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Analysis of the environmental aspects of oil management in the Baltic Sea fishing fleet

Włodzimierz Kamiński, Marcin Szczepanek

Maritime University of Szczecin, Faculty of Mechanical Engineering, Institute of Ship Power Plant Operation
70-500 Szczecin, ul. Wały Chrobrego 1–2, e-mail: {w.kaminski; m.szczepanek}@am.szczecin.pl

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Abstract

The paper presents an analysis of ecological aspects of oil management in the Baltic Sea fishing fleet based on studies held as part of the project Operational Programme "Sustainable Development of the Fisheries Sector and Coastal Fishing Areas 2007–2013". There have been proposed algorithms to the preliminary estimation of oils consumption in the fishing vessel fleet, the amount of harmful substances emitted into the atmosphere, the amount of used oils reaching the boat bilges, the quantity of hydraulic used on fishing craft.

Introduction

Engine lubricating oils pollute the environment during their production and all the time while they are being used: when they are transported to the users, being stored for a long time, when they are used in an engine, while being disposed of or recycled after the operation.

In all those situations the degree of influence on environment is different and it depends on the following factors:

– chemical composition of oil;
– working conditions (working temperature above all) in the device (fuel engine);
– the way oils are treated;
– the possibility of being biodegradable;
– the possibility to recycle oil wastes or the used oil.

Chemical composition is the potential factor influencing the environment and it also determines the most ecological and economical way of recycling the used oil.

Working conditions for engine oil determine the quantity of its consumption and its quality (the working temperature mainly influences the intensity of physical / chemical changes, i.e. oxidation).

The grade of oil toxicity is different and depends on components structure, yet they are hazardous for soil and water too.

According to hazard for natural waters, oils are segregated into classes (the higher the class, the more serious the hazard):

- Class 0 – vegetable and mineral highly purified oils (the so called pharmaceutical and cosmetic oils);
- Class 1 – basic oils;
- Class 2 – trade lubricating oils;
- Class 3 – used by engines lubricating oils.

Hazard analysis for the environment

Factors influencing marine environment can be divided into 2 groups:

1) influencing marine water environment;
2) influencing the atmosphere.

All kinds of "thrown away" oils from fish catching craft belong to the first group, entering sea waters directly and indirectly, intentionally or unintentionally.

The quantity and type of the "thrown away" oils depends on many factors:

– the number of crew members;
– "pro-ecological" education of the crew;
– the size of the craft;
– the equipment of the craft in the fishing gear and accommodation stuff;
– technical equipment of the craft.

The joint power of the engines installed on cutters and fishing boats in Poland (881 craft) is of 99857.89 kW [7].

It is estimated that the required quantity of oil for engine lubricating systems for normal operation amounts 0.3–0.5 kg of oil /kW of engine power [7]. Having in mind the total power of engines installed on cutters and fishing boats, it can be calculated that the momentary quantity of oil consumed on cutters and fishing boats amounts from 30,000 to 50,000 kg. Engine lubricating oils used on cutters and fishing boats belong to the quality class CD, viscosity SAE 15W/40 coming from renown oil producers.

Due to the fact that engines installed on cutters and fishing boats are of old generation (10 years old or more), it is estimated that the consumption of oil in them amounts to 5 g/kWh. For engines of new generation (less than 10 years old) consumption of oil amounts up to 3 g/kWh.

Consumption of oil (Z) in the fishing fleet can be calculated according to the algorithm:

- For newer engines (up to 10 years old):

$$Z = 3 \cdot N \cdot W \cdot DP \cdot 24 \cdot 10^{-6} \text{ [Mg]} \quad (1)$$

- For older engines (more than 10 years old):

$$Z = 5 \cdot N \cdot W \cdot DP \cdot 24 \cdot 10^{-6} \text{ [Mg]} \quad (2)$$

where:

Z – consumption of lubricating oils in the Polish Baltic Sea fishing fleet;
N – total power of engines installed on fishing crafts (99,857.9 kW);
W – simultaneity coefficient of the used power for installed engines;
W = Σ power used during fishing days / total installed power;
DP – number of fishing days.

