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Analysis of damage caused by siloxanes in stationary reciprocating internal combustion engines operating with landfill gas

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ABSTRACT

Failures in reciprocating internal combustion engines operating with landfill gas are not uncommon. In general, damage is located in the combustion chamber surfaces and in the ring grooves, where a layer of non-volatile combustion products is deposited. These deposits attached to the surfaces reduce heat transfer and increase inner temperature, which produces a knocking phenomena damaging the crank bearings and fusing of the piston head material. Lubrication problems also appear due to the formation of a layer of soft paste silicone deposits in the rings grooves, which increases friction losses and accelerates wear on cylinder and rings.

In this paper, some typical examples of damaged engines are presented. The deposits found were analysed using Scanning Electron Microscope and Energy Dispersive X-ray Spectroscopy (SEM–EDX). Additionally, the engine oil used was also analysed by Infra-Red Spectrometry (IR) and the results were compared with known organo-compounds. A method to detect incipient failure caused by organo-compounds contained in landfill gas is introduced.

Silica appears in the layers covering the combustion chamber, as well as silicone compound in the top cylinder zone, piston and ring grooves. Damage is associated with siloxanes (organo-silicon compounds) contained in the landfill gas, which decompose in the combustion chamber, generating silicic acid and formaldehyde under the high temperature conditions throughout the combustion processes.

1. Introduction

Reciprocating internal combustion engines (RICE) are used in some power plants to transform the chemical energy contained in gas fuels into mechanical energy for running electrical generators with acceptable brake specific fuel consumption and reliability, and also providing useful heat for application in other industrial processes, thus increasing the overall efficiency of the cogeneration plant. Depending on the kind of fuel used, RICE can be classified into two groups, one operating under the Diesel concept and another operating under the Otto concept. Engines used in landfill plants are of the Otto type. Their designs have been changing for the last 20 years to adapt to the characteristics of the new gas fuels.

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Landfill gas (LG), natural gas (NG), low heating value gases and natural gas-hydrogen mixtures are the new fuels commonly used in these types of power plants. The composition of these new gas fuels fluctuates due to different reasons [1]. Consequently the RICE used require capacity to operate with the variations in the chemical composition of these new fuels [2].

A typical landfill gas power plant is composed of many extraction wells with pipes which merge into a common gas collector. The gas of this collector is cleaned and pumped to be used as fuel in RICE, or burned in a torch. The landfill gas is a major source of air pollution if it is allowed to escape to the atmosphere; the methane contained within is a powerful greenhouse gas, according to the Intergovernmental Panel on Climate Change (IPCC), the methane global-warming potential (GWP) index, in reference to carbon dioxide, is 34 times more over 100 years [3], although its lifetime is 12.4 years. Today, the mandatory Directive 2009/28/EC in Europe is aimed at a share of 20% of energy produced from renewable sources in 2020. Accordingly, US regulations set a target of 25% for the energy generated from renewable sources in 2025.

The landfill gas, obtained basically in Municipal Solid Wastes (MSW), is generated during the anaerobic decomposition of organic substances. The MSW contains about 150–250 kg of organic carbon per ton of waste, which is converted to landfill gas by micro-organisms via anaerobic processes. The landfill gas generated, with 40–60% methane, has an average heating value of 17765 kJ/N m^3. With an energy conversion efficiency of 34% the electric energy produced is of 2.5 kW h/N m^3 approximately [4].

The main factors that affect landfill gas quantities generated are: Waste composition, humidity content, temperature, age of landfill, and others [5]. The gas production starts one to two years after the waste is deposited in the landfill and lasts 15–25 years. The continuously decreasing gas volume can be compensated by the disposal of additional waste during this period. As an example, Table 1 shows the variation in the main components of a typical landfill gas.

However the gas obtained is not clean and contains other minor components such as hydrogen sulphide, organic silicon compounds (siloxanes) and others, that can be dangerous when found in the landfill gas used as fuel [6,7]. Siloxane compounds decompose under high temperature levels in the combustion chamber [8,9], and the landfill gas must be analysed because a small quantity of siloxanes can cause severe damage to the engines when deposited over a longer period [10,11]. Consequently some engine manufacturers recommend siloxane limits in landfill gas in order to ensure the maintenance operations are not dependent on the siloxane levels [12].

When landfill gas is used as fuel, the engine design and the operating parameters are established according to the Otto concept. The efficiency and reliability of engines in these power plants are important issues. For good efficiency the compression ratio has to be as high as possible, but not too high, in order to keep combustion knocking under control. Consequently, in landfill gas engines, if the compression ratio is too high the knock combustion mode can appear, in the same way as in engines using natural gas and hydrogen mixtures [13,14].

Landfill gas engines are Diesel engines that have been adapted with a thermodynamic cycle changed from the Diesel to the Otto concept. This requires important changes in all aspects, in the mechanical design, in the hardware and software of the control systems, in the oil engine and lubrication system, in the cooling system, and other subsystems. For safe operation of the engine, the regulation and control systems need to be intelligent in order to adapt the engine to possible fluctuations in the fuel characteristics and in the chemical composition. Neural networks, genetic algorithms, fuzzy logic and other mathematic procedures can be used for that purpose [15]. These changes have been improved thanks to the maintenance process and the analysis of failures. This information has been very important in order to adapt step by step the design and the engine operation conditions according to the gas fuel used.

The combustion chamber is designed to improve the thermodynamic efficiency. It operates with a lean mixture fuel/air ratio and it has a special ignition system because the mixture, at the moment of ignition, is heterogeneously distributed, from stoichiometric between spark plug electrodes to very poor on the combustion chamber end. The engine also has a high turbulent pre-chamber on the piston head as well as pipes with a geometry designed to generate turbulence. In order to stabilize the output power it may be necessary to introduce some devices with the aim of adjusting the fuel/air ratio mixture and the gas flow rate as used in biomass and other low heating value gases power plants. This device can compensate the variations of the mixture with time.

When the combustion chamber is covered with a layer of silicates, heat transfer is reduced and the consequences over time are:

- Increase of combustion knocking mode conditions.
- Possible heating of surface with incandescent points producing ignition without control.

Table 1
Range of the main landfill gas components, including Non-Methane Organic Compounds (NMOCs).

Component	Composition (by volume)
Methane (CH_4)	40–60%
Carbon dioxide (CO_2)	35–50%
Nitrogen (N_2)/sulphur/NMOCs	5–25%
Oxygen (O_2)	0–3%
Water vapour	Saturated