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THE PRELIMINARY PROJECT OF THE RIVER TOW VESSEL POWERED BY A PYROLYSIS GAS GENERATOR POWER PLANT

The article is dedicated to the one of many options of a practical application of the pyrolysis gas generator, which is its installation on the typical river-class tow vessel. The essence of the idea is the installation of the pyrolysis gas power plant that includes gas generator, gas filtering system, power plant and electric engines that would drive the vessel. The gas generator of the inverted type is able to create flammable gas out of either wood, or charcoal, or so-called RDF (the RDF should be taken of specific proportion of its ingredients, corresponding to the ecologic laws of the operator's country), thus, allowing the vessel to be powered by typical industrial and household wastes, delivered from all the city. Since such types of ships are mostly used within the range of a city and more often even within ports only, the fuel for the vessel would always be available in sufficient volumes. The vessel itself should be able to reach the necessary velocity (taking into a count the flow velocity of the river) and also be able to push the certain barge or another vessel in order to do some practical tasks. This vessel will be independent from fossil fuels and it could be powered even by wood chops, collected in any forest near the river or by a big pack of charcoal, purchased in the supermarket. The presented calculations show some possible technical solutions for the given task, taking into a count the lowest possible price and availability of components. However, there is no limit in pyrolysis technology improvement and the project of this vessel can be improved as well depending on the available funding.

Key words: *pyrolysis gas, vessel, river transport, RDF, gasification, wastes disposal, power plant, gas-powered piston engines*

Introduction. This project is a part of a major research of the properties and opportunities of pyrolysis gas applications in different spheres of life. Stationary gas generators and pyrolysis afterburner equipped heaters have already become popular gadgets in private houses.

However, when it comes to the application of the gas generator onto a vehicle, there arise some new issues that should be solved in a proper way. First of all, the working engine consumes different amount of pyrolysis gas at different operation modes, thus, there supposed to be a system for gas production control. Secondly, the gas generator itself is a heavy item, which is supposed to be added to the vehicle's total weight, while in the meantime the overall maximum power of the gasoline engine will decrease up to 50%, depending on the quality of gas filtration, the type of solid fuel that was gasified (i.e. what amount of carbon was present there), the type of air and pyrolysis gas carburetor applied, etc.

Despite the fact that gas-generator-equipped cars were massively produced during the whole first half of the 20th century, the only case when they were more preferable to gasoline-powered cars, was the European part of the World War II, when both Allies and Axis States faced fossil fuels supply lacks on different stages of the war. Also, pyrolysis gas powered cars still would be inconvenient for modern day average citizen due to the necessity of initial burning of the gas which would take at least 10-15 minutes. The author had been seeking some other practical applications of pyrolysis gas power and have come up with an idea of application of this type of power plant on vessels. A good vessel to start would be not a small boat with outboard motor, but a concept of pontoon vessel, based on the existing designs of pontoon boats and port tow boats either. The designed vessel would be initially suitable for commercial application on river routes and ports.

The analysis of existing research. The author has performed basic research on application of the RDF as a fuel for pyrolysis gas generators along with traditional solid fuels such as charcoal, wood, etc. [1] The real existing prototypes of stationary pyrolysis gas generators have been used during performing the basic research. Each of them was capable to produce a certain amount of flammable pyrolysis gas which was successfully tested for burning. The only disadvantage of stationary gas generators is the fact that the fuel must be constantly poked so that all its amount would be exposed evenly to the temperature inside the gasification chamber. There exist several solutions for solving this issue, thus, allowing gas generator to produce the constant amount of gas that would power converted gasoline engine, attached to the electric generator, for instance.

Aim of the work. The aim of this project is to show the opportunity of commercial application of pyrolysis technologies on the example of river vessel and business, related to it [2].

Idea of the work. The idea of this work is to design a pyrolysis power plant using existing components only in order to reduce the cost of research and development of any vehicle where it would be installed on. Also, this power plant will be a way of proper city wastes disposal according to the most modern ecologic laws of Ukraine and the EU.

