



## Full Length Article

# Experimental and numerical analysis of turbulent premixed combustion of low calorific value coal gases in a generated premixed burner

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## ABSTRACT

This study describes experimental and numerical studies of low-calorific value coal gas combustion under turbulent premixed combustion conditions. Any conventional natural gas burner is not convenient to burn a low calorific value coal gas efficiently and properly. Therefore, a newly generated premixed burner that can burn a low calorific value coal gas has been designed and manufactured in the present study. This burner has also got a hydrogen pipe (as non-premixed) by which hydrogen can be supplied into the flame zone in order to enhance the combustion performances of the low-calorific value coal gases. In the numerical part of this study, the generator gas has been modelled numerically by a computational fluid dynamics code. The predicted temperature distributions of the generator gas have been compared with the experimental data. According to the comparison, it can be said that the predicted temperature profiles are satisfactorily in good agreement with the experimental data in terms of trends and values. In the experimental part of the present study, the blast-furnace gas flame was not observed without hydrogen supply during the experiments as it includes few combustible gases excluding carbon monoxide. However, the maximum flame temperature of the generator gas was measured as of 1220.1 K without hydrogen supply. It has also been concluded that the flame temperatures of the low calorific value syngases were enhanced as the hydrogen was supplied from the center of the newly generated burner into the flame zone. In addition to the temperature measurements, emissions such as nitrogen oxide, carbon monoxide and carbon dioxide were also examined by a gas analyzer inside the combustor. The results show that the nitrogen oxide emission levels increase as the hydrogen is supplied into the flame region because of thermal nitrogen oxide mechanism. It may also be concluded that carbon dioxide levels ascend as hydrogen is supplied because of water gas shift reaction. It can be eventually concluded that the newly generated burner provides more stable flame and hydrogen addition improves the combustion performances of the low calorific value coal gases under premixed combustion conditions.

## 1. Introduction

Combustion is one of the most common methods used in generating heat and electricity. Fossil fuels that are classified as solid, liquid and gas are normally consumed in any combustion processes. However, the scientists estimate that fossil fuels run out of in the near future. It is especially said that crude oil and natural gas reserves are less than that of coal. On the contrary, coal reserves are abundant. In addition, their reserves are positioned comparatively evenly all over the World. Therefore, use of coal in generating heat and electricity is getting more and more promising.

Syngases are fundamentally derived from coal and biomass in gasification or carbonization processes and classified as low, medium and high calorific values. Low calorific value syngases are mostly called as generator and blast-furnace gases. Air is directly blown over coal in a

gasification reactor where the generator gas, which is composed chiefly of high amounts of nitrogen and carbon monoxide, is produced [1]. The blast-furnace gas, which consists mainly of nitrogen and carbon dioxide, is a by-product of blast furnaces when the iron ore is reduced with coke to metallic iron [2]. There are also another kind of syngas types such as coke oven gas and water gas including high amounts of hydrogen comparatively. These types of syngases are generally classified as having medium calorific value syngases.

Premixed combustion is a promising combustion condition as fuel and oxidizer are mixed better inside burner before entering to the combustor. The scientists are closely interested in premixed combustion and many studies related to premixed combustion are available in the literature. Bidi et al. [3], for instance, have modelled methane-air combustion considering radiation effect under premixed combustion conditions in a cylindrical chamber. They conclude that the numerical

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**Nomenclature**

$S_T$	Turbulent flame velocity
$S_L$	Laminar flame speed
2D	Two-dimensional
$\text{NO}_x$	Nitrogen oxide
$c$	Reaction progress variable
$Sc_t$	Turbulent schmidt number
$n$	Number of products
$Y_i$	Mass fraction of species $i$
$Y_{i,ad}$	Mass fraction of species $i$ after complete adiabatic combustion
$\text{H}_2$	Hydrogen
$\text{CH}_4$	Methane
$\text{CO}$	Carbon monoxide
$\text{CO}_2$	Carbon dioxide
$\text{N}_2$	Nitrogen
LHV	Lower heating value
kW	Kilowatt

