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THE ENERGY OF TOMORROW - HYDROGEN AND CATALYTIC BURNERS

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Abstract: *In this study is presented a brief overview of hydrogen-based energy, mentioning different types of catalytic burners and a parallel between hydrogen energy and combustible natural gas. Use of hydrogen in buildings services facilities can make its presence felt through natural gas installations, by injecting up to a maximum of 20% hydrogen to the gas network, the remaining 80% being natural gas. Consequently, the use of hydrogen energy for the technical and economic comfort of dwellings, residential complexes, commercial and service spaces, could be found in the near future.*

Key words: *hydrogen, energy, fuel, burning.*

1. Introduction

Hydrogen will be one of the energy resources to be used in the near future, this being used in a wide range of uses.

Today, hydrogen is considered a synthetic fuel transporter or energy for the post-fossil era. It has many properties to highlight, complementing unconventional primary energy sources and providing a convenient form of takeover by consumers [14].

Hydrogen is a universal gas, being also fuel and raw material for the industry. With all the advantages which fossil fossils have, hydrogen, unlike them, is devoid of the problem of polluting the environment, at its burning, the only secondary product being water.

2. Catalytic Burners

In the process of designing a catalytic burner, the operating temperature, low temperature ignition, lighting temperature, flame stabilization and low explosion, combustion exhaust temperature and combustion efficiency should be considered. These factors are very important and, sometimes, they are in conflict with each other. Considerations related to the design and construction of catalytic burners are usually applied to optimize the performance of a catalytic fuel. At catalytic burners, design, heat

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transfer issues and catalyst durability are the main priorities. One of the main components of the hydrogen catalytic combustion plant is the type of burner used.

They are now classified according to several criteria, among which [18]:
- by flame shape, flame burners: cylindrical, flat, short and long;
- by flame orientation, flame burners: horizontal and vertical;
- by type of flame, flame burners: stoichiometric, oxidising and reducing;
- by flame ejection speed, burners at speed: low, medium and high.

Due to the hydrogen fuel type features, there is currently no widespread expansion of these types of catalytic burners.

Prototype catalytic burners and hydrogen plates have been featured in the many types of solar houses that have been demonstrated over the last 40 years [3]. The first incentives to adopt catalytic combustion were safety, because the hydrogen flame is hardly noticeable, and implicitly low NOx production. Catalytic burning can provide a safety solution by the presence of a catalytic material that shines in proportion to the burner temperature and indicates that the burner is on.

One of the burner prototypes was presented by Roger Billings in the "Hydrogen House" project, as shown in figure 1 [19].

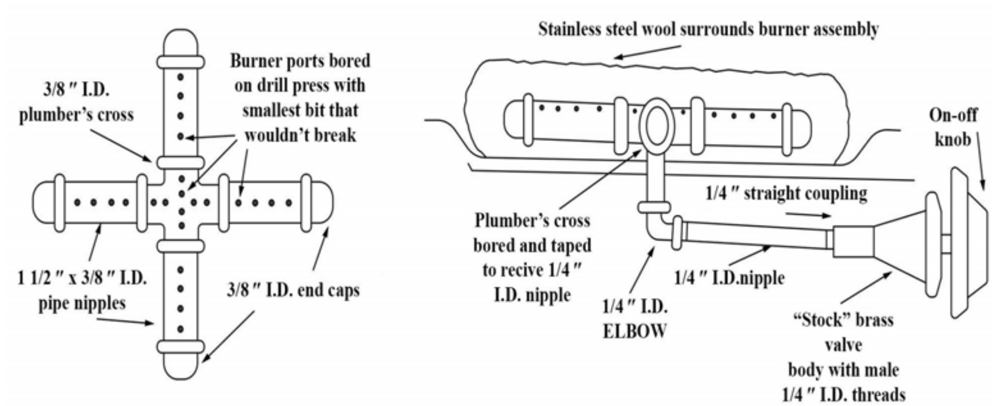

Fig. 1. *The flame assisted by the catalytic burner*

In this type of burner, the stainless steel matrix surroundings inhibited the mixing of air and hydrogen and created a stable hydrogen rich zone around the burner head.

It is worthy to be highlighted another type of burner, namely the double-layer wire burner, due to the two stages, ignition and preheating.

The use of the double-layer wire burner is represented by the two characteristic layers. The first layer provides a rapid thermal reaction of the catalysts with a wire mesh for ignition with hydrogen, followed by a rapid heat release for preheating and stabilizing the burning of hydrogen on the second layer.

