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Effect of Sea Temperature on Crude Oil Spill Condition – Simulator Pisces II

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Dorota Jarząbek[1] , Kinga Drwięga[2]

Abstract:

Purpose: *The purpose of this study was to analyze influence of sea temperature on oil spill at constant air temperature. The possibility of using computer simulation to predict the behavior of oil spills at sea enables both to make better use of the forces and resources at their disposal to control them. Therefore, an attempt was made to analyze effect of selected simulation parameters (related to hydro meteorological conditions) on the response of the oil spill depending on the type of spill (type of oil spilled) under the same simulated weather conditions.*
Methodology: *The study was conducted using a Pisces II oil spill simulator.*
Crude oil at various densities (light, medium and heavy) was tested at different sea water temperatures.
Findings: *On the basis of the research carried out, data were obtained showing the relationship between temperature and the physical properties of crude oil.*
Practical Implications: *Researches presented can have direct influence in studies regarding the effectiveness of Oil spill cleaning up operations.*
Originality/Value: *Studies conducted under simulated conditions have shown the relationship of oil spill behavior to existing hydro meteorological conditions.*

Keywords: *Simulator Pisces II, sea temperature, crude oil, viscosity, oil spill.*

JEL codes: *R490.*

Paper Type: *Case study.*

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[1]*Maritime University of Szczecin, Poland, ORCID 0000-0003-3745-1932*
d.jarzabek@am.szczecin.pl
[2]*Maritime University of Szczecin, Poland, ORCID 0000-0001-8208-070X*
k.drwiega@am.szczecin.pl

1. Introduction

Research on the characteristics of crude oil has been carried out for years. This product is the basis of today's energy, transportation and many other areas of life such as the petrochemical industry. Crude oil consists of paraffinic, cyclic and aromatic hydrocarbons and contains sulphur, oxygen and nitrogen compounds (http://chemia.wiedza.diaboli.pl/ropa-naftowa---wlasciwosci-i-przerobka/).

Oil spill at sea is subject to physical and chemical processes, the intensity of which depends on the type of oil as well as weather conditions (Fabisiak, 2008). The most important ones include water dissolution, evaporation, dispersion, adsorption, sedimentation of heavy fractions, oxidation, and microbial biodegradation. The mentioned above processes significantly affect the distribution of crude oil residues in the marine environment. When oil spill occurs, the spread of oil on the sea surface begins (Fabisiak, 2008).

The computer simulation used in the prediction of the behavior of oil spills at sea enables better use of the resources available to control them. Therefore, an approach was made to verify the influence of selected simulation parameters (related to hydro meteorological conditions) on the crude oil spill.

2. Crude Oil

According to past research, oil field has been formed by the decaying remains of both plant and animal organisms(www.ekologia.pl). Spilled crude oil is subject to various transport and transformation processes, collectively referred to as evaporation, which result in a marked change in its physical and chemical properties.

Some of the key weathering processes that determine the performance the spilled oil are, evaporation, spreading, dissolution, natural dispersion in the water column, advection, turbulent diffusion, hydrolysis, photo-oxidation or biodegradation (Onyelucheya, 2014). Crude oil is a thick, oily fluid with a strong odor and, depending on its chemical composition, varies in color from yellowish-brown to brown to black, sometimes greenish, reddish or colorless. Crude oil is insoluble in water but dissolves in organic solvents. It is flammable liquid.

Sulfur compounds are present in all types of crude oil, and the amount of sulfur ranges from 0.01 to 8% by weight. The more sulphur in crude oil, the density of the oil increases (Politechnika Gdańska, Wydział Chemiczny, Katedra Technologii Chemicznej, Chemia Środowiska – Likwidacja rozlewów substancji ropopochodnych metodą sorpcyjną, 2009; http://weglowodory.pl/rodzaje-ropy-naftowej/).

