PREDICTION THE BEHAVIOR OF AN INTERNAL COMBUSTION ENGINE TO BE FED WITH GAS FROM BIOMASS, COMPARED WITH FEEDING WITH GASOLINE, USING MATHEMATICAL MODELING

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Abstract. *The behavior of an internal combustion engine fueled with biomass gasification gas is evaluated by using an elaborate mathematical model, which with the thermodynamic properties of fuel supplied, the geometric characteristics and engine operating conditions, can predict the interior temperature profiles, heat flow, work and pressure in relation to crank angle. The model also was used to evaluate the influence of rotation speed, air ratio and angle of initiation of combustion on the engine indicated power. Among other things, found that feeding the engine with biomass gas can be obtained between 59 and 65% of the power output when powered by gasoline. Furthermore, all results are compared to the feeding gas under the same conditions.*

Keywords*: gasification, internal combustion engine, biomass, mathematical modeling.*

1. INTRODUCTION

The use of biomass gasification gas as fuel for internal combustion engines is a technology that has been used for over a century. The spark-ignition engines, usually fueled with gasoline are capable of operating only feeding gas from biomass. Diesel engines can be adapted to run on producer gas by reducing the rate of compression (when necessary to prevent uncontrolled self-ignition of the gas) and installing a spark ignition system (FAO, 1986).

Since the efficiency of internal combustion engine depends on various parameters including the quality of fuel supplied, geometry and some other engine operating conditions, it is desirable to use mathematical modeling to evaluate the behavior of an internal combustion engine fueled specifically with biomass gas, especially because this gas is composed of many species whose proportions are different depending on several variables in the gasification process.

In this paper, we present the results obtained with a mathematical model that simulated an internal combustion engine fueled with biomass gasification gas.

2. ABOUT THE MATHEMATICAL MODEL USED

It was based on an elaborate mathematical model whose details are presented in Ferguson's book (1986), which were made some changes so it can accept biomass gasification gas as fuel. The main difficulty of the modification of the model is that the contents of the species present in the biomass gasification gas (CO, CO2, H2, CH4 and N2) are usually not fixed and vary according to operating conditions of the gasifier, then the model should be able to predict the thermodynamic properties of biomass gas for each temperature within the range of engine operation. It is not the aim of this paper present the details of the mathematical formulation and due to the large amount of details and little space available, we recommend the interested reader to reference of Ferguson (1986) which provides details of the original model and also refer to master's dissertation of Centeno (2010) which publishes the details of the changes to the original model.

3. VALIDATION OF MATHEMATICAL MODEL

To validate the engine model results were compared with experimental test results obtained by Martinez (2009) in the laboratories of Excellence Group in Thermal and Distributed Generation (NEST) in the Itajubá Federal University (UNIFEI). Table 1 shows the data generated by the model and the corresponding experimental data for five different engine load conditions. Figure 1 shows a bar graph comparing the electrical power measured by Martinez (2009) against the electrical power predicted by the model, in this same figure shows the indicated power predicted by the model. With reference to the experimental measurements, model predictions have an average error of 11.53%.These predictions could be improved by modifying the model data such as engine wall temperature, thermal conductivity and wear of piston engine.

Table 1. Comparison of electrical power measured by Martinez (2009), against those predicted by the model.

#	V1	V2	V3	V4	V5
1	100000,00	0,94	8,88	6,04	5,12
2	87890,63	0,89	7,28	4,95	4,50
3	71679,69	0,87	5,68	3,86	3,67
4	53710,94	0,84	3,92	2,67	2,75
5	28320,31	0,86	1,68	1,14	1,45

#: Test
V1: Initial pressure [Pa]
V2: Fuel - Air equivalence ratio
V3: Indicated Power [kW]
V4: Electrical Power (model) [kW]
V5: Electrical Power (experimental) [kW]