Figure 2 shows the image and scheme of the double-layer wire catalytic burner. The combustion chamber is made of a quartz tube with an internal diameter of 2.5 cm. Wire mesh catalysts are fixed between the flange and the quartz tube. The separation distance between the wire mesh catalysts is 1-3 cm. The larger distance shown in the image is to make the net more clear. The analyzed catalyst is made of platinum-coated metal alloys. For testing, the air is supplied by a compressor system, while hydrogen and carbon monoxide, with different volumetric ratios, are supplied from gas cylinders to simulate syngas [9].

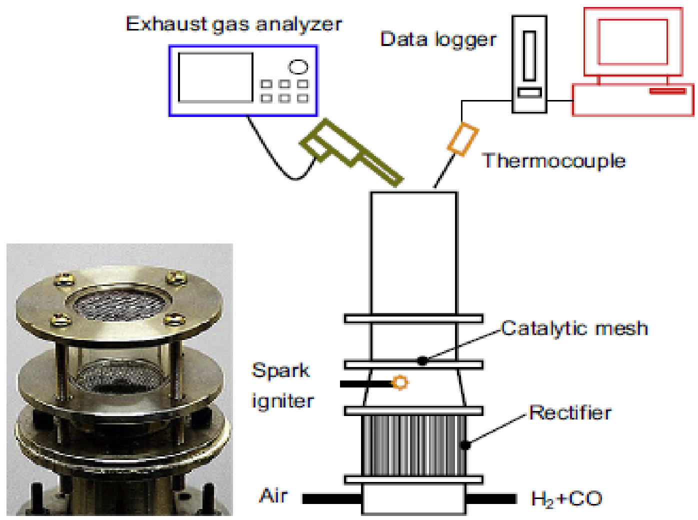

Fig. 2. *Picture and scheme of the* double-*layer wire catalytic burner.*

Emigration to a hydrogen-based energy system is a high-tech issue whose solution requires more disciplines covering multiple areas, not only of engineering sciences, but also of social sciences. The use of hydrogen in any technology, application and economy is supposed to be one of the best solutions for the replacement of fossil energies and the protection of the environment [6].

3. Hydrogen-Specific Characteristics as Possible Future Fuel as Compared to Natural Gas Fuel

Hydrogen is flammable and can react dangerously under certain conditions. Therefore, just like other flammable fuels, including natural gas and gasoline, should be treated responsibly. Also, hydrogen is odorless, colorless and insipid, so it is imperceptible to human senses. It has a large diffusion force of about 3.8 times faster than natural gas, which means it is rapidly diluted in a non-flammable concentration. Hydrogen increases about 6 times faster than natural gas, that is, at a speed of 20 m/s. So, in case of a leakage, it could gather in undetectable areas, such as ceiling, corners, etc. which is a disadvantage. Hence, the use of hydrogen sensors is required because no mercaptan gas like solution has yet been found, which does not contaminate hydrogen cells.

Pure hydrogen burning is a long-term goal for power generation [2]. Injecting hydrogen into the natural gas network can improve combustion stability in conventional gas power plants [15].

According to some specialized studies, low temperature catalytic combustion is potentially advantageous compared to conventional flame combustion types, to the residential use of hydrogen due to fire safety and the elimination of pollutants. The burning difference between methane and hydrogen is related to the flammability, with the wider limits of hydrogen to methane, the faster burning rate and lower ignition energy than methane. When hydrogen is burnt as a mixture with natural gas, in principle, its combustion characteristics bring positive characteristics. Ignition of the burner continues steadily due to increased flammability limits and reduction of the ignition and re-ignition energy. In industrial areas, hydrogen is mostly burned with other fuels. However, conventional burners are not adaptable for hydrogen and natural gas mixtures in homes for safety and environmental reasons, only with respect to the percentages of maximum 20% of hydrogen and 80% of natural gas [9].

According to the work of Hord J. of "International Journal of Hydrogen Vol.3", the burning properties for hydrogen, propane and methane are presented in Table 1 [5].

Burning properties for hydrogen, methane and propane Table 1

Properties	Hydrogen	Methane	Propane
TPN gas density (a) [kg m-3]	0.0838	0.6512	1.87
Combustion Heat (b) (low) [MJ m-3]	10.78	39.72	99.03
Combustion Heat (b) (high) [MJ m-3]	12.75	35.80	91.21
Range of flammability (limits) in air (c) [%]	4.1 - 75	5.3 – 15	2.1 – 10
Stoichiometric composition in the air (c) [%]	29.53	9.48	4.02
Minimum ignition energy [mJ]	0.02	0.29	0.26
Minimum self-ignition temperature (d) [K]	858	813	760
The temperature of the adiabatic flame in the air [K]	2318	2158	2198
Burning speed (d) [cm/s-1]	237	42	46
The range of detonation resistance in the air (c) [%]	18 – 59	6.3 - 13.5	3.1 – 7.0
Gaseous fuel explosive energy (b) [MJm-3]	9.9	32.3	93

(a) TPN= temperature and normal pressure (293.15K, 0.1013 MPa);
(b) 273.15 K, 0.1013 MPa; (c) Volumetric report; (d) Stoichiometric mixture.

