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ANALISIS PENYEBARAN FENOL DAN OIL AND GREASE DARI AIR TERPRODUKSI HASIL DARI LAPANGAN MIGAS DAN DAMPAKNYA TERHADAP LINGKUNGAN LAUT LEPAS

SPREADING ANALYSIS OF PHENOL, OIL AND GREASE OFPRODUCED WATER FROM OIL AND GAS FIELD AND THEIR IMPACTS TO OFFSHORE ENVIRONMENT

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Abstract: *Sea is one of natural resources, which has potential to provide human needs. However, due to resident growth and there are many industries have activities, the sea is started to be polluted and negative impact to people and environment is arisen. One of industry, which has potential to pollute Indonesian sea, is oil and gas production in Natuna Sea. Produced water, which is produced by oil and gas production process in PT. Star Energy, may contain few contaminant constituents including phenol, oil and grease. Distribution of phenol and oil and grease is done using MuQual3D software, which includes hydrodynamic model and qualitative water model. Simulation of phenol distribution and oil and grease from produced water is done for a year for each discharge location within two layers of sea water layer which are mean sea water layer and sea bottom layer. Phenol concentration spreading at the depths of 7 m and 75 m such as 0.012 - 0.14 µg/L, where as oil and grease concentration such as range between 0.15-1.7 µg/L. These spreading simulations show that produced water discharge have complied the sea water quality standard for aquatic biota. From laboratory results of aquatic biota for phytoplankton and zooplankton, are indicated that there is occurrence of ecological pressure within the aquatic area, but still in moderate and stable condition, which means that it could be changed according to the surrounding environment. Where as, from Chanos chanos toxicological model simulation about 9.53-10.12% of study area has impacted. For balancing the ecosystem of Natuna sea, produced water discharge management and other research for aquatic biota in study area are needed.*

Key words*: Produced Water, Phenol, Oil and Grease, Impacts, MuQual3D, Natuna Sea*

Abstrak: *Laut merupakan salah satu sumber daya alam yang berpotensi untuk memenuhi kebutuhan manusia. Namun seiring dengan pertumbuhan penduduk dan banyaknya industri yang beroperasi, laut mulai tercemar sehingga timbul dampak negatif terhadap manusia dan lingkungan. Salah satu industri yang berpotensi dalam mencemari laut Indonesia,khususnya Laut Natuna adalah industri minyak dan gas bumi. Air terproduksi yang dihasilkan oleh proses produksi minyak dan gas di PT. Star Energy, mengandung beberapa senyawa kontaminan termasuk fenol dan oil and grease. Penyebaran fenol dan oil and grease dilakukan menggunakan software MuQual3D yang mencakup model hidrodinamika dan model kualitas air. Simulasi penyebaran fenol, oil and grease dari air terproduksi dilakukan selama 1 (tahun) untuk masing-masing lokasi pembuangan dalam 2 (lapisan air laut) yaitu lapisan permukaan dan lapisan dasar laut. Penyebaran konsentrasi fenol pada kedalaman 7 m dan 75 m berkisar antara 0.012 - 0.14 µg/L sedangkan konsentrasi oil and grease berkisar antara 0.15-1.7 µg/L. Hasil simulasi penyebaran tersebut menunjukkan air terproduksi yang dibuang masih berada di dalam baku mutu. Dari hasil pengukuran plankton, baik fitoplankton maupun zooplankton diperoleh bahwa terdapat tekanan ekologis terhadap struktur komunitas laut, namun masih dalam kondisi yang moderat atau stabil, artinya dapat berubah sesuai dengan keadaan lingkungan sekitarnya. Sedangkan dari hasil simulasi model toksikologi Chanos-Chanos didapat sekitar 9.53% sampai dengan 10.12% wilayah yang terkena dampak pembuangan air terproduksi. Untuk menjaga kestabilan ekosistem Laut Natuna diperlukan pengelolaan pembuangan air terproduksi dan penelitian lebih lanjut untuk biota laut di wilayah studi.*

