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An assessment of the operating efficiency of a condensing boiler fed by fuel with different amounts of hydrogen in the mixture

Evaluarea performanțelor în funcționare pentru o centrală în condensare alimentată cu procente diferite de hidrogen în combustibil

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Abstract. *The current trends converge towards minimizing the carbon footprint on the environment in the operation of all thermal equipment and need finding alternative solutions compared to what the market offers at the moment. Utilizing hydrogen in combustible mixtures with methane gas to fuel condensing boilers is one solution. The benefit is that it reduces carbon dioxide emissions into the atmosphere as only water vapor is produced when hydrogen undergoes combustion. The effects of adding hydrogen at percentages of 23%, 30%, 35% and 45%, respectively, to the combustible gas mixture are examined in the paper.*

Key words: *hydrogen; condensing boiler; carbon footprint*

1. Introduction

A practical option to decarbonize the energy sector is to incorporate hydrogen into natural gas pipes as mixes of hydrogen and methane. It makes use of already-built infrastructure, lowers greenhouse gas emissions, and provides a way to store extra renewable energy. To achieve a smooth transition, though, issues with safety, infrastructural improvements, and hydrogen generation must be resolved [1-3]. Hydrogen-methane mixtures could be a key component of a low-carbon, sustainable energy future as technology develops and renewable hydrogen becomes more widely available [4,5]. The compatibility of employing hydrogen-methane mixes with current natural gas distribution networks and pipelines is one of their main benefits. Hydrogen-methane mixtures are often employed with very slight alterations [7], but retrofitting pipelines for pure hydrogen can be expensive and time-consuming.

In Romania, using hydrogen in combustible mixtures is considered a way to ensuring the energy security by maximizing the potential of renewable resources and this is best reflected by the advance which legislation in this country has made through the introduction of the norm 237/2023. Romania may become a regional leader in energy security by "increasing and modernizing storage capacities compatible with the use of new gases and hydrogen". Also, according to the principle "energy efficiency first" one of the main objectives for 2030 is increasing the share of SRE and low-carbon fuels in the transport sector - including advanced biofuels, hydrogen, fuels made from waste [8].

Numerous investigations related to the operation of combustion equipment with methane hydrogen mixture were carried out in Romania by testing laboratory part of the Technical University of Civil Engineering Bucharest research team. This laboratory is accredited by the National Accreditation Body for performance testing of boilers in operation for the purpose of applying the European marking CE [9]. The current work exclusively examines, both theoretically and practically, how condensing boilers behave when fed fuel mixtures with a high hydrogen content are used.

2. Methodology

High-performance and precise measuring instruments, such as thermocouples, pressure sensors, flowmeters, and a flue gas analyzer, are employed on the experimental stand throughout the testing process-Figure 1. The testing team has been evaluating boilers for more than 10 years, and a routine test also offers safety tests for boilers using gas type G222, also known as flame return limit gas according to the regulations. This gas contains a percentage of 23% hydrogen mixed with methane and the purpose of the test is to evaluate if the flame of the burner has a tendency to stick to its surface or even to go further backwards.

The team intensified testing with this type of gas and also looked into how the equipment behaves at even higher percentages of hydrogen, like 30 or 35%, due to the current preoccupations about implementing hydrogen obtained from renewable sources mixed with methane in the distribution networks of gaseous fuels [10-12].

In this direction, the laboratory has concluded a collaboration protocol with the Delgaz Grid company, on the basis of which numerous equipment will be tested when operating with high percentages of hydrogen in the combustible, in order to determine whether the operation is appropriate.

The methodology aims to determine how the main parameters vary when the percentage of hydrogen in the fuel mixture increases. The main direct effect is on the reduction of the fuel's heat of combustion, since hydrogen has a lower heat of combustion compared to methane at the same unit of volume. Thus, when such mixtures are used, in order to maintain the same thermal load of the equipment it is necessary to increase the fuel flow rates.

Due to the fact that burning hydrogen only produces water vapor, the principal benefit associated with present-day environmental protection concerns is the reduction of carbon dioxide emissions.

Fig. 1. Experimental stand

3. Results

The assessment of the heat released from fuel combustion was carried out up to a maximum percentage of 40% hydrogen in the mixture, which represents a maximum limit considered according to the research carried out to date, so that no significant interventions and changes are made in the natural gas distribution networks. Table 1 presents both net calorific value and gross calorific value due to the fact that the condensing boilers, which are mandatory according to Romanian norms operate with the gross calorific value.

