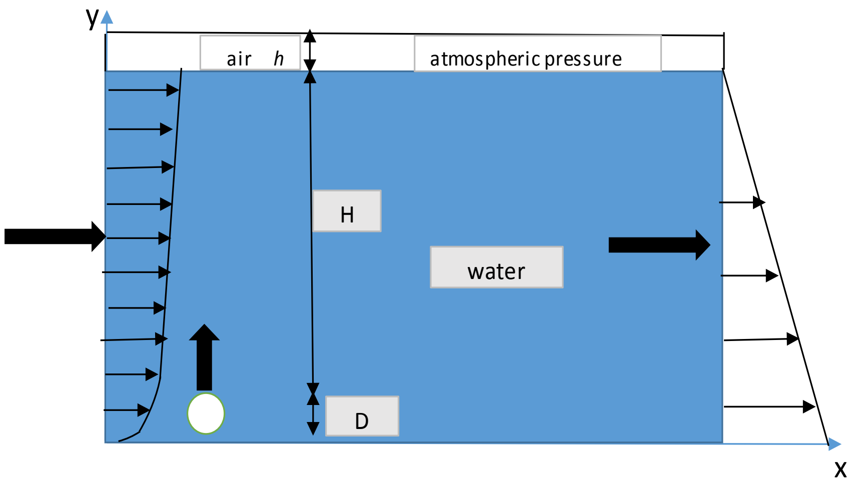
FVM (finite volume method) is employed to discretize above equations. All the simulations are carried out using a commercial software package FLUENT 14.0. In calculations, Patankar's well-known SIMPLE algorithm, applied well in many similar simulation studies is employed to solve the pressure velocity coupling to satisfy the conservation law of mass. In order to ensure the accuracy of calculation, second-order upwind scheme and second-order central-differencing scheme are used for convective terms and diffusion terms, respectively. For convective terms, second-order upwind scheme can save CPU time, while for diffusion terms second-order central-differencing scheme is a good choice. The convergent criteria for all calculations are set as that the residual in the control volume for each equation is smaller than 10^{-4}.

3.2.3 Computational Domain and Mesh

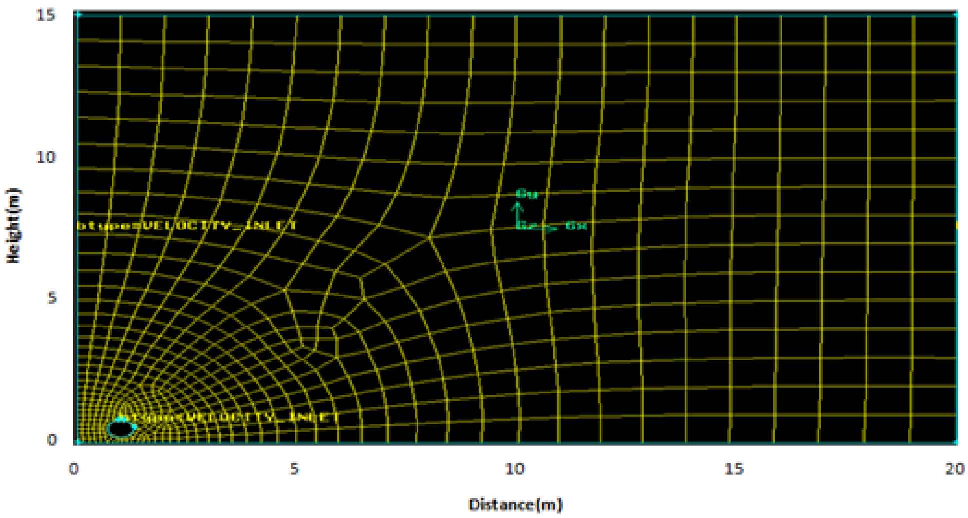
A two-dimensional flow simulation is accurate enough to capture the maximum horizontal migration distance. In addition, three-dimensional simulation needs a higher CPU cost. Due to time limitations, 2D simulation is applied in this work.

Fig. 3.1 shows a sketch of the geometry and numerical grid for computational domain investigated in this study. The whole computational domain is a rectangle with a length of 20 m and 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, There is a leakage hole on the top of pipe, opening upwards. The size of the leakage hole (d) is a variable ranging from 0.01 m to 0.05 m with increment of 0.01 m, in order to examine the effect of leak size.

GAMBIT 2.3 mesh-generator is employed to perform all geometry generation and meshing. As shown in Fig. 3.2.3-1, computational domain is divided into two blocks. The water occupying region is discretized with triangular cells, while the upper region is discretized with quadrilateral cells. 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. At last, the number of grid cells used in calculation is 9011.



(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. / Energy 64 (2014) page 887-899)*

3.2.4 Boundary Conditions

A logarithmic velocity profile is adopted to meet the actual flow near seabed as $v_w = v_{wmax}\left\{1 - \left[1 - \frac{y}{H+D}\right]^2\right\}$,where $v_{\,wmax}$ is the maximum velocity ($v_{\,wmax}$ =0.1 m/s, the most commonly measured maximum flow rate in Bohai Sea surface) presenting at the free surface, H is the height from leakage hole to the free surface, y is the independent variable (0 ≤ y ≤H +D) and origin of coordinates is located in the seabed. This velocity profile is defined for the left inlet of computational domain. In order to find the effect of water velocity on the displacement of oil droplets, the maximum water velocities are taken as 0.04 m/s and 0.07 m/s in comparing cases. For the right outlet, a linear static pressure profile is employed to meet the actual hydrostatic pressure distribution as $p_{out} = \rho g(H + D - y)$.

In Bohai oil field, due to corrosion or flow erosion, perforations usually present in submarine pipelines. Only a few pipes have cracks on them due to mechanical damage. According to a lot of failure marine pipe tests, the perforation holes mainly show circular shape or roughly circular shape. For roughly circular shape, we can use a circular instead of it with an equivalent diameter (the two have the same equal area). By measuring a large number of perforation holes, the pore sizes mainly range from 0.006 m to 0.08 m. For analysing the effect of pore size, five different leak diameters, 0.01 m, 0.02 m, 0.03 m, 0.04 m and 0.05 m, are chosen in simulations.

Oil leaking rate is related to leak size, hydrostatic pressure of water above the pipe, the pressure within the pipe and pressure drop of oil flowing through the leak. Therefore, perforations in different oil pipelines or in different locations at one oil pipeline have the different oil leaking rates. In the Bohai Sea environment, oil leaking rate usually ranges from 0.1 m/s to 10 m/s. In order to facilitate comparative analysis, we have selected five rates ranging from 1 m/s to 5 m/s to conduct simulations. Pressure inlet boundary condition with value of 0 Pa is used for the three edges of air region.

3.2.5 ICEM CFD

ICEM CFD is mesh 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).

3.2.6 Fluent

The Fluent solver is based on the center 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.

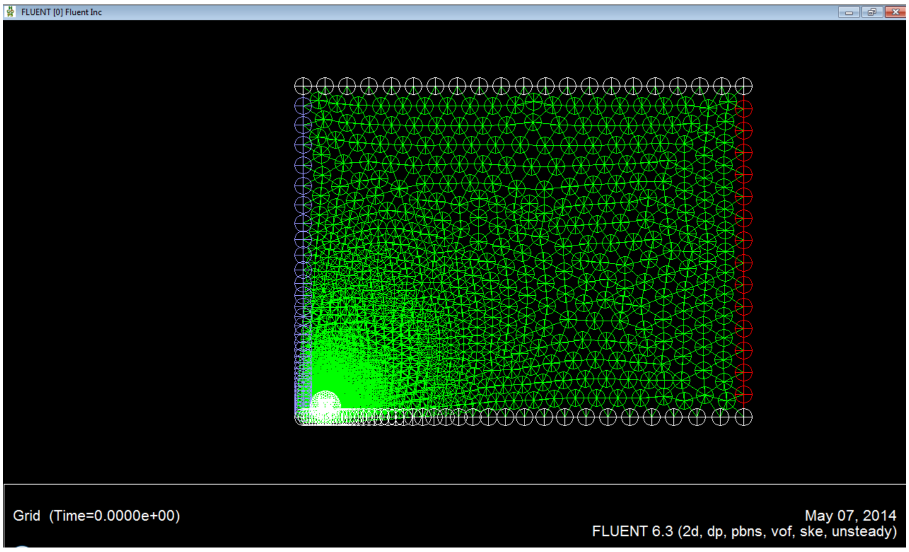


Figure 3-2: The display grid in the Fluent after import mesh file from Gambit.