Kata kunci*: Air Terproduksi, Fenol, Oil and Grease ,dampak, MuQual3D, Laut Natuna*

1. INTRODUCTION

Sea could be polluted by both land and the sea (marine based pollution). This pollution could be related to some sea industrial operation activities such as heat pollution, noises, turbidity, and also pollution which caused by chemical matter, hazardous metals and radioactive material. One of the activities that could cause pollution in offshore is an exploration of oil and gas. Natuna archipelago which is located at north Indonesia has potential resources of oil and natural gas. It is predicted that Natuna still has 14.386.470 barrel of oil and 112.356.680 barrel of natural gas. Therefore, many industries operate in this area and one of them is PT. Star Energy.

The location of oil and gas activity is located in Kakap Block of Natuna Sea, which is in District of Siantan, Regency of Natuna, and Province of Riau. Kakap Block is situated about 250 km of distance from Natuna Besar Island and 190 km from Matak Island. The oil and gas activity is covering 4 offshore platforms, which is KH, KF, KG and KRA. The production of oil and gas in Kakap Block is also involving a Floating Process Storage and Offloading (FPSO). The oil production of Kakap Block currently reaches 15,000 BOPD, 32,000 BWPD of produced water and 68 MMSCFP of gas.

Sources of water pollution that gain the most attention are produced waters, drilling mud and oil spills. Produced water comes from the process of lifting of oil and gas from water - bearing formations– typically ancient sea or lake. As oil and gas is lifted to the surface, water is brought along with them. Produced water is either naturally present or being injected into the reservoir to maintain the production. The proportion of water produced increases as the oil field matures. Some of this water is re-injected.

Produced water is the largest volume of aqueous waste arising from production operations. The composition of produced waters varies considerably, but typically may include: inorganic salts, heavy metals, solids, production chemicals, benzene, *polyaromatic hydrocarbons* (PAHs) and on occasions naturally occurring radioactive material. Produce water discharge, that contain these chemical matters, could pollute ecosystem that effect organism life and disrupt the balancing of ecosystem. The impact of produced water also depends on quantity, spreading, and receiver component.

Produced Water Characteristics

Produced water is not a single commodity. The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geological formation with which the produced water has been in contact for thousands of years, and the type of hydrocarbon product being produced. Produced water properties and volume can even vary throughout the lifetime of a reservoir.

In its natural components, produced waters from oil production may contain groundwater or seawater (generally called “source” water) injected to maintain reservoir pressure, as well as miscellaneous solids and bacteria. Most produced waters are more saline than seawater (Cline 1998). They may also include chemical additives used in drilling and producing operations and in the oil/water separation process. Treatment chemicals are typically complex mixtures of various molecular compounds. These mixtures can include:

- Corrosion inhibitors and oxygen scavengers to reduce equipment corrosion;
- Scale inhibitors to limit mineral scale deposits; biocides to mitigate bacterial fouling;
- Emulsion breakers and clarifiers to break water-in-oil emulsions and reverse breakers to break oil-in-water emulsions;
- Coagulants, flocculants, and clarifiers to remove solids; and
- Solvents to reduce paraffin deposits (Cline, 1998).

Impacts of Produced Water Discharges

The chemical constituents found in produced water, either individually or collectively, when present in high concentrations, can present a threat to aquatic life when they are discharged

or to crops when the water is used for irrigation. Produced water can have different potential impacts depending on where it is discharged. For example, discharges to small streams are likely to have a larger environmental impact than discharges made to the open ocean by virtue of the dilution that takes place following discharge. Numerous variables determine the actual impacts of produced water discharge. These include the physical and chemical properties of the constituents, temperature, content of dissolved organic material, humic acids, presence of other organic contaminants, and internal factors such as metabolism, fat content, reproductive state, and feeding behaviour (Frost et al. 1998).

