COMPRESSION RATIOS COMPARISON BETWEEN ENGINES OPERATING WITH PRODUCER GAS

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ABSTRACT: Compression ratio is one of the main properties of a reciprocating internal combustion engine defined by its geometry. Typical values are between 8 and 12 for Spark Ignition (SI) engines and between 12 to 24 for Compression Ignition (CI) engines. The ignition in engine operating with producer gas takes place via spark and thanks to a higher octane rating compared to gasoline, it is possible to use engine with a higher compression ratio in order to increase the thermal efficiency of the process. To test the behaviors of the producer gas combustion with different compression ratios four engines were used. Two of them were GM Vortec 3 Liters, with 8.3:1 and 10.5:1 compression ratios respectively, in this case the comparison was based on the exhaust emissions and on the maximum electrical power output reached. The other two were Ashok Leyland 3.8 Liters both with compression ratios higher than the GM engines, which were 12:1 and 16:1. This time, the comparison related mostly to the manifold absolute pressure and to the input from a Bosch Knock sensor. Both the Ashok Leyland engine heads were disassembled from the crankcase in order to inspect pistons and combustions chamber. Results obtained with the two GM engines showed higher performances of the 10.5:1 one in terms of maximum power output compared to the 8.3:1, and similar emissions. The test with the two Ashok Leyland showed lower manifold absolute pressure at the same power output for the 16:1 engine, indicating better performances. During the engine inspection no signs of erosion or wear were observed, confirming the input from the knock sensor about the total or near-total detonation absence.

Keywords: Engine, syngas, energy, efficiency

1 INTRODUCTION

The renewable sources are a sustainable alternative to fossil fuels for energy production [1]. Biomasses are one of these, and their abundance makes them very interesting for electrical and thermal power generation [2], especially low-quality biomass such as vine prunings [3], grass biomass [4], corn cobs [5] etc. In order to use in an efficient way the biomass chemical energy, it is possible to convert it an a gaseous flammable gas, called syngas, through the gasification thermochemical process [6] [7]. This gas is a mixture of H_2, CO_2, CO, N_2, CH_4, H_2O [8][9].

Internal combustion engines are a promising option for the energetic exploitation of the syngas produced by small scale gasification system [2].

Nevertheless, literature concerning syngas fueled engines is quite modest, probably especially due to the non-availability of standard gasification systems [10].

In particular, this work is focused on studying the behavior of engines with different compression ratios.

This is one of the parameters that defines the basic geometry of a reciprocating engine and it represents [11]:

$$CR = \frac{Maximum\ cylinder\ volume}{Minimum\ cylinder\ volume}$$

(1)

It plays a role for the efficiency of the engine, that is higher for high compression ratio due to the increasing in the in-cylinder pressure and expansion work [12].

It is the only factor on which depends the Otto-cycle reversible efficiency:

$$\eta_{\vartheta} = 1 - \frac{1}{CR^{\gamma-1}}$$

(2)

Where γ is the ratio between the constant-pressure and constant-volume heat capacity [13].

Spark ignition engine have a compression ratio usually between 8 and 12, while compression ignition from 12 to 24 [11]. Syngas can operate in both SI and CI engines, but in the first ones can be the only fuel, because it needs a certain amount of diesel to start the combustion in absence of the spark [14]. CI engines can be quite easily converted to SI substituting the diesel injector with spark plugs, and this possibility it is quite interesting for their robustness and reliability for stationary applications [15]. Nevertheless, high compression ratio is often avoided for engines running on syngas for an alleged knocking tendency [10].

Reed and Das say that the compression ratio can be increased up to 14:1 [16], while Sridhar and Yarasu have tested 17:1 engine without any audible knocking [10].

In order to obtain further information on the possibility of using high compression ratio for syngas operated engines a series of tests were carried out.

Two gasifier-engine power plants were used, both manufactured by the ALL Power Labs company, and four different compression ratios were tested. Various parameters were monitored such as manifold absolute pressure (MAP), power output (PO), pollutant emissions etc. to assess the behavior of the different machines.

The results of this tests will be summarized and discussed below.

2 MATHERIALS AND METHODS

2.1 The facilities of the tests

Two gasifier-engine power plants were used, both manufactured by the ALL Power Labs company, the PP20 Power Pallet and the PP30 Power Pallet.