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 inter-phase transfer there is both a number of drag models available along with other transfer mechanisms such as lift forces, turbulent dispersion etc. 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*)

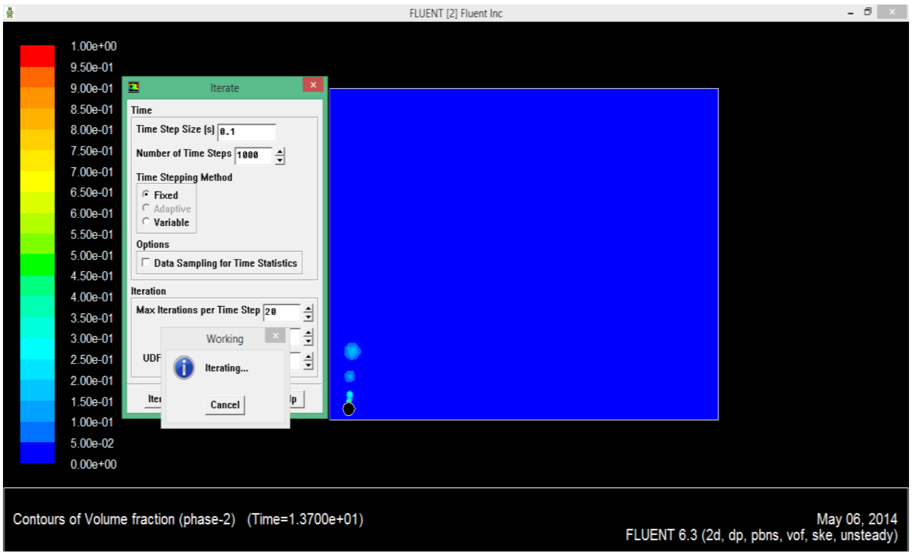


Figure 3-3: Iteration process in the Fluent.

3.3 Effect of Oil Leaking Rate

Oil leaking rate is one of the key factors which impacts the diffusion of oil spill. Figure 3.2 depicts the process of oil spill from submarine pipeline to free surface at different oil leaking rates. 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. From Fig. 2.6.2, we can also see more dispersed oil droplets present in computational domain at high leaking rate. 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.

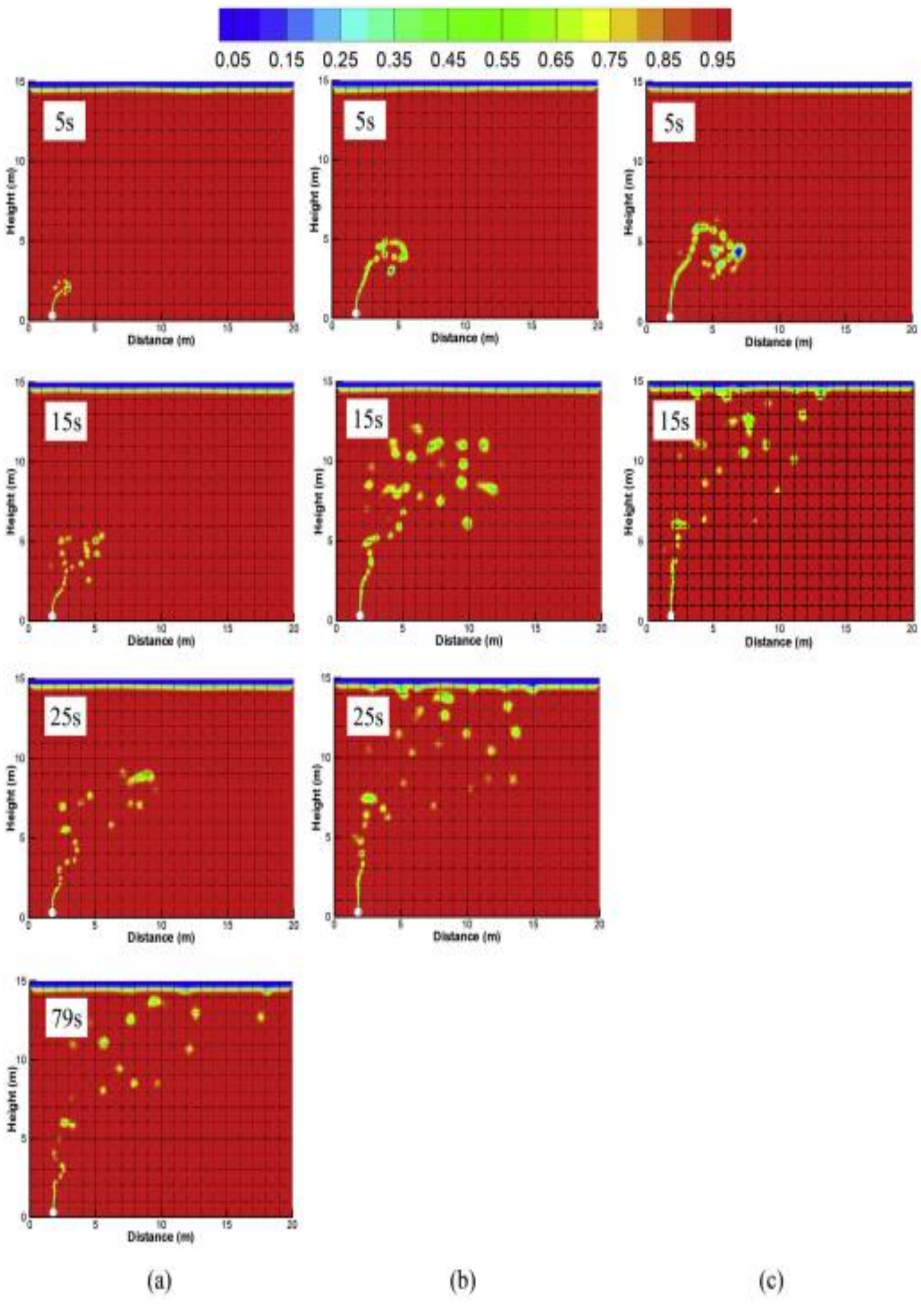


Figure 3-4: The process of oil spill from submarine pipeline to free surface at different oil leaking rates: (a) v_0 =1 m/s; (b) v_0 =3 m/s; (c) v_0 =5 m/s.(*H. Zhu et al. / Energy 64 (2014) page 887-899)*

3.4 Dimensionless Analysis

The Figure 3.2 shows that the dimensionless time required for oil droplets which have the longest horizontal migrate distance when they reach the sea surface is analyzed and the fitting formulas are obtained. We can clearly see that the larger the density of oil, the process of oil spill consists of rising process and drifting process. For drifting process, the main motion of oil droplets is moving downstream along the free surface, and water is acting as a carrier.