Impacts are related to the exposure of organisms to concentrations of various chemicals. Factors that affect the amount of produced water constituents and their concentrations in seawater, and therefore their potential for impact on aquatic organisms, include the following (Georgie et al. 2001):

- Dilution of the discharge into the receiving environment,
- Instantaneous and long-term precipitation,
- Volatilization of low molecular weight hydrocarbons,
- Physical-chemical reactions with other chemical species present in seawater that may affect the concentration of produced water components,
- Adsorption onto particulate matter, and
- Biodegradation of organic compounds into other simpler compounds.

Phenol and *alkyl phenols* are dangerous to marine environment because these compounds can be endocrine disrupters especially for fish. The definition of endocrine disrupters is exogenous agent which is disrupting production process, release, transportation, metabolism, bonding, action and elimination from natural hormone (IMR 2002, p.6). Mean while oil and grease is important compound in produced water. This compound is formed by 3 (three) singular chemical that are free oil, dispersed oil and dissolved oil. Oil and grease is found in form of film layer at the water surface as well as an absorbed emulsion. Film formation at the surface water inhibits gas diffusion and photosynthesis and also causes odour and dangerous gas.

Model Application

Mathematic model can be used to simulate the spreading of pollutant in sea water, where the solution of this mathematic method helps with numeric method. Numeric method is really aided in solving mathematic model which is influenced by many variables and complex. Some mathematic models that commonly used are two dimension version (vertical averaged) from three dimension model, and unsteady flow with Non orthogonal Contra variant Boundary Fitted in spherical coordinate system, which developed by Muin (1993) in Narragansett (1997).

MuQual3D (3D Hydrodynamics and Produced Water Quality Model)

MuQual3D, which is developed by Mr. Muslim Muin, Ph.D, is software in Windows application. MuQual3D can simulate Hydrodynamics and Water Quality, Suspended Sediment and Eco Toxicological Model that occur around strait, bay, estuary, or others marine environment.

The result of simulation can show:

1. Hydrodynamics Model, simulate the height of water level and water current (MuHydro3D);
2. Water Quality Model, to predicts the dynamic of conservative and conservative pollutant transport and dispersion of discharge material (salinity, temperature, oil content, BTX etc);
3. Suspended Sediment Model, to simulate time varying fields of suspended concentration and rate of deposition or erosion the spreading (MuSed3D);
4. Oil Dispersion (MoTum); and
5. Geography Information System (GIS).

MuQual3D is needed to describe a model of phenol and oil and grease produced water from oil and gas field and to observe their impacts in Natuna sea generally. These pollutant

spreading models can be implemented in decision making and determining policy for produced water management. This research is carried out in South Kakap field, the area of oil and gas production of PT. Star Energy (Kakap) Ltd, in Natuna area, South China Sea as shown in **Figure 1.**

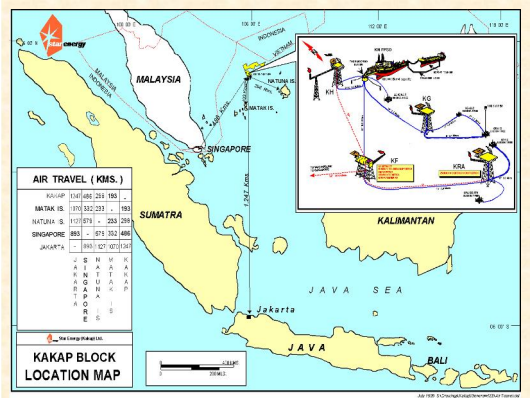


Figure 1. Oil and Gas Production Location in Kakap Block

2. METHODOLOGY

The research is carried out in few steps. The first step is identification on the produced water quality and determination some pollutants discussed in this research. This determination is based on concentration of pollutant and their impact in offshore environment.

Sea condition of the research area was taken from a literature study, research area observation, and collecting and analyzing data. Sea condition is important due to simulation of the hydrodynamic model, transport and process of pollutant in sea water.

Data needed, includes physic, chemical, and biological data for each sampling location (platform) is:

- Physic data are daily discharge of produced water that enter into the sea, sea temperature, climatology, out fall location and empiric parameter, such as wind velocity and direction, current sea, temperature, and other oceanography factors.
- Chemical data are temperature, salinity, concentration of phenol, oil and grease in produced water, and sea water quality.
- Biological data are phytoplankton and zooplankton value as biology indicator in sea water.