Based on the sulfur content, crude oil is divided into:

- low-sulphur

- medium
- sulphur
- high-sulfur.

Some of the physical and chemical properties used to determine crude:

- density
- sulphur, chloride, paraffin content
- water and solid contaminants
- viscosity
- fractional composition (characteristic distillation)
- vapor pressure
- acid value
- total nitrogen content.

The most important are density, viscosity, flow temperature, volatility and sulfur content (http://www.nw.pwr.wroc.pl/?page_id=853).

3. Density

One of the basic physical crude oil properties is density, expressed as the ratio of a substance's mass to its volume, measured in units of kg/m^3 or g/cm^3 at the same temperature. The relative density is commonly used, which is the ratio of the density of a substance at a given temperature to the density of a standard, i.e., water temp. 4, 15 lub 20^oC. Relative density is a non-dimensional measure (Jarząbek and Juszkiewicz, 2016).

Density of crude oil at temperature of 20°C is 0,73-1,03 g/cm^3. Due to various values of density crude oil is categorized as: light (< 0,87 g/cm^3), medium (0,87-0,92 g/cm^3), heavy (0,92- 1 g/cm^3) and super heavy (> 1 g/cm^3), (http://produkty.totalpolska.pl/wiedza/rozdzial%2004.pdf).

In the petroleum industry the API (*American Petroleum Institute*) unit is commonly used for density. It is based on the measurement of the density of a liquid at 60^oF ($15{,}6^oC$) and comparing the resulting value to the density of water at that temperature. Crude oil at API= 38 is called as a light, at API 22 to 38 is called medium, and with API below 22 is called as heavy (Jarząbek and Juszkiewicz, 2016).

The formula to calculate API is shown in equation 1:

$$API = \frac{141{,}5}{d} - 131{,}5 \tag{1}$$

Where: **d-** density of crude oil.

4. Viscosity

Viscosity is the one of the most important oil parameter. It determines the movement of the oil during the whole transportation process and when spilled into the ground or water (Jarzabek and Juszkiewicz, 2016). Under the influence of atmospheric factors, oil ages, which significantly changes its viscosity (Onyelucheya, 2014).

In addition, viscosity is a measure of a flow resistance of oil. The measure of kinematic viscosity is Stokes (St), in practice a used unit 100 times smaller called centistokes (cSt) (http://produkty.totalpolska.pl/wiedza/rozdzial%2004.pdf).

5. Volatility

Crude oil volatility is another important technological parameter. When talking about volatility of crude following need to be taken into account: fractional composition, content of gaseous hydrocarbons (C1-C5) and vapor pressure. (http://produkty.totalpolska.pl/wiedza/rozdzial%2004.pdf).

6. Simulations

The case study was conducted on the Pisces II simulator (PISCES II (version 2.93), Transas Ltd., 2008), analyzing 3 types of oil at 3 different water temperatures.

The simulator allows modeling the processes of dispersion of oil spills in water, their evaporation and sinking under various hydro meteorological conditions, like: air and water temperature, wind direction and speed, sea state, and parameters of sea current. All these parameters can be actively changed during the simulation.

The study was conducted for following types of crude: light - Bent Horn A-02, medium - Arabian medium and heavy - ADGO. The characteristics of these fuels are presented in Table 1.

Table 1. *Characteristics of the types of oil used in the experiment*

Fuel characteristic	**Bent Horn A-02**	**Arabian medium**	**ADGO**
group	II	III	IV
density	41.9 [API]	29.5 [API]	16.8 [API]
surface tension	17,6 [dyne/cm]	18.6 [dyne/cm]	16.8 [dyne/cm]
viscosity	14.8 [cSt]	33 [cSt]	65 [cSt]
maximum water content	86%	85%	70%
emulsification constant	20%	0%	0%
pour point	- 17 [°C]	-10 [°C]	-23.33[°C]
flash point	- 14 [°C]	-13 [°C]	-43[°C]

Source: *PISCES II Manual (version 2.93), Transas Ltd., 2008.*

During the experiment simulating spillage of 500 tons of 3 types of crude at constant air temperature 5ºC in different water temperatures 0ºC, 5ºC and 15ºC was monitored for the 24 hours period.

