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Numerical investigation: Performances of a standard biogas in a 100 kWe MGT

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ABSTRACT

Designed to operate with natural gas, the MGT are devices technologically recent with a noticeable number of functional advantages. Energetically and environmentally respectful and with high performance, they produce low emissions mainly of nitrogen oxides of which the toxic devastating effects are a recent scientific medical discovery. Their main problems are in sensitivity to the variation in flux. Many theoretical and experimental investigations applied to improve their functions and characteristics as well as for understanding their flexibility also by operating with fuels different from the natural gas such as the several biofuels.

For reasons related to the design economies, the preliminary numerical investigations such as that of the work in question on a model of combustor of a 100 kWe MGT are essential. To limit nitrogen oxides production, established lean premixed conditions. It is studied the behavior of a standard biogas M_{65} starting from the mouth of flame, through the laminar model up to the whole combustor but through the model $k-\epsilon$, at different adducted flows. It is liked also to submit a hint related to the variation of thermal profiles or of concentrations in the combustor when the supplied natural gases have different composition, as well as at different flows and when adopted simplified kinetic paths of model to understand a sort of acceptable degree of simplification, for studies of first approximation.

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1. Introduction: fossil or bio-methane supplying

According to the aims of Directive 2009/28/EC, many researchers are evaluating the developments of new solutions for the use of alternative and renewable energy sources. This investigation, was suggested from a previous numerical study of the author (Liguori, 2014a,b): the good performances presented from a standard biogas in a 100 kWe MGT, in lean premixed condition via laminar flamelet model, from the comparison among natural gas and other biofuels. At the pilot flame, the biogas showed the best behavior in terms Directive 2009/28/EC of the lowest temperatures and the lowest nitrogen oxides emissions. To deepening, the study via the $k-\epsilon$ fluid-dynamic model, so to have an idea about what happens in the whole burner. The current dearth of fossil fuels focuses the attention to a new approach to the energy sources and solutions are the distributed micro generation and the smart grids. The small facilities of production are to install the closest possible to the different new renewable energy sources: wind, sun, biomass,

solid waste, geothermal. The point is to realize and maximize an energy self-production and the self-use, in diversified available sources on the diversified geographical locations. The MTG identifies a small power generation system (size <500 kWe) based on a gas regenerative cycle. Compact, durable and at low emissions, its main worth are in the possibilities of expandable modular solutions; findable on conventional machines as turbochargers for automotive use; auxiliary power units for aircraft and military applications or, even, on small jet engines for the aviation industry. Their technological structure is since the 60's but continuously reviewed and improved on the cycle's solutions and the performances; composed by a compressor, a turbine, a heat recovery unit, a generator and an electric part of interface for the transfer of power to the grid. The smallest units operate at high RPM and on radial turbomachines (Minghetti, 1996). The largest, always operate in simple cycle and in axial technology. The use of gas turbines for electric power generation on a small scale is certainly an innovative reality and their real economic and energy competitiveness on the market is for power units until 5–10 MWe. The fuel burned is the biogas: obtained from the anaerobic digestion of manure or slurry, the biogas is the best alternative renewable fuel mainly for farms with substantial cattle holdings realizing the cyclical use of resources by enhancing the natural waste of cows by returning as

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Nomenclature and specifications

Laminar flamelet model

$$\chi = D \left(\frac{\partial Z}{\partial x_i} \right)^2 \quad \text{scalar dissipation rate}$$

$$Z_i = \xi = \frac{Y^{(*)} - Y^{(*)}_2}{Y^{(*)}_1 - Y^{(*)}_2} = \frac{Y^{(*)}}{Y^{(*)}_1} \quad \text{mixture fraction}$$

$$\tau_\chi = \frac{v_d}{D} = \frac{1}{D_z |\nabla Z|^2} = \frac{2}{\chi} \quad \text{diffusion time}$$

$$\dot{\omega}_k \omega_T \quad \text{weighted mixtures fraction respect to } k \text{ species or temperature } T$$

k-ε model

$$P_k = \frac{\partial}{\partial x_j} \left[\frac{\mu_t}{\sigma_k} \frac{\partial k}{\partial x_j} \right]; \quad k \text{ production term}^*$$

$$D_k = -2\nu s_{ij} s_{ji} = \varepsilon; \quad k \text{ dissipation}^*$$

$$\text{div } T = \frac{\partial}{\partial x_j} \left[\frac{1}{\rho} u_i p - \frac{1}{2} u_i u_j u_j - 2\nu s_{ij} s_{ji} \right]; \quad \text{diffusion}^*$$

EGR Exhaust Gas Recirculation

MGT micro gas turbine

* Here not written the corresponding relation for ε equation. The mathematical model is globally dependent on 5 constant σ_k ; σ_ε ; $c_{\varepsilon 1}$; $c_{\varepsilon 2}$; and $c_\mu = 0$ fixing conveniently wall conditions.

Table 1

Conditions in the thermodynamic cycle: the MGT.