In table 1, there have been given calculated quantities of lubricating oil consumption (in tons) by old and new engines for boats and fishing cutters at different simultaneity coefficients of the used power and the number of fishing days.

The influence of oil properties on harmful compounds emission to atmosphere

Engine lubricating oils pollute the environment during their production and all the time while they are being used: when they are transported to the users, being stored for a long time, when they are used in an engine, while being disposed of or recycled after the operation. The grade of oil toxicity is different and depends on 3 factors: chemical composition of oil, working conditions (working temperature) in the fuel engine and the way oil is treated. Chemical composition is the potential factor influencing the environment and it also determines the most ecological and economical way of recycling the used oil.

The quality, composition and physical / chemical properties of the engine oil are important factors for the engine operation and they can influence in a great way the composition and level of toxic emissions being formed, while the engine is working. The influence of oil on the m/a indicators is a complex phenomenon, not quite well known. Some possibilities of oil type influence on toxic emissions have been shown in figure 1.

Extensive investigation about oil influence on toxic emissions of exhaust gases composition have been done by Manni, Flori and Gommellini [4, 5]. They have shown that the replacement of classic mineral oil SAE 15W/40 by fully synthetic oil SAE 5W/40 in the ZS engine reduces considerably emission of CO and PM and lowers smokiness

Table 1. Calculated total lubricating oils consumption by the Polish Baltic Sea fishing fleet

Simultaneity coefficient of the used power for installed engines	Minimum calculated lubricating oils consumption for "new" engines installed in the fishing fleet [Mg]					Minimum calculated lubricating oils consumption for "old" engines installed in the fishing fleet [Mg]				
0	0	0	0	0	0	0	0	0	0	0
0.1	18	72	108	144	180	30	120	180	240	300
0.2	36	144	216	288	360	60	240	360	480	600
0.3	54	216	324	432	540	90	360	540	720	900
0.4	72	288	432	576	720	120	480	720	960	1200
0.5	90	360	540	720	900	150	600	900	1200	1500
0.6	108	432	648	864	1080	180	720	1080	1440	1800
0.7	126	504	756	1008	1260	210	840	1260	1680	2100
0.8	144	576	864	1152	1440	240	960	1440	1920	2400
0.9	162	648	972	1296	1620	270	1080	1620	2160	2700
1	180	720	1080	1440	1800	300	1200	1800	2400	3000
	25	100	150	200	250	25	100	150	200	250
	Number of fishing days					Number of fishing days				

