Mirosław DORS[1], Tomasz IZDEBSKI[1], Bartosz HRYCAK[1], Jerzy MIZERACZYK[1,2], Marcin HOŁUB[3], Michał BONISŁAWSKI[3]

The Szewalski Institute of Fluid Flow Machinery Polish Academy of Sciences (1),
Gdynia Maritime University, Department of Marine Electronics (2),
West Pomeranian University of Technology (3)

Microwave plasma module for destruction of oil slicks

***Abstract**. Design of mobile device for oil slicks destruction on the sea using microwave plasma is presented. Microwave plasma was formed in nitrogen flowing with a rate of 10 L/min. Such plasma causes evaporation and partial oxidation of oil separated from water. In the next step gaseous hydrocarbons are fully oxidized in a reactor of dielectric barrier discharge.*

***Streszczenie.** Przedstawiono projekt pływającego urządzenia do niszczenia plam ropopochodnych na powierzchni morza za pomocą plazmy mikrofalowej. Plazma mikrofalowa jest generowana w azocie przepływającym z natężeniem 10 dm^3/min. Plazma powoduje odparowanie i częściowe utlenienie składników ropopochodnych oddzielonych wcześniej od wody w separatorze. W kolejnym etapie następuje całkowite utlenienie gazowych węglowodorów w reaktorze wyładowania barierowego. (**Moduł plazmy mikrofalowej do niszczenia plam ropy**).*

Keywords: plasma, microwave discharges, oil slicks.
Słowa kluczowe: plazma, wyładowania mikrofalowe, wycieki ropy.

Introduction

During the last decade shipping has steadily increased, reflecting intensifying co-operation and economic prosperity around the Baltic Sea region. An average of 2,000 ships are at sea each day, including 200 tankers carrying oil or other potentially harmful products. It is estimated that the transportation of goods by sea will double by 2017 in the Baltic region. General cargo and container traffic is expected to triple, and oil transportation may increase by 40%. The expansion and construction of oil terminals on the shores of the Gulf of Finland and regional economic growth may lead to even higher increases in shipping. Increasing maritime transportation threatens fragile ecosystems and the livelihoods of many people who depend on the sea. Increased shipping is accompanied with increased operation in Baltic Sea ports. As a result frequency of small leakages of oil and bilge water become higher, most of all in the port and docs area. Since the only available way of destruction of such waste is incineration, pollution of air in the Baltic Sea region with combustion products increases. Moreover, incineration is energetically inefficient and expensive. In this work we present a new mobile device as a tool for removal and destruction of all kind of pollutions discharges from ships and operating installations. Using mobile devices which could destroy oil and oil-kind slicks directly on the sea surface would much decrease both energy consumption and air pollution.

Concept of the plasma device

The concept of the entire device is based on the module construction (Fig. 1). All modules will be fixed on the platform equipped with floats (Fig. 2). The following main modules has been developed:

- power supply module – which provides proper voltage and current to all electrical components of the device, including pumps, valves, rotors, high voltage sections of plasma modules,
- first plasma module – the role of which is using microwave plasma for conversion of oil slick polluting sea surface to gaseous hydrocarbons,
- second plasma module – it has to decompose gaseous hydrocarbons transported from the first plasma section into harmless products,
- third plasma module (optional) – which should clean the output if the second plasma unit could not provide completely unpolluted exhaust gas.

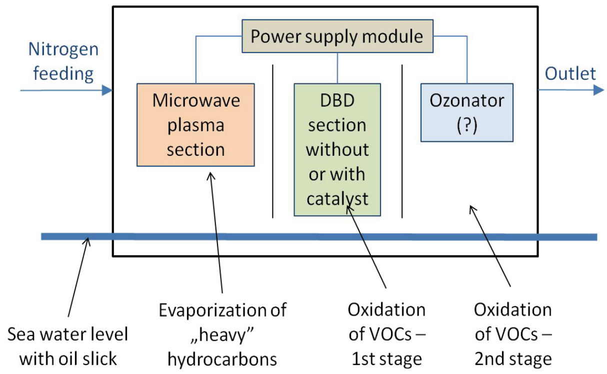

Fig.1. Concept of plasma device for oil slicks removal on the surface of seawater.

