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STUDY TO DESIGN AND MANUFACTURE
A DUAL-FUEL BIOGAS/DIESEL ENGINE BASED ON ONE CYLINDER STATIONARY ENGINE

Specialty: HEAT ENGINE ENGINEERING
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ABSTRACT OF TECHNICAL THESIS

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This thesis can be lookup at:
- Learning Information - Resource Centers, The University of Danang.
- Learning Resource Centers, The University of Danang.
INTRODUCTION

1. THE REASON

To meet the needs of biogas applications in internal combustion engines, the solution that a traditional engine is improved on biogas engine must meet the following conditions: high universal nature; when the engine run on biogas, the process of the original engine system does not change, it can use the petrol as before renovation, the biogas conversion kit for diesel engines have high reliability, ease of installation, operation, low cost, suitable for the used in rural areas, farms …

Therefore, a fundamental study is how to design and manufacture a biogas engine as a complete industrial product that users could buy and use immediately with low cost and high quality is an urgent need. So "Study to design and manufacture a dual-fuel biogas/diesel engine based on one cylinder stationary engine" subject is scientific and practical.

2. THE PURPOSE

Study to improve (upgrade) the original diesel engine to dual-fuel biogas/diesel engine which is prototype, compact, and usable. It can use biogas in dual fuel mode, ignition by diesel pilot injection or only use diesel as traditional designs.

3. LIMITATION

The study only focus on improving the diesel engine Vikyno EV2600-NB to dual-fuel biogas/diesel engine Vikyno EV2600-NB-BIO:
- Modeling of the combustion in dual-fuel biogas/diesel engine;
- Designing the biogas/air mixer;
- Calculate the additional speed controller to adjust the mixture generated automatically.
4. METHODOLOGY

Combining theoretical, modeling, and empirical study establish the optimal parameters of the complement system design.

- Study in theory and modeling: study turbulent flow of biogas-air mixture through the mixtures into the combustion chamber to set the properties of mixtures, study the modelling of biogas-air mixture combustion ignited by diesel pilot injection to predict the economic and technical performance of the engine with the operating modes and various fuel components. The results help to reduce the cost of experimentation.

- Experimental study: measurement of engine power on a dynamometer power by only diesel and biogas/diesel in dual-fuel mode; measurement the engine speed characteristics using biogas/diesel; compare results for by modeling and experimentation.

Base on the results of theoretical research, modeling and empirical studies, we upgraded diesel engine Vikyno EV2600-NB into compact dual-fuel biogas/diesel engine.

5. MEANING OF SCIENCE AND PRACTICE OF THE THESIS

5.1. SCIENTIFIC SIGNIFICANCE

This thesis takes part in a depth study of dual-fuel engines biogas/diesel in Vietnam.

5.2. PRACTICAL IMPLICATIONS

This thesis takes part in making a practical products, timely response needs of economic and social life.

6. CONTENTS

- Introduction;
- Content: includes 5 chapters;
- General Conclusions And The Development;
7. NEW RESULTS IN THIS THESIS
- Successfully designed the venturi for Vikyno EV2600-NB engine working in dual-fuel biogas/diesel modes.
- Using FLUENT to simulate the combustion of engine using dual-fuels biogas/diesel.
- Based on simulations have identified a maximum aperture of biogas valve according CH\(_4\) content in biogas.
- Design a biogas governor located inside Vikyno EV2600-NB using dual-fuel biogas / diesel.
  Identify the pilot injection advance angle is 300 before top dead center suitable for Vikyno EV2600-NB at 2000rpm, CH\(_4\) concentration of 70% by volume of biogas.
1.1. ENERGY AND ENVIRONMENT ISSUE

1.1.1. Fossil fuels and outbreak climate

Increasing in Concentration of greenhouse gases is the reason why atmosphere temperature is increasing too so that the global is warming. There is no doubt who the main culprit is CO\textsubscript{2}, the gas causing the greenhouse effect from the combustion products of fossil fuels. When the atmospheric temperature increase exceeds a threshold value, it will continue to increase until it reaches the maximum value. This phenomenon is known outbreak climate.