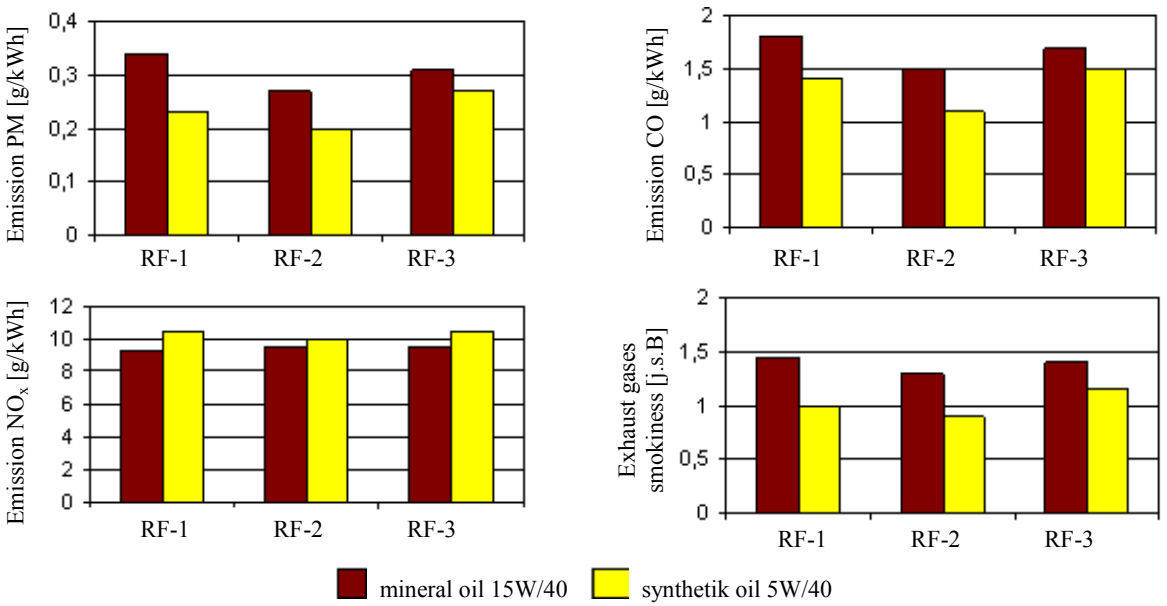

Fig. 1. Differences of toxic components emissions and smokiness of exhaust gases for ZS engine using mineral oil and fully synthetic oil, depending on the use of fuel type

of exhaust gases at a little increase of NO_x emissions (Fig. 1). They have also pointed out that there is a strong connection between oil emission and used fuel (Table 2).

Low emission of products from incomplete combustion for synthetic oils is caused by better combustibility of synthetic basic oil than that of mineral base. Additionally, mechanical losses are less due to lower viscosity of oil 5W/40. Due to low viscosity and volatility of synthetic oil its consumption is also lower [8].

Different additions to oils, e.g. Nulon, Slick, Moton, etc. are of unfavourable influence on exhaust gases toxicity. Most of them are based on PTFE (Teflon). Particles of Teflon enter the combustion chamber together with the oil and create very toxic products (e.g. phosgene) which are emitted to atmosphere jointly with exhaust gases.

Toxic components emission of exhaust gases is strictly connected with the consumption of oil by the engine. In papers [2, 3] cause and effect relation to the intensity of consumption and the level of toxic compounds emission have been described; it mainly refers to hydrocarbons (including PAH) and solid particles. It is worth remembering, that the oil consumption is only 0.5–0.1% of the fuel consumption, so 16–18% increase of PM emissions is considerable for the double increase of oil consumption [8].

The increase of engine oil consumption depends on many processes taking place inside the cylinder and their effects. They are [1]:

- scraping the oil, by rings, to the combustion chamber;
- the increase of oil layer remaining on the cylinder sliding surface after the piston is gone when the mean temperature is higher;
- absorption-desorption processes of fuel and oil pairs;
- adsorption of oil pairs by soot or other oil particles;
- the increased quantity of evaporated oil as a result of cavitation.

Table 2. Oil and test fuels properties [6]

Engine oil					
Class	Type	Viscosity at temp. 100°C [mm/s]	Viscosity at temp. 40°C [mm/s]	Viscosity index	Noacka Volatility [%m/m]
SAE 15W/40	SAE 15W/40	SAE 15W/40	117	140	9.5
SAE 5W/40	SAE 5W/40	SAE 5W/40	66	181	8
Fuel oil (distillate)					
Determination (Research Fuel)	Density at tempt. 15°C [kg/m]	Sulphur content [ppm]	Cetane number	Mono / diaromats Content [%m/m]	IBP/FBP [°C]
RF-1	RF-1	RF-1	58.6	18.0/3.5	194/353
RF-2	RF-2	RF-2	62.6	12.3/4.4	184/372
RF-3	RF-3	RF-3	51.2	22.8/3.9	179/351

The final effect of the m/a phenomena is the appearance of not combusted hydrocarbons and some hydrocarbon solid particles ($PM_{HC} \sim PM_{sof}$) coming mainly from the consumption of lubricating oil PM_{Lube} (LUBE-*Lubrication Effect*).