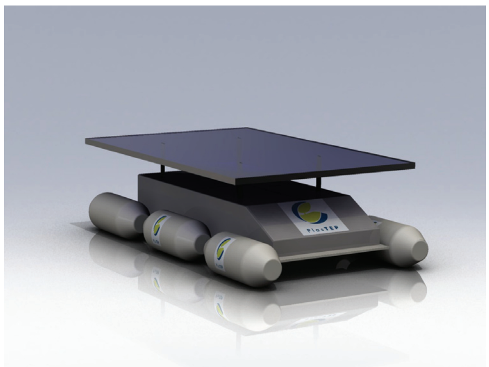

Fig.2. Proposed mobile device for the oil slicks destruction - digital visualization.

On the platform, besides above mentioned modules, also other element of the device will be installed, such us high pressure flask with nitrogen delivering gas to plasma modules, and drum separator for oil-water separation (Fig. 3).

Microwave plasma module

This paper presents only microwave plasma module, which is the first step in destruction of oil slick. Preliminary tests with other electrical discharges forming plasma and kerosene as a simulator of oil slick showed that corona discharge, spark discharge and dielectric barrier discharge (DBD) transform the kerosene slick into aerosol only without any evaporation. The conclusion is that electrons accelerated and gaining high energy in corona, spark and DBD has not enough power neither to heat up the liquid hydrocarbon nor to brake bonds in their molecules producing volatile hydrocarbons. The same conclusions concerns oxidizing species such as ozone and oxygen atoms produced by above discharges. Their oxidizing potential is too low to convert liquid hydrocarbons into gaseous.

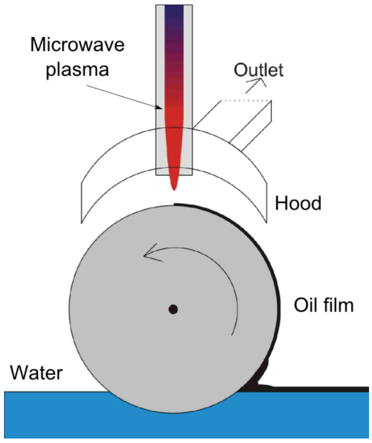

Fig.3. Oil-water separator with oleophilic foil.

The only possible solution that could be then concerned is high temperature plasma such as arc plasma. In our laboratory a microwave plasma torch, similar to arc, was used for evaporation of kerosene from the oleophilic metal plate. The advantage of microwave plasma is that in contrast to arc plasma it does not have contact with discharge electrode and does not make erosion of the electrode which could pollute water with metals. The microwave plasma torch was generated in a quartz tube in the system presented in Fig. 4 using nitrogen as a plasma generating gas flowing with a rate of 10 L/min.

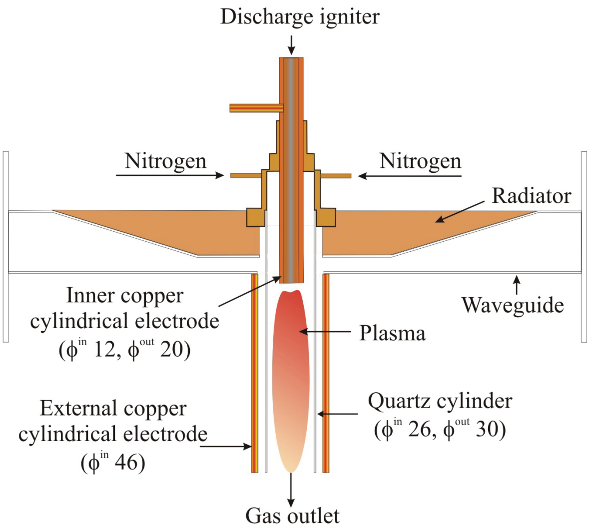

Fig.4. Microwave plasma source (MPS) for oil destruction.

