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SI engine assessment using biogas, natural gas and syngas with different content of hydrogen for application in Brazilian rice industries: Efficiency and pollutant emissions

Willian Cézar Nadaleti [a,*], *Grzegorz Przybyla* [b]

[a] *Center of Engineering, Post-Graduation Program in Environmental Sciences, Federal University of Pelotas, Rio Grande do Sul, Brazil*

[b] *Faculty of Energy and Environmental Engineering, Silesian University of Technology, Gliwice, Poland*

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ABSTRACT

After Asia, Brazil is the world's largest rice producer. During the processing of the grain, large amounts of husk are generated, corresponding to 22% of its weight. On the other hand, in the process of parboiling, in turn, the final result is considerable volumes of effluents rich in organic matter, generating large amounts of methane gas through anaerobic treatment. Therefore, the SI engine can operate with mixtures of biogas and syngas, generating electricity and heat in the Brazilian rice industries. In addition, it reduces the emissions of polluting gases that are generated with a direct burning of the husks instead of their gasification, as well as the use of methane gas. Accordingly, in this work, it was used the spark-ignition engine operating with one of the typical biogas and syngas compositions generated in the rice industries, named Bio65 (containing 65% of CH_4 by vol.), syngas1 (containing 18,3% of H_2 by vol.), and syngas2 (containing 13,5% of H_2 by vol.), respectively. Additionally, the tests with natural gas as a reference fuel have been performed. It was evaluated the emissions of polluting gases such as CO, NO_x and HC, as well as the thermal and electrical efficiency of all tested fuels. An important result that could be observed was that for both natural gas and biogas fuel, the increase in excess ratio (λ) value from 1 to 1.5 led to lower NO_x and CO emissions, even if with increased HC emissions. On the other hand, the Indicated Specific Energy Consumption increased to all the fuels tested in lean conditions in almost all ignition advances angles. The research tried to show that biogas and syngas can be used in parboiling rice industries, taking the advantage of the generated gases for energy self-sufficiency as well as reducing emissions.

* Corresponding author.
E-mail addresses: williancezarnadaletti@gmail.com, willian.nadaleti@ufpel.edu.br (W.C. Nadaleti).

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Nomenclature

Abbreviations

CO	carbon monoxide
NO_x	nitrogen oxides
HC	hydrocarbon
CO_2	carbon dioxide
H_2	hydrogen
RS	Rio Grande do Sul State
Bio65	biogas with 65% of CH_4 by vol.
COV	coefficient of variation
TDC	top dead center
ECU	Electronic Control Unit
CH_4	methane
SI	spark ignition
LHV	lower heating value
AFR	air-fuel equivalence ratio
IMEP	Indicated Mean Effective Pressure
e_{dv}	lower heating value of air - fuel mixture

Symbols

p	pressure
t	time
T	temperature
K	Kelvin
η	efficiency
ρ	density
kg	kilogram
%	percentage
Nm^3	normal cubic meter
λ	lambda
kWh	kilowatt hour

Introduction

Rice is the second most important crop in the world after wheat, with Asia being the largest producer and consumer [1] and Rio Grande do Sul state in southern Brazil concentrates most of the grain production in the country [2]. As Brazil is the ninth largest rice producer in the world [3], some residues are generated during the cereal treatment, like husks and effluent, which need to undergo adequate treatment so as not to cause environmental liabilities [4]. To effluent treatment, usually it is used the UASB reactor [5], and the final result is biogas and hydrogen generation [6]. On the other hand, the state of Rio Grande do Sul generates 46% of all the husk produced annually in the country [7], favouring its use for energy purposes [8]. However, the common husk-burning process generates highly polluting compounds [9] that harm the environment and humans. The conversion of rice husk into electricity through gasification or thermally generated electricity is a well-known technology. Moreover, the gasification process can minimize emissions, including the gasification of rice husks [11], [12]. According to a study developed by Nadaleti [13], just during the year 2017, the relation between the volume of syngas and volume of biogas produced in a rice industry in Brazil was 1/198 Nm^3/day, that is, despite the high volume of methane produced, the synthesis gas is produced in larger quantities in the industries.

Both biogas and syngas can be used in CHP systems (Combined Heat and Power) generating heat to industrial processes and electrical energy to local use. Considering the syngas with the typical composition of rice husks gasification for application in Spark Ignition engines - SI, no work has been reported in the literature. Generally, the number of studies on the use of synthesis gas from biomass gasification or pyrolysis in SI engines is quite limited and usually concerns the gasification of different kinds of woods or seeds.

Furthermore, it was not found any experiment in the literature analysing syngas from rice husks gasification and biogas with 65% of methane content originated from the anaerobic treatment of rice parboiling effluents. It is more common papers reporting experiments using only syngas in SI engines [14,15]. Considering biogas and syngas application to SI engines, solely one work was reported, however, the authors used horticultural residues and not rice husks [16].

An important factor is that most of the studies that consider biofuels from biomass energy in SI engines with emission reductions and energy efficiency [17] are generally directed to the transport sector. Thus, a novelty of this study is to show that the use of biogas and syngas generated in the industries can produce renewable energy when the SI engine is operating with stoichiometric and lean mixture. In addition, CHP systems deliver two types of industrial energy: thermal and electrical energy, thereby reducing dependence on local utilities and reducing costs.

Generally, studies involving mixtures of methane and hydrogen rely on natural gas as a substitute for methane throughout the experiments. Besides that, no analysis was reported in the literature employing biogas emission and efficiency analysis with 65% methane and 35% CO_2 (Bio65). The present study shows the possibility of using two compositions of syngas and biogas in SI stationary engines at Brazilian rice industries.

Another important factor is that the use of biogas and syngas generated in the rice industry can reduce dependence on the purchase of electricity, in some cases promoting self-sufficiency only with locally produced waste. In addition, comparing the CHP system with steam turbines, the first presents greater efficiency in energy production. However, one of the most important factors is that the carbon dioxide emitted with the utilization and burning of these gases in the CHP system is not considered a greenhouse gas because it has already been absorbed in the rice production process, with no additions to the atmosphere.

Considering the above, this study evaluated the use of biogas with 65% in methane content (Bio65) and synthesis gas in an SI engine. The production of electricity, as well as the gases emitted, were evaluated using a gas analyser coupled to the system. The objective, besides evaluating the emission of pollutants is to contribute to the incentive of the use of industrial residues for the production of clean energy. The potential of thermal and electric energy production of the parboiling industries of rice in Brazil is high, reducing the need to purchase electric energy from the concessionary, besides the possibility of commercialization of the surplus energy.

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