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Floating Plastic Waste Processing, Artificial Diesel Fuel Production, Storage and Offloading

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Abstract

Researched and developed of the ocean floating plastic waste processing into liquid hydrocarbons. It is illustrated one of the best way for this waste utilization is the creation of special vessels with processing equipment deployment on the board. Special small plastic waste ships-collectors supply processing vessel by raw materials. The result of the plastic waste processing is artificial diesel fuel, which will be a commercial product and its part can used for main and auxiliary engines of his fleet. Processing equipment operates in continuous mode and realizes three stage treatment cycles: plastic waste melting, decomposition and creaking. Processing equipment is fully autonomous and not requires the energy sources from outside. Plastic taste technology is environment friendly and emissions of harmful substances do not exceed established standards.
KEY WORDS: *floating plastic waste, processing equipment; artificial diesel fuel; floating processing vessel*

1. Introduction

The problem of the environment protection from technogenic impact is extremely relevant and worldwide. Plastic waste is one of the dangerous compounds which are produced in a huge amount and pollute not only the continents, but also water space, including rivers, seas and oceans. The amount of stored plastic waste and its annual production is difficult to estimate. According to expert's means, the amount of stored plastic waste varies within 7…8 billion tones, and annually increases by 350 million tons. Unfortunately 10% of the annually plastic waste have been processed into secondary products or destroyed by incineration along with other solid waste.Approximately annually 8 million tons of plastic waste flows into the oceans from coastal regions [1, 2]. Plastic waste processing land industry has not enough capacity for treatment significant amount of this waste. Unfortunately floating plastic waste is collecting in a negligible amount and transporting to the landfill for disposal or incineration. This plastic waste does not processed into commercial product at all.

Absence of the floating plastic waste processing technique and specific natural processes in Pacific Ocean contributed to the formation of huge plastic waste floating clusters. Well-known the Great Pacific Garbage Patch which is a collection of marine debris in the North Pacific Ocean. It is the largest of the five offshore plastic storage areas in the world's oceans. It is located halfway between Hawaii and California. The Great Pacific Garbage Patch covers surface approximately of 1.6 million square kilometers and contains of 80,000 tons of plastic waste. Annually this amount increases up to 1.0…2.5 million tones [3]. This plastic waste cause enormous damage to the fauna and flora of the seas and oceans.

The Great Pacific garbage patch formed gradually as a result of ocean or marine trash and plastic waste pollution gathered by ocean currents and winds. This trash is captured in the water currents and winds surface currents gradually move debris toward the center. The main source of marine debris is attributed to improper waste disposal or management, especially pertaining to plastic waste [4].

Fig.1 illustrates Great Pacific Garbage Patch location and its formation [5]; Fig.2 illustrates real situation with stored trash and plastic waste inside Great Pacific Garbage Patch [6].

It exist some problem in floating plastic waste processing: collection, transportation and efficient processing. An extra small, small and middle size particle is floating on surface of water and significant its amount floating under water to a depth up to the 20 meters. It makes collecting difficult and expensive. Plastic waste has small density and requires vessels of huge displacement for transportation. It is expensive too. Finally, landfill or incineration is not the most cost-efficient plastic waste processing method.

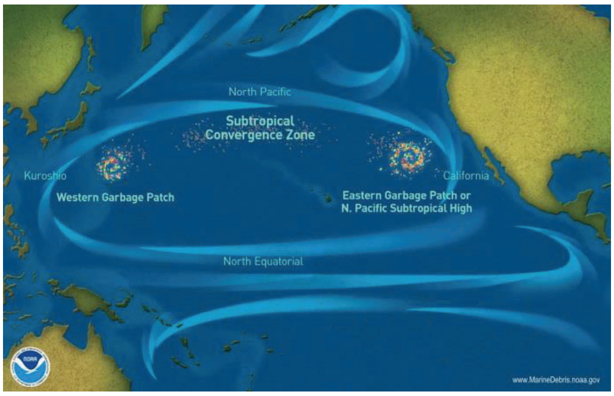

Fig. 1 Great Pacific Garbage Patch location [5]

Fig. 2 Great Pacific Garbage Patch: Trash and Plastic Waste [6]

Plastics production is based on polymerization, poly-condensation or poly-addition of low molecular source materials released from natural gas, such as, for instant, benzene, ethylene, phenol, acetylene and other monomers. Therefore plastic waste processing may be implemented on the reversing decomposition reactions and the final product will be artificial oil, diesel fuel or other liquid hydrocarbons.