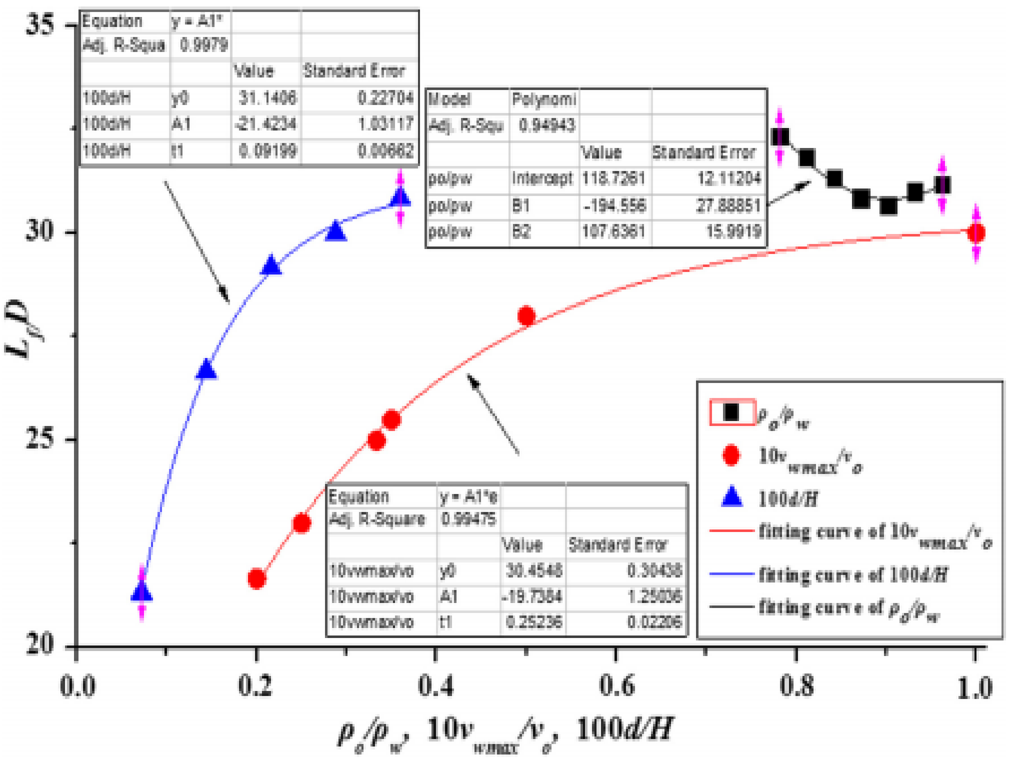


Figure 3-5: Dimensionless time required for oil droplets which have the longest horizontal migrate distance when they reach the sea surface ($v_o t/H$) versus ρ_0/ρ_w,$10v_{wmax}/v_o$ and 100 d/H. (*Zhu et al. / Energy 64 (2014) page 887-899)*

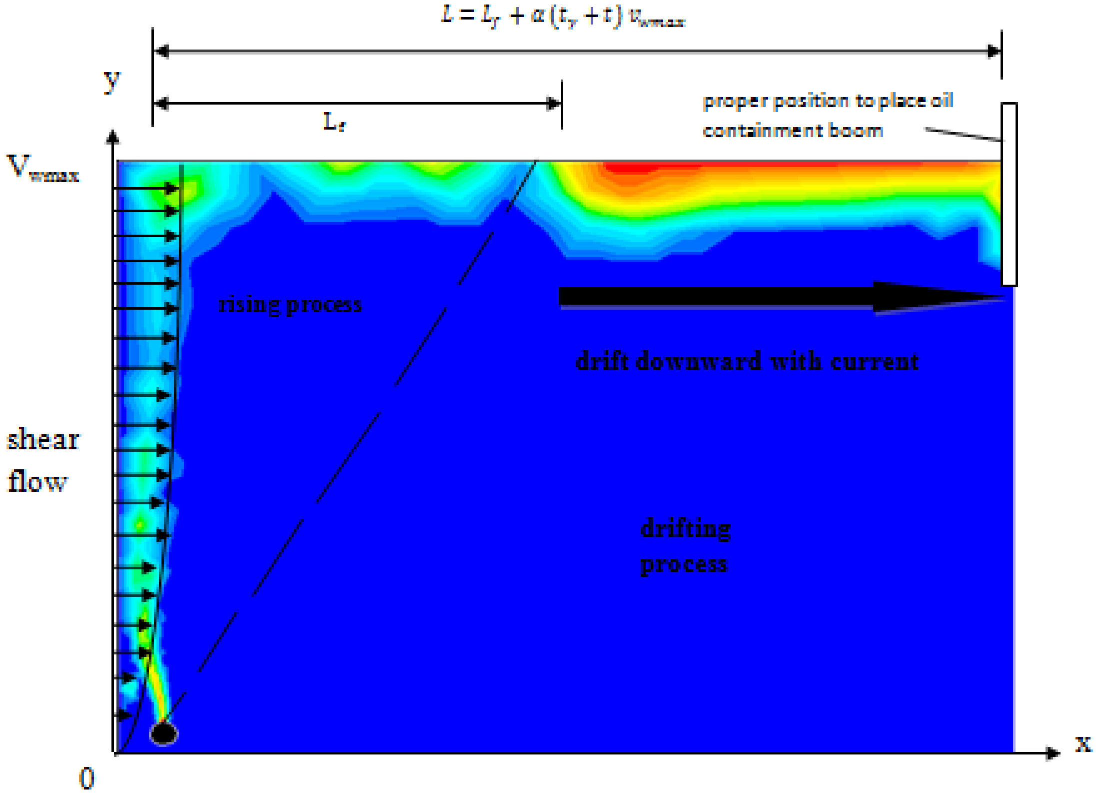


Figure 3-6: The whole process of oil spill.(*Zhu et al. / Energy 64 (2014) page 887-899)*

3.5 Summary

Usage of the computational domain generated from the Gambit Software, and further iterations with values of heat transfer and dimensions, illustrates a graph of dimensionless time required for oil droplets which have the longest horizontal migrate distance when they reach the sea surface (V_0/H) versus ρ_0/ρ_w, $10v_{wmax}/v_0$ and 100d/H. The above simulations conducted are essential to study the effect of oil density on the length of time for oil to reach the sea-surface and the distance for oil moving downstream.

4 RESULTS AND DISCUSSION

4.1 Overview

In this section, it is to study the effect of oil leaking rate on the length of time for oil to reach the sea-surface and the distance for oil moving downstream, simulations are conducted by changing the oil leaking rate which were 1 m/s, 3 m/s, and 5 m/s. The other parameters of oil density, leak size and water velocity were set constant at 780 kg/m^3, 0.1 m, 0.1 m/s respectively.

4.2 Standard Case

We adopt case 1 (as shown in Table 4.1) as the standard case. Fig. 4.1 presents the volume fraction of water at different times, corresponding to the process of oil spill from submarine pipeline to free surface. It is indicated 39 s are required for oil droplets which have the longest horizontal migrate distance when they reach the sea surface.

4.3 Effect of Oil Leaking Rate

The study the effect of oil leaking rate on the length of time for oil to reach the sea surface and the distance for oil moving downstream, simulations are conducted by changing the oil leaking rate while leaving other parameters same as those in the standard case. Figure below shows that the illustrates the process of oil spill from submarine pipeline to free surface at three different oil leaking rates. The size of the leakage hole on the top of pipe, opening upwards which is 0.05 m. GAMBIT mesh generator is employed to perform all the geometry generation and meshing. At small leaking rate (v_o = 1 m/s), 25 s is required for the oil flow to reach the free surface of the sea. However, for the higher leaking rate (v_o = 5 m/s), just 9 s is needed for oil to reach maximum horizontal migrate distance when it reaches the free surface. It can be explained that high-speed leaking oil has more ascending kinetic energy and more dispersed oil droplets present.

