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Sewage Sludge Based Producer Gas of Rich H₂ Content as a Fuel for an IC Engine

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Abstract

The manuscript presents investigation on hydrogen rich gas combustion in an internal combustion (IC) engine. The gas is obtained from gasification process of sewage sludge which is by-product of waste water treatment in a municipal sewage treatment plant. Recently introduced EU regulations of environmental protection do not allow to use such sludge as a soil fertilizer or substance for landfilling the ground due to its biological toxicity. On another hand, this sludge contains organic content of approximately 45-55% and from this point of view the sludge looks as an attractive material for fuel production through its gasification. This technology, primarily applied for wood gasification, has been also successfully implemented for gasification of sludge. It was found that the producer gas obtained in this way is rich of hydrogen content even up to 25%. This is because of high water content in the sludge that provides favorable conditions for steam reforming resulting in increase of hydrogen in the products of gasification. The high hydrogen content in the producer gas can lead to improper combustion particularly when the combustion takes place in the internal combustion engine. That improper combustion might appear as combustion knock and it is the main problem for the engine in which hydrogen is used as a fuel [1]. Onset of the knock during combustion contributes to rapid increase in heat transfer to the piston crown causing the piston to be quickly overheated that leads to surface erosion and damages. Additionally, engine body vibration coming from the knock significantly shortens engine durability. Conclusions from this investigation provide good premises for combusting the sludge producer gas in the IC engine without any improper combustion anomalies, thus considers this gas as worthy fuel for a stationary engine driven a power generator. The presentation shows results of producer gas combustion in both the spark-ignited and the compression ignition engine with particular focus on engine working cycles repeatability and potential knock onset. Additionally, these two quantities for methane, biogas (consisted of 65% CH₄ and 35% CO₂) and hydrogen combustion has been also determined. It was conducted for making comparison between these gases and the sludge based producer gas with respect to applying them as fuels for the IC engine.

1 Sewage Sludge Characteristics

The sewage sludge utilization is important because of the following:

- greenhouse effect (methane emission),
- stink (fermentation and putrid processes),
- bacteriological contamination of water and soil when sludge is landfilled.

It has been stated that the organic content in the municipal sewage sludge is high enough to justify its further thermal utilization. The organic content in the sludge can exceed more than

50% by mass after its drying [2,3]. Then, it can be satisfactorily gasified in the gasification reactor. As a result of this thermal treatment the sewage sludge can be neutralized and the producer gas is generated. In the table 1 there are properties of dry and wet sludge. The table 2 contains properties of the exemplary producer gas with high H₂ content in terms of hydrogen combustion knock investigation.

Table 1: Municipal sewage sludge properties [2].

Property	Percentage	Municipal Sewage Sludge	
		Wet	Dried
Moisture	%	79 - 80	11.3 - 13.2
Ash	%	7.1 - 8.8	30.5 - 36.3
Sulphur	%	0.30 - 0.31	1.29 - 1.30
LHV (Low Heating Value)	MJ / kg	0.62 - 0.67	10.9 - 11.4

Table 2: Composition of the producer gas.

Composition of the producer gas	Percentage by volume	Percentage by energy content
Hydrogen	16 %	50 %
Carbon monoxide	13 %	19 %
Carbon dioxide	16 %	0 %
Methane	3 %	31 %
Nitrogen	52 %	0 %
Molar Weight	26.04 kg/kmol	
LHV	3.4 MJ/Nm ³	
A/F stoic (by volume)	0.98 Nm ³ /Nm ³	

2 Gasification System

Chemical energy contained in the sewage sludge will be converted to electrical energy and heat in the steps as follows (Fig 1.):

- gasification of the sewage sludge after preliminary drying,
- burning the producer gas in a CHP set including the IC engine driving a power generator for electrical energy production.

Usage of this gas as a fuel for the IC engine makes several difficulties due to low calorific value and unstable composition of the producer gas during sludge gasification. It contributes to unsteadiness of engine work [4]. There is also problem with tar content in the gas, however, it can be overcome through applying scrubbers and filters.

