Generation of Hydrogen at a Gas Distribution Station

A A Karimova¹, R R Farukhshina², E A Kuznetsova³

¹Master's student, Department of Transportation and Storage of Oil and Gas, USPTU, Kosmonavtov st., 8/3, 450044, Ufa, Russia
²Associated Professor, PhD in Engineering, Department of Transportation and Storage of Oil and Gas, USPTU, Kosmonavtov st., 8/3, 450044, Ufa, Russia
³Master's student, Department of Transportation and Storage of Oil and Gas, USPTU, Kosmonavtov st., 8/3, 450044, Ufa, Russia

E-mail: karimova_ulya@mail.ru

Abstract. In 2019 the UN announced a course to achieve carbon neutrality of industries by 2050. In this connection interest in hydron fuel has increased. Hydrogen due to its ecological characteristics is considered to be one of the most promising energy sources. It does not pollute the atmosphere, as the product of its combustion is water; it has a high energy intensity and is also the most abundant element on the planet. Despite the fact that most of the hydrogen is produced by the steam reforming of methane, the most environmentally friendly way to produce hydrogen is the electrolysis of water. However, the problem with this method is the high cost of electricity, which in addition in most cases is a product obtained from the combustion of primary energy sources. A modern gas transmission system can become a secondary source of electricity for hydrogen production, thereby solving the problem of utilizing excess pressure energy at gas distribution stations (GDS). The technological solution for using this energy is the installation of turboexpanders and the electrolysis of water at the GDS in order to generate hydrogen.

1. Introduction

In recent decades governments of many countries have been focusing on research and implementation of technologies based on the use of renewable energy sources. According to the Technical Report provided by the International Energy Agency in 2019, the demand for hydrogen fuel has tripled in comparison to 1975 [1].

Due to the intensive growth of carbon dioxide emissions, the course for decarbonization of production by 2050 was held by the UN. Canada, the USA, Japan and other countries have developed energy strategies to achieve carbon neutrality by 2050.

2. Properties of hydrogen

In virtue of its ecological characteristics, hydrogen is recognized to be one of the most promising sources of energy. It does not pollute the atmosphere as the product of its combustion is water; it also has high energy density compared to other energy sources (Table 1) and it is the most abundant element on the planet [2].
Table 1. Energy intensity of different types of fuel.

| Energy intensity | Type of fuel | 
|------------------|--------------|
|                  | Hydrogen     | Natural gas | Gasoline | Diesel fuel | Methanol |
| Weight, kWh/kg   | 39.45        | 15.45       | 13.36    | 10.17       | 6.47     |
| Volumetric, kWh/m³ (at P=1 atm) | 3.53 | 11.11 | 9.89 | 8.3 | 4.99 |

Analyzing the Table 1, we can make a conclusion that the combustion value of hydrogen is much higher than the indicators of conventional energy sources but unfortunately, hydrogen is inferior to them in terms of volume indicators almost three times. Despite not being a source of energy, it plays the role of a means of converting other sources of energy into chemical energy in the form of stored pure hydrogen which can further be used in its oxidation. This circumstance leads to developments in the field of storage and transportation of hydrogen using hydrocarbons as well as coal, water and biomass, which creates some difficulties for the widespread development of hydrogen energy.

In Russia the mission of developing hydrogen energetics is enshrined in the key sectorial strategic planning document – the updated Energy Strategy of the Russian Federation for the period up to 2035. The document is aimed at increasing of production and use of hydrogen as well as joining the country among the world leaders in its production and export. Even today Russia owns important competitive values in the development of hydrogen energy: the presence of significant generating capacities and resource base, the presence of underutilized generating capacities, geographical proximity to potential hydrogen consumers, scientific groundwork in the field of production, transportation and storage of hydrogen an also the presence of operating transport infrastructure.