The increase of oil layer and the increase of oil temperature influence the intensity of absorption (desorption) processes between fuel and oil. In the absorption of fuel pairs in the oil layer there is a decrease of viscosity in the surface layer. That is why in the exhaust stroke there is a take off of oil particles due to whirls of exhaust gases. It is possible because there is oil-fuel mist over the surface of oil layer due to desorption. Is the result of not combusted hydrocarbons that can be changed into more or less developed hydrocarbon groups, while their oxidation cannot take place any longer. There is absorption of oil pairs in the compression stroke as well. The quantity of absorbed oil depends on the density and temperature of the oil layer on the cylinder sliding surface. These factors are strictly connected with the quantity of oil consumption. Thicker layer causes the temperature rise and that increases evaporation, so the consequence of that is the increased absorption of oil. Oil pairs released in the desorption process can oxidize, or pyrolisis and pyrosynthesis take place. Yet, very little of desorptioned oil pairs can oxidize and the emission of hydrocarbons coming from engine oil cannot be reduced much.

Decomposition (pyrolisis) or reconstruction (pyrosynthesis) of oil pairs hydrocarbon structures take place due to high temperature influence on gases. It exerts badly influence on the harmfulness of emitted compounds. Due to pyrolisis and pyrosynthesis heavy hydrocarbons are created, called PAC (Polycyclic Aromatic Compounds), including PAH (Polycyclic Aromatic Hydrocarbons) and heterocyclic hydrocarbons (with additional single atom of sulphur, nitrogen or oxygen in their structure). Further formation of emitted hydrocarbons can happen in the exhaust system. Some desorptioned oil pairs enter the cold surface over the piston. Low exhaust gases temperature and very little oxygen content in them cause the exhaust of not reconstructed hydrocarbons [8].

Emission of harmful compounds coming from lubricating oils to atmosphere is influenced mainly by technical equipment of a craft, such as:

– engine construction;
– engine technical condition;
– the type of lubricating oil used.

The so called products of combustion and not combusted particles of 50–70% of the consumed lubricating oil are transmitted to atmosphere. Having that in mind, it is possible to calculate the quantity of harmful substances from lubricating oils of fishing boats engines that are emitted to atmosphere (E). The presented below algorithms can be used:

For newer types of engines (up to10 years):

$$E = 3 \cdot 0.5 \cdot N \cdot W \cdot DP \cdot 24 \cdot 10^{-6} \text{ [Mg]} \quad (3)$$

For older engines (more than 10 years old):

$$E = 5 \cdot 0.7 \cdot N \cdot W \cdot DP \cdot 24 \cdot 10^{-6} \text{ [Mg]} \quad (4)$$

where:

E – quantity of harmful substances from lubricating oils emitted to atmosphere;
N – total power of engines installed on fishing craft (99,857.9 kW);
W – simultaneity coefficient of the used power for installed engines;

Table 3. Emission of harmful substances coming from lubricating oils to atmosphere

Simultaneity coefficient of the used power for installed engines	Minimum annual calculated emission of harmful substances coming from lubricating oils for new engines installed in the fishing fleet [Mg]					Minimum annual calculated emission of harmful substances coming from lubricating oils for old engines installed in the fishing fleet [Mg]				
0	0	0	0	0	0	0	0	0	0	0
0.1	9	36	54	72	90	21	84	126	168	210
0.2	18	72	108	144	180	42	168	252	336	420
0.3	27	108	162	216	270	63	252	378	504	630
0.4	36	144	216	288	360	84	336	504	672	840
0.5	45	180	270	360	450	105	420	630	840	1050
0.6	54	216	324	432	540	126	504	756	1008	1260
0.7	63	252	378	504	630	147	588	882	1176	1470
0.8	72	288	432	576	720	168	672	1008	1344	1680
0.9	81	324	486	648	810	189	756	1134	1512	1890
1	90	360	540	720	900	210	840	1260	1680	2100
	25	100	150	200	250	25	100	150	200	250
	Number of fishing days					Number of fishing days				

W = Σ power used during fishing days / total installed power;

DP – number of fishing days.

