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An overview on safety issues related to hydrogen and methane blend applications in domestic and industrial use

Livio de Santoli[a], Romano Paiolo[a,] *, Gianluigi Lo Basso[a]

[a]*DIAEE-Department of Astronautics Electrical Energy Engineering, Sapienza, University of Rome, Via Eudossiana 18, Rome 00184, Italy*

Abstract

The share of electrical energy hailing from renewable sources in the European electricity mix is increasing. The match between renewable power supply and demand has become the greatest challenge to cope with. Gas infrastructure can accommodate large volumes of electricity converted into gas whenever this supply of renewable power is larger than the grid capacity or than the electricity demand. The Power-to-Gas (P2G) process chain could play a significant role in the future energy system. Renewable electric energy can be transformed into storable hydrogen via electrolysis and subsequent methanation.

The aim of this paper is to provide an overview of the required technical adaptations of the most common devices for end users such as heating plants, CHP systems, home gas furnaces and cooking surfaces, wherever these are fuelled with methane and hydrogen blends in variable percentages by volume. Special attention will be given to issues related to essential safety standards, firstly comparing existing Italian and European regulations in this regard, and secondly highlighting the potential need for legislation to regulate the suitability of hydrogen methane blends. Finally, a list of foreseeable technical solutions will be provided and discussed thoroughly.

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Keywords: Power to gas; hydrogen and methane blends; safety; regulations; CHP and boiler.

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* Corresponding author. Tel.:342.0822901; fax: +0-000-000-0000 .
E-mail address: romano.paiolo@uniroma1.it

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1. Introduction

Hydrogen is being pursued as a sustainable energy carrier for fuel cell electric vehicles (FCEVs) and as a means for storing renewable energy at utility scale. Hydrogen can also be used as an eco-fuel in stationary fuel cell systems for buildings, backup power, or distributed generation. Furthermore, blending hydrogen into the existing natural gas pipeline network has been proposed as a means of increasing the output of renewable energy systems such as large wind farms. If implemented with relatively low concentrations, ranging in 5%-30% of hydrogen by volume, this storage strategy and delivering renewable energy to markets appears to be viable without significantly increasing risks associated to the blended gas utilization in end-users devices (e.g. household appliances) [1]. Additionally, all public safety features, as well as the existing natural gas pipeline network durability and integrity are not strongly affected by the hydrogen enrichment. However, the appropriate blend concentration may vary significantly due to NG composition within pipelines and the end-user typology, which is the reason it must be assessed on a case-by-case basis. Blending hydrogen into natural gas pipeline networks has also been proposed as a means of delivering pure hydrogen to markets, using separation and purification technologies downstream to extract it close to the point of delivery. In such a way, blending can defray the building costs of dedicated hydrogen facilities or other costly delivery infrastructure during the early market development phase. This paper deals with key issues related to the hydrogen mixtures uses, which are described briefly in the following sections: an overview of benefits of blending, the impact on end-use systems in terms of modification in different set-up, furthermore a great attention was paid to all of safety issues related to the most common and user devices as well as their material durability and integrity management [2].

2. Chemical-physical properties of hydrogen

Hydrogen is characterized by a wide range of flammability and by a high speed of flame propagation. Indeed, in the case of combustions with air, the flame's laminar propagation speed is equal to 270 cm/s, compared to 37 cm/s in methane/air flames. The consequence can be severe control issues in addition to the risk of the insurgence in premixed flames of the backfiring phenomenon, which involves the propagation of the flame front in the direction opposite to that of the premixed reagent source, leading to the potential risk of explosions or other serious damage to the burner. Another unique characteristic is the high adiabatic flame temperature (2380 K compared to 2222 K in methane combustion with air), which implies problems with materials and, in general, makes dilution necessary before exhaust gas inlet in burners of several devices such as gas turbines internal combustion engines and boilers.

The preheating temperature influences the flame front propagation speed, which increases it significantly. This is why it is possible to stabilize hydrogen flames even at high efflux speeds (160 m/s).

Another important aspect can be the emergence of thermo-acoustic instability. This kind of instability can lead to self-sustaining oscillations with amplification of the pressure fluctuations within the combustor. The consequence would then be considerable vibrations that could cause serious structural damage.

A solution to all these problems is offered by new, more advanced combustion technologies characterized by the absence of drastic temperature gradients and by high levels of control over the kinetic-chemical process. Applying these technologies implies the general redesign of the combustion system (burner-combustion chamber) and the development of adequate methods of design and controls.

To this end, this paper reviews the impact of the use of hydrogen blended with natural gas on the performance of engines as well as the most common appliances, and on emissions with reference to research activities in this field. It must be noted that the percentage of hydrogen that can be used in thermal engines has a maximum threshold strictly dependent on the knock limit, which is a function of the compression ratio; this is normally quite high in thermal engines. Consequently, that threshold must always be kept in mind, along with the methane number (MN), which indicates the gas quality and, more specifically, its capacity to resist auto-ignition. That parameter was defined as the percentage by volume of methane blended with hydrogen that exactly matches the knock intensity of the unknown gas mixture under specified operating conditions in a knock testing engine. For the range beyond 100 MN, methane-carbon dioxide mixtures were used as reference mixtures. In accordance with the definition, the MN is 100 plus the percent CO_2 by volume in the reference methane carbon dioxide mixtures. Malenshek et al. [3] have