Researches and development in Advanced Energy Technology Lab (AETL) of Admiral Makarov National Shipbuilding University allow to propose more efficient way for floating plastic waste processing. The main stream is designing of special fleet – Floating Plastic Waste Processing, Oil Production, Storage and Offloading (FPWPOPSO). Like as a floating production storage and offloading (FPSO) unit. This vessel will be accept plastic waste from floating garbage collector's ships, processed this plastic waste into the artificial oil or diesel fuel, storage and transferring to tankers.

The efficient plastic waste processing technology and equipment for its implementation, located on the special vessel is the main goal of this paper.

2. The Main Principal

Plastic waste thermal destruction occurs at high temperatures in an inert atmosphere or in a vacuum. In most event, the plastic thermal decomposition proceeds as a radical chain process with the stage of initiation, growth, and chain termination. The initiation of thermal decomposition is passing due to the rupture of two types chemical bonds: weak, for instance, allyl or peroxide, and repeating bonds of the main chain. In accordance with this, the most plastic waste thermal decomposition proceeds in two stages: at different temperatures and with significantly different activation energies. The main plastic amount breaks up in the second stage thermal decay, as a rule.

Compliance with thermodynamic criteria is necessary, but not a sufficient condition for de-polymerization. For its development, so that the macro-radicals with an active center at the end of the chain are accessible precisely stable, and the plastic did not contain mobile oxygen atoms yes, usually found at tertiary carbon atoms, usually located at tertiary carbon atoms.

Artificial oil and diesel fuel production from plastic waste is an effective technological solution for the economically feasible disposal of large plastic amount that cannot be reused (regenerated) as a result of known physical processes. Plastic waste thermal degradation and cracking processes is realizing without air access or other oxidizing agents. Such processes ensure the plastic waste disposal with artificial oil, diesel and heavy fuels. In the process of plastic waste cracking, are heated to a high temperature, such that their macromolecular structures become unstable and break down into shorter molecules, leading to the formation of hydrocarbons of a wide chemical and fractional composition. These hydrocarbons can be separated into non-condensable gas, condensing liquid fractions (consisting of paraffins, olefins, naphthenes and aromatic), and solid residues (coke).

Plastic waste thermal destruction in a first approximation seems simple and straightforward. However, thermal cracking is often leads to the formation of low quality hydrocarbon fuels having a very wide composition, sometimes extending from light alkane gases to coke. Therefore, it is necessary to very carefully determine the parameters of thermal destruction processes, rational hardware design of these processes in order to obtain high-quality commercial products as diesel fuels. Catalytic destruction leads to the formation of hydrocarbon fuels of a much narrower chemical and fractional composition, which ensures higher quality fuels, which can be obtained in this process.

The kinetics models of the decomposition of polymers with common parameters describe the pyrolysis process by simplified reactions [7]. Each individual destruction reaction can be considered as a complex chain reaction. Most theories use the standard energy model to describe the pyrolysis process losses:

$$\frac{d\alpha}{dt} = k_0 e^{\left(\frac{E_a}{RT}\right)} \left(1-\alpha\right)^n$$

where α is the conversion coefficient and n is the reaction order. Standard Arrhenius parameters are given by the following values: k_0 is the preliminary exponential factor and E_a is the activation energy. Kinetic parameters and reaction order are evaluated according to standard thermo-gravimetric analyzers (TGA).

Product yield data during plastic thermal decomposition are not sufficiently represented in literature. But it is extremely important for technological process and equipment estimation.