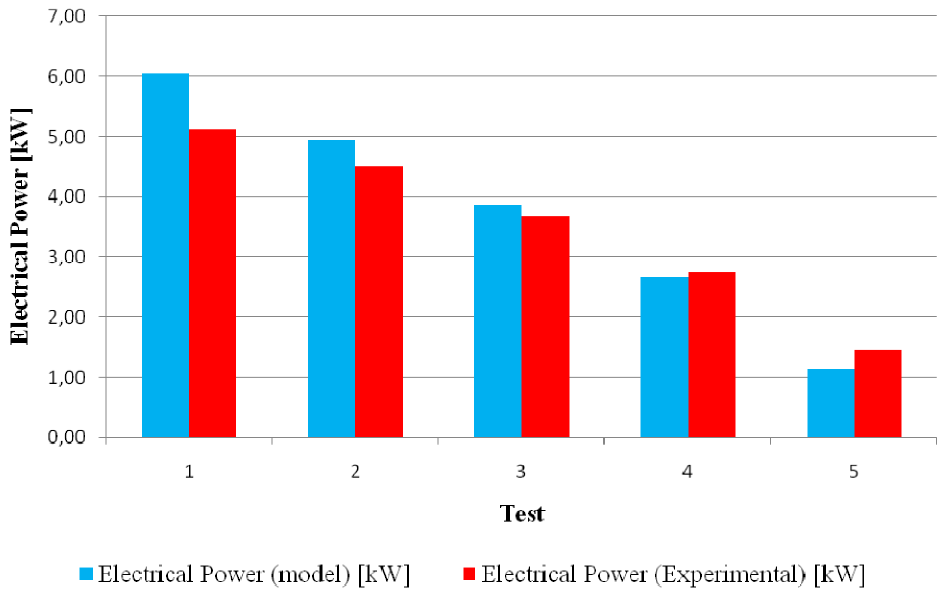

Figure 1. Comparison of electrical power measured by Martinez (2009), against those predicted by the model.

4. RESULTS

We used the model to make some simulations that predict the behavior of the internal combustion engine running on gas from biomass. For the simulations was used YANMARBTD22 geometry engine, which was the same engine used in the experiments. The engine was originally built to work with Diesel, but was later modified by adding a spark ignition system to work with natural gas. Table 2 shows some characteristics of the motor.

Table 2. Geometric parameters used in the simulation

Description	value
Bore (m)	0.09
Stroke (m)	0.09
Compression ratio	12
Number of cylinders	2

4.1. Evolution of gas temperature and heat flux in the motor, in relation to crank angle

Figures 2 and 3 represent the evolution of temperature and heat flux (from inside the engine to the outside) in relation to crank angle respectively, one can see that both figures are very similar due to the fact that the heat flux is proportional to the temperature inside the motor. It is possible to verify the temperature of the unburned gases for both petrol and gas from biomass are practically the same; while for combustion gases are different, being shorter for biomass gas supply compared to gasoline-powered. Another important observation is that in the range between 20 ° before TDC and 50 ° after TDC, there are reported temperatures for both burned gases to unburned gases, this is due to the fact that this is the length of burning time and during this time are two types of mixtures of gases inside the engine.