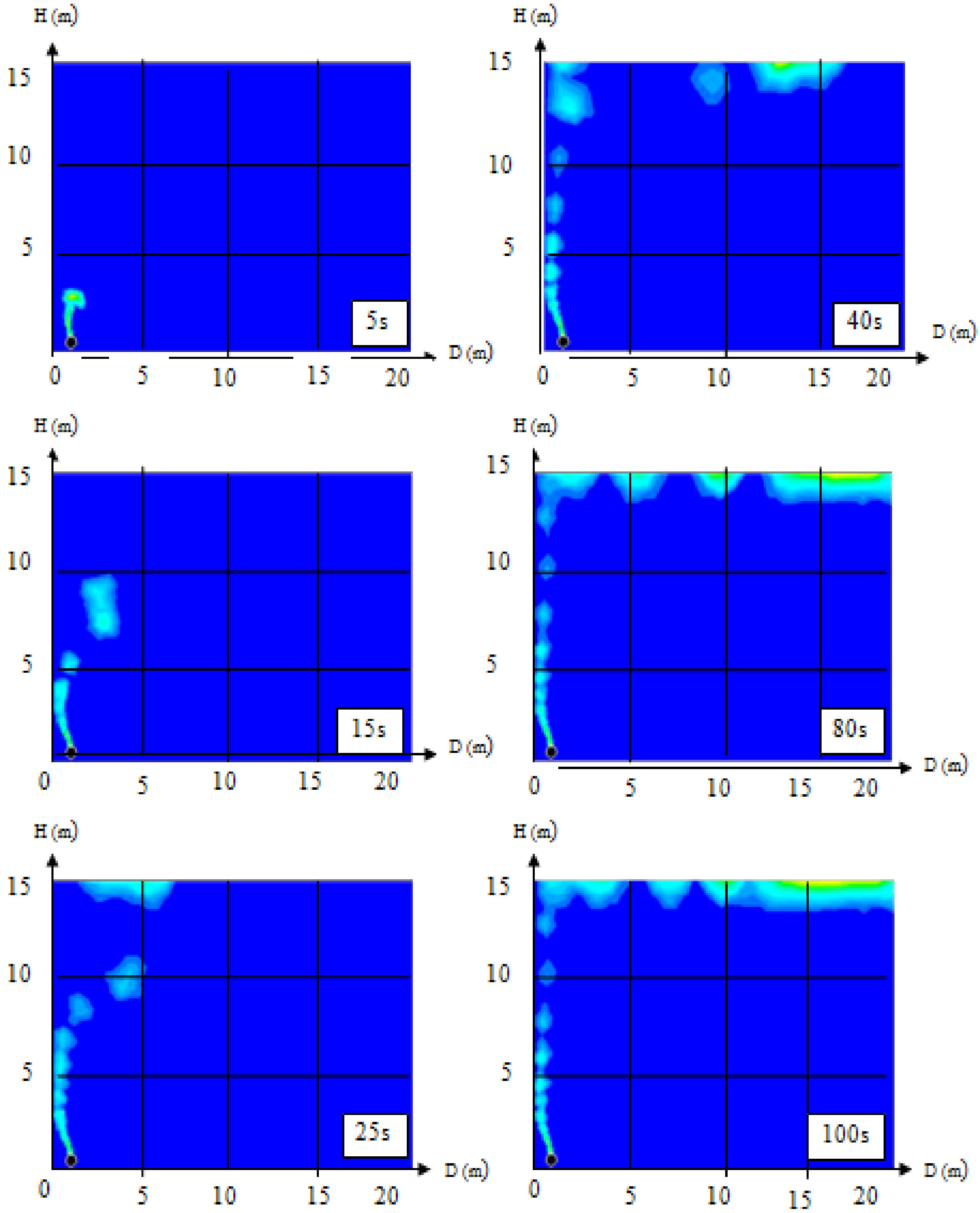


Figure 4-1: The process of oil spill from submarine pipeline to free surface until 100 seconds at V_o = 1 m/s

The study was based on a 15 m height by 20 m domain scale reading. From the Figure 4.1 (Vo = 1 m/s), process of oil spill to the free sea surface was simulated at difference time intervals. The oil leak size and water velocity were fixed constant at 0.1 m and 0.1 m/s for this research. For the first 5 seconds, a small oil spill with a light blue contour can be seen on the domain of the first quadrant indicating the leak. As the time proceeds, the distance and the height of the oil spill starts to increase in the first quadrant until a cloud of oil formed at height 10 m (15 seconds). At 25 seconds, the clouds of droplets start to form in larger sizes and higher from its initial position and reach the surface. At 40 seconds, the oil droplets that already reach the surface will slowly migrate until reach the distance 15 m. For 80 seconds time interval, the oil spill reach 20 m of migrate distance and at last 100 seconds the oil spill already gather at the end of 20 m migrate distance. From the observation above, a deduction can be made that the time interval for oil with 1 m/s oil leaking rate reach the surface at 25 seconds and reach the maximum migrate distance which is 20 m at 80 seconds. As a conclusion, the research supports the hypothesis that when the oil leaking rate increases, the time taken for the oil spill to reach the surface is much faster at constant water velocity and leak size.

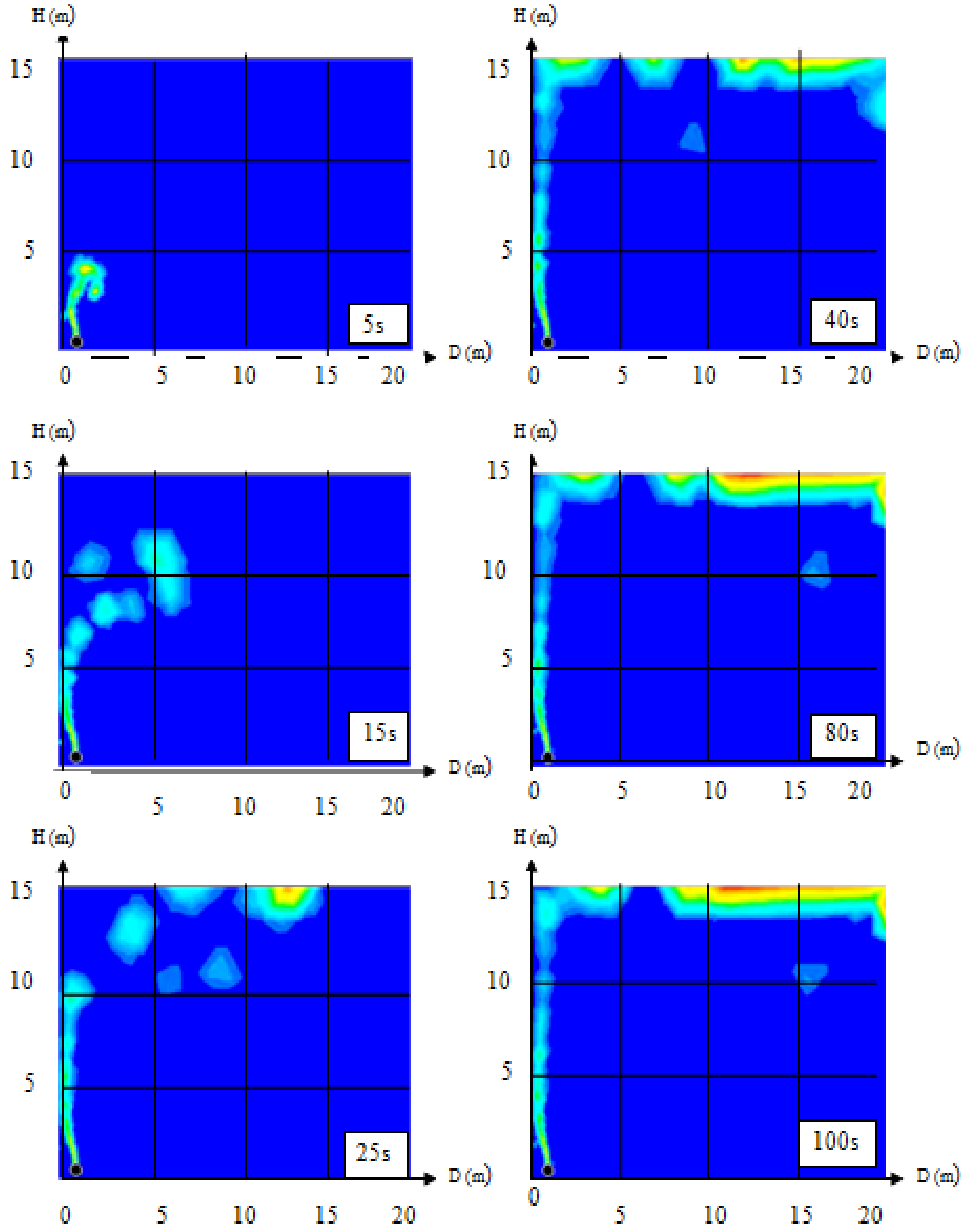


Figure 4-2: The process of oil spill from submarine pipeline to free surface until 100 seconds at V_o = 3 m/s.