Length	1400 mm
Diameter	400 mm
Configuration	Single shaft
Speed rotation	64 000
Combustion chamber load losses [%]	5
T_2 , out temperature compressor	468 K
T_{2r} , inlet temperature to burner	905 K
T_3 , inlet temperature to turbine	1223 K
T_4 , exhaust gas from turbine	951 K
T_{4r} outlet temperature	530 K
T out gas to stack	403 K
η_{ad} , radial compressor	0.75
η_{ad} , radial turbine	0.85
η regenerating heat exchanger	0.90
η_c combustion efficiency	0.98
m_{air}	0.808 kg/s
m_{fuel}	0.00735 kg/s

* Fuel natural gas Hi = 47 500 kJ/kg.

Table 2

MGT plant performances.

Plant performances	
P_M mechanical power to shaft	110 kW
η_T global efficiency alternator terminals	0.334
η_T global efficiency	0.304
P_T thermal power to user	108 kW
T out gas to stack	403 K
Fuel utilization index	0.670
Energy saving index	23.25%

- Effects of the simplification.
- NOx productions.

2. Analysis

2.1. Applying thermal energy: operative framework and design outcomes

The work develops on the numerical comparison of combustion among biogas and classic natural gases, those last supplied at two different compositions, proceeding on the idea of their common base in methane even if in different percentage. The flows, chosen at values of start of combustion and at technological constraint of dimensions of diameters of the nozzles. To reduce NOx production, the MGT works in excess of air, double than the stoichiometry, in lean premixing conditions, as previous settings of Nicol and Malte (1999); Huang and Chen (2005), Cameretti et al. (2007); Cameretti et al. (2012) and of many others. Gas turbines are very sensitive to variations of flow (Pavri and Moore, 2001). The increase of flows produces, e.g., superheating on components of turbine and compressor, the growth of the differential between the margin of compression to the own control point at the decreasing of the rotation speed. Moreover, the increase of efficiency of a MGT at simple cycle and the decreasing of the net efficiency if the combined cycle (see Table 1, from Tuccillo and Cameretti, 2005).

Tables 2–4 schematize the MGT, the fuels and operational conditions.

The fluid-dynamic investigation CFD is realized through a commercial software (Fluent 12.4), by modeling the burner with a grid of not structured blocks of more than 38 000 vertices of triangles and tetrahedrons, the mesh on Table 4. A two-dimensional model, accuracy in double precision and axisymmetric symmetry. The operational conditions of the flows (see Table 5):

Considering the effects of the presence of CO₂ on combustion of the supplied mixture (Wasiu et al., 2012), the biogas in the burner

electric energy the waste they produce. The large part of homologated recovery processes produces what in literature named standard biogas often indicated as M₆₅ from the methane percentage, considering his composition made of methane/carbon dioxide in molar relation 0.65/0.35. Through specific processes, you try to obtain biogas (Di Profio et al., 2014) or to enrich the methane content of it (Annesini et al., 2013; Arca and D'Alessandro, 2013; Comotti and Bertagna, 2012; Carucci et al., 2012), since a higher content of methane is the indication of higher energy content of the fuel. Many investigations, trying to understand and improving the various technological aspects related to the use of biogas (Brambilla et al., 2014; Makareviciene et al., 2013). The biogas performance limit into the MGT is in process of extensive study also because of his own novelty as fuel: Williams and Friederick had valued the critical issues in a small power plant annexed to a dairy farm in California, (2001), working by methane gas obtained from manure of cows. The power plant had produced small variable discrete quantities of electric energy 17 or 20 or 25 kW for self-consumption but with limitations related to the addiction to changes of weather for the period of study and experimental validation of a year and an half. Bruno and Coronas (2004) had described MGT limits at different potential when powered by biogas of different origin. Fiordaus Basrawi Bin et al. (2012), had verified the performance of gas from sewage in a MGT in cogeneration, at supplied electric potentials of 30; 65; 200 kW. Kang et al. (2012), had reported about behavior of mixtures of biogas at different percentages of methane, in turbines at simple cycle or at recovery cycle considering as independent variables the actions of heating on turbine's blades and the leakage of air from the compressor. The "sliding combustion" requires a good quality of the fuel: pure and with a sufficiently high calorific value. The biogas has generally low calorific value so it will require of greater flows or an enrichment in methane content, deciding in base of technological or a cost benefit evaluation.

Main goals:

- The fluid-dynamic of the combustion of the biogas performed via the laminar flamelet model and the k-ε model and at different fed flows. Comparisons with natural gas.
- A sort of sensitivity investigation on energy at the changing of compositions and flows.

Table 3

Fuels: compositions, thermodynamical features.

	g/mol	MJ/kg	Fuels chemical composition molar %						
	PM	LHV	CH ₄	CO ₂	CO	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	N ₂
NG	17.34	47.2	0.92	0.0015	0	0.037	0.01	0.025	0.029
NMG	16.64	51.93	0.96	0	0.0009	0.021	0.005	0	0.0173
BIOGAS	29.44	32.5	0.65	0.35	0	0	0	0	0

Legend: PM molecular weight; LHV low heat value.

can be thought as an EGR system: the CO₂ of mixture the inert of combustion and the methane as the live part of the fuel. The EGR percentage: $EGR_{BIOGAS} \approx 54\%$ ($EGR_{BIOGAS} = \frac{y_{CO_2}}{y_{CH_4}} = 0.5358 * 100$) fits perfectly, according to previous conclusions of the [Piazzesi \(2007\)](#) on the same combustor, to the well performed combustion composition range, assured up to an EGR = 65%.