6.1 Simulation no 1- Oil Spill at 0ºC of Sea Temperature

The simulations were conducted over a period of 24 hours, and the spill of the total amount of oil occurred gradually, over a period of 5 hours releasing 100 tons of oil into the sea every hour. Over the next hours, the movement, evaporation, and dispersion of the oil spill were observed. The record of spill data was made automatically every 15 minutes.

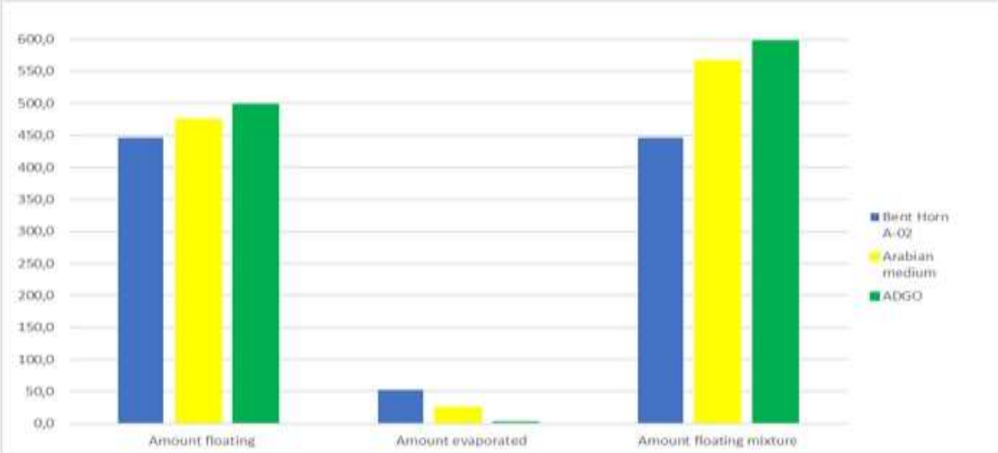
The recorded data (Table 2) show that at 0^0C of sea temperature the highest evaporation of light fractions occurred for light crude oil, while the lowest for heavy oil. The maximum thickness was obtained by the spot formed from heavy oil, while the smallest from light oil. As the thickness of the spill increased, its viscosity increased. Opposite situation was observed for size of the oil spill, with the largest area for light oil and the smallest area for heavy oil, as a result of the oil thickness and viscosity mentioned earlier (Figure 1).

Table 2. *Summary of oil spill simulations after 24 hours at 0^0C of sea temperature*

		Type of spilled oil					
		Bent Horn A-02(light)		Arabian medium (medium)		ADGO (heavy)	
	Indicator name	Quantity	Percent	Quantity	Percent	Quantity	Percent
1	amount of spilled oil	500 [t]	100%	500 [t]	100%	500 [t]	100%
2	amount of floating oil	446,6 [t]	89.3%	475 [t]	95%	497.7 [t]	99.5%
3	amount of evaporated oil	52,9 [t]	10.6%	24.8 [t]	4.96%	2.3 [t]	0.46 %
4	amount floating mixture	446,6 [t]		566.8 [t]		596.8 [t]	
5	maximum thickness of the spill	2.4 [mm]		3.4 [mm]		4.2 [mm]	
6	area of the oil spill	0.42 [km ^{2}]		0.36[km^2]		0.3 [km ^{2}]	
7	viscosity	89.6[cSt]		165 [cSt]		205 [cSt]	

Source: *Own study.*

Figure 1. *Oil Spill simulation results for different types of oil at 0^0C of sea temperature*



Source: *Own study.*

6.2 Simulation no 2- Oil Spill at 5^0C of Sea Temperature

The conditions for performing the simulation were same as those in simulation no 1, the only change being a 5^0C of sea temperature. As can be seen from Table 3, the highest evaporation of light oil fractions occurred similarly to the simulation discussed above. The other parameters discussed also performed similarly to simulation no 1. It is worth to mention that as the sea temperature increased, the viscosity of all types of oil decreased (Figure 2).