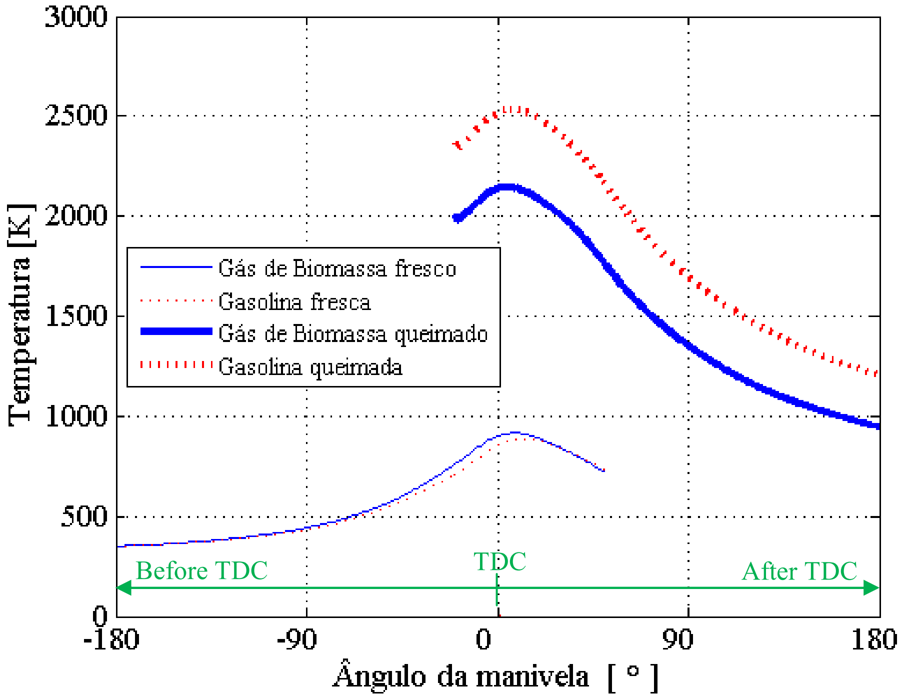

Figure 2. Temperature versus crank angle

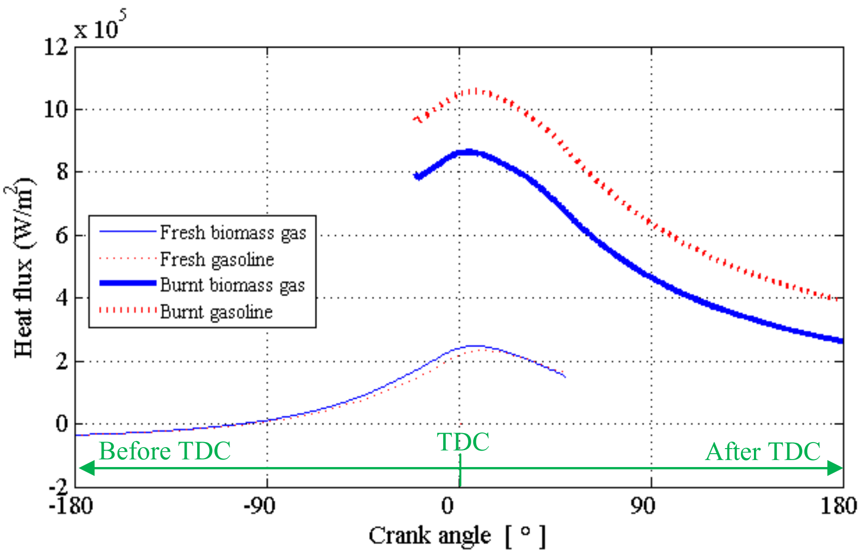

Figure 3. Heat flux versus crank angle

Figure 4 shows the heat transfer from inside the motor for the exterior, with respect to crank angle. It is noted that the heat transferred during the compression stage (from -180° to -20°) is practically the same for gas supply of biomass for power with gasoline, but it should be noted that the values of heat transfer in compression stage (-180° to -20°) are slightly below zero, this is because the fresh fuel mixture being compressed has a temperature lower than the engine walls. From -20° (20° before TDC) combustion starts and therefore the transfer of heat to the outside of the engine, note that this area of heat transfer gas supply of biomass feeding less than gasoline, which would be the expected behavior.

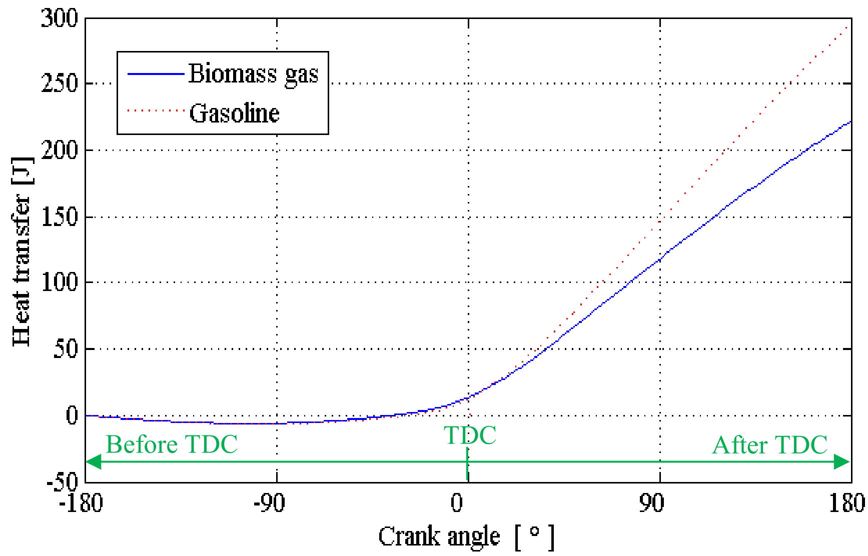

Figure 4. Heat transfer versus crank angle

4.2. Pressure evolution in the interior and engine work in relation to crank angle:

Figure 5 shows that the pressure inside the engine both for feeding gasoline and for feeding biomass gas, are practically equal until the crank reaches 20° before TDC, thereafter the pressure in inside the engine fueled with biomass gas is less than feeding gasoline, this is the expected behavior because from then starts burning and calorific value of biomass gas is lower than gasoline.