These data are taken from produced water quality monitoring prepared by PT Star Energy. The measuring method of produced water and sea water quality is shown in **Table 1** and **Table 2**. Sampling location of produced water and sea water monitoring is shown in **Figure 2**.

The second step is selection of model or software used in research. There are few important aspects need to be considered, such as:

- Suitability with real condition, which is related to an assumption in a model.
- The importance of using model according to information needed.

MuQual3D is the best choice because this software can simulate current sea dynamic and spreading of pollutants quickly and accurately. After all data are collected, the next step is to input the data to MuQual3D. One of input data is to create grid with Non-Orthogonal Curvilinear Coordinate Technical of the location.

Using MuQual3D, spreading of phenol, oil and grease from produced water are simulated in one year (January 2008 until December 2008) for each monitoring location, which are KN-FSO, KF and KG. Beside pollutant spreading, impacted area has been done by simulation of Chanos-Chanos toxicological model. In addition, to improve the accuracy, the

simulation result will be validated with analytic method at several points. The Final Step is to analyze and to conclude the analysis.

Table 1
Produced Water and Sea Water Quality Measurement

Parameter	Unit	Methode
Physical Properties		
Temperature	^{0}C	Expansion
Chemical Properties		
Phenol	mg/L	Spectrophotometric
Oil and Grease	mg/L	IR-Spectrophotometric

Table 2
Sea Water Quality Measurement

Parameter	Methode	Equipment
Physical Properties		
Temperature	Expansion	Thermometer
Chemical Properties		
Phenol compound	Spectrophotometric	Spectrophotometer
Oil and Grease	IR-Spectrophotometric	IR-Spectrophotometer
Biological Properties		
Phytoplankton	Membrane Filter	Membrane Filter
Zooplankton	Membrane Filter	Membrane Filter

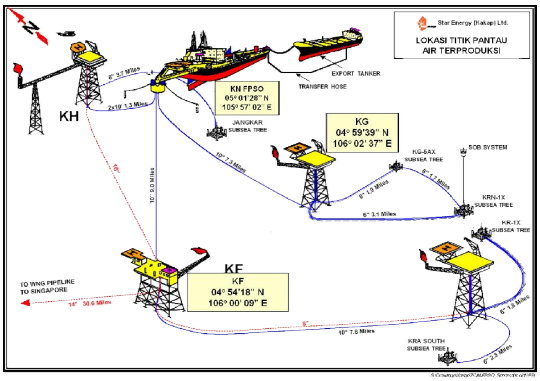


Figure 2. Sampling Location of Produced Water and Sea Water Monitoring

RESULT AND DISCUSSION

Produced water discharge is located at 3 (three) different location that are KN-FSO, KF and KG. For KN-FSO, discharge has been done at a depth of 7 m (layer 15) where as produced water discharge from KF and KG platform at a depth 75 m (layer 1). Produced water volume is shown in **Table 3** and produced water quality is shown in **Table 4**. Sea water quality is shown in **Table 5**.

Table 3
Produced Water Volume

Platform	Volume (BWPD)	Volume (m^3/hari)	Volume (m^3/sec)
KN	26739.741	4251.271	0.049
KF	584.667	92.954	0.001
KG	11126.185	1768.919	0.020

Table 4
Produced Water Quality

No.	Parameter	Unit	Platform			Average
			KN	KF	KG	
1	Temperature	^{0}C	41.30	30.44	56.14	42.63
2	Phenol	mg/L	1.920	4.020	3.766	3.235
3	Oil and Grease	mg/L	23.333	45.417	30.450	33.067

Table 5
Sea Water Quality

No.	Parameter	Unit	Platform			Average
			KN	KF	KG	
1	Temperature	^{0}C	28.00	27.70	28.39	28.03
2	Salinities	mg/L	31.53	31.68	31.84	31.69
3	Phenol	mg/L	0.001	0.001	0.001	0.001
4	Oil and Grease	mg/L	1.000	1.000	1.000	1.000

Wind data as used in simulation is taken from routine measuring from 2002 until 2007. From those data, Windrose is created to represent wind condition for years. **Figure 3** shows January until December Windrose (2002-2007). Then these data are inputted in to MuQual3d.