Vietnam is one of the five countries most severely affected by climate change. As sea levels rise 1 meter, part the Red River Delta and Mekong Delta flooding; When 2m sea level rise, much of this land were flooded and sea level rise, most 3m the whole Red river Delta and Mekong river delta, including Ho Chi Minh City, located below sea level.

1.1.2. Alternative fuels derived from solar

In the alternative fuels, biogas is as a source of renewable energy potential and is derived from the sun energy. The use of this energy does not increase the concentration of greenhouse gases in the atmosphere.
1.2. USING BIOGAS AS INTERNAL COMBUSTION ENGINES FUEL

1.2.1. BIOGAS PROPERTIES

1.2.2. Quality requirements for biogas as a fuel for internal combustion engines

Depending on the concentration of impurities allowed in biogas used for equipment, we have different filtering schemes:

![Biogas purification requirements diagram](image)

**Figure 1.10: Biogas purification requirements**

For biogas used as fuel for internal combustion engines to generate electricity, we have filtered H2O, H2S and solid particles.

1.2.3. Technology filtering impurities in the biogas in Vietnam

1.2.4. Methane number

1.3. RESEARCH AND APPLICATION OF BIOGAS

1.3.1. Research and application of biogas in the world

1.3.2. Research and application of biogas in Vietnam

Professor Bui Van Ga and his colleagues in The University of Da Nang have started to study in biogas engines since 2007 till now many low, medium and high power biogas generators were successfully installed across the country. These have undergone a period of stability operations and take advantage of all sources of biogas produced, bringing huge profits to farmers.

Major and prominent products in research of the application process for biogas combustion engines of Professor Ga are Gatec-20 and Gatec-21 universal converters. They are installed and operated for the engine over country.
1.4. SMALL BIOGAS ENGINE MARKET IN VIETNAM

1.4.1. Market for electric generators and agricultural machinery

1.4.2. Characteristics of the Gatec 20 kit

Advantages of Gatec-20 kit is:
- A Gatec-20 can be used for many different engines in a range of capacity allows.
- The engine can use diesel when sources of biogas exhaust.

However, in process universal converters still has some of disadvantages such as:
- Taking a place next to the engine makes difficult to arrange additional load of its.
- Due to its universal character, reliability and working stability of the instrument cluster is not high.
- Socio-economic efficiency is not high because of the manual conversion, producing on every single engine and time-consuming.

1.4.3. Engine suitable for study

If the conversion of diesel engines to dual fuel engines was produced to a finished product by an engine factory, the social and economic huge efficiency bring to people, researchers and producers.
- Elimination of the intermediate cost of engine conversion process into biogas engines helps to reduce the cost of product.
- Increasing stability of the engine in operation.
- Take advantage of distribution channels and product warranty companies, products easily reach more people.
- Increasing the confidence of people in synchronized production equipment.

1.5. CONCLUSION
Chapter 2

PLAN FOR UPGRADING DIESEL ENGINE TO DUAL-FUEL BIOGAS/DIESEL ENGINE

2.1. SOLUTIONS FOR IMPROVEMENT

When a diesel engine is improved that can use biogas fuel, there are two different solutions on how to burn biogas.

- Solution of spark ignition engine: an engine uses spark to ignite the mixture ignition biogas/air charge into the engine

- Solution of dual fuel engine: an engine uses diesel pilot injection to burn the mixture ignition biogas/air charge into the engine

2.1.1. Solution of spark ignition engine

2.1.2. Solution dual-fuel engine

The advantage of this solution: when the engine is operating in dual-fuel mode, the motor can be replaced from 0 to 85% of energy supply from diesel fuel by biogas energy, but the engine can still ensure the operational capacity as with 100% diesel fuel.

The disadvantage of this solution: amount of diesel fuel required for ignition and cooling nozzle is always used. It is in the range of 10 ÷ 20% of diesel fuel when the engine used only diesel.