Table 1

Mixtures' burning performance

Combustible mixture	Net calorific value [kJ/m3]	Gross calorific value [kJ/m3]
G20 (methane)	36,879	40,970
20% hydrogen+ methane	30,798	34,340
G222 (23% hydrogen+ methane)	29,930	33,480
30% hydrogen+ methane	28,297	31,551
35% hydrogen+ methane	27,047	30,157
40% hydrogen+ methane	25,796	28,763

In the following table, the volume of air required for the combustion of a unit volume of fuel (1 m3), the resulting volume of combustion gases, the way in which the fuel flow changes, as well as the value of carbon dioxide emissions, assuming as a benchmark a condensing boiler having a thermal power of 28 kW and an air excess of 1.3. This particular values were chosen based on the research team's experience.

Table 2

Mixtures' burning features

Combustible mixture	Necessary air volume [m3]	Flue gases volume [m3]	Flow [m3/h]	Carbon dioxide [m3/h]
G20 (methane)	12.38	13.38	2.82	2.82
20% hydrogen+ methane	10.51	11.42	3.37	2.7
G222 (23% hydrogen+ methane)	10.24	11.12	3.47	2.67
30% hydrogen+ methane	9.59	10.44	3.67	2.57
35% hydrogen+ methane	9.126	9.95	3.84	2.5
40% hydrogen+ methane	8.66	9.46	4.03	2.42

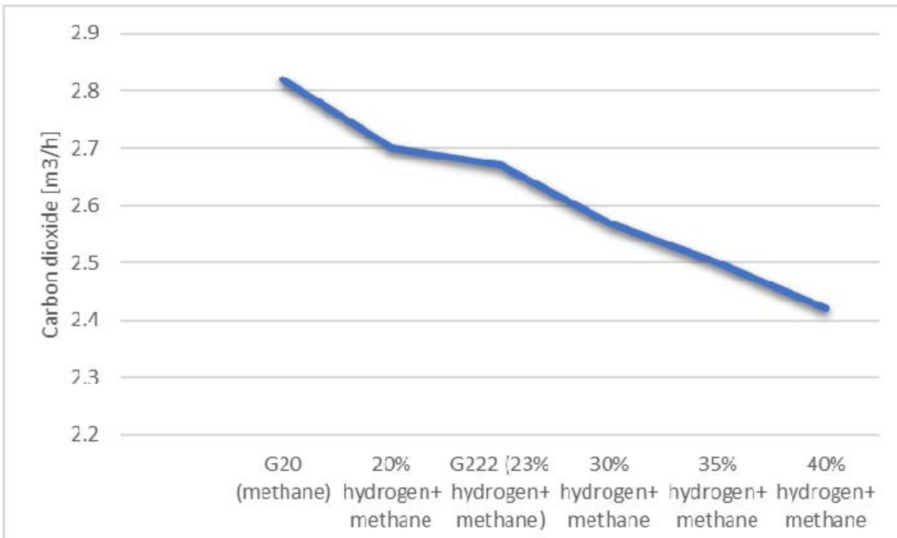

Fig. 2. Carbon dioxide emissions

4. Conclusions

The research team emphasizes the following essential points that must be taken into consideration in the process of adopting hydrogen in the distribution networks of consumer gas supply, as a result of the experience gained from the theoretical as well as experimental evaluations of numerous combustion equipment.

The higher the percentage of hydrogen introduced into the mixture, the more the heat of combustion of the fuel mixture will decrease, thus to ensure the same thermal load of the equipment in operation, the fuel flow must be increased.

The positive impact envisaged with the introduction of hydrogen is maintained even with this increase in fuel flow, i.e., the amount of carbon dioxide emissions in the environment notably decreases, which is highlighted in Figure 2.

The assessments presented solely address the thermal performance and emissions of the equipment; they do not cover the functionality and behavior of the gas distribution networks when injecting the mixtures.

The idea that the hydrogen to be used in combustible mixtures must be obtained from renewable energy sources and with a minimal carbon footprint possible in all stages of production, must be reinforced, along with the highlighting of the benefits brought in terms of the reduction of harmful emissions in the atmosphere, so that, looking at the overall picture, the effect is positive.

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