2.2. The laminar flamelet model

The MGT runs the thermodynamic cycle showed on [Figs. 1 and 2](#). The laminar flamelet model gives connections of developments between fluid-dynamics and kinetic ([Poynsot and Veynante, 2001](#)) of combustion reactions. Studies to understand the development of nitrogen oxides production through the model in laminar flames is a very interesting line of research, evaluated from different points of view, e.g. by varying, in particular, the supplied power sources, ([Chen and Chang, 1992](#)) or by indicating the different Pdf of gases composing the exhausted flow ([Chen and Chang, 1996](#)), by their structures and extinction ([Williams, 2000](#)). The diffusive flames, in terms of probability density functions of temperature and concentration $T(Z)$ and $C(Z)$ of the mixture's fraction Z , reproduced Kolmogorov's conditions at the minimum length of fluid's swirls and the slow endothermic conversions of the nitrogen in its oxides. The Kolmogorov conditions between speed and length of the flame:

$$-0.1 < \frac{v'}{s_L}, \quad \frac{l}{l_f} < 10. \tag{1}$$

The flamelets expression ([Peters, 2000](#) and then by [Williams, 2000](#))

$$Y_k = F_{Y_k}(Z; \chi(Z)) \tag{2}$$

solution of material and energy balances below:

$$\rho \frac{\partial Y_k}{\partial t} = \dot{\omega}_k + \frac{1}{2} \rho \chi \frac{\partial^2 Y_k}{\partial Z^2} \tag{3}$$

$$\frac{\partial T}{\partial t} = \dot{\omega}_T + \frac{1}{2} \rho \chi \frac{\partial^2 T}{\partial Z^2}. \tag{4}$$

Table 4

Meshing size quality features.

Mesh size ^a	Mesh quality ^b
Level	0
Cells	91 218
Faces	184 006
Nodes	92 779
Maximum cell squish	5.77110e-001
Maximum cell skewness	7.88887e-00
Maximum aspect ratio	1.50643e+001

^a 4 cell zones, 26 face zones.

^b Applying quality criteria for triangular/mixed cells.

2.3. The $k-\epsilon$ fluid-dynamic equations

In the field of fluid-dynamics RANS for control purposes on the whole combustion chamber ([Mohammedi and Piroenneau, 1994](#); [Laudering and Spalding, 1979, 1990](#); [Pope, 2000](#)): the $k-\epsilon$ model of Jones Lauder in case of jets with recirculations, rotations, or separations, as in our case of combustion of which equations:

$$\frac{\partial k}{\partial t} + U_i \frac{\partial k}{\partial x_i} = P_k - D_k + \text{div} T \tag{5}$$

$$\frac{\partial \epsilon}{\partial t} + U_i \frac{\partial \epsilon}{\partial x_i} = P_\epsilon - D_\epsilon + \text{Di}_\epsilon. \tag{6}$$

It defines the relationship between the turbulent kinetic energy and the velocity of dissipation of standard or altered kind.

2.4. Chemical kinetics paths

The previous research of [Meintjes and Morgan \(1987\)](#); [Jones and Linstedt \(1988\)](#); [Calchetti et al. \(2002\)](#) and others suggested about kinetic models and the limits of simplification on the combustion reactions for fossil or renewable fuels. The problem plans the evaluation of more aspects: the thermodynamics of the involved species, the dimensioning of the reaction areas and the specific reactions, previously analyzed by [Molino and Braccio \(2013\)](#) but our hypothesis: the natural gas mixture burns in a simplified schema of kinetic, via the eight reactions model

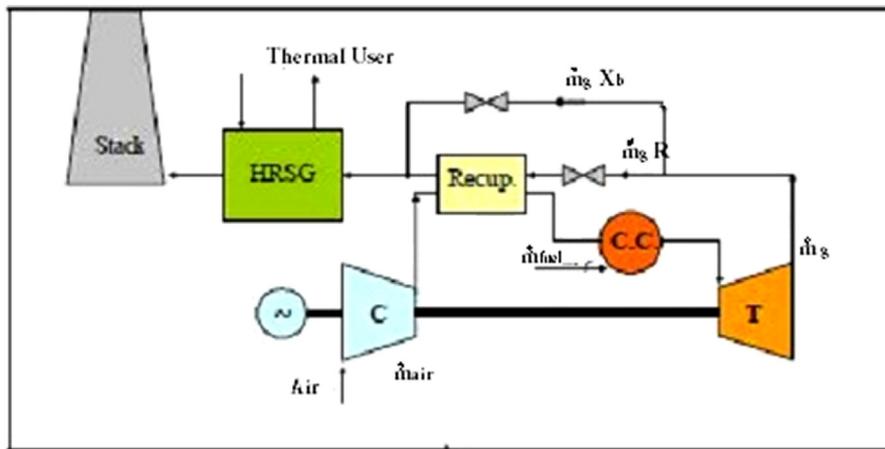


Fig. 1. 100 kW MGT—the plant.