Pollutant Spreading

From pollutant spreading simulation, the spreading models of phenol and oil and grease compound are precisely similar. Some factors that affect a model of spreading pollutant in marine environment are physic-chemical properties and sea water dynamic. Particular physic-chemical properties cause some pollutants dissolve in sea water. The solubility of phenol in sea water is higher than oil and grease. Sea water dynamic effected chemical compounds transportation in sea water. Where as the movement and circulation of sea water cause pollutant move from a location to another location then pollutant concentration distribution in area and time.

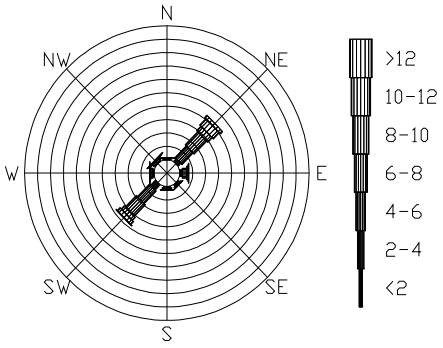
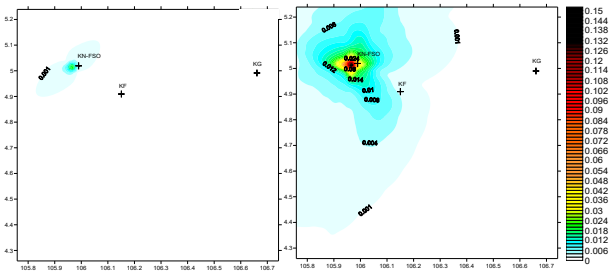
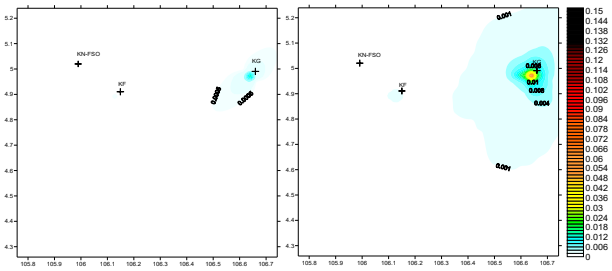


Figure 3. January until December Windrose (2002-2007)



(a) (b)

Figure 4. Average Spreading (a) and Maximum Spreading (b) of Phenol at a Depth



(a) (b)

Figure 5. Average Spreading (a) and Maximum Spreading (b) of Phenol a Depth of

Phenol

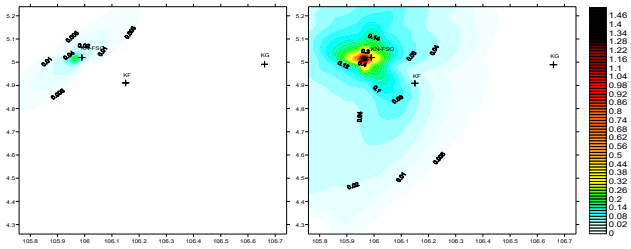
Phenol (C_6H_5OH) is one of pollutant that causes negative effect to marine environment. Phenol is a toxic organic compound and known as carbolic acid. This compound can also generate odour and taste. Based on Kep MENLH No.51 Tahun 2004 about Sea Water Regulation for Aquatic Biota (Attachment III), phenol compound standard is 0.002 mg/L or 2 µg/L where as oil and grease standard is 1 mg/L or 1000 µg/L.

Phenol average and maximum concentration distribution at 7 and 75 m are shown in **Figure 4** and **Figure 5**. Maximum phenol concentration at a depth of 7 m such as range 0.017 – 0.14 µg/L and maximum concentration at 75 m such as 0.014 – 0.059 µg/L. From those data, it conclude that study area has complied the regulation.