3. Test Bed and Experimental Results

An experimental researches and development on plastic waste processing and product yield definition were performed in the AETL. Technological parameters and equipment design were directed to production artificial oil, diesel and heavy fuels. The general diagram of an experimental test facility for plastic waste processing into the diesel fuel is shown on Fig.3. The main equipment are following: plastic processing reactors, distillation unit, environment protection unit, diesel generator, cooling system, pyrocarbon abandon system, safety, driving and controlling system. An experimental facility products the artificial diesel fuel of wide fraction. The properties of this diesel fuel are satisfactory for supplying diesel and gas turbine engines.

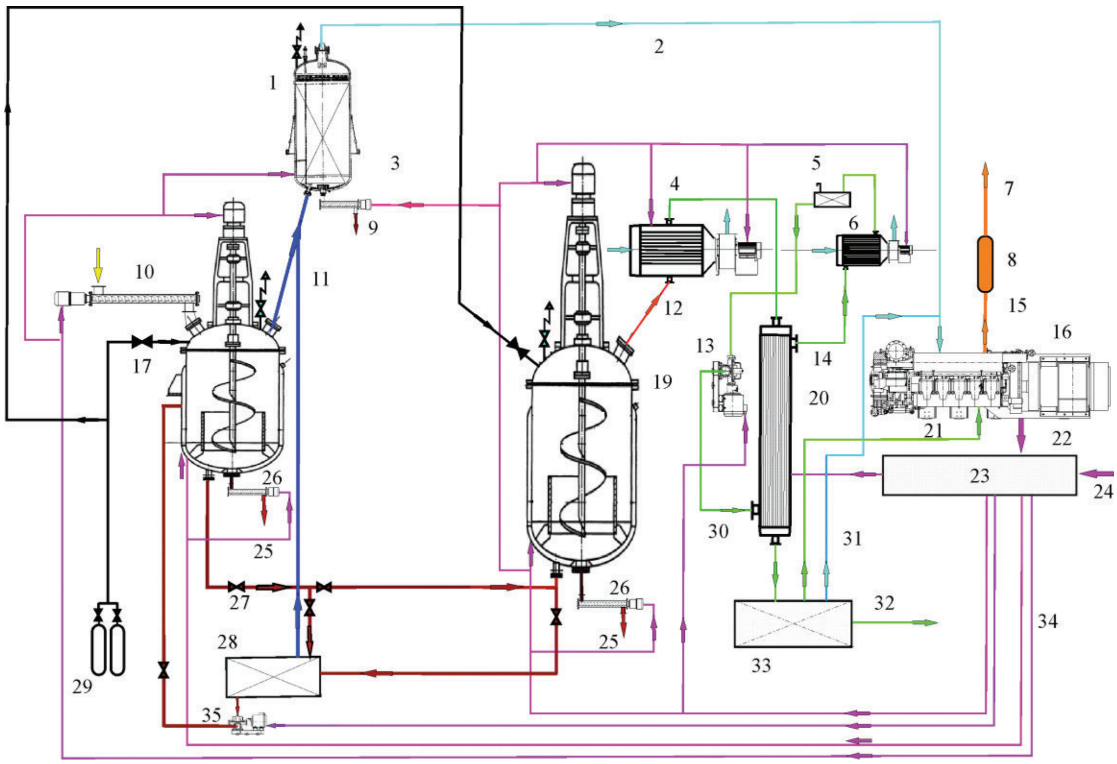

Fig. 3 The general diagram of an experimental test facility for plastic waste processing into the diesel fuel: *1* – Wet scrubber bubble type; *2* – The purified mixture of the hydrocarbon gases; *3* – Chemical agent uploading feed; *4* – Dephlagmator; *5* – Expansion tank; *6* – Cooler; *7* – To Environment; *8* – Noise silencer; *9* – Waste chemical agent; *10* – Plastic waste feed screw; *11* – Melting and depolymerization gases; *12* – Crackin gases; *13* – Cooling system; *14* – Output of the cooling water; *15* – Exhaust gases; *16* – GenSet; *17* – Melting device; *19* – Cracking device; *20* – Condenser; *21* – Liquid fuel to GenSet; *22* – Electricity; *23* – Central driving and controlling system; *24* – Option: Electricity from net by night tariff; *25* – Coke; *26* – Coke uploading screw; *27* – Melted plastic waste; *28* – Tank for melted plastic waste; *29* – Nitrogen ramp; *30* – Input of the cooling water; *31* – Uncondensed hydrocarbon's gases; *32* – Trade Diesel Fuel to Consumer; *33* – Storage diesel fuel tank; *34* – Electricity; *35* – Melted plastic waste back pump

