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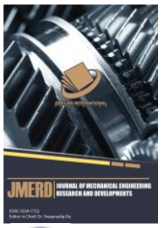

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RESEARCH ARTICLE

RESEARCH AND CALCULATION OF THE BIOGAS FUEL SUPPLY SYSTEM FOR A SMALL MARINE DIESEL ENGINE

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ABSTRACT

Biogas is a type of renewable energy generated from solar energy, so the combustion product of biogas will not emit CO_2 which affects the environment. Currently, the use of biogas for internal combustion engines such as vehicles and diesel generators is used in many countries in the world as well as in Vietnam. For the shipping industry, diesel engines are used, so the use of biogas on marine engines to meet the target of reducing harmful engine emissions into the environment and application strategies Renewable fuel sources for use on marine engines are very significant. The paper shows the results of the calculation of the conversion of diesel generators to become engines with biogas/diesel mixed fuel with the main contents: studying the necessary equipment for conversion engine to use biogas-diesel blended fuel.

KEYWORDS

Biogas, fuel supply system, research,and design for conversion of a dieselengine

1. INTRODUCTION

Energy issues in the world are currently being debated regarding technical, economic and environmental aspects [1]. Energy sources are being used today, such as coal, oil, natural gas and even nuclear energy will become exhausted [2]. Oil is the first source of fossil energy that we must mention [3]. The problems of this type of fuel such as reserves catches and prices are always a global theme [4]. Petroleum products, a form of fossil energy such as oil (DO, distillate fuel), or heavy fuel, also known as fuel oil (HFO), are traditional fuels used for ship engines [5]. Therefore, if there is no sooner to find an appropriate alternative energy source, the energy supply for the shipping industry in the coming time also faces a serious shortage [6,7].

If the combustion process of the air and fuel mixture in the combustion chamber of the engine is ideal, the combustion product is only CO_2, H_2O, N_2, and a small fraction of SO_2 [8-10]. However, due to the heterogeneity of the mixture of air and fuel as well as due to the complexity of the physiological phenomena that occur during combustion, the combustion product will have environmental pollutants [11,12]. In the toxic fire products of internal combustion engines, COx, HC, NOx is the main factors causing environmental pollution, climate change, harm to human health [13-15].

CO_2 gas is the main factor causing an increase in the greenhouse effect due to fossil fuel combustion products increasing the temperature of the earth's surface [4,16]. When the temperature of the atmosphere increases, there will be a lot of special harms, such as sea level rise. Sea level rose to 0.2-0.4m when atmospheric temperature increased by 1^{o}C. Vietnam is one of the countries considered to be severely affected by rising sea levels. Also, when the temperature of the earth's surface increases, phenomena such as desertification and barren land are rapidly causing great impacts on the agricultural sector. NOx, CO are toxic substances that harm human health [17].

The use of fossil fuels has seriously polluted the atmosphere. CO_2, the fossil fuel combustion product is a greenhouse gas, the main culprit that raises ground temperature leading to climate change and sea level rise, threatening the life of humanity. On the other hand, there are limited sources of fossil fuels [18]. High-intensity exploitation in recent decades has caused this energy source to deplete rapidly. The recent rise in oil prices reflects this situation. The ability to find a large source of oil that can be commercially exploited as in the past has almost no hope.

One question is when fossil fuels are exhausted, what energy sources will humans use instead [19]. Nuclear energy has long been considered salvation, but the Chernobyl nuclear disaster in 1986 and Fukushima in 2011 has caused people to re-issue the problem. Germany has declared a complete abandonment of nuclear energy by 2022; Japan is also considering closing nuclear plants after the double-earthquake-tsunami-nuclear disaster ... only a source of renewable energy Solar-based creation can guarantee the maintenance of human civilization until the solar system disappears.

Environmental protection is not only a requirement of each country but also a region that has a global meaning [20]. Depending on the conditions of each country, rules and standards on environmental pollution are applied at different times and severity levels [21].

Biogas is an abundant source of renewable energy in traditional agricultural countries like Vietnam [22,23]. Researching technology using them is important in fossil fuel savings and reducing the level of greenhouse gas emissions in the atmosphere [24].