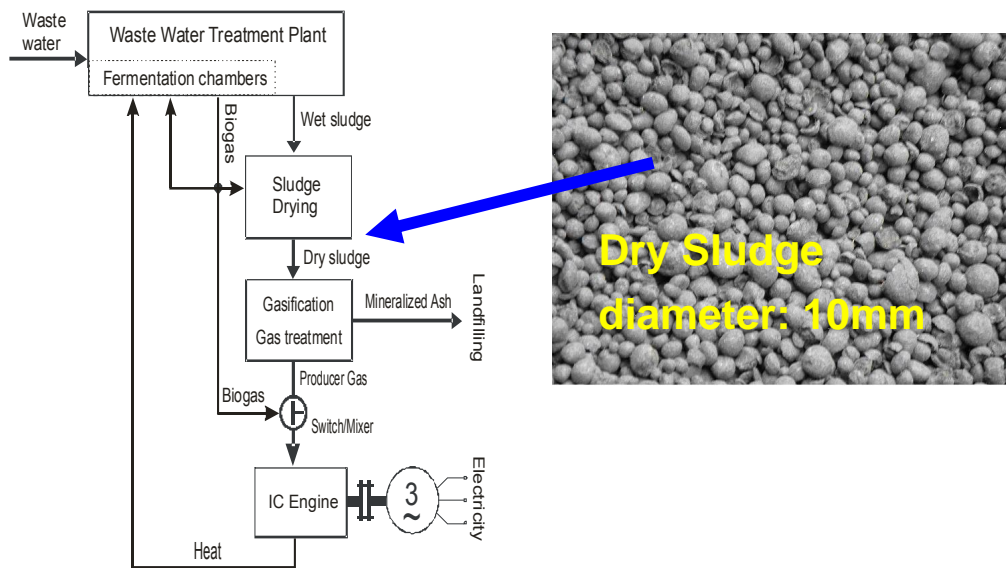


Figure 1: Diagram of sludge thermal utilization.

3 Combustion in the Internal Combustion Engine

The engine applied for the research:

- a) modified Deutz FL511 to work as the spark ignited (SI) engine, swept volume: 825 cm³, compression ratio CR = 8 or 12,
- b) modified Deutz FL511 to work as the dual fuel compression ignition (CI) engine with diesel pilot of 15% (with respect to its nominal dose), swept volume: 825 cm³, CR = 17 [5].

Exemplary in-cylinder pressure traces from 100 consecutive combustion events vs crank angle and averaged in-cylinder pressure vs cylinder volume are presented in the figures 2.a and 2.b. respectively. As plotted, the green coloured pressure traces come from retarded spark timing in the SI engine. On the contrary, red pressure traces are for spark timing which was too advanced.

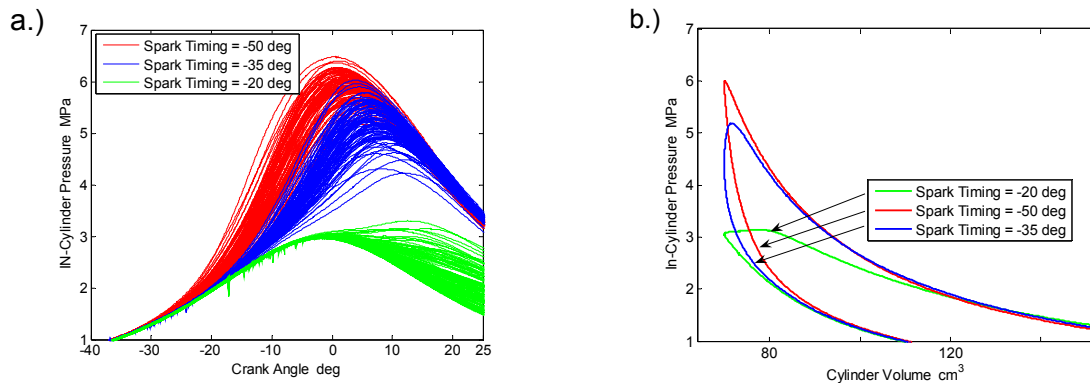


Figure 2: a) In-cylinder pressure history (superimposed 100 working cycles) for producer gas combustion in the SI engine at spark timing -20, -35 and -50 deg ATDC, CR=12, Relative air number $\lambda=1.1$, b) averaged p-v plots determined from the test series shown in the fig.2a.