The concept of a pontoon boat. The calculations of the pyrolysis power plant would be performed basing on some initial data about this vessel [3]. Its weight without power plant & propulsion system is equal to 1400 kgs in the first approach. The length of the vessel is 7,58 and the width is 2,5 m, which is compatible to a small bus. The vessel is of full-metal design, having two aluminium pontoons, stainless steel deck and a comfortable wheelhouse for a single duty crewman. The boat is propelled by a 7-blade, 400 mm in diameter, propeller that ismanufactured out of marine grade bronze АНЖ 9-4-4 (U.S. C61900). The operational velocity of the vessel is set at 5 knots (2,57 m/sec). Once again, the following initial data is going to be used for all required calculations:

– Vessel length: L = 7,58 m
– Vessel width: B = 2,5 m
– Immersion: T = 0,4m
– Water displacement volume: V = 5,634 m^3
– Velocity: υ = 2,57 m/sec
– Vessel aspect ratio: L/B = 3.032
– Number of propellers & sterns: 1 propeller & 1 stern

At first, the calculations for determination of requires engine power have been performed. After calculating the value of the water resistance force for the designed vessel, there exists an opportunity to estimate the value of required engine power, which is:

$$N_R = \frac{R\upsilon}{745}(h.p.)$$

$$N_R = \frac{R\upsilon}{745} = \frac{4206.845 \times 2.57}{745} \approx 14.5(h.p.)$$

However, there also exists a need to include such an important factor as the presence of water flow velocity of the river. For the case of Dnipro river, the average value is equal to 1.2 m/sec. Therefore, the required power of the vessel's power plant must be equal to:

$$N_R = \frac{R\upsilon}{745} = \frac{4206.845\times(2.57+1.2)}{745} \approx 21(h.p.)$$

Basing on this result were performed the calculations of propeller rotation velocity, diameter & propeller pitch. The rotation speed was determined to be 1300 sec^{-1}, while the propeller diameter value is 400 mm and its pitch is equal to 310 mm. This allows to select a three-phase electric motor that would turn the shaft & propeller. The selected engine is Ukrainian-made АИР160М4 asynchronous motor by ELMO Motors with IP54 protection class – i.e. it is protected from both dust and liquids. The maximum value of rotation velocity for its M4 modification is 1470 RPM at 18,5 kWt of maximum power which is quite sufficient for our case [4].

The other important issue of this exact model is the availability of CW & CCW rotation. The only condition is to fully stop the motor before changing the rotation direction, but this is totally acceptable during the operation of the designed vessel.

The engine selection. Pyrolysis gas can power a gasoline engine. However, the maximum power of any gasoline engine would significantly drop due to the fact that the specific combustion heat of combustion of the pyrolysis gas ranges from 10 to 15 MJ/kg, while the typical range of this value for petrol ranges within 40-44 MJ/kg. It is obvious that the selected engine has to produce 20 h.p. being initially designed for a considerably greater value of produced power using the petrol. In general, the power of a piston engine is determined by the following formula:

$$N_e = \frac{V_h p_e n}{120}(kWt)$$

where V_h is an engine volume, p_e is the average effective pressure and n is RPM of the engine.

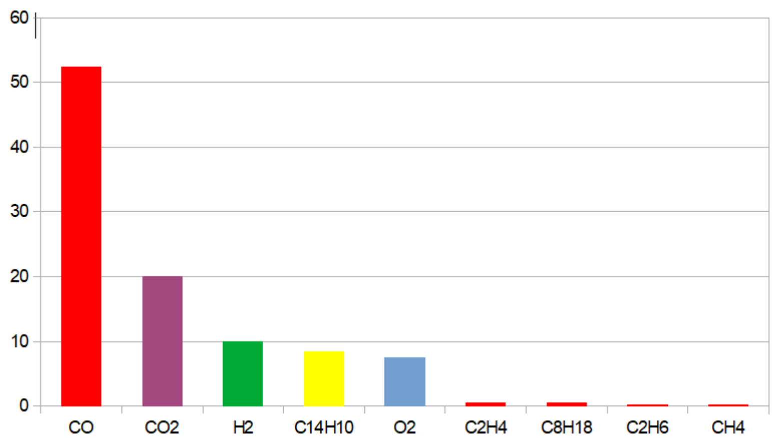

Fig. 1. Percentage of pyrolysis gas components

Using the data from fig. 1, it is possible to determine the interrelation of flammable components volumes in the pyrolysis gas: carbon monoxide CO — 0,5; hydrogen H_2 — 0,1; antracen C14H10 and other aromatic compounds — 0.4.

The several iterations of calculations lead to the choice of the Toyota 3RZ-FE 4-stroke 4-cylinder automotive engine of volume 2,693 liters. This gasoline-powered engine is capable to produce 150 h.p. at 5800 RPM [5]. In case of its conversion to the pyrolysis gas it would produce the following power:

$$N_e = \frac{5500\times2.693\times0.2}{120} \approx 24.7(kWt)$$

while the average estimated pyrolysis gas consumption would be equal to:

$$G_e = N_e g_e \approx 25(kgs/h)$$

The selected model of the electricity generator is WHI184G by the 1STALL company. This is a three-phase brushless generator, designed for maximum amount of 1500 RPM, while the value of its nominal power is 25 kWt, which is suitable for our case.