The study was based on a 15 m height by 20 m domain scale reading. From the Figure 4.2 (Vo = 3 m/s), process of oil spill to the free sea surface was simulated at difference time intervals. The oil leak size and water velocity were fixed constant at 0.1 m and 0.1 m/s for this research. For the first 5 seconds, a small oil spill with a light blue contour can be seen on the domain of the first quadrant indicating the leak but compare with 1 m/s, the oil spill already reach 5 m in height. As the time proceeds, the distance and the height of the oil spill starts to increase until a cloud of oil formed at height 12 m and at distance 7 m (15 seconds). At 20 seconds, the clouds of droplets keep increasing and reach the sea surface. At 25 seconds, the distance of oil spill was 15 m. At 40 seconds, the oil spill reach 20 m of migrate distance and at last 100 seconds the oil spill already gather at the end of 20 m migrate distance. From the observation above, a deduction can be made that the time interval for oil with 3 m/s oil leaking rate reach the surface at 20 seconds and reach the maximum migrate distance which is 20 m at 30 seconds. As a conclusion, the research supports the hypothesis that when the oil leaking rate increases, the time taken for the oil spill to reach the surface is much faster at constant water velocity and leak size.

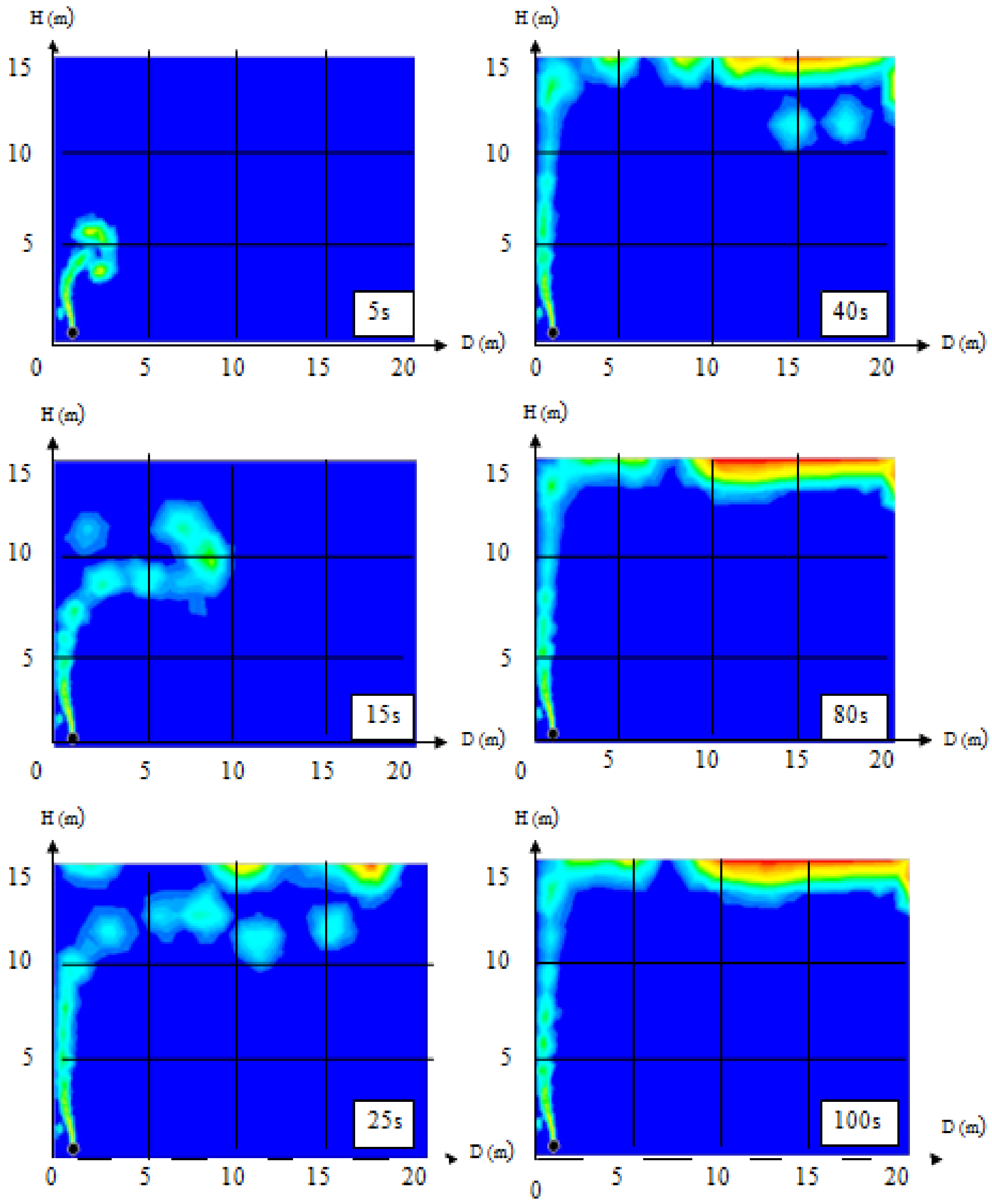


Figure 4-3: The process of oil spill from submarine pipeline to free surface until 100 seconds at V_o = 5 m/s.

The study was based on a 15 m height by 20 m domain scale reading. From the Figure 4.3 (Vo = 5 m/s), process of oil spill to the free sea surface was simulated at difference time intervals. The oil leak size and water velocity were fixed constant at 0.1 m and 0.1 m/s for this research. For the first 5 seconds, a small oil spill with a light blue contour can be seen on the domain of the first quadrant indicating the leak but compare with 3 m/s, the oil spill already reach 6 m in height. As the time proceeds, the distance and the height of the oil spill starts to increase until a cloud of oil formed at height 13 m and at distance 10 m (15 seconds). At 18 seconds, the clouds of droplets keep increasing and reach the sea surface. At 25 seconds, the distance of oil spill was 18 m and the red colour contour can be seen. The red colour indicated that the amount of oil gather at a place compare to blue which is lowest and yellow lower in comparison. At 40 seconds, the oil spill reach 20 m of migrate distance and at last 100 seconds the oil spill already gather at the end of 20 m migrate distance. From the observation above, a deduction can be made that the time interval for oil with 3 m/s oil leaking rate reach the surface at 18 seconds and reach the maximum migrate distance which is 20 m at 26 seconds. As a conclusion, the research supports the hypothesis that when the oil leaking rate increases, the time taken for the oil spill to reach the surface is much faster at constant water velocity and leak size.

