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Safe operating conditions determination for stationary SI gas engines

K. Saikaly[a], S. Rousseau[b], C. Rahmouni[a], O. Le Corre[b,*], L. Truffet[b]

[a]Veolia Environnement — CREED — Zone portuaire, 291 Av. Dreyfous Ducas, 78520 Limay, France
[b]Ecole des Mines de Nantes — 4 rue Alfred Kastler, BP 20722, 44307 Nantes Cedex 3, France

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ABSTRACT

Knock is a major problem when running combined heat and power (CHP) gas engines because of the variation in the network natural gas composition. A curative solution is widely applied, using an accelerometer to detect knock when it occurs. The engine load is then reduced until knock disappears. The present paper deals with a knock preventive device. It is based on the knock prediction following the engine operating conditions and the fuel gas methane number, and it acts on the engine load before knock happens. A state of the art about knock prediction models is carried out. The maximum of the knock criterion is selected as knock risk estimator, and a limit value above which knock may occur is defined. The estimator is calculated using a two-zone thermodynamic model. This model is specifically based on existing formulas for the calculation of the combustion progress, modified to integrate the effect of the methane number. A chemical kinetic model with 53 species and 325 equilibrium reactions is used to calculate unburned and burned gases composition. The different parameters of the model are fitted with a least squares method from an experimental data base. Errors less than 8% are achieved. The knock risks predicted for various natural gases and operating conditions are in agreement with previous work. Nevertheless, the knock risk estimator is overestimated for natural gases with high concentrations of inert gases such as nitrogen and carbon dioxide. The definition of a methane number limit based on the engine manufacturer's recommendation is then required to eliminate unwarranted alerts. Safe operating conditions are thus calculated and gathered in the form of a map. This map, combined with the real time measurement of the fuel gas methane number, can be integrated to the control device of the CHP engine in order to guarantee a safe running towards fuel gas quality variation.

1. Introduction

For many years natural gas has been and still is of first interest in an environmental point of view, since its H/C ratio is high (about 4). Its use for heat and power application is opportune to fuel either SI engines or gas turbines. Although natural gas is often considered to be methane, its composition depends on its geographical origin. Following the deposit, its methane concentration varies between 78 and 98% by volume. In addition, the composition of the natural gas varies with time for a same deposit. Combined with the interconnections of natural gas networks in E.U. and with the stock spread around the world, this leads to important variations in the quality of the natural gas delivered to plants. The methane number MN is commonly used to represent the gas quality, i.e. its ability to resist autoignition [1]. It is equal to 100 for pure CH_4 and 0 for pure H_2. This indicator is the equivalent of the Research Octane Number (RON) used for liquid fuels such as gasoline

* *Corresponding author*. GEPEA Ecole des Mines de Nantes CNRS UMR 6144. Tel.: +33 2 51 85 82 57; fax: +33 2 51 85 82 99.
E-mail address: olivier.lecorre@emn.fr (O. Le Corre).

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Nomenclature

Physical symbols

AFR	air-fuel ratio [–]
B	bore [m]
C_v	specific heat at constant volume [J/kg/K]
h	specific enthalpy [J/kg]
K_c	knock criterion [–]
L	connecting rod length [m]
LHV	low heating value [J/kg]
m	mass of gas [kg]
m_c	mass of gas transferred from unburned to burned zone during combustion [kg]
MN	methane number [–]
MNL	methane number limit [–]
MKc	maximum of knock criterion, also called knock risk estimator [–]
MKcL	knock risk estimator limit [–]
p	in-cylinder pressure [Pa]
p_{inlet}	intake pressure [bar]
p_0	normal pressure, i.e. 1.01325×10^5Pa [Pa]
Q	combustion heat release [J]
Q_p	heat transfer to the wall [J]
r	ideal gas constant [J/kg/K]
S	stroke [m]
SA	spark advance [deg BTC]
S_L	laminar flame speed [m/s]
$S_{L,0}$	laminar flame speed in normal conditions of pressure and temperature [m/s]
t	current time from spark [s]
t'	current time from the start of combustion [s]
t_k	moment when knock appears [s]
T	in-cylinder temperature [K]
T_0	normal temperature, i.e. 273.15 K [K]
V	in-cylinder volume [m^3]
V_c	clearance volume [m^3]
[X]	molar concentration of specie or mixture X [%]
X_b	mass fraction burned [–]
Y	molar concentration [%]
λ	air–fuel equivalence ratio [–]
ϕ	fuel–air equivalence ratio [–]
ρ	gas density [kg/m^3]
τ	autoignition function [s]
θ	crank angle [deg]
$\Delta\theta_i$	ignition delay [deg]

Subscripts

b	burned gas
C_nH_m	hydrocarbon mixture
fuel	engine feed gas
H_2	hydrogen
u	unburned gas
t	value at moment t
t'	value at moment t'
st	value at spark timing
sc	value at the start of combustion
stoich	stoichiometric conditions

Abbreviations

ABC	after bottom center
ATC	after top center