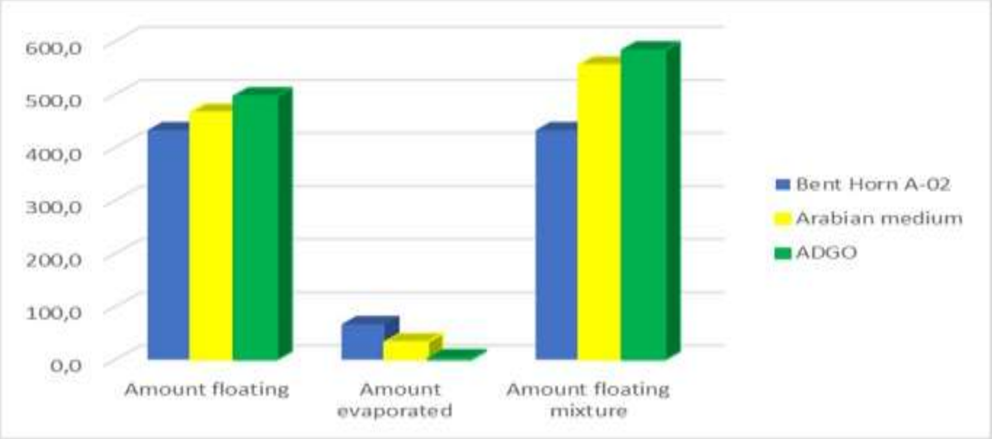
Table 3. *Summary of spill simulations after 24 hours at 5^0C of sea temperature*

		Type of spilled oil					
		Bent Horn A-02(light)		Arabian medium (medium)		ADGO (heavy)	
	Indicator name	Quantity	Percent	Quantity	Percent	Quantity	Percent
1	amount of spilled oil	500 [t]	100%	500 [t]	100%	500 [t]	100%
2	amount of floating oil	432.4 [t]	86.5%	466.2[t]	93.2%	496.7 [t]	99.3%
3	amount of evaporated oil	66.8 [t]	13.4%	33.5 [t]	6.7%	3.3[t]	0.65%
4	amount floating mixture	432.4 [t]		555.5 [t]		583.4 [t]	
5	maximum thickness of spill	2.4 [mm]		3.4[mm]		4.6 [mm]	

6	area of oil spill	0.41 [km ^{2}]		0.36 [km^2]		0.2 [km ^{2}]	
7	viscosity	62 [cSt]		102[cSt]		102[cSt]	

Source: *Own study.*

Figure 2. *Oil Spill simulation results for different types of oil at 5^{0}C of sea temperature*



Source: *Own study.*

6.3 Simulation no 3- Oil Spill at 15^{0}C of Sea Temperature

As can be seen from Table 4 all the studied parameters behaved comparably to previous simulations (Figure 3).

