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INITIAL THEORETICAL STUDY FOR A HEAVY DUTY DIESEL ENGINE CONVERSION TO BIOGAS FUELLING

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Abstract: *Converting compression ignition engines to run on biogas raises specific problems that need to be addressed before undergoing such transformations. A theoretical study was developed for evaluating various factors when considering the conversion of a heavy duty diesel engine to biogas fuelling in an installation featuring cogeneration of heat and power. Required biogas flow was calculated and other necessary modifications are covered by the paper, so that stable operation can be obtained, with a high overall thermal efficiency.*
Key words: *biogas, diesel, dual-fuel, engine, cogeneration*

1. INTRODUCTION

As it is the product of ideal combustion for any hydrocarbon fuel, reducing carbon dioxide (CO_2) emissions can only be achieved by increasing efficiency or by using low carbon fuels. One way of combining these two methods is using biogas in a cogeneration installation. While new technologies like fuel cells are highly efficient, internal combustion engines are very reliable, easily serviceable, can be quickly started and shut down and adapt very well to partial loads (Irimescu et al., 2009). As it features low cetane numbers, biogas is generally used in spark ignition (SI) engines (Hunt, 2007). However, given the higher fuel conversion efficiency of compression ignition (CI) engines, using heavy duty diesel engines fuelled with biogas can significantly improve fuel economy compared to employing SI engines.

When investigating such a conversion of diesel engines to biogas operation, the use of a thermodynamic model such as the one presented in this paper can reveal important aspects that can significantly contribute to the successful operation of a cogeneration plant fuelled with biogas. Control strategies can be based on the results obtained from such theoretical studies and system optimization can be achieved in order to gain maximum thermal efficiency with low emissions.

2. DUAL FUEL SYSTEMS AND EMISSIONS MITIGATION

Given that biogas has a low cetane number, a dual fuel system is necessary when converting a diesel engine to biogas operation (Papagiannakis et. al, 2010). Gaseous fuel is mixed with air prior to the intake process, while diesel fuel is injected at the end of the compression stroke to ignite the air-biogas mixture (Bedoya et. al, 2009). This liquid fuel injection is much shorter than under normal diesel operation and is known as a “pilot injection”.

CI engines, as well as biogas fuelled engines, operate on lean mixtures. As a result, carbon monoxide (CO) and unburned hydrocarbons emissions (HC) are relatively low (Papagiannakis et. al, 2010), and even the strictest regulations can be complied with by using an oxidation catalyst to treat the exhaust gases. The major issue is nitrous oxides (NO_x) emissions mitigation, as simple installations such like three way catalytic converters are not efficient during lean operation. For this reason, selective catalytic reduction (SCR) systems are used, with very high efficiency, but also much more expensive (Saravanan & Nagarajan, 2009).

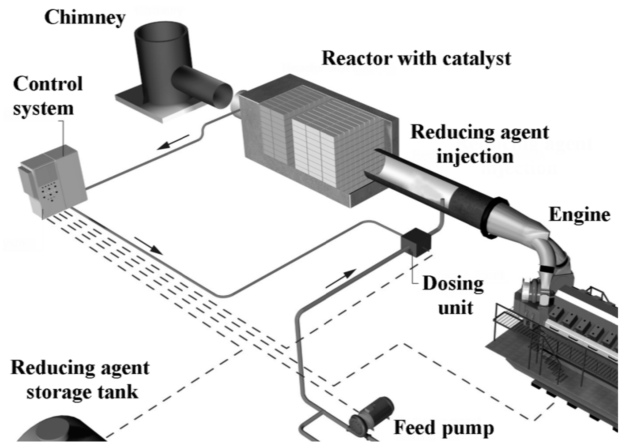

Fig. 1. Schematic layout of the SCR system for lean burn engines (source: www. wartsila.com)

3. THERMODYNAMIC MODEL

A simple model was used for calculating the main thermodynamic parameters of the working cycle. Intake and exhaust were considered as constant pressure processes, while for compression as well as expansion, a constant polytropic coefficient was used. During combustion, heat released through fuel oxidation (Q_f) is transferred to the piston as work (W), gases inside the cylinder are heated to a higher level of internal energy (U) and part of Q_f is lost to the walls of the combustion chamber (Q_w).

$$dQ_f = dU + dW + dQ_w \tag{1}$$

where released heat Q_f, internal energy U, work W and heat transferred to the walls Q_w are all measured in J.

From ignition to completion, combustion was divided into three separate processes. The first phase was considered as a constant pressure increase (dp) rapid combustion, the second an isobaric process at maximum pressure (p_{max}), and finally a slow burn phase, considered as an isothermal process, at maximum temperature (T_{max}).

$$p_{\max} = p_i + dp \cdot \theta \tag{2}$$

where maximum pressure during combustion p_{max} and the pressure level at ignition p_i are measured in Pa, rate of pressure increase dp in Pa / deg and combustion duration θ in deg.

As stationary engines are operated at constant speed, load was the main factor that was analyzed. Fuel conversion efficiency for CI engines is higher than that of SI engines.

Higher ratios are possible for SI engines when using biogas, however, during partial load operation CI engines have the advantage of lower pumping losses, resulting in a much better efficiency for light loads.

4. OPERATIONAL STRATEGIES

Biogas lower heating value (LHV) depends on its composition. As a result of biological material fermentation, methane and CO_2 are produced, along with traces amounts of other elements. The quality of biogas is given by its methane content, ranging from 50 % to 70 % and higher, depending on operating parameters and organic material (El-Mashad & Zhang, 2010).