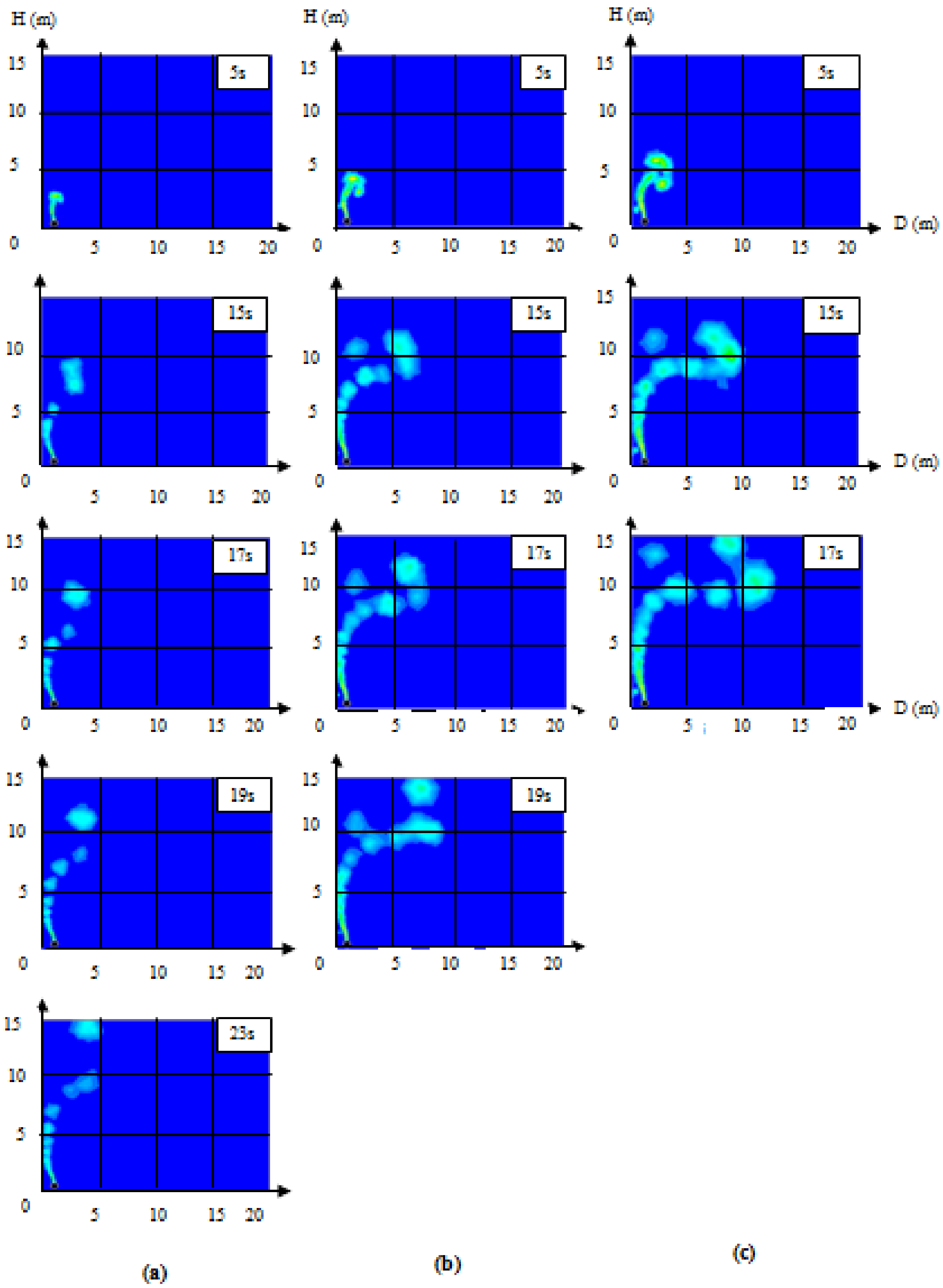


Figure 4-4: The process of oil spill from submarine pipeline to free surface at different oil leaking rates: (a) v_0 =1 m/s; (b) v_0 =3 m/s; (c) v_0 =5 m/s.

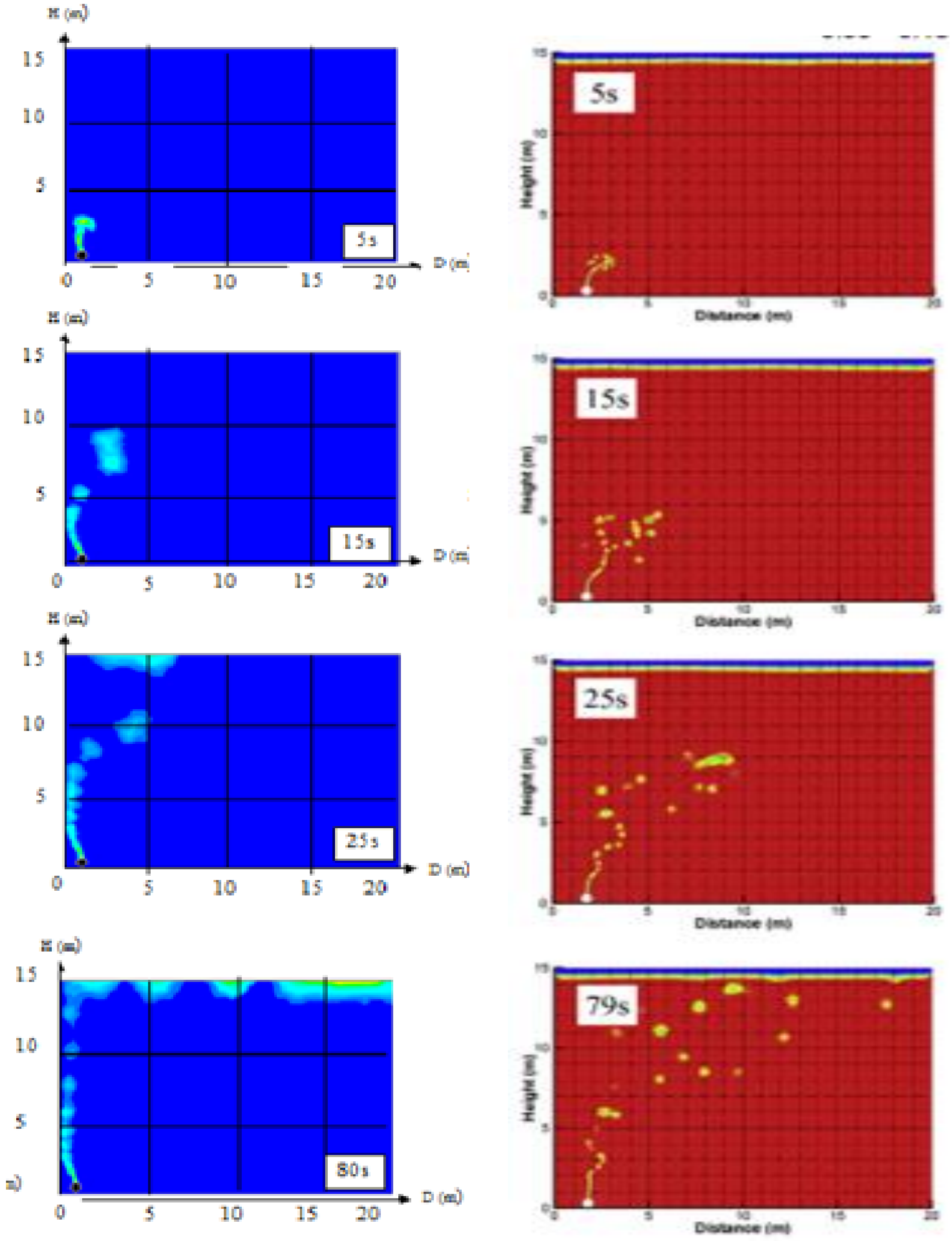
From the **Figure 4.4** above, a comparison study was made between oil leaking rate of 1 m/s, 3 m/s and 5 m/s for 5, 15 and 17 seconds respectively. The study was based on a 15 metres in height and 20 metres domain scale reading. At **5 seconds,** for v_o= 1 m/s, the oil leakage were observed to still have not reach 5 meters height scale and migration was less than 2 metres. As for 3 m/s, the oil reached 5 m axis with an oil migration distance more than 2 metres. At 5 m/s, the oil leakage migration distance was above 5 metres from seabed with the distance of almost 4 metres from the source of oil leak. From the observation above, we can say that the time for oil leakage migration was faster at higher oil leaking rate. At **15 seconds**, for 1 m/s, the oil leakage were observed to have smeared a distance of almost 4 metres and a height around 10 metres from seabed. At 3 m/s, the oil leakage is observed in clear clouds at a height of 12 metres from the seabed. As for 5 m/s, the oil migration has reached 10 metres from leak pipe. From the observations above, we can deduce that the cloud appearance of oil leakage were more visually seen and further apart from the source of leakage compared to that 5 m/s. At **17 seconds**, for 1 m/s, the oil leakage begun to combine and become larger. At 3 m/s, the oil migration has passed through the quadrant to a migration of almost 7 metres from the source of oil leak. From the observation above, it can be conclude that the oil leakage spread further apart at 19 seconds and with clearer appearance of oil leakage.