Plastic waste processing into the artificial diesel fuel occurs in three stages. The first stage is plastic waste melting in special device *17* with continuous stirring for uniform and constant melt temperature. The second stage is melted plastic waste depolymerizaton in the same device *17*. The third stage is cracking process in device *19* at higher temperature and pressure. Cracking gases enter in condenser *20* and are turning up into liquid artificial diesel fuel of wide fraction. Plastic waste consisted of polyethylene, polypropylene, polystyrene, polyamide, polyurethane, polyethylene terephthalate. Processing equipment does not require energy supply from outside. All its needs are provided by own diesel generator. Facility's electricity needs is about 950…1050 kW×h/tone.

Results of the experimental studies. The wide fraction artificial fuel yield is 890 kg, 40 kg is pyrocarbon, 35 kg is flammable gas mixture and unbalance losses are 35 kg approximately from 1000 kg of the plastic's waste processing [8]. The diesel fuel properties are shown in Table 1 [7]. Commercial products yield strongly depend on the process parameters. Tuning process temperature, pressure treatment duration allow to product predominantly the following. Maximum heavy fuel yield up to 85% may be realized at low processing temperature and high pressure;

maximum diesel fuel yield up to 80% – at middle processing temperature and low pressure; maximum light (gasoline/kerosene fraction) fuel yield up to 60% – at higher processing temperature and low pressure; maximum flammable gas yield up to 50% – at processing temperature more than 1000 K and low pressure, less than 0.3 MPa.

Table 1

Main properties of the artificial diesel fuel

№	Properties	Indexes
1	Cetane index, not less	45
2	Kinematics viscosity at 293 (k), ct	3.5
3	Frizzing point, (k)	252
4	Flash point in closed pot, (k)	323
5	Content of water-soluble acids and alkalis	absent
6	Concentration of the resins, {mg[100 cm^3]}	20
7	Acidity, {mg KOH[100 cm^3]}	5
8	Iodine number, {g iodine [100 g of the fuel]}	6
9	Sulfur content	absent
10	Test on the cooper plate	passed
11	Ahs content, %	0.02
12	Coke ability of the 10% reminder, %	0.2
13	Content of the mechanical admixtures, %	absent
14	Water content, %	absent
15	Density at 293 (k), kg/m^3,	815
16	Calorific capacity, kJ/kg	41900

Air pollution indexes, representative for the processing facilities operation with a mixture of plastic waste waste are shown in Table 2. Analysis of these data allows to make a conclusion that concentration of any hazard substance does not exceed the maximum permissible concentration level.

Table 2

Processing equipment pollution

№	Hazard substance	Real concentration in air, mg/m^3	Permissible concentration, mg/m^3
1	Carbon oxide	2.3	20
2	Oliphatic hydrocarbons saturated Cl–Cl	31.1	300
3	Toluene	2.2	150
4	Xylene	0.4	50
5	Benzene	0.4	15
6	Ethyl alcohol	2.5	1000
7	Formaldehyde	0.13	0.5
8	Acetate aldehyde	0,40	5.0
9	Styrene	1.32	5.0
10	Methanol	2.50	5.0

Project proposals. Projects of high and middle displacement tankers can be used as prototype for creation of floating plastic waste processing vessels. Processing equipment located in one or more tanks of the vessel. The parts of tanks are used for plastic waste acceptance and storage as operational ware. The rest of tanks are used for liquid hydrocarbons or diesel fuel storage.

The processing vessel must have the plastic waste acceptance equipment and pumping unit for fluid hydrocarbons delivery to serving tankers.

Produces wide fraction liquid hydrocarbons can be used as a fuel for diesel and gas turbine engines or direct to refinery for high quality light fuels and related products.

The general arrangements of the processing equipment on the vessel are shown in Fig.4 and Fig.5.