Biogas is renewable energy derived from solar energy, so using this energy does not increase the concentration of greenhouse gases in the atmosphere [25]. The presence of CO_2 in biogas reduces heating value, reduces the burning rate but it increases the anti-knocking properties of the fuel, allowing to increase the compression ratio of the engine [26,27]. So in cases where biogas is used at the production site, we do not need to filter out CO_2. This allows us to reduce the operating costs of the system providing biogas for the engine [28,29].

Biogas is the product of anaerobic decomposition of organic compounds. The composition of biogas is mainly CH_4, CO_2 and other components such as N, H_2S, O, CO, ... [30,31]. Methane is used as fuel and the main component of biogas and other components do not have the role of heat generation during combustion of biogas [28].

The conversion of traditional diesel engines to run on biogas can be done by the method of spark ignition engine, dual fuel (biogas-diesel) method [16,21]. Dual fuel method uses a minimum amount of diesel injection to ignite the ignition engine ignition [32]. In operation, the minimum amount of injection required for ignition only accounts for less than 10% of the injection when a diesel-powered engine is in rated mode [33,34]. However, to prevent the nozzle from overheating during operation with biogas, the minimum amount of spraying should be maintained between 15% and 20% of diesel injection in the rated mode [35]. Biogas-diesel bi-fueled engine method is in principle the same as dual fuel engine, but regarding engine structure, there are two independent speed regulators of diesel fuel and biogas fuel [11,20,36]. With this structure, the engine can reuse diesel when necessary. This option is suitable for places with limited biogas supply.

Research and design for conversion of an original marine diesel engine into a mixed fuel (biogas-diesel) engine. In which the post-conversion engine can run with biogas in the form of mixed fuel, diesel fuel plays an ignition role for the biogas/air mixture; or can operate with diesel fuel as the original engine.

2. MATERIALS AND METHODS

2.1 Properties and requirements of biogas

Biogas is the product of anaerobic decomposition of organic compounds [16]. The composition of biogas is mainly CH_4, CO_2 and other components such as N_2, H_2S, O, CO, ... Methane is used as fuel that is the main component of biogas, and other components do not play a role in heat generation during combustion of biogas.

Table 1: Components in biogas [26]

Compounds	Symbol	% Volume
Methane	CH_4	50-75
Carbonic	CO_2	25-45
Steam	H_2O	2 (20^{0}C) – 7 (40^{0}C)
Oxygen	O_2	<2
Nitrogen	N_2	<2
Ammonia	NH_3	<1
Hydro	H_2	<1
Hydrosulfite	H_2S	<1

Table 2. The concentration of CH_4 (theoretical) [28]

Material	Liter gas/kgNL	CH_4 [%]	CO_2 [%]
Protein	700	70÷71	29÷30
Fat	1.200-1.250	67÷68	32÷33
Carbohydrates	790-800	50	50

Table 3. shows physical properties of biogas.

Table 3: Physical properties of biogas [25]

Properties	CH_4	CO_2
Molecular weight	16,04	44,01
Proportion	0,554	1,52
Boiling point	144^{0}C	60^{0}C
Freezing point	-165^{0}C	-39^{0}C
Density	0,66 kg/m^3	1,82 kg/m^3
Dangerous temperature	64,5^{0}C	48,9^{0}C
Dangerous pressure	45,8 KG/cm^2	73 KG/cm^2
Specific heat capacity (1KG / cm^2)	6,962.10^{-4}J/kg^{0}C	
Rate Cv /Cp	1,037	1,303
Burning heat	55,403 J/kg	
The rate of fire completely in the air	0,0581 (mass)	

The content of methane in the composition of biogas is used to determine the heating value of biogas. The formula for determining the heating value of biogas is:

$$Q_{biogas} = Q_{CH4} \times \%CH_4 \quad (1)$$

In which: Q_{biogas} is the heating value of biogas, Q_{CH4} is the heating value of methane, % CH_4 is the content by volume of CH_4.

The criteria for determining the standard for biogas are Heating Value - HV, Specific Gravity - SG, Wobbe Index, Methane Number.