A heavy duty diesel engine was used for analyzing the case study of biogas fuelling. Main characteristics of this engine previously used in railway propulsion systems are presented in table 1.

Maximum power	920 kW @ 750 rev/min
Specific fuel consumption	231 g/kWh @ 920 kW
Compression ratio	11,25
Displacement	133 litres
Bore x Stroke	280 mm x 360 mm
Number of cylinders	6
Boost pressure	0,86 mbar @ 920 kW

Tab. 1. Engine characteristics

The use of biogas is limited to light loads of 39 % to 44 % by the lower flammability limit, while for higher loads only up to 85 % of the liquid fuel can be replaced by gas, as combustion becomes unstable above this limit. Figure 2 shows the control strategy with calculated biogas flow and figure 3 presents pilot injection quantity for the entire load range of the engine considered for this case study, for different methane concentration (50 %, 60 %, 70 % and 80 % CH_4).

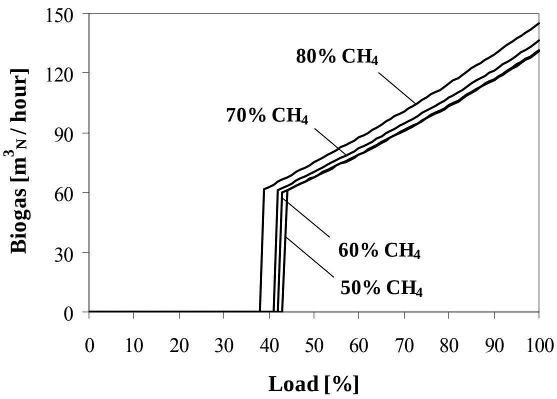

Fig. 2. Biogas flow control strategy

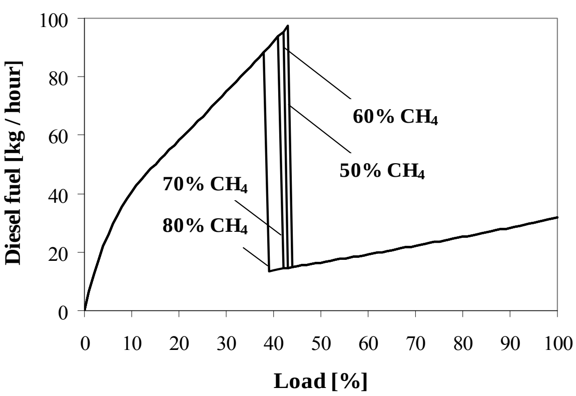

Fig. 3. Diesel fuel pilot injection control strategy

In addition to modifications required to be adopted in fuel control strategy, a speed regulator must be used to keep engine speed at a constant value so that power is delivered at the prescribed frequency. Also, this regulator will control the quantity of fuel for the pilot injection. Given that maximum power and fuel conversion efficiency is obtained at an engine speed of 750 rev/min, an additional gearbox will be required, so that the electrical generator speed is maintained at a constant value of 3000 rev/min for power delivered at 50 Hz frequency.

5. CONCLUSIONS

A simple thermodynamic model was developed an used to evaluate aspects of converting a heavy duty diesel engine to biogas fuelling in a cogeneration installation. As it is obtained from biomass, biogas is carbon neutral and by using it as a fuel in such an adapted CI engine, a reduction of up to 85 % in CO_2 emissions can be achieved, while obtaining a high overall thermal efficiency.

Future studies will include an experimental validation of the control strategies developed based on the model presented in this work, as well as investigations on adding a steam generator to cover high heat loads during times when electrical load is low. Also, emissions mitigation is another area of research that needs to be addressed when converting such CI engines to dual fuel operation for using biogas in cogeneration of heat and power installations.

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7. REFERENCES

Bedoya I. D., Arrieta A. A., Cadavid F. J. (2009). Effects of mixing system and pilot fuel quality on diesel–biogas dual fuel engine performance. *Bioresource Technology*, Vol. 100, No. 24, (December 2009) 6624-6629, ISSN 0960-8524

El-Mashad H. M., Zhang R. (2010). Biogas production from co-digestion of dairy manure and food waste. *Bioresource Technology*, Vol. 101, No. 11, (June 2010) 4021-4028, ISSN 0960-8524

Hunt J. (2007). Reciprocating engines for CHP, developments allow competition with gas turbines. *Cogeneration & On-Site Power Production*, Vol. 8, No. 4, (July-august 2007) 69-77, ISSN 1469-0349

Irimescu A., Călin L., Jădăneanț A. (2009). Aspects concerning the efficient use of biogas obtained from sewage water discarded by the beer industry. *Journal of Environmental Protection and Ecology*, Vol. 10, No. 4, (December 2009) 1137-1145, ISSN 1311-5065

Papagiannakis R. G., Rakopoulos C. D., Hountalas D.T., Rakopoulos D. C. (2009). Emission characteristics of high speed, dual fuel, compression ignition engine operating in a wide range of natural gas/diesel fuel proportions. *Fuel*, Vol. 89, No. 7, (July 2010) 1397-1406, ISSN 0016-2361

Saravanan N., Nagarajan G. (2009). An insight on hydrogen fuel injection techniques with SCR system for NO_X reduction in a hydrogen–diesel dual fuel engine. *International Journal of Hydrogen Energy*, Vol. 34, No. 21, (November 2009) 9019-9032, ISSN 0360-3199

*** (2010) http://www.wartsila.com - Solutions Power Industry Air emission control - gas and dual fuel engines, *Accessed on: 2010-05-21*