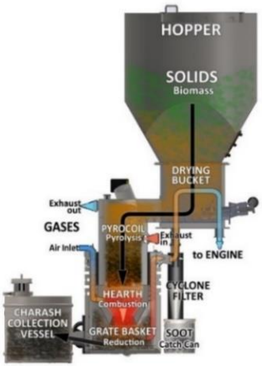

Figure 1: ALL Power Labs gasification system [17]

The PP20 is an Imbert downdraft gasifier with internal heat recovery [18]. It is equipped with a GM Vortec 3 liters engine, and the 8.3:1 and 10.5:1 compression ratios were tested.

Figure 2: GM 8.3:1 and 10.5:1 pistons

Figure 2 shows a GM 8.3:1 piston on the left and a GM 10.5:1 piston on the right. The low compression one had already been used for several hours before being substituted with the new high compression piston.

The PP30 is an evolution of the PP20 and it is equipped with an Ashok Leyland 3.8 liters, in this case the CR tested were 12:1 and 16:1.

Figure 3: Piston heads of the AL 12:1 on the left and of the AL 16:1 on the right.

2.2 Data collection

All the four engine – gasifier permutations were tested for several hours in order to acquire data on the engines behavior. For the PP20, emissions and maximum power output were monitored.

In this case, two instruments were used for the emissions, the Pollution Polaris FID Portable TOC Analyser for the volatile organic compound (VOC) measurement, and it complies with the EN 12619:2013 and EPA Method 25A, while the MRU Vario Plus Industrial for the Carbon monoxide and nitrogen oxides (CO and NOx), and it complies with USEPA methods CTM-030 and CTM-034, international ASTM D6522, and it is certified according to DIN EN 50379-1 and DIN EN 50379-2. Both the engines were tested with and without a three-way catalyzer (CAT).

Concerning the PP30, the emissions were measured only for the 12:1 engine with the three-way catalyzer, but VOC were not considered. Not only the maximum power output was measured for both the Ashok engines, but also the manifold absolute pressure and the knock input parameter through the MS3Pro standalone engine management system, used both for data acquisition and to manage the spark ignition with different timing advance (T.A.).

The emissions were monitored in different operating point for every engine – gasifier permutation, varying the electrical power output, the timing advance and the lambda value (λ) that is the air-fuel ratio divided by the stoichiometric air fuel ratio [19].

Both the Ashok Leyland engine heads were removed in order to inspect the combustion chamber state after some tens of running hours.

3 RESULTS

3.1 Emissions measurement

Table I, II and II summarize the most relevant results obtained during the emission measurement tests.

Table I and II focus on the GM engines comparison. It shows that VOC and NOx tend to be higher the for high compression, while CO is quite similar. This behavior is in line with the literature. For high CR there is a lower gas temperature during the latter part of the expansion stroke, so hydrocarbons have less chance to oxidize [11]. Concerning the NO emissions, some studies claim an increase for high CR, others a slight decrease [11]. Nitrogen oxides formation increases exponentially with temperature [20], therefore it is reasonable a higher production of this pollutant in high CR engines, due to the higher peak temperature reached [21].

Table I: PP20 50Hz emissions comparison at λ = 1

CR	PO [kW]	T. A.	CAT	VOC *	CO *	NOx *
8.3:1	6	36°	OFF	53	4955	242
10.5:1	6	20°	OFF	76	6218	279
10.5:1	6	22°	ON	41	504	9
8.3:1	12	22°	OFF	28	6884	187
10.5:1	12	22°	OFF	94	6040	470
10.5:1	12	22°	ON	40	681	0

*mg/m3@11% O_2

Table II: PP20 50Hz emissions comparison at λ = 1.1

CR	PO [kW]	T. A.	CAT	VOC *	CO *	NOx *
8.3:1	6	22°	OFF	13	753	158
10.5:1	6	26°	OFF	55	715	443
10.5:1	6	26°	ON	39	3	257
8.3:1	12	22°	OFF	21	577	190
10.5:1	12	20°	OFF	52	621	746
10.5:1	12	22°	ON	30	17	695

*mg/m3@11% O_2

Table III sums up the values measured with the GM 10.5:1 and AL 12:1 engines operating in the best operating conditions with the three-way catalyzer. It is possible to see that the emissions are quite similar and very low for both the systems. For the 10.5:1 also the VOC were measured and a value of 3.9 ppmvd at 15% O_2 was detected.