As presented in the figure 3 the producer gas combusted at CR=12 is less sensitive to spark timing than the same gas combusted at CR=8.

The unrepeatability of engine work cycles can be expressed by the coefficient of variance of IMEP (COV IMEP). It is defined as follows: $COV\ IMEP\ \% = \frac{\text{standard deviation of IMEP}}{\text{mean of IMEP}} * 100\%$.

The COV IMEP is depicted in the fig.4. As presented the high work cycles unrepeatability is observed for producer gas combustion at CR=8.

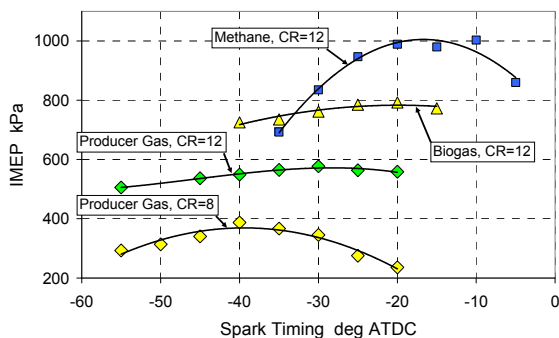


Figure 3: IMEP vs spark timing for the SI engine at nearly stoichiometric combustible mixtures.

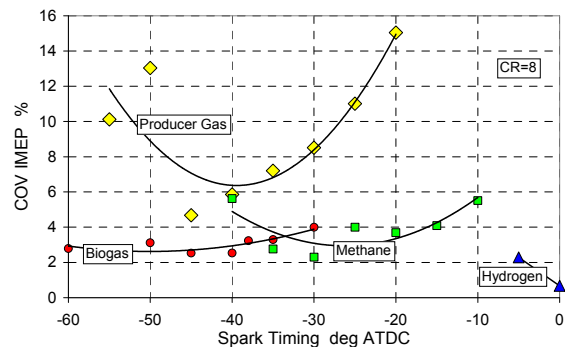


Figure 4: COV IMEP vs spark timing for the SI engine at CR=8 and nearly stoichiometric combustible mixtures.

Another potential problem concerns knocking during combustion. The knock combustion is abnormal combustion typical for SI engines and is mainly caused by spontaneous self-ignition of the combustible mixture during proper combustion process at its end phase. Intensity of the combustion knock can be expressed by peak value of high frequency oscillations of the in-cylinder pressure. Such the knock intensity was determined and

presented in the fig.5. As seen, the producer gas is resistant to combustion knock even if it contains significant amounts of hydrogen, which, at favorable conditions, is prone to generate extremely high pressure oscillations during its combustion in the engine.

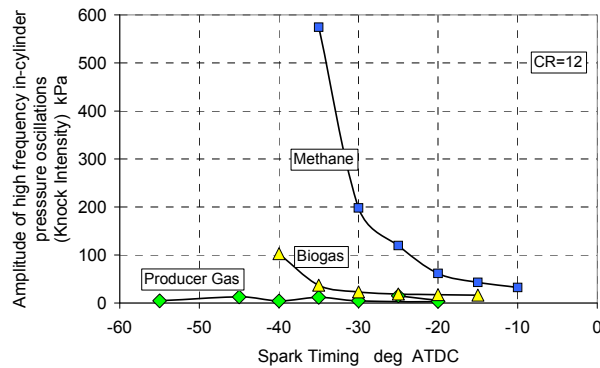


Figure 5: Knock intensity vs spark timing for the SI engine at nearly stoichiometric combustible mixtures.

Investigation presented here also includes gaseous fuels combustion in the dual-fuel CI engine with diesel pilot for ignition. Several in-cylinder pressure – crank angle plots are presented in the figure 6. Due to low calorific value of the producer gas both the peak pressure (fig.6) and the IMEP are relatively low when compared with methane or biogas combustion.