In table 3, there have been given calculated emissions quantities of harmful substances coming from lubricating oils for old and new engines at different simultaneity coefficients of the used power and the number of fishing days.

Taking into consideration the received calculated values of harmful substances coming from lubricating oils used in the Baltic Sea fishing fleet emitted to atmosphere, it can say that the quantities of the substances are alarmingly high, although they have been calculated as minimum values and can be higher in fact. Mistakes in the calculation of real emission arise from the difficulty to determine practically coefficients taken in calculating algorithms; the assumed calculating coefficients may be described as optimistic ones.

Due to their special harmfulness, pollution coming from this source of emission is extremely high. The scale of the emission strictly depends on the mean quantity of engine working hours.

It is worth-mentioning that the mean calculated emission of harmful substances coming from lubricating oils for newer engines is more than twice lower in comparison with the emission from older engines.

Oils used on fishing boats are factors polluting environment

Oil primary components such as aromatic and unsaturated hydrocarbons and heteroorganic compounds (that include sulphur, nitrogen and oxygen) are harmful for a man. Mineral oils are mainly received from selective refining with solvents, e.g. phenol, furfulol or hydrocarbon processes (hydrocracking, hydrofining) by means of which quite many unwanted components are removed, harmful to human heath as well. In the refining industry, for the measurement of content in polycyclic oils of aromatic hydrocarbons (PAH) their grade of extraction with dimethyl sulfoxide (DMSO) is commonly used. Petroleum products of more than 3% extract are considered to be dangerous for a man. Some additions, the so called refined, containing compounds of such elements as chlorine, sulphur, phosphorus are also dangerous to natural environment. The content of very harmful to health additions containing chlorine, barium and lead have been eliminated or limited in many countries.

Lubricating oil in operation provides among others, absorption and removal of products coming from oil combustion and wear out of engine parts. These pollutants are mainly kept in oil which also contains, apart from primary dangerous components, additional ones such as zinc, copper, nickel, chromium etc. Some oil is combusted in the engine, evaporated, or there are leaks. According to PN-C-96050 the used oils are defined as the ones of pertoleun or ester origin that have lost their practical properties while being used and cannot be longer used for their original purpose and so are oil-water blends. Used oils should not contain harmful substances, which could make the regeneration process difficult, or enrich the regenerate.

In accordance with Polish ecological law used oils are recognized as hazardous waste.

Life or heath hazard or the risk for environment arising from the m/a is fully justified, if the chemical content of the used oil is analyzed, taking into consideration the source of origin for particular components, physical-chemical changes that affected the oil in operation and possible pollution of oil while being disposed of and stored. As a result of fuel oil combustion and engine petrol in particular, process of hydrocarbons pyrolisis takes place which causes the creation of polycyclic aromatic hydrocarbons with pyrene benzoate which may have carcinogenic properties following biological and medical research.

When an engine is in operation, there are not only changes in hydrocarbon component of a particular lubricating oil. The so called refined additions are changed above all, and the changes make them pass to another chemical and physical structure. Generally speaking, the changes cause destruction of particles and transition to simple substances. Calcium carbonates, magnesium and barium carbonates are created. Sulfides, tiophosphates, metal oxides are created. More complex substances are created as a result of inorganic substances chemical activity on hydrocarbons destruction products. There are also present products of thermal and mechanical decomposition of polymers.