Depending on the heating value is burning high heating value (HHV) or lower heating value (LHV) that have low or high Wobbe index. The Wobbe WI criteria are defined in the European gas fuel standards table (Table 4). According to European regulations, there are two groups of gas fuels: the group with high heating value (H group) and the group with low heating value (L group). H Group is for gas containing a large amount of methane and some other hydrocarbons. The L group for gases containing less methane and contains a significant amount of carbon dioxide or nitrogen.

Table 4: The criteria follow the DVGW G 260 standard set [37]

Criteria	Symbol	Unit	L group	H group	Note
Standard density	d		0,55 – 0,7		Allow deviation
Heating value	HV	KWh/m³	8,4 – 13,1		Allow deviation
Wobbe index	WI	kWh/m³	10,5 – 13,0	12,8– 15,7	Strict rules

Sweden has a set of national standards for biogas as fuel for transport vehicles in 1999. Tables 5 and 6 describe the main parameters of the standard.

Table 5: Swedish biogas standard [38]

Criteria	Unit	Limitation in regulations
Low Wobbe index	kWh/m³	12,2 – 13,2 ([CH_4] = 95-99%)
MON	-	>130
Dew point of water	⁰C	<$t_{ambient}$ -5
$CO_2 + O_2 + N_2$	% vol	<5
O_2	% vol	<1
Total sulfur	mg/m³	<23
NH_3	mg/m³	20

Table 6: German biogas standard

Criteria	Unit	Limitation in regulations
High Wobbe index	kWh/m³	10,5-13 (in H) 12,8-15,7 (in H)
Standard density	-	0,55-0,75
Dew point of water	⁰C	<nhiệtđộmặtđất
CO_2	% vol	<6
O_2	% vol	<3

2.2 Conversion engine

Diesel engine for generator K657 M2 6Ч12 / 14 (Figure 1) was selected to study the conversion to use fuel including both biogas and diesel. The basic parameters of the engine are shown in Table 7. The components of the engine's fuel system are shown in Figure 2.

Table 7: Marine diesel engineK657 M2 6Ч12/14

Parameters	Value
Type	4 stroke, no turbochargers
Number of cylinder	i = 6
Bore	D = 120 mm
Stroke	S = 140 mm
Rated rotation	n = 1500 v/ph
Rated power	Ne = 50 kW
Fuel consumption rate	g_e = 264 g/kW.h
Crank radius	Rc = 70 mm
Length of connection rod	l = 252 mm
Compression ratio	ε =15

Figure 1: Marine diesel engineK657 M2 6Ч12/14

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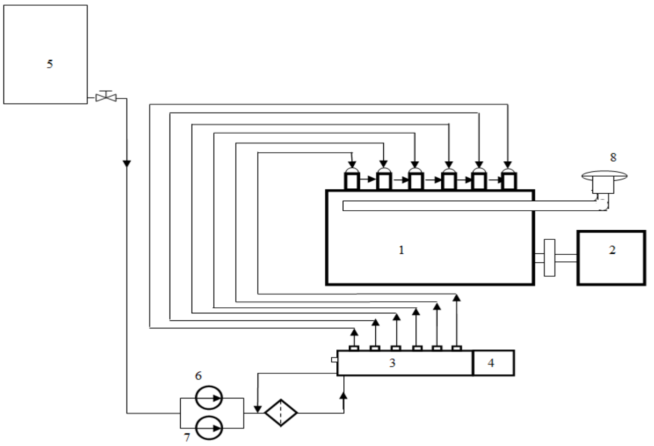

Figure 2: DO fuel system of marine diesel generator

1. *Diesel engine; 2. Generator; 3. High-pressure pump; 4. Governor; 5. DO service tank; 6. Boost pump; 7. Hand pump; 8. Air filter.*

The original engine uses diesel fuel (DO), has a fuel system diagram as shown in Figure 2. The engine uses a high-pressure cluster pump (Figure 3) in combination with a mechanical speed regulator**.**