Table 5
Starting f_1 flow rates, T , P conditions.

Fuels [] = kg/s	Air		Air		
	Pilot origin	Main	Liner	Primary	Main
NG	0.00175	0.01925	0.0834	0.0282	0.031
NMG	0.00071	0.00499	0.0363	0.0115	0.00125
BIOGAS	0.00166	0.00499	0.0848	0.0268	0.00298
T (K)	907	907	907	300	300
Pressure (Pa)	384 400	384 400	384 400	577 000	577 000

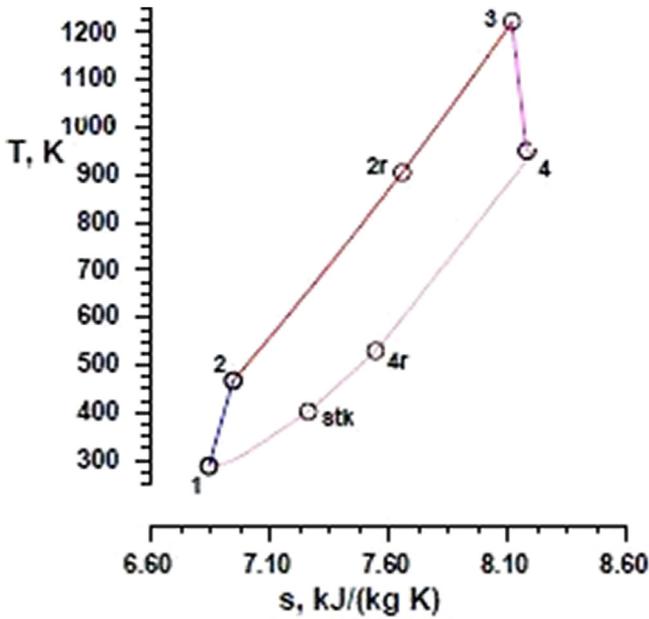


Fig. 2. Thermodynamic cycle.

proposed by Novoselov and Malte (2007) and Nicol and Malte (1999).

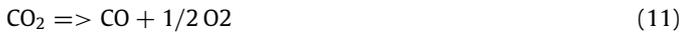
simplified kinetic schemas



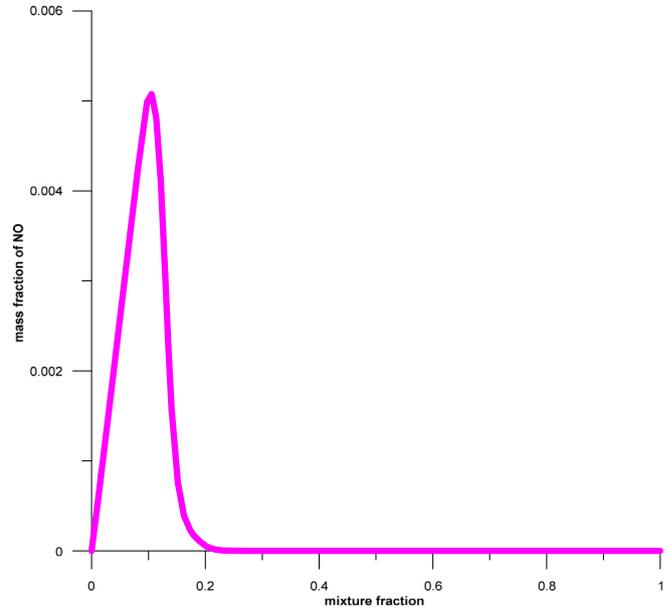
$r_1 = 10^{13.354-0.004628P} [CH_4]^{1.3-0.01148P} [O_2]^{0.01426} \times [CO]^{0.1987} e^{-\frac{21932+26904P}{T}}$ (8)



$r_2 = 10^{14.338-0.1091P} [CO]^{1.359-0.0109P} \times [H_2O]^{0.0912+0.0909P} [O_2]^{0.891+0.0127P} e^{-\frac{22398+75.1P}{T}}$ (10)



laminar flamelet model,
Probability density fraction of NO molar concentration
bidimensional, unless of scalar dissipation evolution
CH4-CO2 M65 mixture



*Maximum mixture fraction of [NO] = [5.69 * E-0003] kmol/m^3.

Fig. 4. Laminar flamelet model 2d Pdf main NO mixture fraction Z.