$T_{real}$	The corrected temperature value
$\sigma$	Stefan-Boltzman
$T$	The measured temperature value
$H$	Convective heat transfer coefficient
$w_R$	Uncertainty
$R$	A given function
$X_n$	An independent variable
$\emptyset$	Equivalence ratio
GG	Generator gas
GGH1	7.5 kW from the generator gas and 2.5 kW from the hydrogen
GGH2	5 kW from the generator gas and 5 kW from the hydrogen
BFG	Blast furnace gas
BFGH1	7.5 kW from the blast-furnace gas and 2.5 kW from the hydrogen
BFGH2	5 kW from the blast-furnace gas and 5 kW from the hydrogen
LPG	Liquefied petroleum gas
CFD	Computational fluid dynamics

simulation results with radiation model are in better agreement with the measurements and the effect of radiation of gases can influence the temperature and emission distributions under premixed combustion conditions. Schefer et al. [4] have studied combustion of hydrogen-enriched methane experimentally and numerically under lean premixed combustion conditions. They determined that hydrogen addition leads to a considerable effect on the flame structure. Singh et al. also [5] performed experimental and numerical studies to determine laminar flame speeds of syngases at elevated temperature under premixed combustion conditions. In addition, they investigated the effect of water addition on their laminar flame speeds. They have concluded that flame speed ascends with up to 20% water addition and then descends with any further water addition. Daniele et al. [6] have conducted an experimental study to ascertain turbulent flame speeds of different syngases under premixed combustion conditions. It has been shown that  $S_T/S_L$  depends on preferential diffusive thermal effects considerably. It has also been demonstrated that  $S_T/S_L$  ratio increases as hydrogen content in the fuel mixture is increased. Halter et al. [7] have investigated the effects of hydrogen addition into methane under premixed combustion conditions. They have concluded that not only instantaneous but also average flame characteristics are highly effected when a small amount of hydrogen is added into methane. Williams et al. [8] completed an investigation regarding effect of syngas composition in a optically accessible premixed swirl-stabilized combustor. They also scrutinized how carbon dioxide-diluted oxygen affects syngas performance. They have observed that the presence of hydrogen in the syngas mixture leads to more compact flame of which temperature increases. Halouane and Dehbi [9] have reported a comparison between different modelling methods, namely the traditional Eddy Dissipation Model and the more advanced Turbulent Flame Closure models and they have decided that both models predict reasonably well the combustion process for all cases studied in the reported study. Cam et al. [10] have investigated effect of equivalence ratio on combustion behaviours of premixed hydrogen/air flames in a micro cylindrical

combustor. They have determined that the most uniform temperature distribution has been achieved between equivalence ratios of 0,8 and stoichiometric combustion conditions. Greco et al. [11] have modelled biogas combustion by using flamelet generated manifold in laminar premixed flame. The results showed that methane composition in biogas highly effects combustion performance of biogas. Reichel and Paschereit [12] have conducted an experimental study for premixed hydrogen combustion. It has been shown up that fuel momentum affects on axial velocity distribution strongly at the mixing tube outlet. It can also be stated that hydrogen alters stability limits under premixed combustion conditions. Knudsen et al. [13] have performed some analyses to model a National Aeronautics and Space Administration model aircraft combustor burning Jet-A fuel. They considered the spray and combustion model coupling by simulating single drop evaporation experiments. They have also extended the analysis to Large Eddy Simulation. Zuo et al. [14] have developed a micro elliptical tube combustor and compared with regular micro circular tube combustor. They investigated the combustion characteristics of hydrogen-air flame under premixed combustion conditions. They have concluded that the micro elliptical tube combustor has higher emitter efficiency and combustion efficiency. Li et al. [15] have simulated combustion dynamics and nitrogen oxide emissions of partially premixed methane-air flame by using Large Eddy Simulation. They have revealed that swirl number, equivalence ratio and nitrogen dilution affect on combustion dynamics and nitrogen oxide emissions of partially premixed methane-air flame considerably. There are also some another experimental and numerical studies directly related to premixed or blending fuels combustion [16–28].

It is known that low calorific value coal gases are not suitable for existing natural gas-fired systems as they are more complex in terms of their contents. They include high amounts of nitrogen and carbon monoxide contributing to flame instability and reducing combustion performance, which these situations are undesirable conditions in any combustion process. However, to integrate the low calorific value coal

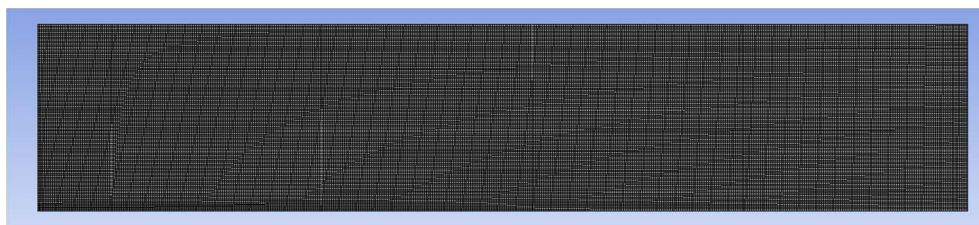


Fig. 1. The grid structure.

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