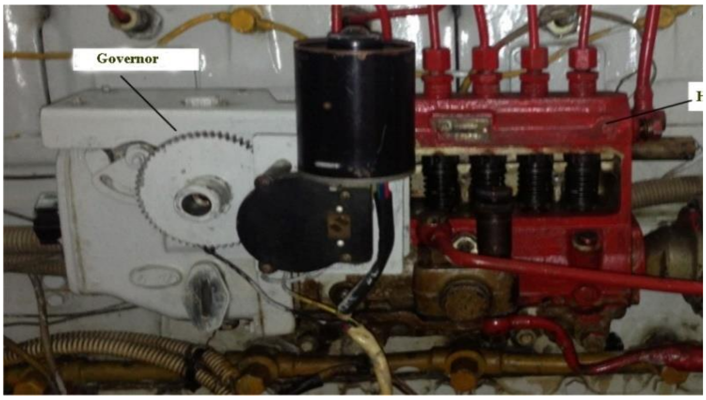

Figure 3: High-pressure pump

3. CALCULATION OF BIOGAS FUEL SUPPLY SYSTEM FOR ENGINES

3.1 Biogas fuel supply system

3.2

When using biogas fuel diagram of the fuel supply system for a diesel engine for generator K657 M2 6Ч12 / 14 as shown in Figure 4.

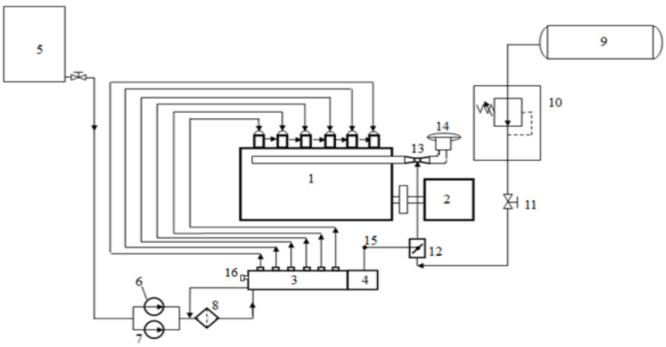

Figure 4: Biogas supply system of a marine diesel engine

1.Diesel engine; 2. Generator; 3. High-pressure pump; 4. Governor; 5. DO service tank; 6. Boost pump; 7. Hand pump; 8. Fuel filter; 9. Biogas tank; 10. Regulator; 11. Biogas cut down valve; 12. Biogas supply valve; 13. Mixer; 14. Air filter; 15. Control unit for the mixer; 16. Gear of high-pressure pump.

3.2 Calculate the mixer

Calculate the mixer to determine the following sizes: mixer size; throat mixing size; the size of a biogas digester.

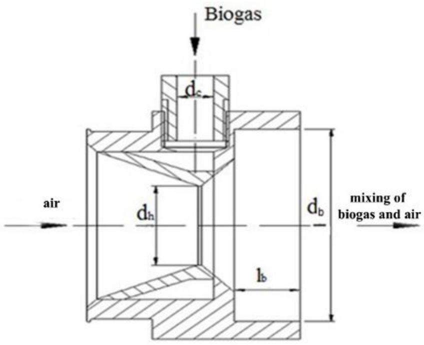

Figure 5: Diagram of calculating sizes

3.3 Determine the flow of diesel fuel and biogas when the engine uses mixed fuel

The low heating value of biogas is calculated according to Mendeleep formula:

$$Q_H = 0{,}385 * CH_4 * 1000 \quad [\text{kJ/m}^3] \qquad (1)$$

The low heating value of biogas is:

$$Q_{HB} = \frac{Q_H}{\rho_B} \quad [\text{kJ/kg}] \qquad (2)$$

To achieve a power of 50 kW, the heat generated by burning diesel fuel is complete:

$$Q_0 = \frac{Q_{HD}.G_{nl}}{3{,}6} \quad [\text{J/s}] \qquad (3)$$

In which: Q_{HD} is the low heating value of diesel fuel, Q_{HD} = 42530 (kJ/kg)

G_{nl} of diesel fuel consumed in 1 hour,

$$G_{nl} = \frac{N_e.g_e}{1000} \quad [\text{kg/h}] \qquad (4)$$

When switching to using diesel/biogas mixture, the amount of fuel supplied to the engine to ensure the operation of the engine in idle mode and provide enough energy to ensure the combustion process of biogas/air. Assuming that when the engine runs in full-load mode, the amount of heat emitted by diesel fuel is 5%, and this amount is adjusted constantly throughout the engine's working process.