$r_3 = 10^{15.8144+0.07163P} [CO_2] e^{-\frac{64925.8-334.31P}{T}}$ (12)



$r_4 = 10^{14.122+0.0376P} [O_2]^{1.1805+0.0344P} \times [CO]^{0.8888-0.0006P} e^{-\frac{46748+126.6P}{T}}$ (14)

$r_5 = 10^{29.8327-4.7822\log(P)} [O_2]^{2.4613} \times [CO]^{2.7911-0.04880P} e^{-\frac{61265+704.7P}{T}}$ (15)

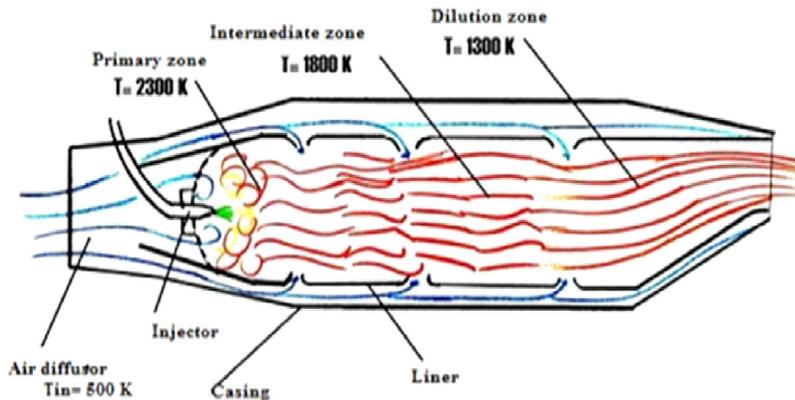
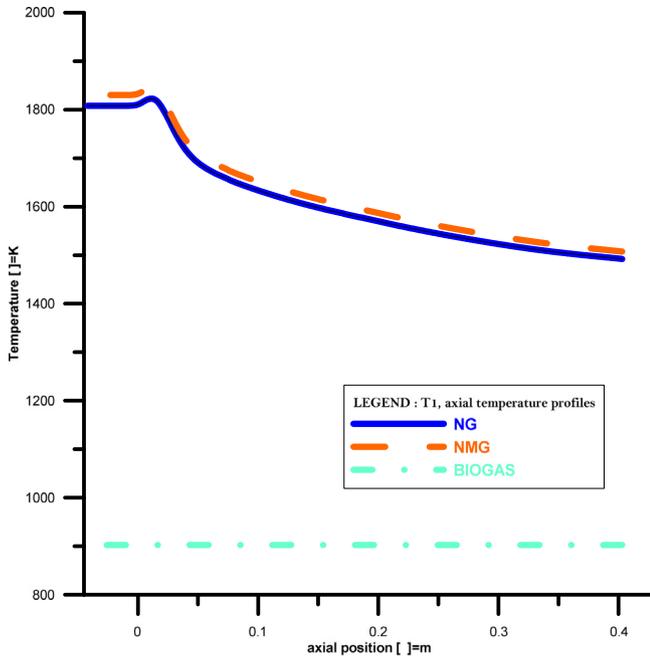


Fig. 3. 100 kWe MGT combustion chamber.

Fig. 5. Axial T profile, f_1 flows.

$$r_6 = 10^{14.592} [\text{N}_2][\text{H}_2\text{O}]^{0.5} [\text{O}_2]^{0.25} T^{-0.7} e^{-\frac{69158}{T}} \quad (16)$$

$$r_7 = 10^{10.317} [\text{N}_2] [\text{O}_2] e^{-\frac{69158}{T}} \quad (17)$$

$$r_8 = 10^{14.967} [\text{N}_2][\text{O}_2]^{0.5} T^{-0.5} e^{-\frac{68899}{T}}. \quad (18)$$

The kinetics of all other species different from methane and the reaction of rearrangement, completion and equilibrium between CO and CO₂



will be neglected. The natural gases, also compared in their different composition. This model has been chosen also because it is a good simplification that provides the kinetic schemas of production of nitrogen oxides.

3. Results

3.1. k - ε axial profiles

The Fig. 3 shows all the remarkable areas of the MGT's combustion chamber. By the k - ε simulation, a sort of "thermal axial strength", difference between recorded extreme values of axial temperatures, explains the thrown strength from each fuel in the burner, giving a visual idea of the propulsive action. The biogas, because of its low calorific value, requires be supplied to the burner at higher flows than the conventional fossil natural gases because at the lower f_1 flow, does not preserve the good quality of combustion as from conclusions of the laminar flamelet model, Fig. 4. It does not give any driving force: $\Delta T_{f_1} \text{ BIOGAS} = 0$. Reached only the thermal equilibrium at the temperature $T = 902.5$ K of the hot inlet air, because of the mixing in counter flow. The expected value of the maximum flow to which the biogas ignites is calculated in $f_2 = 3 * f_1$. The similar thermic shapes of half-hyperbola at the two flows of natural gas mixtures are plausible, since the MGT approved to run with those kind of gases.

Any difference of compositions is sustainable. Their main difference is on the ignition temperatures. The thermic developments depend on a complex and rich motivation: compositions, heats of reactions, reaction times, specific chemistry effects (see Tables 6–8).