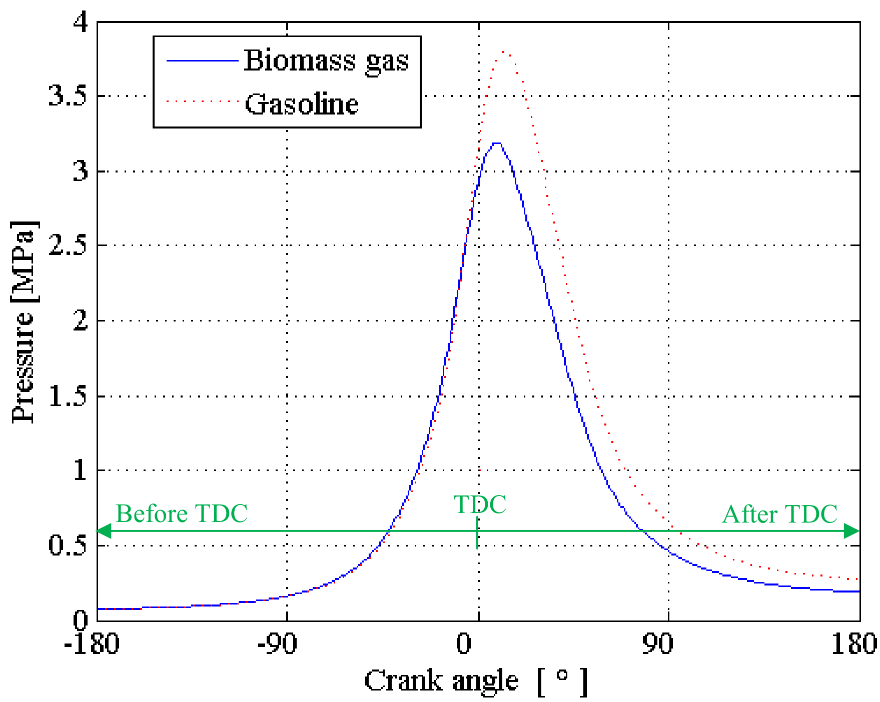

Figure 5. Pressure versus crank angle

Similar to that observed in the previous figure, the fig. 6 shows that working with gasoline-powered engine is virtually the same as in the biomass gas supply up to 20° before TDC, from this angle the working gasoline-powered engine is greater than that obtained with the engine fueled with biomass gas.

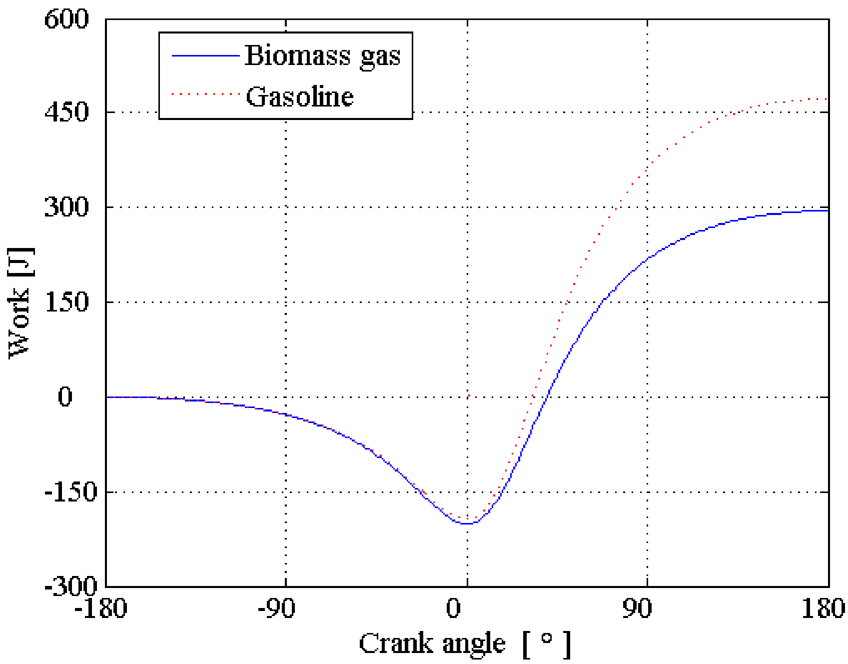

Figure 6. Work versus crank angle

4.3. Indicated power in relation to the speed of rotation of the combustion engine:

Figure 7 shows that for both (gasoline and biomass gas), the ratio of indicated power and the engine rotation speed is linear and proportional. For variations of engine speed within the range simulated, the output power with the engine running on gas from biomass is about 65% of operating on gasoline obtained under the same conditions, these results agree with observations Tinaut (2006) which states that operate with gas from biomass could be obtained 2/3 of the power output with gasoline. Note that theoretically, both the line representing the relationship to power on gasoline, the line representing the relationship for biomass gas supply should be straight lines through the origin of the coordinate system and therefore the relationship between these should be a constant, i.e. a horizontal line. In the fig. 7 verifies this behavior for high speed, but also shows that for low speed moves away from this performance.