The heat generated by diesel fuel when the engine works:

$$Q_{0D} = \frac{Q_0..5}{100} \quad [\text{J/s}] \qquad (5)$$

The heat generated by biogas fuel is:

$$Q_{0B} = Q_0 - Q_{0D} \quad [\text{J/s}] \qquad (6)$$

The amount of biogas needed to supply the engine in 1 hour will be:

$$G_{nlB} = \frac{Q_{0B}.3{,}6}{Q_{HB}} \quad [\text{kg/h}] \qquad (7)$$

The amount of diesel fuel supplied to the engine in 1 hour is:

$$G_{nlD} = \frac{Q_{0D}.3{,}6}{Q_{HD}} \quad \text{[kg/h]} \quad (8)$$

The total amount of fuel for biogas and diesel for 1 hour is:

$$G_{nl} = G_{nlD} + G_{nlB} \quad \text{[kg/h]} \quad (9)$$

The mass fraction of diesel fuel in 1 kg mixed is:

$$D_{hh} = \frac{G_{nlD}}{G_{nl}}.100\% \quad (10)$$

The mass fraction of biogas in 1 kg mixed is:

$$B_{hh} = \frac{G_{nlB}}{G_{nl}}.100\% \quad (11)$$

Heating value of diesel / biogas mixture is:

$$Q_H = Q_{HD}.D_{hh} + Q_{HB}.B_{hh} \quad \text{[kJ/kg]} \quad (12)$$

Calculationresultsare:

G_{nlB}(kg/h)	G_{nlD}(kg/h)	G_{nl} (kg/h)	Q_H (kJ/kg)
19,08	0,657	19,737	28330

3.4 Calculate the mixing chamber diameter

The formula for determining the composite chamber diameter is:

$$d_b = a_n.\sqrt{V_h.i.\frac{n}{1000}} \quad \text{[mm]} \quad (13)$$

In which: d_b is the inner diameter of the mixing chamber (mm);V_h is the working volume of a cylinder, [dm^3]; i is the number of cylinders that share a mixer;n is the speed of rotation of the engine [v / p];a_n is the coefficient of oscillation of the gas flow, depending on the number of cylinders that share a mixer;

Table 8: The coefficient of variation of the gas flow

Number of cylinders	1	2	3	4	5	6
Coefficient a_n	24,2	17,1	14,15	13	12,85	11,9

- The length of the mixing chamber is determined as follows:
-

$$l_b = (0{,}8 \div 1{,}8)d_b \quad \text{[mm]} \quad (14)$$

With the above parameters, we have the following calculation results:

d_b (mm)	l_b(mm)
54	45

3.5 Calculate diffuse throat diameter

Choose a preliminary throat diameter:

$$d_h = (0{,}6 \div 0{,}8)d_b \quad \text{[mm]} \quad (15)$$

The vacuum at the throat diffuses Δp_h:

$$\Delta p_h = \frac{\rho_{kk}}{2}\left[S.\left(\frac{D}{d_h}\right)^2.\frac{n.i}{2.60}.\frac{\eta_n}{\mu_h}\right]^2 \quad \text{[N/m}^2\text{]} \quad (16)$$

In which: S is piston stroke, [mm]; D is the cylinder diameter, [mm]; n is engine speed, [rpm]; d_h is diffuse throat diameter, [mm]; μ_h is the flow coefficient of the throat (μ_h = 0.8 - 0.9); η_n is the gas loading coefficient.