Modernization of the tanker project 17015 as an example was considered. Tanker main dimension are the following: length – 182.9 m; width – 32.2 m; depth – 18.6 m; deadweight – 45,000 t; draft – 12.27 m; speed – 13.5 knots. It has 8 cargo tanks for oil transportation. Total cargo tanks volume is 44400 m^3, approximately. Bow tank has volume 3800 m^3 and other 7 cargo tanks have volume 5800 m^3. Four plastic waste processing units are located in tanks #3 and #4. Bow tank and tanks are intended for liquid hydrocarbons storage. Tank #8 is intended for plastic waste acceptance from trash collector ships, storage and preliminary waste treatment.

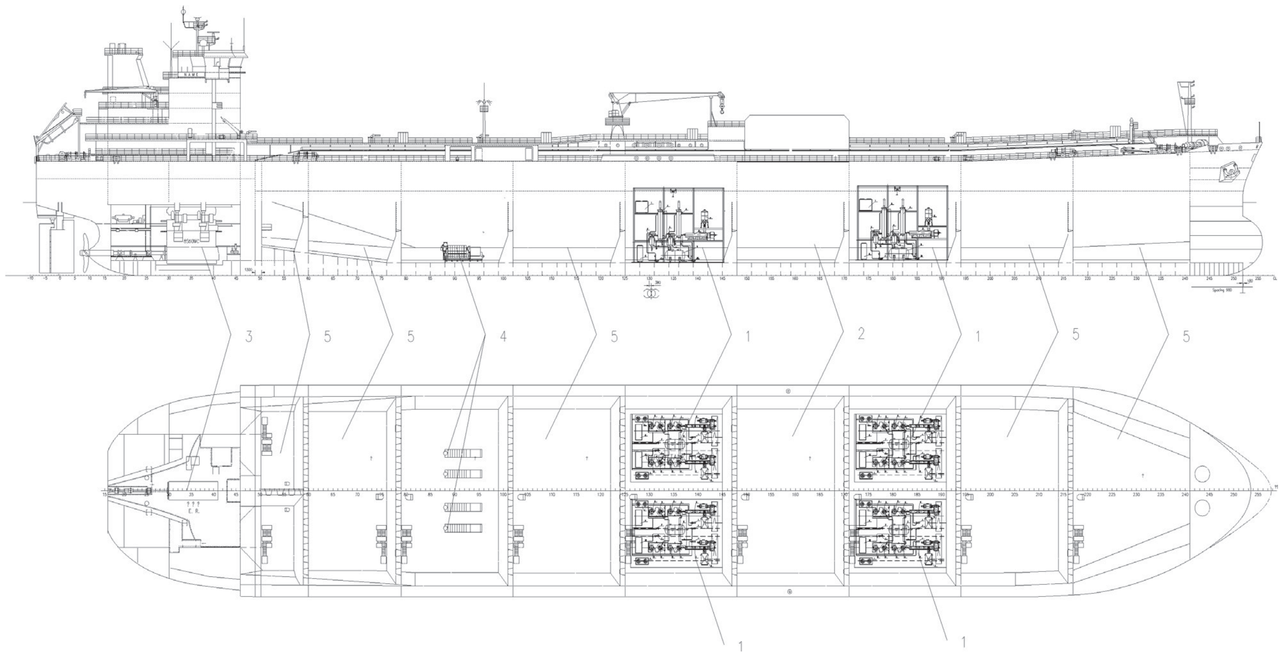

Fig. 4 The general arrangements of the processing equipment in the tanker of Ukrainian project # 17015: *1* – Processing facility (total 4 units); *2* – tank for plastic waste accepting; *3* – Main engine; *4* – GenSets for processing equipment electricity supplying (4 units ×MAN 8L27 IMO Tier-III total power 10560 kW); *5* – tanks for hydrocarbons storage and transfer to serving tankers

This tank can accept up to 3000 m^3 plastic waste only because a half its full volume is intended for technological needs. Plastic waste bulk density is 200…400 kg/m^3 and depends on morphologic waste structure.