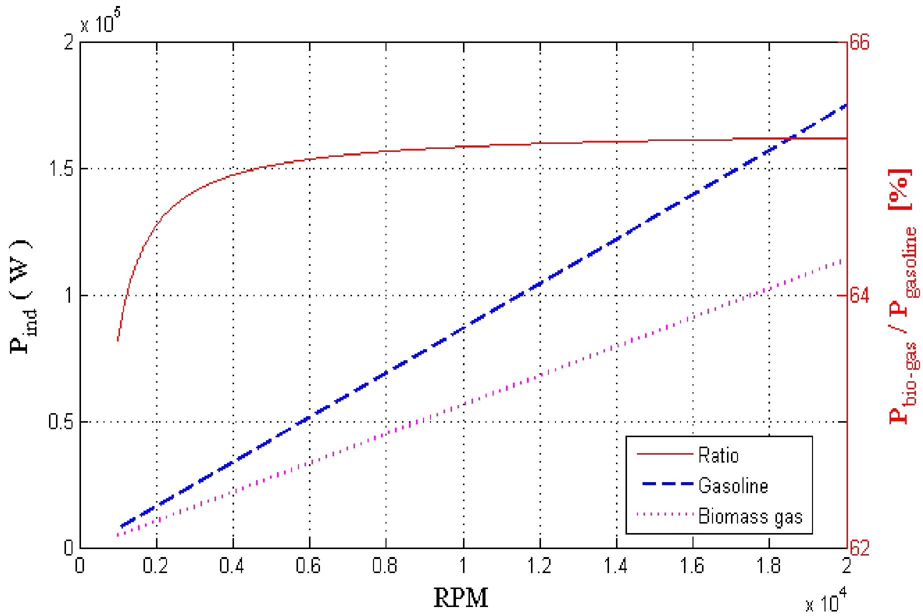

Figure 7. Indicated power versus RPM

4.4. Indicated power versus the amount of air fed to the engine:

Figure 8 shows the variation of the power indicated in accordance with the amount of air fed to the motor. This figure shows the expected behavior, the power increases up to the stoichiometric air ratio and starting from this point begins to decrease with the increase in the amount of air. It is important to note that near the stoichiometric air ratio, the output power with the engine running on gas from biomass is around 60% of the power output to operate on gasoline.

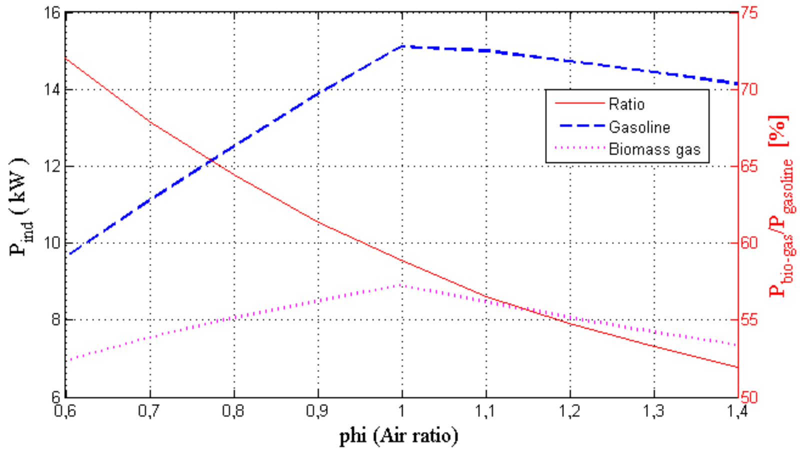

Figure 8. Indicated power versus air ratio

4.5. Indicated Power in relation to the angle of igniting

Figure 9 shows that for angles (start of combustion) greater than 25° before TDC, the engine used was not obtained significant increase in power. It is also noted that the operating power range simulated biomass gas varies between 62 and 65% of the obtained operating on gasoline.