Table 4-1: Effect of Oil Density on The Time Taken for Oil to reach The Free Surface (Present).

Case	Oil leaking rate (m/s)	The maximum water velocity (m/s)	Oil density (kg/m^3)	Diameter of leak(m)	Volume flux of leaking oil(m^3/s)	Time taken to reach free surface(s)
2	1	0.1	780	0.05	0.0019625	23
3	3	0.1	780	0.05	0.0058875	19
4	5	0.1	780	0.05	0.0098125	17

Table 4.1 above was tabulated based on the framework analysis obtained from the simulation process. Based on the time step iteration graph, it was observed that the fluctuation settled for all three different oil leaking rate are at 20000 iterations. The higher the leaking rate, 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).

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 proposed. The slower the oil leaking, the larger the density of oil, or the smaller the leak size, the longer the dimensionless oil spill time is. The three fitting formulas of dimensionless time meet the natural logarithm distribution well. The dimensionless longest horizontal distance increases with the in-crease of leak size, while increases with the decrease of oil leaking rate. With the increase in oil leaking rate, the dimensionless longest horizontal distance decreases firstly and then increases. The two formulas for dimensionless rate and dimensionless leak size meet the natural logarithm distribution, while the formula for dimensionless density meets the polynomial. Using the formulas we can obtain when and where to see oil reaching the sea surface, and conduct rapid response. We have taken V_0 = 1 m/s for example to show the using method of formulas. The calculated results are 35.86 s and 18.69 m.



(a) (b)

Figure 4-5: The comparison process of oil spill from submarine pipeline to free surface at v_0 =1 m/s for (a) and (b) (Zhu et al., 2013)

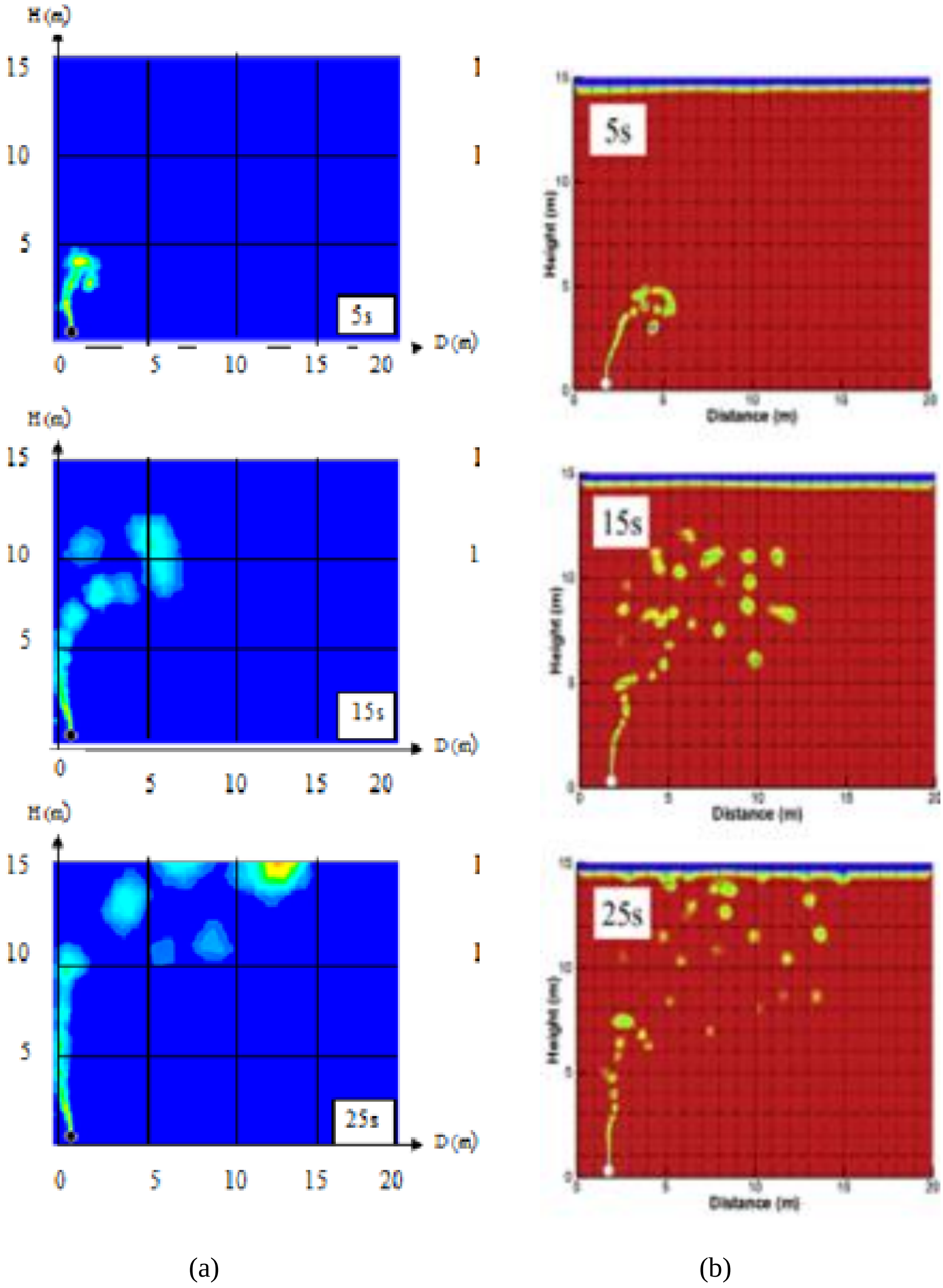
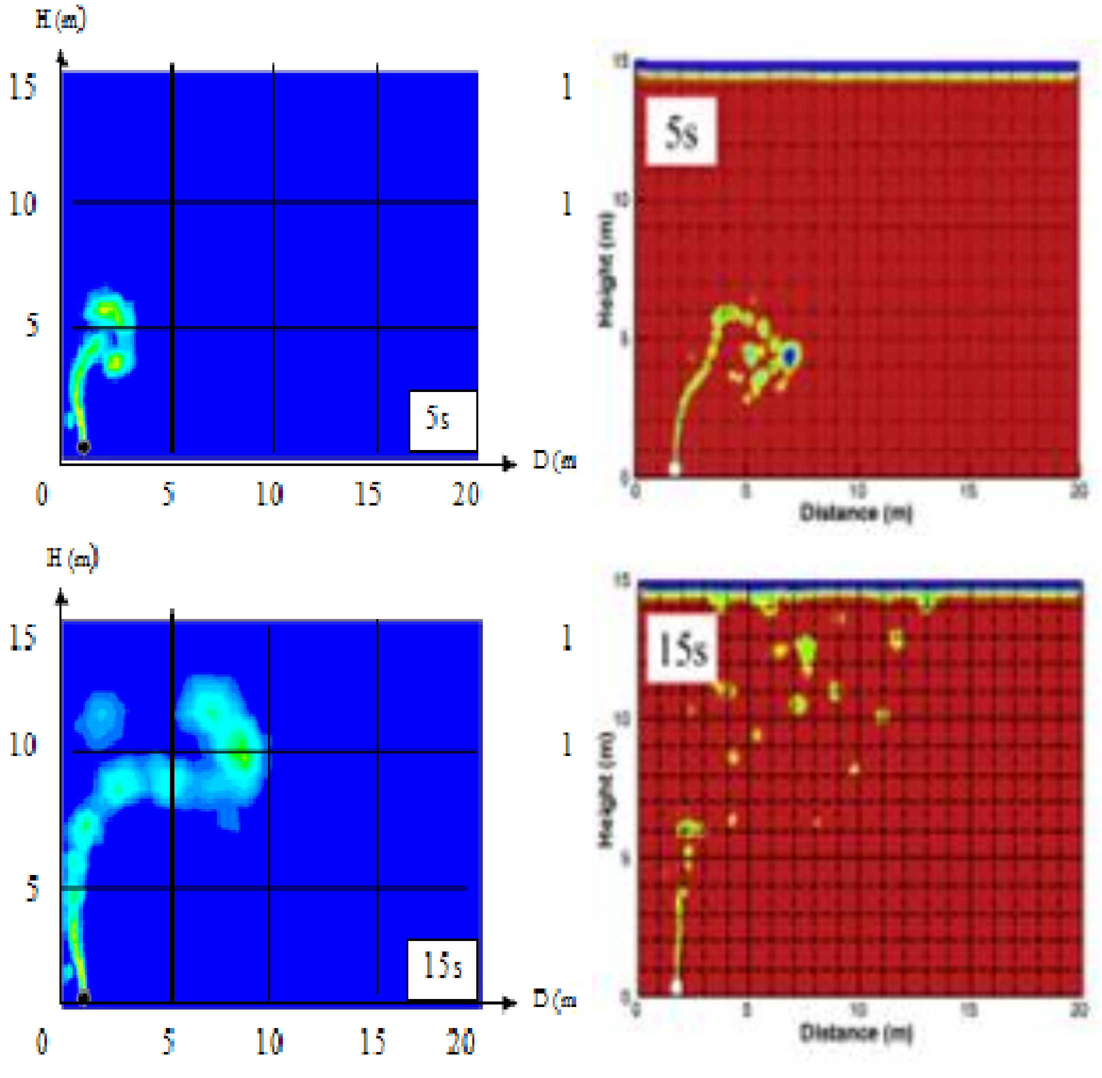