The main parts of the microwave plasma module are: a microwave generator (magnetron), a microwave plasma source (MPS), a microwave supplying and measuring system and a nitrogen gas supplying system [1]. The microwave power (2.45 GHz, 1 kW) was supplied from the magnetron to the MPS via a rectangular waveguide (WR-430) having a reduced-height section. The absorbed microwave power P_A (0.6-5 kW), i.e. microwave power delivered to the discharge was calculated as P_I - P_R, where P_I and P_R are the incident and reflected microwave powers, respectively. The incident and reflected microwave powers P_I and P_R were directly measured using directional coupler (MEGA IND. 0G9Y7-66078-704) equipped with HP 478A bolometric heads and HP 432A power meters (Fig. 5).

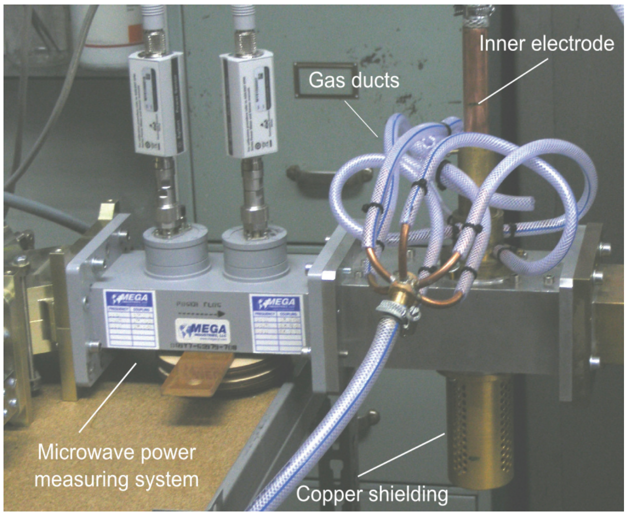

Fig.5. Microwave plasma source (MPS) with measuring system.

Nitrogen is introduced into the plasma by the four gas ducts creating the swirl flow in the cylinder. The swirl concentrated near the quartz cylinder wall and stabilized plasma generation. The swirl held the discharge at the centre of the cylinder and thus protected the cylinder wall from overheating.

The diameter of the copper shielding cylinder is 46 mm, so microwave at a frequency of 2.45 GHz cannot be guided along the copper shielding cylinder (operation below the cutoff frequency). This causes lower losses of microwave energy, i.e. higher microwave power is delivered to the unit volume of the plasma. Moreover, the copper shielding cylinder placed coaxially around the quartz discharge cylinder protects the personnel and instrumentation from the electromagnetic radiation.

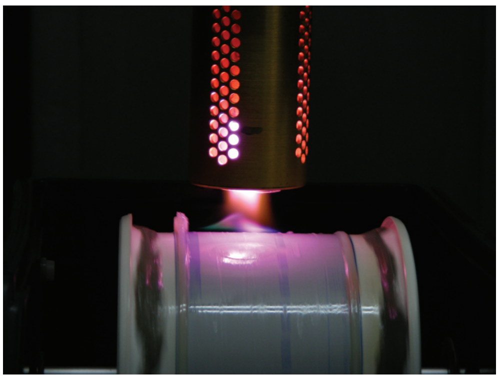

Fig.6. Microwave plasma destroying oil separated from water.

The plasma is directed towards the kerosene separated from the water and forming a thin layer on the oleophilic surface of the drum separator (Fig. 6). As a result immediate evaporation of kerosene with partial oxidation is observed. Gaseous products of evaporation were analyzed by FTIR spectrophotometer and identified as:

- oxygen: ca. 13%,
- nitrogen: ca. 87%,

- water vapour: ca. 1.5%,
- kerosene: ca. 200 ppm,
- products of kerosene oxidation: CO - ca. 200 ppm, CO_2 - ca. 1000 ppm.

In spite of direct contact of hot microwave plasma (gas temperature above 2000 K [2-4]) with the separator, its temperature is not so high. Measurements made by thermovision infrared camera showed that temperature of the separator does not exceeds 100ºC (Fig. 7). Thus, the separator, which is made of polypropylene is not destructed.