Table III: PP20/PP30 lowest emissions comparison with catalyzer

CR	PO [kW]	T. A. [°]	λ	CO [*]	NOx [*]
10.5:1	12	22	1.02	1.1	8.6
12:1	13.3	20	1.012	2	7
12:1	18.3	20	1.017	2	7

*ppmdv at 15% O_2

As a comparison for the measured emissions, the San Joaquin Valley Unified Air Pollution Control District limits are 25 ppmvd at 15% O2 for the VOC and 9 ppmvd at 15% O2 for the NOx [22] and is possible to see that in the best configurations (λ between 1.01 and 1.02 and with the catalyzer on) the emissions are under this limits.

3.2 Power output comparison

Table IV shows the maximum electrical power output reached for every gasifier – engine permutations. It is necessary to specify that the load that can be applied to the engine cannot be increased continuously, but only through 1 kW steps. This could lead to over or underestimate the difference between the various maximum power output reached by the different systems. However, the increase in the maximum power for the higher CR is substantial.

Table IV: Maximum electrical power output

Facility	Frequency	Maximum PO
PP20 – GM 8.3:1 3L	60 Hz	18.9 kW
PP20 – GM 10.5:1 3L	60 Hz	20.4 kW
PP30 – AL 12:1 3L	50 Hz	23.3 kW
PP30 – AL 16:1 3L	50 Hz	25 kW
PP30 – AL 12:1 3L	60 Hz	26.2 kW

3.3 Ashok Leyland engines comparison

Table V compares the two AL 4 liters engines through the knock input value and the manifold absolute pressure measured during the tests. The numbers reported in the table are the averages of the data collected for periods of some tens of seconds, with a frequency of 14 Hz.

Table V: Engine data collections

Facility	Power Output	T. A.	Knock Input	MAP
16:1	13 kW	10 °	31.5%	61.5kPa
12:1	13 kW	10 °	30.5%	70.4kPa
16:1	14 kW	10 °	30.4%	63.7kPa
12:1	14 kW	10 °	28.7%	73.5kPa
16:1	17 kW	9 °	31.0%	71.6kPa
12:1	17 kW	9°	28.3%	81.2kPa
12:1	17 kW	12 °	29.9%	79.1kPa
12:1	17 kW	18 °	27.0%	75.2kPa
12:1	17 kW	22 °	27.5%	73.8kPa

It is possible to see that for the same power output and timing advance, the manifold pressure of the higher CR engine is significantly lower, this indicates that it needs less air fuel mixture to produce the same power output. The knock input value is quite similar for both the cases, slightly higher for the 16:1, but not enough to indicate a real knock tendency of the engine, even if for a better evaluation of the problem an in-cylinder pressure sensor would be necessary.

3.4 Theoretical efficiency

How it is shown with the (2) formula, it is possible to calculate the reversible efficiency of a spark ignition engine knowing the CR and the mixture heat capacities. Considering a simplifying assumption of $\gamma = 1.4$ for the syngas – air mixture, the reversible efficiencies of the tested engines are summarized in Table VI.

Table VI: Engines reversible efficiencies.

CR	η_0
8.3:1	57.11 %
10.5:1	60.96 %
12:1	62.99 %
16:1	67.01 %

As it is possible to see from the previous table, the CR has a huge impact on the efficiency of an engine, so it would be preferable to use high compression engine in the absence of issues like higher NOx emission or detonation. It is important to specify that the reversible efficiency is far from being the real engine efficiency that could reach peak of about 40 % [23] and only in very limited operating condition. This because the engine efficiency depends not only on the reversible efficiency but also on other factors such as volumetric and mechanical efficiencies [11] [24].

3.5 Engine inspection

As it is possible to see from Figure 3, both AL piston heads do not show evidence of wear, and not even the engine heads or the cylinder liners. Nevertheless, there are signs of fouling due to tars and particulate matter present in the fuel gas. These tests were performed in parallel with other tests on the filtering systems, that is also a crucial point of a gasification system [25], therefore the gas was not perfectly clean.

4 CONCLUSIONS

The experimental campaign described in this work shows that coupling a small scale gasification system with an engine with a high compression ratio is very promising.

Considering the not giant amount of data available it is still advisable to proceed with caution, and in the event of an engine choice opt for a CR below 14 as reported by the Handbook of Biomass Downdraft Gasifier Engine System [16]. However, no evidence where found on preferring very low CR (less than 10) for spark ignition engine operating with syngas.

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