Figure 4-6: The comparison process of oil spill from submarine pipeline to free surface at v_0 =3 m/s for (a) and (b) (Zhu et al., 2013)



(a) (b)

Figure 4-7: The comparison process of oil spill from submarine pipeline to free surface at v_0 =5 m/s for (a) and (b) (Zhu et al., 2013)

Figure 4.5, figure 4.6 and figure 4.7 shows that the comparison of oil spill between the finding and result from the journal (Zhu *et al., 2013).* Based on the figure, we can see the different of time taken for oil spill to reach the free surface. At 1.0 m/s oil leaking rate, the time taken the oil spill to reach the free surface is 23 s while from the journal is 79 s. At the moderate oil leaking rate which is 3.0 m/s, the time taken to reach the free surface from the finding is 19 s and from the journal is 25 s. Last but not least, the higher oil leaking rate 5.0 m/s shows that from the finding the time taken is 17 s while from the journal is 15 s. The differentiation of time taken is due to the difference version or series of the Fluent software used to run the simulation.

4.3.1 Effect on the migrate distance

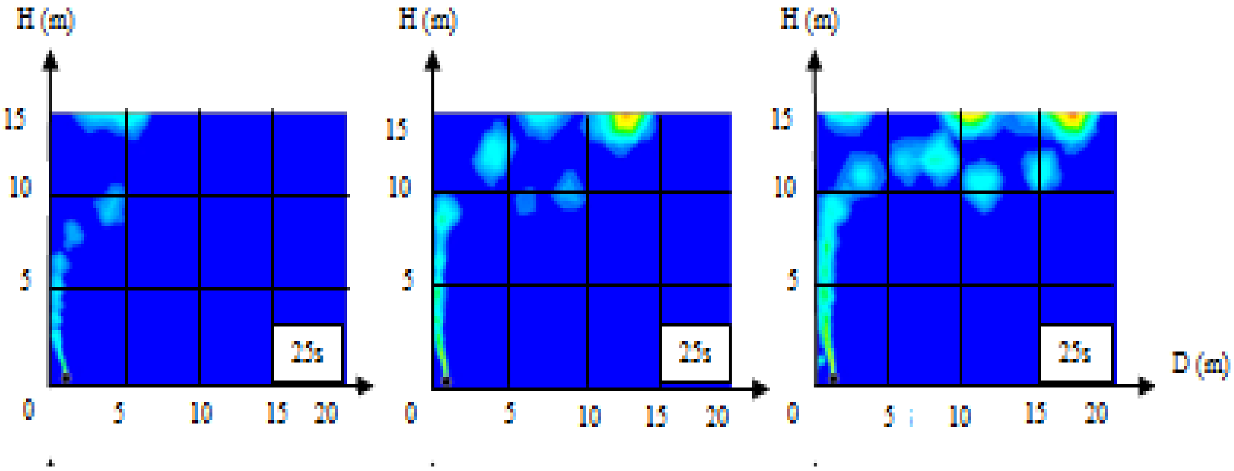


Figure 4-8: Comparison of time(s) for oil migration to free surface at different oil leaking rate.

The Figure 4.5 show the result at 25 second interval. From the simulation above, for oil leaking rate of (a) v_o= 1 m/s, the clouds of oil droplets are said to be at 6 m from seabed. Contrary for the (b) v_o= 3 m/s, the oil droplets have already migrated at a distance of 15 meters to the outlet of the rectangular domain. As for (c) v_o= 5 m/s, the oil droplets were observed to reach free surface earlier at 18 seconds. The oil droplet at the outlet surface (b) and (c) formed a contour image which displayed the fraction of kerosene liquid visible as in themarker range above the figures.

4.4 Summary

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 proposed. Effects of oil leaking rate, oil density and the leak size and water velocity are examined. The slower the oil leaking, the larger the density of oil, or the smaller the leak size, the longer the dimensionless oil spill time is. The three fitting formulas of dimensionless time meet the natural logarithm distribution well. The dimensionless longest horizontal distance increases with the in-crease of leak size, while increases with the decrease of oil leaking rate. With the increase in oil leaking rate, the dimensionless longest horizontal distance decreases firstly and then increases. The two formulas for dimensionless rate and dimensionless leak size meet the natural logarithm distribution, while the formula for dimensionless density meets the polynomial. Using the formulas we can obtain when and where to see oil reaching the sea surface, and conduct rapid response. We have taken V_0 = 1 m/s for example to show the using method of formulas. The calculated results are 35.86 s and 18.69 m.

5 CONCLUSION

5.1 Conclusion

This project focuses on mainly the study of the effects of oil density, leaking rate, leak size and 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. The whole computational domain is a rectangle with a length of 20 m and a height of 15 m. GAMBIT 2.3 mesh-generator is employed to perform all geometry generation and meshing. In this way, the method of approach will be environmental friendly and also capable to cost-effective globally.

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.

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