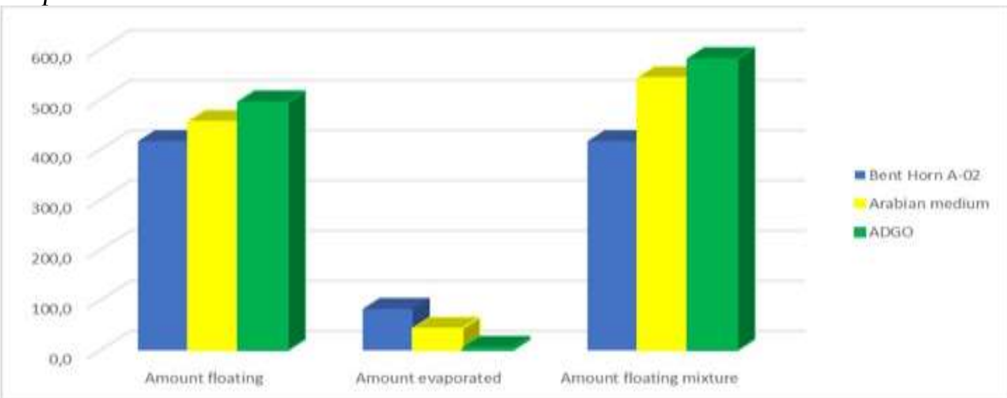
Table 4. *Summary of spill simulations after 24 hours at 15^{0}C of sea temperature*

		Type of spilled oil					
		Bent Horn A-02(light)		Arabian medium (medium)		ADGO (heavy)	
	Indicator name	Quantity	Percent	Quantity	Percent	Quantity	Percent
1	amount of spilled oil	500 [t]	100%	500 [t]	100%	500 [t]	100%
2	amount of floating oil	416.7 [t]	83.3%	456 [t]	91.2%	494.6[t]	98.9%
3	amount of evaporated oil	82.3 [t]	16.5%	43.6[t]	8.73%	5.4[t]	1.07%
4	amount floating mixture	416.7 [t]		543.1[t]		580.7[t]	
5	maximum thickness of the spill	2.4[mm]		3.4[mm]		4.6[mm]	

6	area of oil spill	0.40 [km^2]		0.35[km^2]		0.2[km^2]	
7	viscosity	46.4 [cSt]		68.4 [cSt]		57.1[cSt]	

Source: *Own study.*

Figure 3. *Oil Spill simulation results for different types of oil at 15^0C of sea temperature*

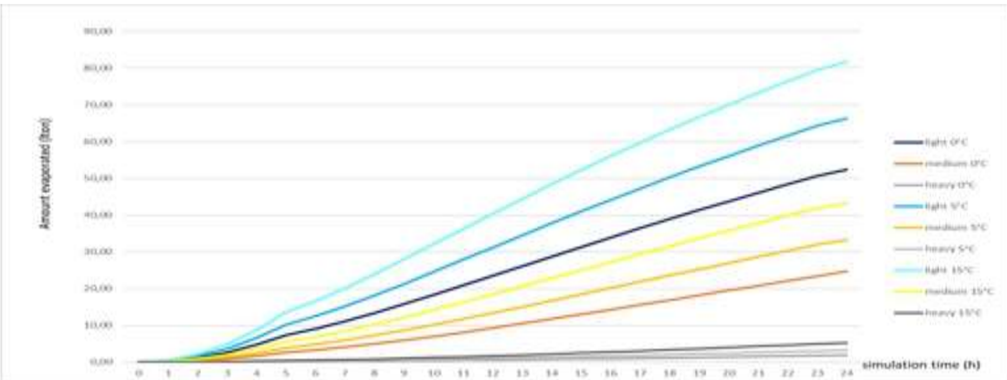


Source: *Own study.*

7. Analysis of the Results of Simulation

The performed studies show that the volatile fractions of oil are rapidly lost through evaporation. As illustrated in the figure below (Figure 4), the largest percentage of oil evaporates within the first few hours after the oil spill occurs. This can be seen by analyzing analysis data from the spill simulations. The largest amount of evaporated light fractions was found for light crude oil (Bent horn A-02). The result oscillated around 16%, for Arabian oil the medium was about 8.7%, while for heavy oil just over 1% was evaporated.