2.2. FEATURES OF ENGINE USING BIOGAS

2.2.1. The biogas spark ignition engines

2.2.2. The biogas/diesel dual-fuel engine

When the engine operate at low and medium speeds, engine power does not emit significantly lower compared to diesel engine. In some cases, it even greater than the power of diesel engine if the size of the intake mixture allows more load air/fuel into the engine. However, in this case, it should be avoided for reasons of ensuring the durability of the engine.
2.3. UPGRAADING DIESEL ENGINE TO DUAL-FUEL BIOGAS/DIESEL ENGINES

Dual fuel biogas diesel engine is the engine which can operate in use not only biogas diesel dual fuel but also fully diesel fuel only in case out of biogas fuel.

2.3.1. The using range of dual-fuel biogas/diesel engines

2.3.2. Design requirements

2.3.3. Identify the design orientations

When a diesel engine is improved on dual fuel biogas diesel engine, some parts of it will be undergone a complete change or improved:

- Studying to calculate and simulate dual fuel biogas diesel combustion process;
- Calculating and simulating, designing biogas air mixer;
- Calculating and designing biogas speed governor.
- Designing engine side cover to integrate new biogas governor and new control bars into the engine.

The others parts of engine are unchanged.

2.3.3.1. The biogas/air mixer

2.3.3.2. Power and speed of engine controls in dual fuel mode

a. Principle of biogas supply and diesel pilot injection
b. Control biogas throttle position manually
c. Automatic engine speed control

When the dual-fuel biogas/diesel engine run on dual-fuel mode with the limitation of pilot injection and biogas governor (Figure 2.10), the biogas flow will be adjusted up or down by the governor as soon as load capacity changes and the engine speed will increase or decrease. So that, the speed inside governor also increase or decrease making change to the position of the moving plate. Through the control bars, biogas flow go into the engine will be adjusted up or down in order to stabilize the engine speed.
2.4. ENGINE FOR THE STUDY

2.4.1. Engine parameters

2.4.2. Size of engine

2.4.3. Features of engine

2.5. CONCLUSION
Chapter 3
MODELING OF THE COMBUSTION IN DUAL-FUEL BIOGAS/DIESEL ENGINE

3.1. THEORY OF GAS COMBUSTION
3.1.1. Theory of non-premixed combustion
3.1.2. Theory of premixed combustion
3.1.3. Theory of partially premixed combustion

3.2. COMBUSTION SIMULATION AND CALCULATION
3.2.1. Set model in ANSYS ® FLUENT
3.2.1.1. The model geometry

The detailed dimensions of the model are shown in Figure 3.12.

3.2.1.2. Meshing the model

3.2.1.3. Installing the model parameters

3.2.1.4. Start the calculation and processing results

3.2.2. Rating dual-fuel combustion

Different from spark ignition engine, biogas diesel dual fuel engine is sparked by diesel pilot injection so Flame front is not from the head of combustion chamber but it is from pilot injection in omega combustion chamber. After gets fire, it burns quickly and forms a high energy torch so that biogas air mixer prepared can burn immediately.

Comparing Figure 3.14 with Figure 3.15 shows that in the same crankshaft rotation angle, flame front corresponding to biogas with 80% CH₄ is larger than biogas with 60% CH₄.

Figure 3.12: Detailed size and shape of the model
3.2.3. Assessing the effects of operating factors to dual-fuel biogas/diesel engines

3.2.3.1. Effect of advanced pilot injection

3.2.3.2. Effect of density mixture

3.2.3.3. Effect of engine speed to the combustion

3.2.3.4. Effect of biogas quality to the engine performance

3.3. CONCLUSION
Chapter 4
DESIGN AND MANUFACTURE DUAL-FUEL BIOGAS/DIESEL VIKYNO EV2600-NB-BIO BASED ON VIKYNO EV2600-NB

4.1. BIOGAS/AIR MIXER DESIGN

4.1.1. Calculate the mixture components through the mixer

4.1.2. Calculate the parameters of mixtures

4.1.3. Designing the mixer

If form of venturi mixer is annular, basic design drawing of the mixer includes following parameters:

![Figure 4.1: Biogas/air mixer](image)

4.1.4. Simulations by ANSYS ® FLUENT software

4.1.4.1. Draw the flow pattern created by the mixture

From the calculated parameters of the mixture, a 3D volume of flow through the mixtures is shown in Figure 4.2

4.1.4.2. Meshing

![Figure 4.2: The flow inside the mixtures used to simulate](image)  
![Figure 4.3: Meshing the flow through the mixer](image)
With the help of automatic meshing tool in Ansys® Fluent software, flow which is through the mixer is created mesh of 11848 nodes.

4.1.4.3. Calculate the boundary conditions

4.1.5. The selected parameters and calculated results of boundary conditions

4.1.6. Calculation results: Distribution of the pressure, CH4, O2, vector speed

![Figure 4.19: Variability in the density $\phi$ engine speed of different fuels with value $\phi=1$ at n=2200 r/min](image)

In Practice of using stationary engine, it primarily works in the rated speed. Due to the engine that can generate power of speed in this mode, we need to create the design of the mixture so that the value of $\phi = 1$ at rated speed. At the low speed mode, the mixture becomes a little darker, but it does not affect the combusting process. Figure 4:19 $\phi$ introduces variation of the engine speed which is calculated from the value $\phi = 1$ at n = 2200 r/min corresponding to the various CH$_4$ content of biogas. The results show that in this condition, when the engine is running at speed n = 1000 r/min, the mixture density of about 1.03 $\div$ 1.04.

4.2. CALCULATION AND DESIGN BIOGAS GOVERNOR

4.2.1. Characteristics
4.2.2. Identify methods to attach the biogas governor to the rotation mechanism available on engine
4.2.3. Position the governor on the upper balancer shaft
4.2.4. Measure the sizing engine side cover
4.2.5. Engine side cover and control bars design
4.2.6. Biogas governor calculation

![Diagram to calculate biogas governor](image)

**Figure 4.33:** Diagram to calculate biogas governor

![Diagram characteristics of the balance of speed](image)

**Figure 4.34:** Diagram characteristics of the balance of speed
4.2.7. Manufacturing the engine side cover, control bars and governor

Figure 4.40: Install the engine cover

Figure 4.41: Complete installation

4.3. CONCLUSION
5.1. EXPERIMENTAL MEASURED ENGINE PERFORMANCE

5.1.1. Layout of the experiment

![Diagram of the experiment setup]

**Figure 5.1: Layout of the experiment.**

5.1.2. The plan to install biogas engine on hydraulic dynamometer

Because the experimental time is long and it need a large amount of biogas for testing and experimentation, so that, we rebuilt the dynamometer's base to meet two different purposes:
- Testing and experimentation in laboratory engines.

**Hình 5.2: New dynamometer’s base.**
- Testing and experimentation at the place which have biogas sources.

5.1.3. The limitation of pilot injection amount

5.1.4. The experimental equipment

5.1.5. Device data sheet

5.1.6. The experimental steps

The experiment processes are presented in Table 5.2:

<table>
<thead>
<tr>
<th>No.</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Measure the external speed characteristics when use diesel</td>
</tr>
<tr>
<td>2</td>
<td>Measure diesel consumption for pilot injection</td>
</tr>
<tr>
<td>3</td>
<td>Measure the speed characteristics when use biogas 60% CH₄</td>
</tr>
<tr>
<td>4</td>
<td>Measure the speed characteristics when use biogas 70% CH₄</td>
</tr>
<tr>
<td>5</td>
<td>Measure the speed characteristics when use biogas 80% CH₄</td>
</tr>
<tr>
<td>6</td>
<td>Measure the speed characteristics when use biogas 90% CH₄</td>
</tr>
</tbody>
</table>

5.1.7. Experimentation

5.1.7.1. Prepare biogas resources for using

5.1.7.2. Measuring diesel pilot injection consumption

5.1.7.3. Results and discussion

When running in dual-fuel mode, a minimum required fuel volume for ignition and cooling nozzle is maintained. Due to the amount of excess air of diesel engine is large, the equivalent ratio of the mixture when the engine runs on dual-fuel mode may be greater than on diesel fuel mode. This leads to the dual-fuel
engine power may be greater than the diesel engine power.