Pyrolysis gas generator design. Taking into a count the data from previous calculations, there exists an opportunity to calculate the parameters of the inverted type gas generator. [6] This type of gas generators is used for gasification of fuels that contain resins, such as wood logs. However, the charcoal, that is used to increase the amount of carbon monoxide during the gasification process, can be also used as a fuel for such type of gas generators, i.e. this gives an opportunity of application of at least two types of fuels [7]. Basing on previous research, there is an opportunity to select the parameters of gas generator for the designed vessel, which are presented in table 1.

Table 1

Gas generator parameters

Hopper diameter (*Db*), mm	396
Tuyeres belt diameter (*Dk*), mm	200
Neck diameter (*d*2), mm	120
Chamber skirt diameter (D_S), mm	270
Distance from tuyere to neck (*h*), mm	87
Active zone height (*H*3), mm	174
Tuyeres belt height (*a*), mm	70
Upper cone height (*b*), mm	96
Chamber wall thickness, mm	12
Tuyeres q-ty and diameter, mm	8×10

The gasification chamber is molded from the 20ГЛ (G21Mn5) molding steel, an alloy steel, which allows performing its thermal treatment and welding jobs, such as welding attachment of the hopper to it. The hopper is manufactured out of regular ANSI 304 stainless steel of 3 mm thickness.

The ash pan design is quite conventional, but the only difference from ones used in furnaces is the necessity of its hatch sealing in order to avoid the gas losses. The air supply vent is manufactured out of 45 mm stainless steel tube and is equipped with air supply regulation valve. This valve is of simple design as well. The spring provides automatic opening of the valve for a certain angle that depends on air flow rate on different engine operation modes. The gas generator's hull is closed by another hatch, while a gas collecting tube with flange is located on the opposite side to ash pan door. The gas flows through this tube to the water filter (gas filtering unit). The water filtering unit is actually a water tank which not only purifies the obtained pyrolysis gas from resins, sulfur oxides, and other undesired additives, but also serves as a protective barrier in case of sudden gas pressure rise. A good example of such case is well-known wood logs' crackle in the chimney. This phenomena is actually a spontaneous pyrolysis gas emission from multiple little chambers inside the log. Such sudden emissions would spoil the constant gas supply to the engine and also might become a reason for gas generator & engine damaging. The design of the water filter is quite simple as well: the pipe from gas collection tube supplies gas to the lower part of the filter. Then, the gas flows through the water and rises to the gas collector in the upper part of water tank, from where it already goes to the radiator. The gas cleaning unit ter could consist of two and even more stages, containing not only water, but also lime solution that cleans gas from sulfur oxides.

The radiator is a system of pipes the task of which is to cool down the obtained gas in order to increase its density which would lead to the increment of its heat creation capacity. Also, there is a start-up fan on the upper tube of the radiator, from where the coll gas goes to the engine, that is used to create the initial air flow in the whole gas generator system until the engine starts pumping air by itself during the air intake stroke.

The gas generator assembly is installed on the vessel’s deck just behind the wheelhouse. The power plant technician loads the batch of fuel each 3-4 hours depending on the fuel type and its humidity. The gas is cleaned in the filtering unit and cooled in the radiator unit. After that, the gas is delivered to the engine via the special carburetor that provides correct air to gas ratio and then the gas is burned inside the engine that in its turn rotates electricity generator that powers all ship’s systems and drives main electric motor, providing the motion of the vessel. [8]

Results of the preliminary design. The render of a boat with gas generator power plant is presented on fig. 2. These calculations, as well as the above mentioned calculations are just preliminary ones and there is a necessity to develop more advanced research and calculations in case of further development of this boat. However, there already exists a basis for performing them, which would save lots of time & resources.

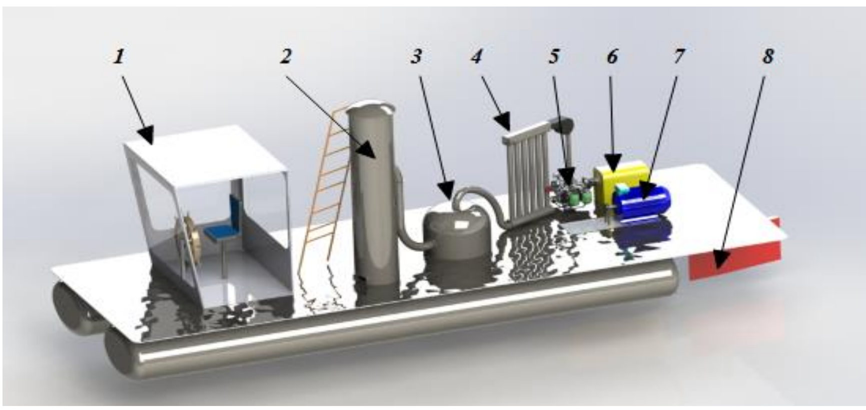

Fig. 2. The general view of the designed tug boat: *1* – wheelhouse, *2* – gas generator, *3* – gas filter, *4* – radiator assembly, *5* – piston engine, *6* – electric generator, *7* – main electric engine, *8* – rudder