At the first step and pilot operation plastic waste processing equipment capacity may be 100…200 tons/day. Storage tank can accepts up to 300 tons/day and since it is necessary to have the plastic waste stock for continuous processing facility operation. Total yield hydrocarbon's amount is up to 160 tons. Total amount of the gensets fuel consumption is 45 tons/day and fuel consumption of the vessel and collector's ship is 15 tons/day approximately. Thus, the commercial hydrocarbon's amount is up to 100 ton/day.

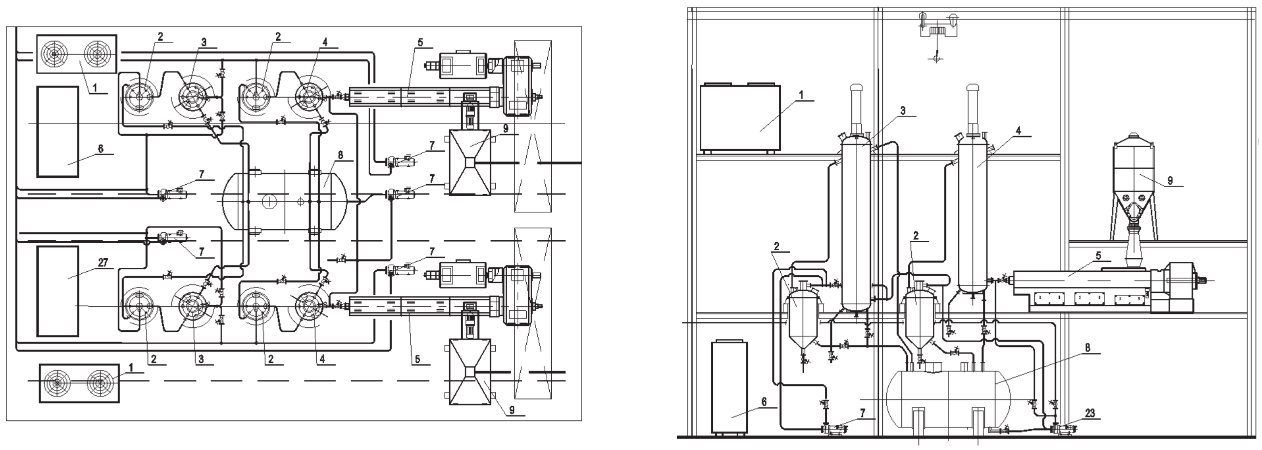

Fig. 5 The general arrangements processing equipment on the platform the in the tanks. *1* – Air cooler; *2* – Filter 0.5-0.6-350-T; *3* – Cracking device 5.0-0.6-450-T; *4* – Melting device 5.0-0.6-350; *5* – Extruder; *6* – Deflegmator; *7* – Circulation pump assembly K18.5M-L; *8* – Emergency capacity tank; *9* – Leveling hopper with dispenser

For future development, processing vessel can accept up to 1200 tons/day of the plastic waste. The most of this amount must be processed into liquid hydrocarbons and 15…20 % of total plastic waste amount is stock for processing equipment continuously operation.

Based on these considerations, processing equipment capacity have been up to 1000 tons/day approximately. Total hydrocarbon's yield will be up to 800 tons/day. Approximately 200 tons of hydrocarbons is discharged a day to ensure the processing equipment operation, the general vessel needs and collector's ships fuel supply.

Thus, commercial hydrocarbon's amount will be 650 tons/day and storage tanks #1…#7 with total volumes of 27000 m^3 and will be filled with liquid hydrocarbons during 40…45 days. These hydrocarbons have been transferred to serving tankers.

4. Conclusions

Floating plastic waste can be treatment and processed in to the hydrocarbons like as artificial oil, diesel and heavy fuels. Processing may be realized with special technology researched and developed in National University of Shipbuilding. Long-time experimental facility examinations illustrated principal opportunity of the plastic waste processing. Processing technology provides a high yield of the liquid hydrocarbons and is friendly for environment.

The special vessels FPWPOPSO are efficient instrument for oceans and seas water cleaning from plastic waste.

We would like to express sincere appreciation to all members of our research team who had participated in this project and had contributed their knowledge, skills and dedication.

At this stage, it is not possible to evaluate the total economic efficiency of the processing vessel and collector's ships, but approximate estimation allows conclude positive economic and ecological results.

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