From the work of Ladaki M. et al. [8] the reaction starts at 77 K on platinum vs. 858 K without catalyst and the burning aspects of hydrogen compared to methane were found: faster flame speed (up to 8 times), wider range of flammability (5-75 vs. 5-15 vol.%), lower ignition energy (0.02 vs. 0.3 mJ), extreme sensitivity to the presence of catalytic surfaces during the reaction with oxygen. Hydrogen burns differently than natural gas with a diffusion rate and a much higher flame propagation rate, requiring special burners different from those of flame classics.

Specialty articles highlight a problem with the combustion of hydrogen related to the combustion rate of 2.65 - 3.25 m/s for hydrogen versus 0.40 m/s for methane. In this context, it means that it is difficult to control the flame, as high pressures are required. The jets must be modified and the hydrogen/air mixture must be well regulated to produce a safe and efficient combustion [21]. In conclusion, the amount of oxygen required for burning hydrogen is four times lower than the methane gas.

4. Current State of Use of Natural Gas

Materials used in natural gas distribution systems are steel and polyethylene. At present, in Romania there is a transition from existing underground pipelines of natural gas to polyethylene because of their resistance and lifetime they are more favorable.

The main components of the National Gas Transmission System at the end of 2016 were 13303 km of main transport pipelines and natural gas supply connections of which 553 km of international transport pipelines, 1138 natural gas measuring stations, out of which 6 import natural gas measuring stations, 6 measuring stations located on the international transport pipelines, with 3 natural gas compressor stations.

According to the Romanian National Institute of Statistics, the length of natural gas pipelines in 2016 was 39,668.8 km, 1.1% higher than in 2015.

The natural gas transport through main streets is carried out at pressures between 6 bar and 40 bar, with the exception of the international transport at 63 bar.

The total technical capacity of the interconnection points located on the international transport pipelines is approx. 70,000 cubic meters/day, both at entry and exit. The internal and international transport of natural gas is ensured through the pipeline network and supply connections with diameters between 40 and 1,200 mm [20].

5. Current State of Use of Hydrogen

Hydrogen pipelines add an extra level of complexity due to a relative lack of experience in installing hydrogen pipelines, which can be transported similarly to methane gas.

After some work, in 2004 there were about 2,900 km of hydrogen pipelines in the US and Europe, compared to over 300,000 km of natural gas pipelines in the US alone.

The first hydrogen network dates back to 1938 in Germany, the Ruhr area, with a length of more than 215 km, was constructed of steel pipelines, carrying compressed hydrogen at a pressure of between 10 and 20 bar, with diameters between 250-300 mm, being functional even today [17]. Other examples of hydrogen pipelines in operation are: a pipeline of 100 km at 20 bar in Leuna, Germany, a pipeline network of about 966 km at 100 bar in Belgium, France and the Netherlands, and a 50 km pipeline system Rotterdam. There is a 16 km pipeline in the UK at a pressure of 50 bar and in Sweden a 18 km pipeline at a pressure of 5 to 28 bar [11]. In the US, there are 1,100 km of hydrogen main streets [7]. From the specialty literature, the most resistant steel pipes, such as X70 or superior grade, are alloyed with materials resistant to hydrogen attack. The best pipelines for the distribution of hydrogen are those from austenitic steels, but they are also the most expensive [1]. Among the less costly solutions one can notice the development of reinforced composite tubes consisting of steel pipe, primer, reinforced composite and outer wrap [12].

6. The Use of Hydrogen in the Mixture with Natural Gas in Romania

A possible shift to the implementation of the hydrogen-based system is to use the current methane gas network to transport a mix of at least 80% natural gas and maximum 20% hydrogen, but considering the specificity of hydrogen transport, such as the hydrogenation of steel which leads to a deterioration in its quality, becoming brittle, the realization of these pipelines requires very large initial investments [7].

At the level of Romania, the natural gas distribution system is made up of two classes of pipes, the first is the steel pipes and the second is the polyethylene pipes. The maximum permissible natural gas velocity in distribution networks and in use facilities is 20 m/s for overground steel pipes and 40 m/s for underground steel or polyethylene pipes [10].