By adding metals from engine moving parts wear out, it can be shown that used oils contain many elements from Mendeleev table in a different physical-chemical form. When oil is in operation, its toxicity increases as a result of different thermo-oxidizing changes (polymerization, condensation). The toxicity grade depends on conditions and time of application, yet pollution with products of incomplete combustion of fuel and oil is their characteristic feature.The increase of toxicity of oil together with longer operational period result from the higher concentration of PAH in it. At present,

collection of the used oils and their controlled recycling in the least harmful to environment way is a must because there are in them polycyclic aromatic hydrocarbons, some products from changes of the so called refined additions (calcium sulfonates, zinc diophosphanes, succinicimide dispergators, sulfurated phenates, highly sodium sulfurated phenates, phenols), and heavy metals (Pb, Zn, Cu, Ni, Cd, Fe, Cr, Mn) which are harmful to life and man's health in particular. The CONCAWE [main petroleum companies] report has shown that more than 50% of lubricating oils is consumed irretrievably. Used oils always get to environment (combustion, evaporation, leaks from lubricating system, spills, oil exchanges, breakdowns).

Fishing boats engine operation is the source of used oils for the fishing fleet. It is highly probable that the oil can enter sea waters due to the lack of any recycling devices for the used oil on boats and the lack of any oil collection in ports and berths. Due to outdated engine construction and their seals it can say that the used oil leaks into boat bilges and is practically pumped out into the sea. There are no oil separating devices because of the complex nature and size of the mechanisms. It is estimated that leaks are about 10% of the oil consumption. The leaks on fishing boats can be regarded as a "thrown away" to the sea.

By using the term "thrown away" of harmful substances or drains containing such substances, it is meant any, no reason stated, outflow from the vessel / fishing craft and comprises any discharge, removal, spillage, pumping out, emission or emptying of oil.

The quantity of used oils getting into bilges as leaks is the function of engine working hours number and the technical condition of the engines.

The quantity of used oils getting into boat bilges (P) can be determined basing on the algorithm formulas (1) and (2).

In fact, the quantity of oil leaks can be larger because of engine construction, fishing crew qualifications and their ecological knowledge. The Calculation of the oil leaks quantity from engines is presented in table 4.

It can be noticed that hundreds of tons of oils coming from boat and cutters engine operation can enter the sea annually. Such quantity of harmful substances getting into sea waters influences badly sea life because:

- oil film on the surface of water limits the light access needed for the development of zooplankton and phytoplankton;
- absorption of harmful substances contained in lubricating oils by living organisms, fishes and zooplankton;
- food worsening for fishes (zooplankton and phytoplankton) poisoned with chemical substances limiting the reproduction of fish types in this way;
- lower tourist attraction of seaside areas.

Hazard coming from operated hydraulic devices

Hydraulic fishing devices – hydraulic winches operate on 205 Polish craft of the Baltic Sea fishing fleet. Hydraulic oils used in these hydraulic systems are a potential factor for the Baltic Sea waters pollution. High working pressure of hydraulic oil, outdated construction and the age of devices is the reason of frequent cracks of lines and hydraulic joints or seals, causing leaks of hydraulic oils to boat bilges. The oil is a potential "thrown away" in the same way as the used oil or leaking oil from

Table 4. Calculated oil leaks quantity from engines of the Baltic Sea fishing fleet

Simultaneity coefficient of the used power for installed engines	Minimum calculated quantity of lubricating oil leaks for new engines installed in the fishing fleet [ton]					Minimum calculated quantity of lubricating oil leaks for old engines installed in the fishing fleet [ton]				
0	0	0	0	0	0	0	0	0	0	0
0.1	1.75	7	10.5	14	17.5	3	12	18	24	30
0.2	3.5	14	21	28	35	6	24	36	48	60
0.3	5.25	21	31.5	42	52.5	9	36	54	72	90
0.4	7	28	42	56	70	12	48	72	96	120
0.5	8.75	35	52.5	70	87.5	15	60	90	120	150
0.6	10.5	42	63	84	105	18	72	108	144	180
0.7	12.25	49	73.5	98	122.5	21	84	126	168	210
0.8	14	56	84	112	140	24	96	144	192	240
0.9	15.75	63	94.5	126	157.5	27	108	162	216	270
1	17.5	70	105	140	175	30	120	180	240	300
	25	100	150	200	250	25	100	150	200	250
	Number of fishing days					Number of fishing days				

operating engines. Hydraulic oils have refined additions which influence sea life in a very negative way, similarly as engine oils for marine environment.