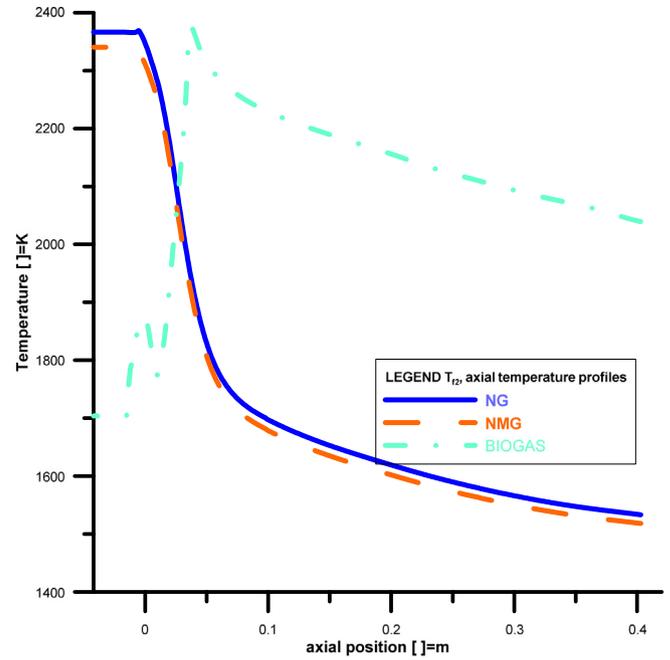
Fig. 6. Axial T profiles, f_2 flows.

Table 6

Axial temperatures ranges, f_1 .

	NMG	NG	BIOGAS
T_{\min}	1507.48	1492.29	902.49
T_{\max}	1844.77	1822.76	902.49

Temperature T [] = K.

Table 7

Axial temperature ranges, f_2 .

	NMG	NG	BIOGAS
T_{\min}	1517.93	1518.26	1554.31
T_{\max}	2344.15	2340.36	2323.70

Temperature T [] = K.

Table 8

Gas energy ratios.

[] = K	Max axial ΔT_{f_1}	Max axial ΔT_{f_2}	$\frac{\Delta E_{f_1}}{\Delta E_{f_2}}$
Natural gas NG	335	826.22	0.59
Natural methane gas NMG	330	722.10	0.543
BIOGAS	0	769.39	

3.2. NOx productions, contours profiles

The current environmental conditions of climate, require a stringent protection of environment, limiting strongly the accepted concentrations of emitted pollutant species, especially from the energy systems. Previously neglected because not immediately visible, the devastating effects of nitrogen oxides have been recognized and evaluated from the newest medical and biological research. The "Silent Pandemic" they produce, even in very low doses, is expressed on damage the nervous systems, mainly on the young people; on the psychic system, reducing mechanisms of learning, giving problems of language and emotional disorders; on the endocrine system, hastening the age of puberty, by acting on the men's fertility and giving problem in pregnancy. Marchionna et al. (1973), had the first intuitions about the NOx production in the MGT combustion chamber and his connection to inlet air and all the thermodynamic and fluid-dynamic parameters. The NOx productions are investigated in

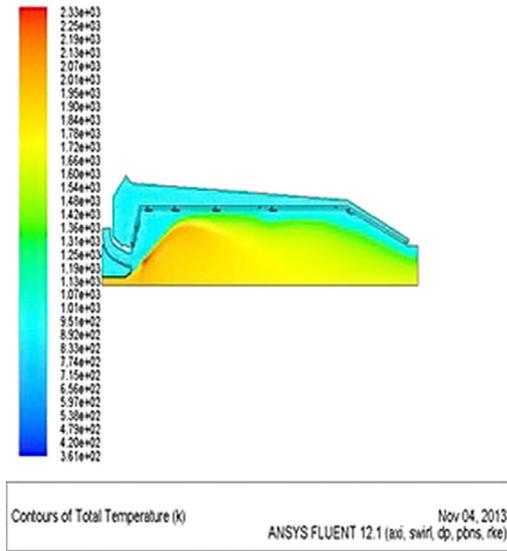


Fig. 7. T profile NG simplified kinetics.

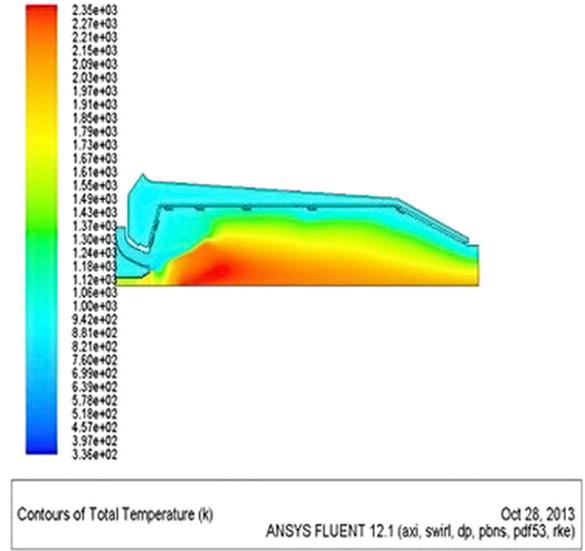


Fig. 8. T profile NmG full kinetics.

Table 9
Temperatures at contours— f_1 and f_2 flows.

[] = K	NMG		NG	
	f_1	f_2	f_1	f_2
T_{min}	357.97	351.63	298.00	351.63
T_{max}	2302.40	2370.74	2286.17	2357.67

Table 10
Emissions at contours, f_1 flow, full kinetics.