The higher CH₄ content of biogas, the higher of maximum power with the given speed and speed position which dual fuel engine power is larger than diesel engine power move to the left of the graph.

Figure 5.16 shows that the effect of the content of CH₄ in biogas to diesel consumption rate of dual fuel biogas/diesel engine running on full load characteristic curve. This result shows that when the engine speed changes from nₘᵢₙ to nₘₐₓ, diesel consumption rate g/HP.h almost unchanged. The effect of CH₄ in biogas components to power consumption of diesel fuel in dual-fuel engines negligible.

5.2. 5.2. THE COMPARISON OF RESULTS BETWEEN SIMULATION AND EXPERIMENTAL

5.2.1. The scope of the comparison

5.2.2. Comparing the effects of density mixture

Figure 5.18 shows the result of variable engine power for simulation and experimentation in position speed 2000 r/min, injection angle 30 degrees
early engines, fuel biogas with 70% CH$_4$. The amount of diesel pilot injection at 10% compared to rated its.

5.2.3. Comparison of the effects of fuel components in addition to the engine characteristics

Figure 5:19, Fig 5:20 and Figure 5:21 compare the characteristics of the engine to the outside by simulations and experiments with biogas containing 80%, 70% and 60% concentration of CH$_4$. We see the level of the nonlinear characteristics in addition to the smaller simulated by the level of the nonlinear characteristics in addition to by experiment. The difference may be due to two reasons, one is we've simplified model of diesel spray combustion spark ignition cylinder and the second is the rate of fire spread membrane taken into account did not cover all affected physical and chemical factors of the place in the actual combustion chamber.

5.3. CONCLUSION
GENERAL CONCLUSIONS AND DEVELOPMENT

The results of this thesis gives these conclusion

1. GENERAL CONCLUSIONS

1. Biogas is renewable energy derived from solar energy so its combustion products do not cause an increase of concentration of greenhouse gases in the atmosphere. The presence of CO$_2$ reduces the heating value of biogas fuel, reduce burning velocity but it increases charateristic of antidetonation of the fuel, allowing increased compression ratio of the engine. So in cases of using biogas at production station, we can not need to filter out CO$_2$. This allows us to reduce operating costs for the biogas engine.

2. H$_2$S is most harmful in the biogas. For fueling stationary engines, H$_2$S concentration in biogas can be reach to a maximum of 500ppm. With this requirement we can just use the cheap adsorbed method instead of using expensive absorption method by chemicals to filter H$_2$S. Adsorbed material can be iron shaving, bentonite soil, laterite...

3. The conversion of traditional diesel engines to run on biogas can be made according to method of spark ignition engine, method of dual-fuel engine or method of bi-fuel dual fuel biogas-diesel engine. Dual fuel engine needs a minimum diesel injection for ignition. In operation, the minimum quantity diesel injection for ignition is only about less than 10% of injection at normal regime. But for preventing of over heat of injection system during operation with biogas, minimum injection should be maintained at between 15% and 20% of diesel injection at normal regime. Bi-fuel dual fuel biogas-diesel engine is in principle the same as dual-fuel engines, but in terms of the structure the engine has two independent speed governors. This option is suitable for cases with limited supplies biogas
4. Bi-fuel dual fuel biogas-diesel engine can use biogas speed regulator fitted outside the engine or compact speed regulator mounted directly on the actuator inside the engine. In the first case, original engine no need much improvement but bulky in drive system. In the second case we need to improve the engine cover and the engine axe but it will be very simple in operation. For both these options, the diesel regulator does not change, the biogas regulator command the butterfly effect in biogas flow.