Due to specific hydraulic systems described above, probability of their breakdown with the leak of oil can be estimated as 0.25. The probability accepted on this level arises from the operational experience of hydraulic systems.

Mean quantity in hydraulic systems of boats and fishing cutters amounts up to 150 dm^3 of hydraulic oil. Mean quantity of the leak from the system because of the breakdown is about 10% of the oil volume used in the hydraulic system.

The quantity of hydraulic oil used on fishing craft can be determined by the algorithm:

$$ZH = 0.25 \cdot 0.1 \cdot H \cdot P \cdot W \cdot DP/365 \ [dm^3] \quad (5)$$

$$ZH = 205 \cdot 150 \cdot 0.1 \cdot 0.25/365 \cdot W \cdot DP \ [dm^3] \quad (6)$$

where:

- ZH – consumption of hydraulic oil in the Polish Baltic Sea fishing fleet;
- W – simultaneity coefficient of hydraulic winches use;
- W = Σ of craft using hydraulic winches during fishing days / total number of craft with hydraulic winches (205 craft);
- DP – number of fishing days;
- P – mean capacity of hydraulic system (150 dm^3);
- H – number of craft with hydraulic winches (205 pieces).

In table 5, there has been presented calculated quantity of hydraulic oil; in fact these quantities can be much larger.

Table 5. Calculated hydraulic oils consumption in the Polish Baltic Sea fishing fleet

Simultaneity coefficient of hydraulic winches use	Calculated minimum hydraulic oils consumption of in the Polish Baltic Sea fishing fleet [dm^3]				
0	0	0	0	0	0
0.1	5.25	21	31.5	42	52.5
0.2	10.5	42	63	84	105
0.3	15.75	63	94.5	126	157.5
0.4	21	84	126	168	210
0.5	26.25	105	157.5	210	262.5
0.6	31.5	126	189	252	315
0.7	36.75	147	220.5	294	367.5
0.8	42	168	252	336	420
0.9	47.25	189	283.5	378	472.5
1	52.5	210	315	420	525
	25	100	150	200	250
	Number of fishing days				

Total quantity of the consumed oil should be regarded as "a thrown away" to the sea. The consumption of hydraulic oil results from leaks, breakdowns and the loss of oil during hydraulic devices operation.

Conclusions

- The calculated results of emissions to atmosphere of harmful substances coming from lubricating oil show serious hazard of atmosphere pollution. Harmful substances coming from oils limitation is possible by means of fishing craft modernization and the exchange of old generation engines into new ones.
- The calculation results of lubricating oils leaks in lubricating systems of boats and fishing cutters show considerable hazard of marine waters pollution with oils because the m/a leaks are regarded as potential "thrown away", that is the outflow of oils from vessels / craft (intentional or unintentional). Limitation of the "thrown away" is possible by means of fishing craft modernization and the exchange of old generation engines into new ones.
- The calculation results of hydraulic oils consumption in the Polish Baltic Sea fishing fleet show considerable hazard of marine waters pollution with hydraulic oils. Consumption of hydraulic oil results from the existing leaks, breakdowns and oil loss during hydraulic devices operation and is regarded as potential "thrown away", so it pollutes marine waters too. Limitation of this pollutant can be done by means of hydraulic systems modernization on fishing craft, use of modern materials and modern hydraulic systems ideas.
- Calculated quantities of emissions and "thrown away" presented in this paper can be larger in reality, due to poor technical condition of fishing fleet. The accepted for calculations of potential emissions coefficients are empirical which serve for the calculations of minimum values.

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