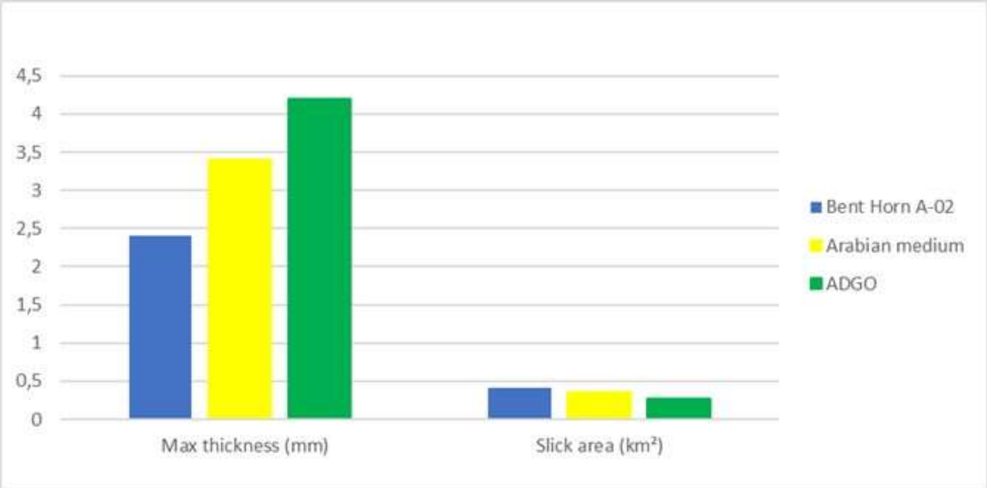
Figure 4. *Oil evaporation rate depending on its type at sea temperature 0^0C, 5^0C and 15^0C*



Source: *Own study.*

The oil spill area in the study found to be the largest for light oil and ranged from 0.42 to 0.40 km^2 (Figure 5), the smallest for heavy fuel and ranged from 3.0 to 0.2km^2. In contrast, oil spill thickness was biggest for ADGO oil and smallest for light fuel.

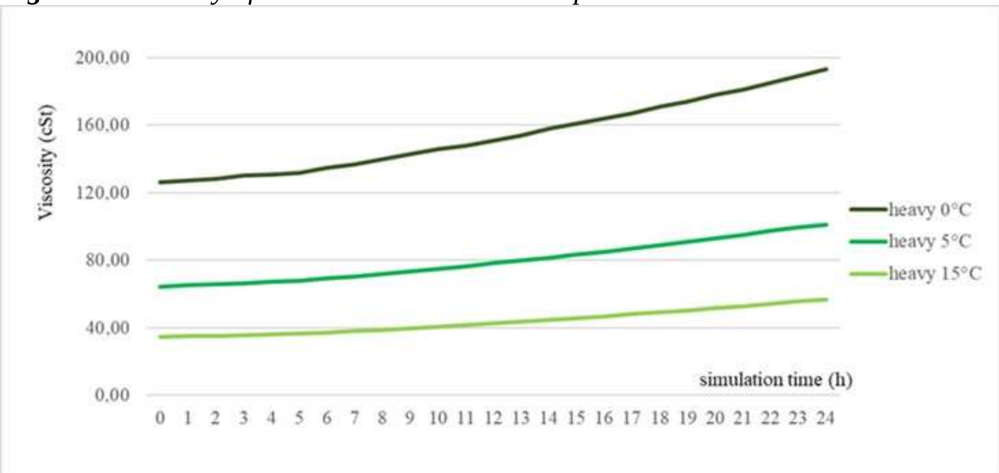
Figure 5. *Size and thickness of oil spill at 0^{0}C of sea temperature*