5. The ventury can create a mixture of fuel characteristics in accordance with the requirements of the engine to dual fuel biogas/diesel. Calculate the flow through the simulated mixing device allows us to identify the basic dimensions of parts with engine sizes. Simulation results show that the equivalent ratio of the mixture decreases as the engine speed increases. When the concentration of CH₄ in biogas is lower the rate of decreasing is higher. But in terms of the absolute value, the decreasing of equivalent ratio is very small, does not affect to the engine's combustion process. For biogas fuel with CH₄ concentrations from 60% to 90%, we can see the value f decreases from 1 (n = 1000 rpm) to 0.96 (n = 2400 rpm). In practical use of stationary engines, engines primarily work at normal speed. Thus for full power of the engine at this regime, we need to design of the mixture device so that the value φ = 1 is at the rated speed. At the low speed, the mixture becomes a little richer, but does not affect to the combustion.

6. We can establish computational model for simulating of combustion in biogas-diesel dual fuel engine based on fluid dynamics software FLUENT with standard k-ε turbulence model, partial premixed combustion model, pilot injection spark model in form of cylindrical geometry with ignition energy can be approximated by diesel jet energy. Fuel composition and thermodynamic characteristics of the mixture is calculated and
stored as PDF file in function of temperature and pressure that can be accessed during the computing process in order to shorten the calculating time. The engine characteristics of VIKYNO-EV2600 when running biogas in dual fuel options given by simulation are fitted well with experimental results on the Froude dynamometer.

7. The dual-fuel engine power may be greater than the power of the engine when running entirely on diesel. At normal speed regime of dual-fuel engines, we can use poor biogas, without filtering CO$_2$, while ensuring the maximum power of the original engine before converting. This is because of quantity of excess air when running on diesel of the engines are so large, we can increase quantity of biogas fuel to increase engine power without any restrictions on equivalent ratio of the mixture.

8. Advance injection timing angle increases as the concentration of CH$_4$ decreases or/and the engine speed increases. When dual fuel engines run at speed of 2000 rpm using biogas containing 70 vol% CH$_4$, the optimal advance injection timing angle is 30 degrees. In the same operating conditions, the maximum temperature and the maximum pressure in the combustion chamber of dual fuel engine increase as the concentration of CH$_4$ in biogas increases, leading to the increase of expansion work and increase of engine power. For rich biogas, the indicating work cycle of the engine decreases with CH$_4$ concentration in biogas fuel. But for poor biogas, the indicating work cycle decreases faster than CH$_4$ decrease rate due to combustion quality is worse when CO$_2$ concentration in the fuel increases. In this case, at the end of the combustion process there is still a significant quantity of unburnt fuel, although the equivalent ratio of the mixture $\phi < 1$.

9. The results of this research allow us to design details of parts for converting of diesel engine VIKYNO EV2600 into dual fuel compact biogas-diesel engine which is compact in structure, convenient in use. The results of this study can be applied on
different types of diesel engines to create new industrial products contributed to the fossil fuel economy and environmental protection.

2. THE DEVELOPMENT OF THIS STUDY

The study results of this thesis are based on improvement technology from diesel engines to biogas/diesel one. To complete the technology, the thesis can be further studied in the following directions:

1. Research-intensive process H\textsubscript{2}S filter to improve filtration efficiency in the direction of using micro-catalytic filter for the large biogas stations offer enhanced efficiency and adsorption filter with conventional materials containing iron.

2. Look at the options of low pressure biogas storage and moderate pressure to ensure uptime required of stationary engines at the request of the user. Simulations of mixtures where biogas supply pressure changes.

3. Pressure gauge indicates the engine combustion chamber pressure compared to directives given by simulations to eliminate the influence of mechanical performance in comparison with experimental results.

4. Research engine life when run on biogas. Research options suitable for lubricating oil when the engine switch to run on biogas.
LIST OF PUBLISHED WORKS