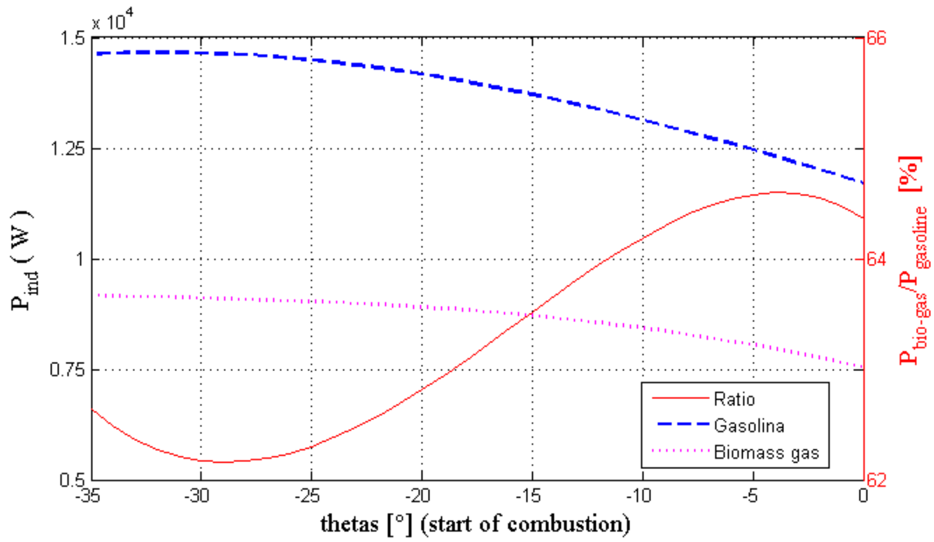

Figure 9. Indicated power versus start of combustion angle

4.6. Indicated power in accordance with the engine compression ratio

Seen in the fig. 10 for gasoline supply was simulated only to a 12:1 compression ratio that is because for higher compression ratios are problems of uncontrolled self ignition. For biomass gas supply was simulated to a compression ratio of 18:1 this is because usually this can be fed to a gasoline engine (compression ratio to about 12:1) or a diesel engine modified (ratio understanding ranging from about 12:1 to 18:1). It is noted that the power increases with the compression ratio and therefore, if you want more power supply with biomass gas is recommended to use an engine with high compression ratio, for example, a diesel engine modified for spark ignition.

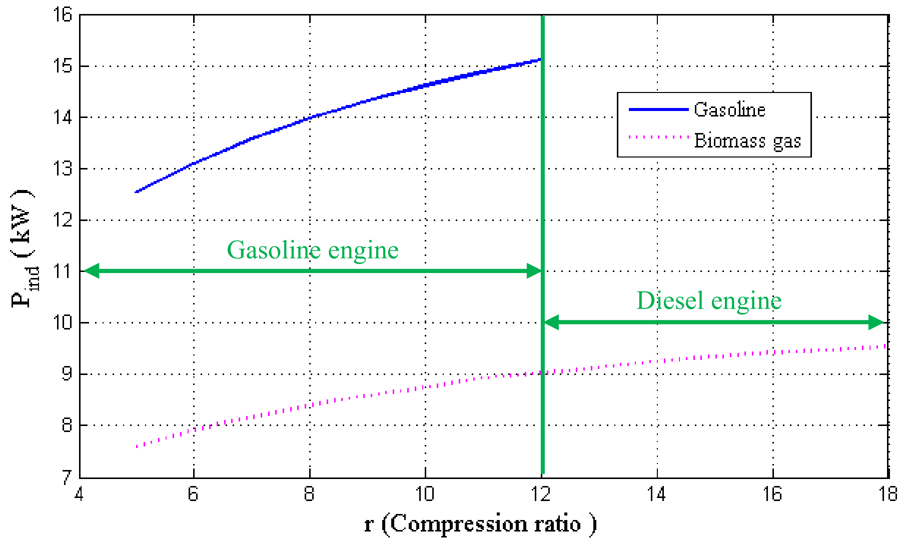

Figure 10. Indicated power versus compression ratio

5. CONCLUSIONS

Operating an internal combustion engine with biomass gasification gas can be obtained an output of between 59 and 65% of that obtained the same engine operating on gasoline. There is an optimum ignition angle may depend on the type of engine and fuel fed to the case tested was 24° before TDC. For more powers for biomass gas supply is recommended to use higher engine compression ratio.

6. ACKNOWLEDGEMENTS

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