Source: *Own study.*

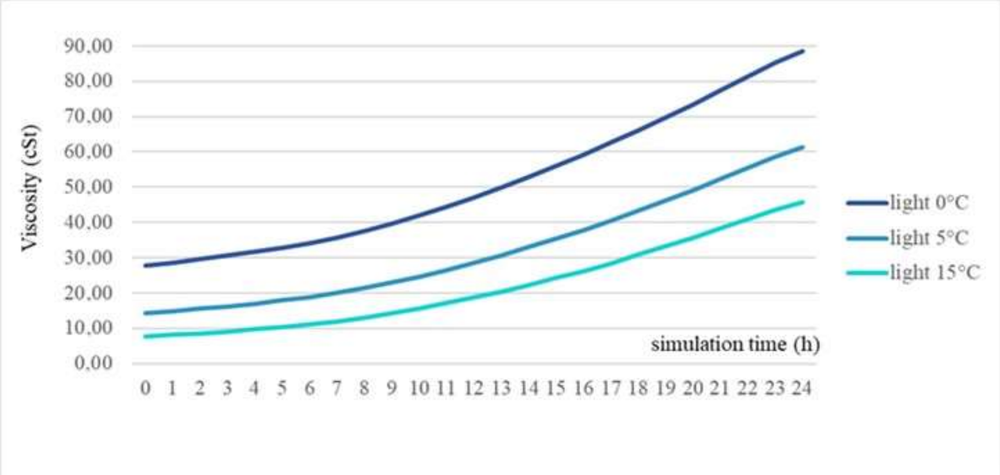
Simulation results from the Pisces II simulator show that as the sea temperature decreases, the viscosity of the oil increases, and thereby so does its density. The highest viscosity was recorded for the heavy fuel 198 cSt at 0^{0}C of sea temperature (Figure 6), the lowest for light oil 46,4 cSt at 15^{0}C of sea temperature (Figure 7).

Figure 6. *Viscosity of ADGO at various sea temperatures*



Source: *Own study.*

Figure 7. *Viscosity of Bent horn A-02 oil at various sea temperatures*



Source: *Own study.*

Several days after spillage, the hydrocarbons in the oil can be biodegraded, the level of biodegradation depending on the chemical composition and temperature. Biodegradation occurs at the water-oil phase partitioning surface. The amount of oil lost through dissolution is very small due to the low solubility of crude oil in water. In the other hand, some of the oil can be dissolved by photo-oxidation, in the presence of enabling factors such as sunlight and oxygen. The final effect is directly proportional to the surface area of the oil film, although the process is very slow (IPIECA IMO OGP CEDRE, 2015; http://www.nw.pwr.wroc.pl/?page_id=853).

8. Conclusions

The results obtained from the simulations confirm the influence of sea temperature on basic parameters such as density, viscosity, evaporation and oil spill thickness. Each of the simulations showed and confirmed past experiments that as the sea temperature increases, the evaporation of light oil fractions increases, the viscosity and size of the spill decreases, while the thickness of the oil patch increases. Low temperatures (0^0C) reduce the occurrence of fires or explosions, while oils increase their viscosity so as it becomes more steady. Heat removal from liquids with high molar masses or mixtures of compounds causes a smooth change in their temperature and characteristics.

Crude oil viscosity and density increases even to a solid consistency. Phase transition temperatures are important parameters that characterize petroleum products and other liquefied refinery products. Cooling of liquid fuels, apart from changes in viscosity, also causes turbidity. The second is a result of release of a separate solid or liquid phase, e.g.: benzene, paraffin, water or other solids (http://produkty.totalpolska.pl/wiedza/rozdzial%2004.pdf).

While spill of crude oil or other refinery products spreads, there is a process of reducing the concentration of hydrocarbons on the water surface. This process is caused by the evaporation of hydrocarbons with low molar masses. The volume of spilled oil can decrease by up to 1/3 of the original volume in 1 day. This implies changes in chemical composition and consequently in physical properties - change in density, metal content, non-metal content (Kurc *et al.*, 2005). The mentioned above changes could be observed in the experiment conducted under simulated conditions.

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http://www.nw.pwr.wroc.pl/?page_id=853

http://produkty.totalpolska.pl/wiedza/rozdzial%2004.pdf

http://weglowodory.pl/rodzaje-ropy-naftowej/