In closer area, about 500 m upstream and 500 m downstream of KN-FSO, the phenol average concentration is about 0.005 µg/L where as maximum concentration is 0.05 µg/L. This

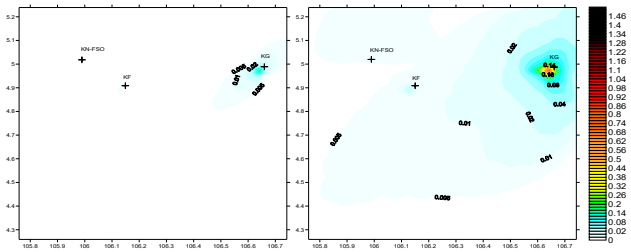
simulation result is accord with phenol concentration in sea water quality monitoring result, which is in **Table 5**, around <0.001 mg/L.

Phenol in study area maybe caused by result of marine microorganism metabolism process which re-degradated, the photooxydation of oil spill because of marine transportation activity and also the formation of topsoil or plant degradation in land.



(a) (b)

Figure 6. Average Spreading (a) and Maximum Spreading (b) of Oil and Grease at a Depth of 7 m



(a) (b)

Figure 7. Average Spreading (a) and Maximum Spreading (b) of Oil and Grease at a Depth of 75 m

Oil and Grease

Oil and grease concentration in natural water especially light fraction hydrocarbon such as methane compound, may come from plankton decomposition process or industrial waste. From study area data, the concentration of oil and grease in produced water is below the effluent standard that is 50 mg/l.

Average and maximum concentration distribution of oil and grease at 7 and 75 m are shown in **Figure 6** and **Figure 7**. Maximum phenol concentration at a depth of 7 m such as range 0.26 – 1.73 µg/L and maximum concentration at 75 m such as 0.17 – 0.71 µg/L. From those data, it conclude that study area has complied the sea water quality standard.

In closer area, about 500 m upstream and 500 m downstream of KG platform, the oil and grease average concentration is about 0.08 µg/L where as maximum concentration is 0.6 µg/L. This simulation result is accord with phenol concentration in sea water quality monitoring result, which is in **Table 5**, around <1 mg//L.

Oil and grease in waters are found in form of film layer at the water surface as well as an absorbed emulsion. Film formation at the surface water inhibits gas diffusion and photosynthesis. Oil emulsion can cover the respiration system of aquatic biota as well as benthos at the sea bottom. In spite of them most of aromatic hydrocarbon is toxic for living aquatic biota.

The Impacts of Pollutant Spreading To Marine Environment

If concentration distribution of phenol, oil and grease in mean sea water and sea bottom layer compared, it can see that the concentration in mean sea water layer is higher than in sea bottom layer. It can be predicted that aquatic biota, especially plankton and nekton will be directly polluted. Some factors that affect higher concentration are volume of produced water discharge, phenol, oil and grease concentration in produced water and also it reaction with sea water.

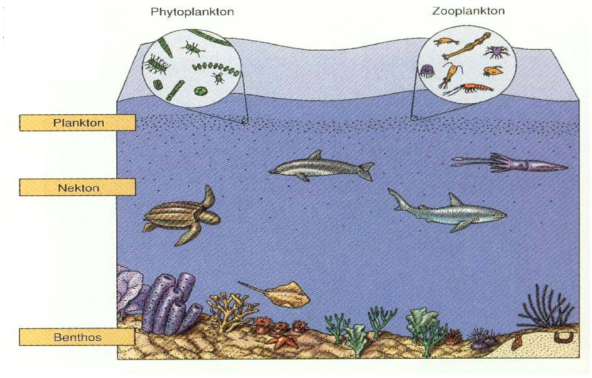


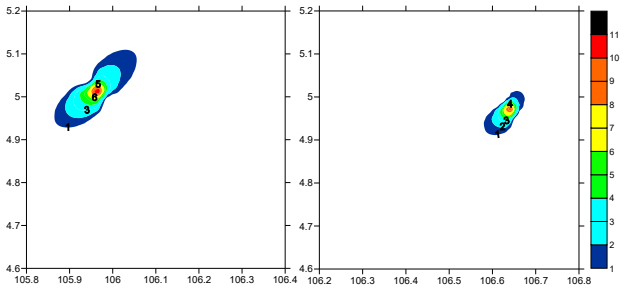
Figure 8. Aquatic Biota (Marine Biology, 2007)