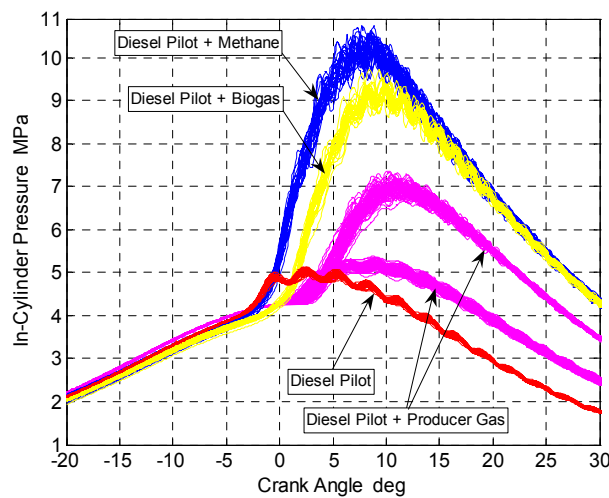


Figure 6: In-cylinder pressure history for various gases combustion in the dual fuel CI engine with diesel pilot at CR=17.

The summary of the knock intensity for several gases burnt in the SI and CI dual-fuel engine is depicted in the fig. 7. As indicated, potential knock can generate pressure oscillations of at least several hundreds kPa. Intensity of these pressure oscillations below the knock limit can come from fast and non-stable combustion and it does not have symptoms of end-gas autoignition as it is typical for combustion knock.

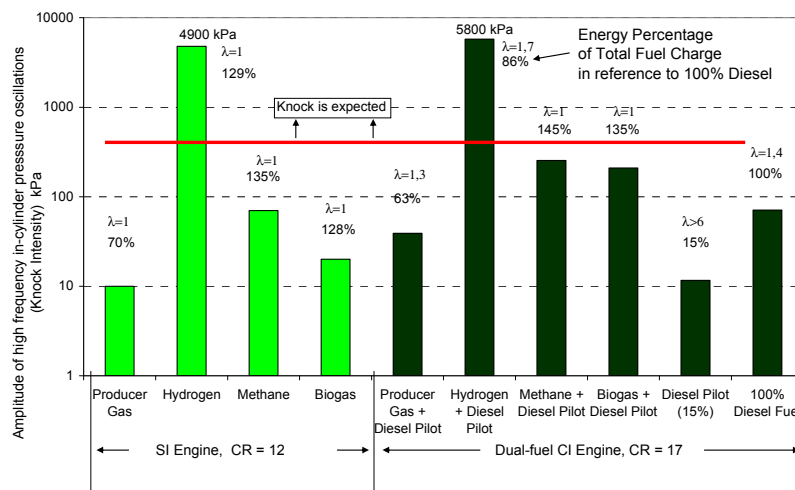


Figure 7: Knock intensity for various fuels combustion at the optimal spark timing in the SI engine (green) and the dual fuel CI engine (black), λ – relative air number.

4 Conclusions

- High unrepeatability (expressed by the COV IMEP) of engine work cycles is observed during producer gas combustion at relatively low compression ratio of 8 in the SI engine. It is mainly caused by both high content of incombustibles (CO_2 , N_2) in the producer gas and relatively low in-cylinder air-gas temperature at ignition.
- The highest knock intensity is observed for hydrogen combustion. It reaches 5 MPa even if hydrogen is combusted under diesel conditions at lean combustible mixture terms. Knock intensity of producer gas combustion appears as negligible in comparison to hydrogen knock, even if the producer gas contains H_2 of 16% (50% by energy).
- Due to significantly high COV IMEP of producer gas combustion in the SI engine, better way is to combust it in the dual-fuel (CI) engine.

References

- [1] Verhelst, S., Sierens, R.: Hydrogen engine-specific properties, International Journal of Hydrogen Energy 26(9)2001
- [2] Municipal sewage sediments: Strategy, Directions, Technologies. Report for Environment, Ministry of Poland 2004
- [3] Siritheerasas, P., Lawrence, A.D.: Incineration of High-Moisture-Content Municipal Waste, Combustion Institute, Canadian Section Spring Technical Meeting, 1998
- [4] Szwaja, S.: Hydrogen rich gases combustion in the IC engine, Journal of Kones – Powertrain and Transport, Warsaw 2009, Vol.16, No.4, 447-455
- [5] Szwaja, S., Grab-Rogaliński, K.: Hydrogen combustion in a compression ignition diesel engine, Int. Journal of Hydrogen Energy, 2009, 34/10, 4413-4421