The speed of air flow through the diffuser throat W_{kk} is calculated as follows:

$$W_{kk} = \sqrt{\frac{2\Delta p_h}{\rho_{kk}}} \quad \text{[m/s]} \quad (17)$$

In which: ρ_{kk} is the density of air, (kg/m^3); Δp_h is diffuse throat vacuum, (N/m^2)

Determine the exact diameter of the throat:

$$G_{kk} = \mu_h.f_h.W_{kk}.\rho_{kk} = \mu_h.\frac{\pi.d_h^2}{4}.W_{kk}.\rho_{kk} \quad \text{[m}^3\text{/h]} \quad (18)$$

In which: G_{kk} air flow through the diffusion throat, can be determined

$$G_{kk} = \eta_v.V_h.\frac{n.i}{120}.\rho_{kk} \quad (19)$$

So we have a diffuse throat diameter that is defined as follows:

$$d_h = \sqrt{\frac{4G_{kk}}{\mu_h \pi.W_{kk}.\rho_{kk}}} \quad (20)$$

With the basic parameters: ε is the compression ratio of the engine, ε = 15; γ_r is the residual gas coefficient, γ_r = 0.005; T_0, P_0 are temperature and air pressure, T_0 = 293 [K] and P_0 = 1 [kG/cm^2]; T_a, P_a is the temperature and pressure in the cylinder at the end of the charging process, Pa = 0.9.P_0 = 0.9 [kG / cm^2] and T_r = 700 [K] is the gas temperature.

Results calculated:

Δp_h(N/m^2)	W_{kk} (m/s)	G_{kk} (kg/s)	d_h (mm)
9169	126	0.1256	36

Therefore, we choose the diameter throat d_h = 36 [mm].

3.6 Calculate the diameter of the biogas supply

The expression determines the speed of biogas flow through the feed pipe:

$$W_b = \sqrt{\frac{2\Delta p_h}{\rho_b}} \quad \text{[m/s]} \quad (21)$$

In which:Δp_h is diffuse throat vacuum, Δp_h [N / m^2]; ρ_b is the density of biogas, ρ_b = [kg / m^3];

Diameter of biogas supply hole will be:

$$F_{vp} = \frac{G_{nlB}}{W_b.\rho_b} \quad \text{[m}^2\text{]} \quad (22)$$

$$d_{vp} = \sqrt{\frac{4.F_{vp}}{\pi}} \quad \text{[mm]} \quad (23)$$

The calculated result is:

W_b (m/s)	F_{vp}(m^2)	d_{vp}(mm)
142,7	4,126.10^{-5}	7,25

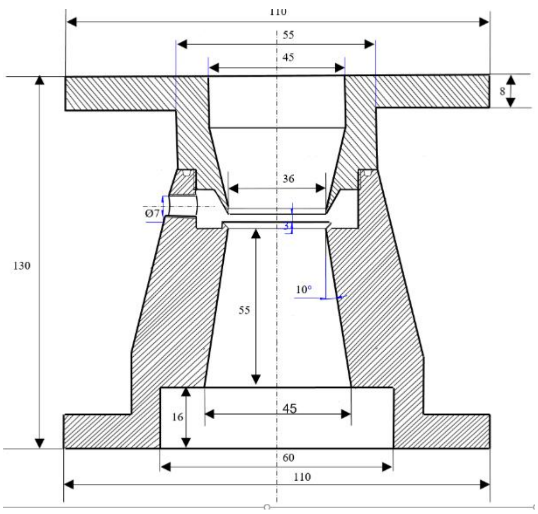

Figure 6: The structure of mixer with a donuts-shaped throat

For convenience of processing, select:

- Mixing chamber diameter: d_b = 45 [mm];
- Mixing chamber length: l_b = 55 [mm];
- Diffuse throat diameter: d_h = 36 [mm];
- Biogas supply hole diameter: d_{vp} = 7 [mm].

4. CONCLUSION

Based on the study of calculation of biogas fuel supply system for K657 M2 6Ч12 / 14 engine can give some conclusions:

A method to convert small-sized diesel engine hybrid generators to the biogas and diesel mixture has been found.

Calculated devices for biogas fuel supply system applied to a specific engine.

The conversion of diesel engines to the use of mixed fuels biogas and diesel does not significantly change the structure of the original engine, so the cost of equipment for biogas fuel supply and engine conversion is not large. , the major conversion is to change the fuel supply system, speed regulator and air intake system.

However, the use of biogas fuel for ship engines will encounter some problems such as onboard storage problems, strict requirements of safety for ships and the current supply is not yet popular.

Since the topic is currently in the scope of theoretical research, it is not possible to fully appreciate all the features of biogas use for marine diesel engines.

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