Table 6
Plankton Monitoring Result Semester I Year 2008

Description	Analysis Result					
	1	**2**	**3**	**4**	**5**	**6**
Phytoplankton						
Abundance (ind./L)	1092	942	982	1260	1056	948
Taxa (S)	19	20	18	21	22	21
Diversity (H ')	1.2126	1.2601	1.3254	1.2938	1.2792	1.2789
Equitability (E)	0.9482	0.9686	1.0559	0.9785	0.9529	0.9673
Dominance (D)	0.068	0.0597	0.0607	0.0539	0.0592	0.0572
Zooplankton						
Abundance (ind./L)	300	138	318	288	186	288
Taxa (S)	5	3	5	4	5	5
Diversity (H ')	0.6263	0.4074	0.648	0.5646	0.6022	0.683
Equitability (E)	0.8961	0.8539	0.9271	0.9378	0.8615	0.9772
Dominance (D)	0.2584	0.448	0.2453	0.2925	0.2986	0.2144

Explanation : 1 KN FPSO Upstream Seawater
2 KN FPSO Downstream Seawater
3 KF Upstream Seawater
4 KF Downstream Seawater
5 KG Upstream Seawater
6 KG Downstream Seawater

Plankton consists of two types, which is phytoplankton and zooplankton. Based on the monitoring result, it has indicated that phytoplankton had moderate or stable diversity index (H') around 1.2126 - 1.3254, well-distributed equitability index (E) around 0.9482 - 1.0559 and low dominance index (D) around 0.0539 - 0.068, whereas zooplankton had low diversity index (H') or precisely stable around 0.4074 - 0.6830, well-distributed equitability index (E) around 0.8539 - 0.9772 and low dominance index (D) around 0.2144 - 0.4480. **Table 6** shows the monitoring result for plankton, phytoplankton and zooplankton.



(a) (b)

Figure 9. Impacted Area Based on Toxicological Model of *Chanos chanos* at Depths of 7 m (a) and 75 (b)

The study area is rich on the nekton yield such as big and small pelagic fishes as well as fishes of sea bottom (from secondary data and interviews results). To identification the impacts of produced water in fishes, MuQual3d has completed with *Penaous monodon* and *Chanos chanos* toxicological model. For the simulation of *Penaous monodon* model, there is no impacted area figured. It means that this species can still accept the chemical concentration in produced water. Whereas, the simulation of *Chanos chanos* model, impacted area around 10.1% until 11.12%. **Figure 9** shows impacted area based on toxicological model of *Chanos chanos* at depths of 7 m and 75 m.

CONCLUSION

Phenol concentration spreading at the depths of 7 m and 75 m such as 0.014 - 0.14 µg/L, where as oil and grease concentration such as range between 0.17-1.73 µg/L. These spreading simulations show that produced water discharge have complied the sea water quality standard for aquatic biota.

Phenol, oil and grease concentration distribution in mean sea water layer is higher than in sea bottom layer. Some factors that affect higher concentration are volume of produced water discharge, phenol, oil and grease concentration in produced water and also it reaction with sea water.

From laboratory results of aquatic biota for phytoplankton and zooplankton, are indicated that there is occurrence of ecological pressure within the aquatic area, but still in moderate and stable condition, which means that it could be changed according to the surrounding environment. Where as, from *Chanos chanos* toxicological model simulation about 10.1% until 11.12% of study area has impacted.

For balancing the ecosystem of Natuna sea, produced water discharge management and other research for aquatic biota in study area are needed.

ACKNOWLEDGEMENT

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