Conclusions. The presented research can be a basis of a real project of any vessel or vehicle that could carry the weight of pyrolysis power plant and remain operable using it. The application of already existing engines, generators, fans, etc. would sufficiently decrease the cost of vessel/vehicle design, allowing to spend the funding on manufacturing the proper multi-fuel gas generator.

Referenses

1. I. I. Obodovskyi, V. S. Morozov. Ohliad ta analiz istorychnykh ta suchasnykh tekhnolohii ta napriamkiv vykorystannia piroliznoho hazu v pobuti ta promyslovosti [The overview and analysis of historic and modern technologies of household and industrial pyrolysis gas application.] “Problems of friction and wear” of National Aviation University, Kyiv, 2021. PP.3-5 (in Ukrainian)

2. Tug and Tows – A Practical Safety and Operational Guide. The Shipowners’ Club. – London, UK, 2015. P.11

3. Online guide on marine calculations –https://marineengineeringonline.com/calculation-of-shaft-power-in-marine-engines-on-ships/ (востаннє відкрито 05.09.22)

4. “ELMO” company online catalog – https://elmo.ua/ru/catalog/elektrodvigatel-air-160/ (востаннє відкрито 05.09.22)

5. Description of Toyota 3RZ-FE engine – https://www.motorreviewer.com/engine.php?engine_id=153 (востаннє відкрито 05.09.22)

6. Obodovskyi Ivan, Varlamov Genadiy. Vibir konstrukcii piroliznogo gazogeneratora dlya zhivlennya gtu piroliznim gazom [the choice of the pyrolysis gas generator construction for gas turbine engine gas supply]. Problems of scientific support of energy industry. Compilation of materials of 19th International Young Scientists’ Conference, Kyiv, 2021, PP.266-267 (in Ukrainian)

7. Morozov, V., & Obodovskyi, I. (2021). COMBINED BIOMASS UTILIZATION SYSTEM. Advances in Aerospace Technology, 88(3), PP. 36–40. https://doi.org/10.18372/2306-1472.88.16010.

8. Pyrolysis gas generator design description -_https://www.researchgate.net/figure/Scheme-of-a-downdraft-gasifier_fig1_315922694 (востаннє відкрито 05.09.22)

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ОБОДОВСЬКИЙ І. І., МОРОЗОВ В. С.

АВАНПРОЕКТ РІЧКОВОГО КАТЕРА-БУКСИРА ІЗ СИЛОВОЮ УСТАНОВКОЮ НА ПІРОЛІЗНОМУ ГАЗІ

Стаття присвячена одному з багатьох можливих варіантів практичного застосування піролізного газогенератора, а саме його встановленню на типовий катер-буксир річкового класу. Суть ідеї полягає в застосуванні корабельної установки, основу якої складає газогенератор, система очищення газу, силова установка та електродвигуни, що рухатимуть судно. Газогенератор оберненого типу здатний перетворювати вугілля, дрова, деревне вугілля, а також т.зв. РДФ на горючий газ (РДФ має бути обраний з правильним процентним співвідношенням компонентів для відповідності екологічному законодавству країни-експлуатанта), забезпечуючи таким чином судно пальним з побутових та промислових відходів, що можливо доставляти з околиць. Оскільки такі типи суден в основному використовуються в межах міст або навіть портів, пальне для них буде присутнє в достатніх кількостях. Буксир має бути здатним досягати заданої швидкості ходу (враховуючи швидкість течії річки), а також буксирувати баржу певних габаритів та маси, або навіть інші судна. Це судно має бути повністю незалежним від нафтопродуктів та може бути приведене до руху з використанням дров, назбираних у найближчому лісі або деревного вугілля з магазину. Представлені розрахунки демонструють деякі можливі технічні рішення для даної задачі, враховуючи наявність готових компонентів за найнижчою ціною. Однак, меж розвитку піролізної технології не існує, а даний проект судна може бути в подальшому доопрацьований в залежності від потреб замовника та наявного фінансування.

Ключові слова: піролізний газ, судно, річковий транспорт, РДФ, газифікація, утилізація відходів, силова установка, поршневі двигуни на газу

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