3. Obtaining methods

Today most amount of hydrogen is produced by the method of steam reforming of methane – the obtaining of pure hydrogen from light hydrocarbons by catalytic conversion of hydrocarbons in the presence of water vapor (Fig. 1) [1]. Hydrogen produced by this method according to the EU classification is called “grey” hydrocarbon and while using the technologies of capturing by-products the hydrogen is “blue”.

**Figure 1.** Methods of hydrogen production in the world.
However, the most environmentally friendly way of production of this type of fuel is electrolysis of water which is the source of “green” hydrogen. The problem of this method is the high cost of electricity which beside that in most cases is the product obtained from the combustion of primary energy sources.

There is a possibility of solving this problem which resides in using the energy of excess pressure (dump energy) that is not usually used while throttling the gas flow at gas distribution stations (GDS) in order to supply it to gas distribution nets for the production of hydrogen.

4. Technological solution
When installing turbo expanders at gas distribution stations dump energy is converted into electrical energy. According to [3] 21 turbo-expanders are installed and are being operated at the facilities of PJSC Gazprom by 2019 with the total generated electrical energy being 74,679 kW∙h. The received electricity is surplus and is mostly used for the needs of the GDS itself. By generating hydrogen at the GDS the Gas Transportation System (GTS) in turn, will thus solve the problem of utilizing this energy.

Taking these facts into account, the technological solution for using the electrical energy generated by the turbo expander is to perform the electrolysis of water at the GDS. In order to produce hydrogen, the voltage called thermoneutral is required. Its value is 1.48 V. The process of water decomposition in this case at 25°C will occur without heat supply from the outside. At this voltage 3.54 kW∙h per 1 m³ of hydrogen is consumed [4]. Installed turbo expanders at PJSC Gazprom can then produce 21,095 m³ of hydrogen in one year.

In the process of electrolysis of water oxygen release will occur at the anode while at the cathode it will be hydrogen in a volume ratio of 1:2. In order to get 1 m³ of hydrogen and 0.5  m³ of oxygen under normal conditions 805 g of water is theoretically required to be spent. Practically water requirement is 820…850 g [4]. The required quantity of water at the maximum water consumption is then 17,931,000 g or at water density of 1000 kg/m³, 17.9 m³.

The source of water in turn at each individual GDS can be the nearest underground or surface watercourse.

5. Electrolyzers
The process of water electrolysis is carried out in electrolysis cells which divided into three types: alkaline, with a solid polymer electrolyte (SPE), with the solid oxide electrolyte (Table 2) [5].

| Type                            | Energy requirements of production 1 m³, kW∙h | Temperature, K | Productivity, m³/h | Pressure, MPa | Efficiency, % |
|---------------------------------|--------------------------------------------|----------------|--------------------|---------------|---------------|
| Alkaline                        | 4.5-5.5                                    | 320-370        | <500               | 0.1-5         | 50-70         |
| Solid polymer electrolyte (SPE) | 3.5-4.5                                    | 350-370        | <100               | 0.1-15        | 80-90         |
| Solid oxide electrolyte         | 2.5-4                                      | 1070-1270      | -                  | 0.1-3         | >85           |

According to Table 2, the most optimal electrolysis cells are SPE as they have a relatively high efficiency at average temperatures of the technological process and also, they operate in a widest range of pressure.

Major producers of electrolysis cells are: Norsk Hydro (Norway), Hamilton Sundstrand (USA), Fuji Electric (Japan), UralKhimMash (Russia).
6. Transportation and storage
The hydrogen generated at the GDS can be transported in compressed and liquified form (by vessel, by rail and by pipeline).

A standard “auto-hydrogen carrier” transports a set of tubular tanks with a total capacity of about 20-25 m$^3$ of compressed hydrogen (pressure 25 MPa) or approximately 0.5-1 tons. Tankers with a payload of up to 4 tons of hydrogen with a capacity of up to 50 m$^3$ are used for transportation in liquified form – this is especially beneficial for long-distance transport (up to 4 000 km). In the future, it is possible to develop this direction – transition from steel to composite materials (which reduces the weight of the “container” and eliminates the corresponding logistic restrictions, pressure growth, etc.).