[] = kmol/m ³	NMG	NG
CO min	0	0
CO max	5.780 * 10 ⁻⁴	5.580 * 10 ⁻⁴
CO ₂ min	0	0
CO ₂ max	1.297 * 10 ⁻³	1.306 * 10 ⁻³
NO min	0	0
NO max	8.490 * e-05	8.119e-05
NO ₂ min	0	0
NO ₂ max	5.220 * e-07	5.090e-07

Table 11
Emissions at contours, f_2 flow, full kinetics.

[] = kmol/m ³	NMG	NG
CO min	0	0
CO max	1.496 * 10 ⁻³	1.409 * 10 ⁻³
CO ₂ min	0	0
CO ₂ max	1.387 * 10 ⁻³	1.370 * 10 ⁻³
NO min	0	0
NO max	1.423 * 10 ⁻⁴	1.487 * 10 ⁻⁴
NO ₂ min	0	0
NO ₂ max	5.270e-07	5.120e-07

terms of nitric monoxide NO because it composes them for more than 90%. Due the sensitiveness of MGT to great flows, the reported contours profiles are at the increased flow f_2 . Tables 9–11 report the natural gases conditions on contours at full kinetics (see Figs. 7–10).

For large lines, the mixtures present the almost similar final temperatures and concentrations, also from the strong similarity of axial thermal profiles between the two natural gases, previously observed in case of full kinetic, Figs. 5 and 6. The imposed simplification on kinetics acts on the final evolutions between the two natural gases and mainly on differences of direction and amplitude. The temperature and chemical profiles of natural gases

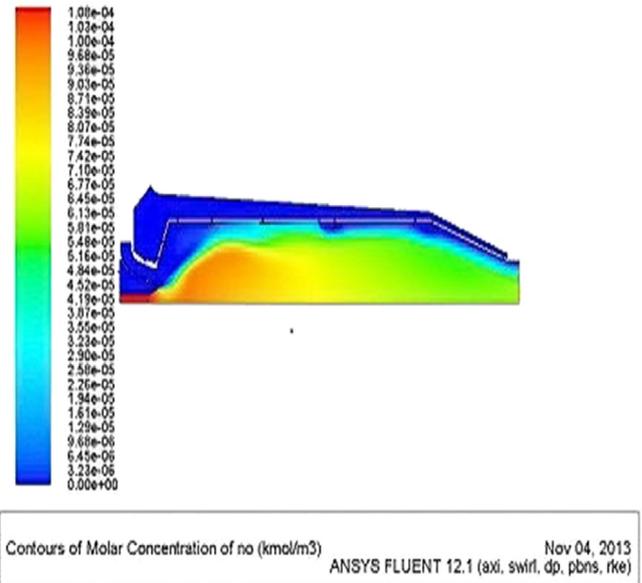


Fig. 9. NO, NG simplified kinetics, f_2 flow.

develop slightly and they do not go more ahead from the initial primary area of the burner.

3.3. Biogas, contours profiles

The findings observed assumed at this point of the study for a generic biogas of fixed composition: the M_{G5} , ignoring his source and the various different underlying processes to its obtaining and enrichment. Conclusions drawn from the study of his combustion in the MGT by the $k-\epsilon$ model prove to have a decisive design value. Tables 12 and 13 show that at f_1 flow, e.g., it does not burn at all: the flow is not sufficient for his combustion; in fact, the temperature is almost stable at the f_1 flow: $T = 902.491$ (approximation to the third decimal digit of the temperature value), (Table 12) and there are not concentrations of carbon monoxide or carbon dioxide in the related burned flow (Table 13).

So it is explained his very low NOx's production that is due to the absorbed heat from mixing to hot inlet air. Figs. 11 and 12 can give an idea of the thermal behavior and the NOx concentration development at the increased f_2 flow of the biogas.

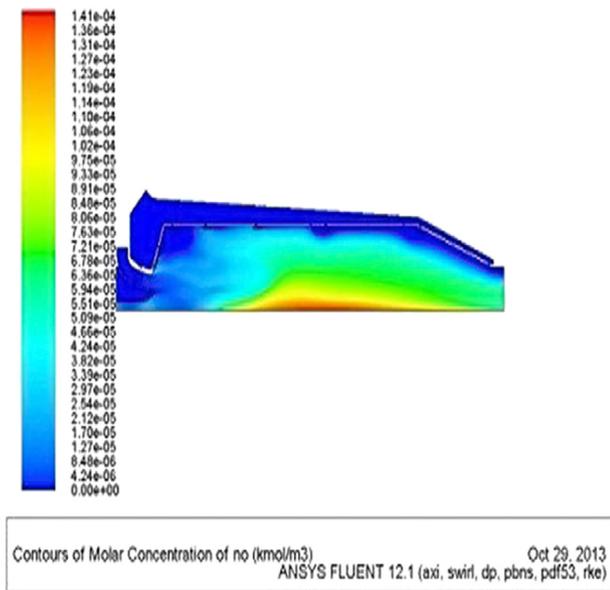


Fig. 10. NO, NmG full kinetics, f_1 flow.