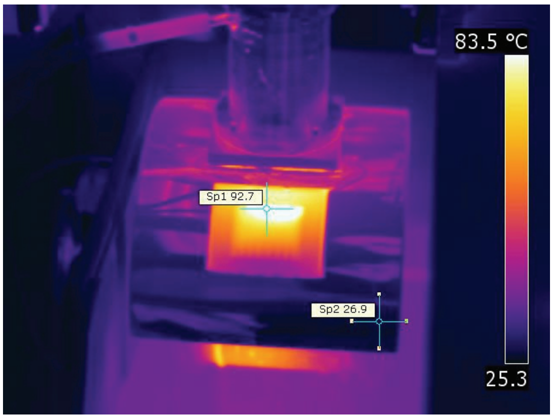

Fig.7. Temperature profile of oil-water separator and hood during the oil destruction by microwave plasma. Highest and lowest temperature is marked as Sp1 (92.7ºC) and Sp2 (26.9ºC), respectively.

Products of the kerosene evaporation and partial oxidation are sucked from the plasma region to the second plasma module. There, DBD reactor is used to complete oxidation of hydrocarbons.

In our laboratory only microwave plasma module and oil-water separator has been built. Power supply module is constructed by a group from the West Pomeranian University of Technology in Szczecin, Poland, whereas the second plasma module is developed by a group from the Leibniz Institute for Plasma Science and Technology in Greifswald, Germany, in co-operation with the Lappeenranta University of Technology in Mikkeli, Finland.

The first successful test of all modules combined into one system were carried out in August 2011. For the purpose of the test and for the final device the source of microwave power was reconstructed. Instead of commercial microwave supply made by Sairem we used a magnetron from a home microwave oven. This modification will allow us to decrease the size and weight of the final floating device without influencing the microwave plasma stability.

This work is supported by the Baltic Sea Region Programme under the PlasTEP project.

REFERENCES

[1] Jasiński M., Dors M., Nowakowska H., Nichipor G.V., Mizeraczyk J., Production of hydrogen via conversion of hydrocarbons using microwave plasma, *J. Phys. D: Appl. Phys.* 44 (2011), 194002
[2] Jasiński M., Mizeraczyk J., Zakrzewski Z., Ohkubo T., Chang J.S., CFC-11 Destruction by Microwave Torch Generated Atmospheric-Pressure Nitrogen Discharges, *J. Phys. D: Appl. Phys.,* 35 (2002), 2274-2280
[3] Green K.M., Borras M.C., Woskow P.P., Flores G.J., Hadidi K., Thomas P., Electronic excitation temperature profiles in an air microwave plasma torch*, IEEE Trans. Plasma Sci.,* 29 (2001), No. 2, 399-406
[4] Uhm H.S., Hong Y.C., Shin D.H., A microwave plasma torch and its applications, *Plasma Sources Sci. Technol.,* 15 (2006), No. 2, S26-S34

Authors*: dr hab. inż. Mirosław Dors, prof. dr hab. inż. Jerzy Mizeraczyk, mgr inż. Tomasz Izdebski, mgr inż. Bartosz Hrycak, Instytut Maszyn Przepływowych im. R. Szewalskiego Polskiej Akadamii Nauk, ul. Fiszera 14, 80-952 Gdańsk, E-mail: mdors@imp.gda.pl; Izdebski@imp.gda.pl, bhrycak@imp.gda.pl*
prof. dr hab. inż. Jerzy Mizeraczyk, Akademia Morska w Gdyni, Katedra Elektroniki Morskiej, ul. Morska 81-87, 81-225 Gdynia, E-mail: jmiz@imp.gda.pl.
dr inż. Marcin Hołub, mgr inż. Michał Bonisławski, Zachodniopomorski Uniwersytet Technologiczny, Wydział Elektryczny, ul. Sikorskiego 37, 70-313 Szczecin, E-mail: michal.bonislawski@zut.edu.pl