Pipelines are suitable for the transporting larger and more constant amounts of hydrogen; they require a significant investment though. As of 2016, there are more than 4500 km of hydrogen pipelines – mostly in the USA and in four European countries (Fig. 2).

![Figure 2. Length of water supply line in the world in 2016 (Source: Shell [6]).](image)

Hydrogen does not require the creation of its own transportation system – there is a possibility of using the existing GTS. For many European countries and the USA this technology is just a “blast from the past” as from the 19th to the middle of 20th century in many cities there were town gas supply systems obtained from coal artificially. The hydrogen content of such a gas was usually about 50%. In many countries different proportions of hydrogen mixing in natural gas from 0.1% (in Belgium, New Zealand, the Great Britain and the USA) to 10% in Germany and 12% in the Netherlands [7]. Thus, the using generated hydrogen at GDS is in contemplation as a fuel gas in gas heaters unit at the same GDS.

The upper limit is defined by national technological standards related to the safety of gas pipelines and gas flaring equipment. NREL studies show [8] that 15% target can be reached in existing GTSs without any major changes and in some cases, it can be seriously exceeded. According to Gazprom Export a 70% limit can be reached in modern Nord Stream gas pipelines [9].

The H21 North of England Project [10] which is being developed by a local gas company in partnership with Equinor supposes a diverting of gas networks and the consumer’s equipment in the north of England to hydrogen, the construction of new hydrogen pipelines – as a result 3.7 million houses and businesses will use hydrogen for heating. The total cost of the project is estimated at $28 billion while carbon dioxide emissions will decrease by 20 million tons per year.
Marine and river transport is possible for hydrogen of different types – compressed, liquified and chemically bound. Nowadays in small amounts (by auto tankers with compressed hydrogen with the help of ferries) river transport is already used however, it is not of great importance. In order to create a global market for hydrogen as an energy carrier, other technologies comparable to the liquified natural gas (LNG) industry are required, for example, large-capacity ocean-going tankers with liquified hydrogen with a total volume of 150-200 thousand m$^3$ which would use the vapor (generated from the heating of hydrogen) for marine engines. The engineering of such sea-crafts began in 1980-1990s in Europe and Japan but there are still no finished samples. Most likely the first hydrogen tankers will appear as part of the beforementioned Japanese-Australian project Hydrogen Energy Supply Chain or a similar Japanese-Norwegian project – Kawasaki Heavy Industries which once built the first LNG-tanker in Japan is responsible for supply chains in these projects. A small demonstration tanker is already being developed and large ships are in the plans for the current decade [11].

According to the classification of the U.S. Department of Energy, the storage methods of hydrogen fuel can be divided into 2 groups.

The first group includes physical methods which use physical processes (mainly compression or liquefaction) to compact gas hydrogen. Stored with the help of physical methods, hydrogen consists of H$_2$ molecules that weakly interact with the storage medium.

Physical storage methods for compressed hydrogen gas:
- CNG cylinders;
- stationary massive storage systems including underground storage tanks;
- storage in pipes;
- glass microspheres;
- capillary structures.

Liquified hydrogen storage methods: stationary and transport cryogenic containers.

The second group includes chemical methods, in which the storage of hydrogen is provided by physical or chemical processes of its interaction with certain materials. These methods can be characterized by strong interaction molecular or atomic hydrogen with the material of the storage medium.

Adsorption hydrogen:
- zeolites and related compounds;
- absorbent carbon;
- hydrocarbon nanomaterials.

Chemical interaction methods:
- alonates;
- fullerenes and organic hydrides;
- ammonia;
- iron sponge;
- water-reactive alloys based on aluminum and silicon.

Absorption in the bulk of material (metal hydrides) is also possible [5].

7. Conclusion

The production and use of hydrogen are one of the promising methods of reducing carbon dioxide emissions and it can become an alternative for utilizing the energy of throttled gas at the GDS.

The list of questions that may arise during the introduction of hydrogen fuel into the existing GTS requires additional research.

8. References

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