At national level, natural gas distribution systems are currently only aggressively produced by polyethylene pipes, except for the situations stipulated in the Norms, where they are made of steel pipes. Due to the degradation of the steel pipes that have occurred during the years of operation, they are now replaced mainly by polyethylene pipes. The transition to hydrogen-based energy is a delicate issue, as the replacement of steel pipes in favor of polyethylene is more profitable both technically and economically. Polyethylene pipes are more reliable, less maintenance-free, corrosion-free and with very good low temperature properties. There are a number of metal degradation processes that can occur in hydrogen environments. The type of attack that leads to degradation will depend on a number of factors such as: hydrogen source, material, temperature and operating pressure, hydrogen concentration, physical and chemical properties of the pipe material, surface conditions of the pipe, nature of any crack of the material and its microstructure. The main concerns in the case of steel gas pipelines are hydrogen fragility and the loss of mechanical properties because pipeline materials can undergo significant changes in strength when exposed to hydrogen by hydrogenation [22].

Used at the same pressure, hydrogen represents 36% of the volumetric energy density of natural gas. At high pipeline lengths where the volume is high, when a change in working pressure occurs in the pipeline system, there is a major change in the amount of hydrogen contained in the pipeline, which is technically and economically beneficial, avoiding the need for storage [16].

7. Hydrogen Mixing in the Natural Gas Network - Scenario I

Injecting hydrogen into the natural gas network has been and represents an energy research topic. In theory, hydrogen can be injected at a maximum of 20% into the natural gas network, with the remaining 80% being methane. At this rate, natural gas enriched with hydrogen is compatible with the current natural gas distribution network. After the study [22], the following percentages of hydrogen and natural gas were found: 2% - 49/1; 5% - 19/1; 10% - 9/1; 20% - 4/1.

Several attempts have been made to determine the most suitable blends, choosing between 5 and 20% hydrogen in natural gas, so that the plant is feasible. In order to better understand the hydrogen injection process in natural gas, it is important to evaluate the potential changes in the Wobbe index, which is a characteristic closely related to the calorific value, being the ratio between the calorific value and the redness of the density relativity [4]. Among the most important properties of hydrogen methane mixtures are the calorific value, the flame rate and the flammability range.

Generally, classic cooking machines use normal aspiration burners, the burners being typically circular and those of the ovens being linear. When hydrogen senses its presence in natural gas, the flame speed increases, creating burning closer to the burner. The more hydrogen is injected into the gas network, the flames tend to shorten and burn closer to the burner base - the horizontal position [13].

8. Reconversion in Romania of the Entire Natural Gas System on Hydrogen - Scenario II

In order to successfully complete the conversion of the entire natural gas distribution system to hydrogen, the technical feasibility of hydrogen transport using natural gas networks needs to be analyzed. It is known that the mixture in some lower proportions of hydrogen and methane is feasible but the conversion of a whole system of natural gas to hydrogen is untested at such a large scale. Natural gas is transported through many interconnected direct distribution networks to consumers. These networks have different characteristics from the type of material to the pressure regime, the age of the pipes and the state of their degradation. Hydrogen distribution at high pressures leads to the main concern over the integrity of high-strength steel pipes, namely hydrogenation. Hydrogen will diffuse in the existing defects resulting from the operation of steel pipes, resulting in loss of ductility, growth or the initiation of new cracks and losses of hydrogen. Switching from steel pipes to polyethylene pipes at a reduced or low pressure regime, polyethylene pipes are more porous to hydrogen than to methane, so the hydrogen leakage through the walls of the pipes would be bigger and harder to control after the conversion. The following aspects to consider are compression stations and measuring counters. In plant use, the most important aspect is safety in use for hydrogen-based installations, with limited knowledge of the risks of using this type of fuel in buildings because hydrogen has properties quite different from those of natural gas. At the same time, the risk of gas accumulation, detection of the presence of hydrogen and its ignition tolerances must be taken into account. It must be mentioned production capacity and storage of hydrogen which is subsequently distributed to finals consumers of the type cooking machines, boilers of thermal power plants, etc to which it is necessary burner conversion to the system based on hydrogen.

In conclusion, the conversion of the natural gas system to the hydrogen system requires a thorough assessment of all components existing in the natural gas distribution system, the most important issue being the existing networks, which in the last years in the country are in the process of passing from the steel pipes to the polyethylene ones.

9. Conclusions

There have been remarkable hydrogenic qualities for fossil energy sources, in this case methane gas, but the air-fuel equivalence ratio to determine the hydrogen output power has to be taken into account. Smaller gliding of hydrogen is believed to derive from both the lower dilution and the lowest oxygen availability resulting from lower airflows. Control of the temperature-dependent hydrogen flux is able to maintain hydrogen slip well below its 4% ignition limit in the air both during the heating phase and during continuous operation.

Hydrogen is advantageous compared to conventional hydrocarbon fuels in low-temperature catalytic combustion, the feasibility of adopting cheap oxidation catalysts and the wide range of heat-adjustable qualities, especially at the bottom.

Hydrogen is considered at this time one of the most promising energy sources of the future. Improving burners for blends of natural gas in household based on hydrogen is being investigated in terms of stable combustion and safety at an acceptably low NOx emission level.

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