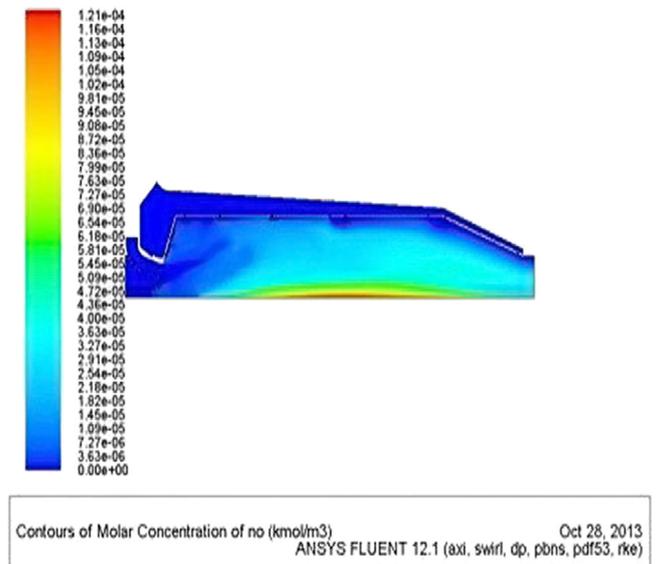


Fig. 12. NO biogas, full kinetics, f_2 flow.

Table 12
Temperatures at contours.

[] = K	BIOGAS	
	f_1	f_2
T_{min}	902.4906	327.62
T_{max}	902.4909	2400.39

Table 13
Emissions at contours.

[] = kmol/m ³	BIOGAS	
	f_1	f_2
CO min	0	0
CO max	0	4.280×10^{-3}
CO ₂ min	0	0
CO ₂ max	0	4.750×10^{-2}
NO min	$5.371106e-07$	0
NO max	$5.371108e-07$	1.205×10^{-4}
NO ₂ min	$1.167371e-07$	0
NO ₂ max	$1.167372e-07$	$4.430e-07$

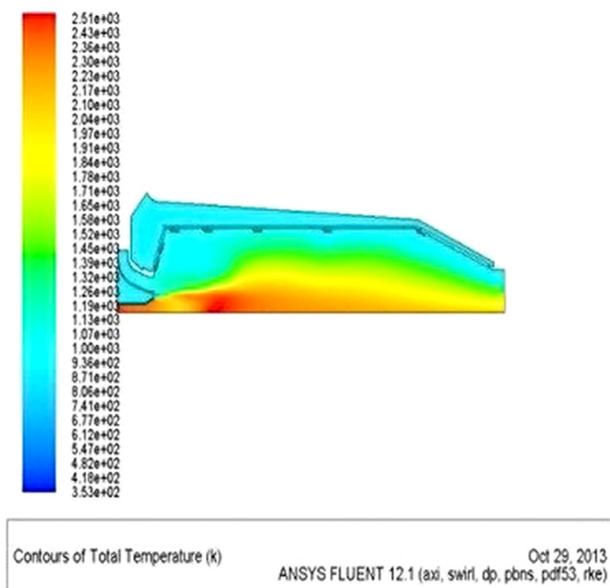


Fig. 11. T profile biogas, full kinetics, f_1 flow.

At the greater flow f_2 , the biogas and the natural methane gas, the both verified on full kinetic patterns, have similar developments at the contours profiles notwithstanding obvious differences on extensions produced from the own characteristic compositions. Moreover, at that flow, the biogas still gives the lowest contribution of nitrogen compounds (Desoete, 1975; Fenimore, 1971; Hill and Douglas Smoot, 2000). Particularly, his highest NO concentration is slight and localized axially at the intermediate area of the burner.

4. Conclusions and perspectives

The biogas has showed numerically a good performance in the 100 kWe MGT at the evaluated operational conditions and from the point of view of the fluid-dynamic and the importance of consciousness of imposing the most appropriate model of investigation. The constraint imposed on the kinetic models gives an immediate, purely qualitative, but important interpretation of related changes: a global glance of the connections of the related evolution to the kind of mixtures or the effect of the length and kind of links of chains of the hydrocarbons of the mixtures and their way to react. Natural gases express perfectly the not so relevance of differences on composition: the thermal strength ratios calculated at the two flows $\frac{\Delta E_{f_1}}{\Delta E_{f_2}}$ have a light deviation because of the almost similar energy contents. Occurs immediately the discrepancy of behavior of biogas in the two considered fluid-dynamic models, but anyway the standard biogas assures an efficient and clean combustion and low NOx, at the maximum flow for the $k-\epsilon$ model. To be pursued: the minimum and maximum possible flow, in working conditions, unless of calculative or functional errors. Future goal is the study in depth of connections on the final equilibrium concentration between the CO-NO and the starting compositions of the supplied mixtures and the numerical evaluation of the performance of biogas when its methane content grows, in a cost benefit assessment. All observations and conclusions are to compare and verify in an experimental validation.

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