TRANSPORTATION OF HYDROGEN BY PIPELINE

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Contents

Summary

Hydrogen exists as a gaseous substance under ordinary temperature and pressure conditions. At present, gaseous hydrogen is also produced by various production methods. The transportation of hydrogen includes transport by pipeline, which is the most common method, and batch transportation, which uses containers as described elsewhere. In the latter method, hydrogen is pressurized, or liquefied, because the density of hydrogen is very low. Here, the transportation of hydrogen by pipeline is compared with natural gas transportation, which is currently being practiced the most.

Hydrogen gas, liquid hydrogen, and slush hydrogen can be transported by pipeline. Liquid hydrogen and slush hydrogen exist only at very low temperatures, and with an extremely small latent heat of evaporation, they evaporate easily. The transportation of liquid or slush hydrogen, therefore, poses many problems at the present technological level due to the extremely low efficiency of the methods available.

This article deals only with the pipeline transportation of gaseous hydrogen, and describes the characteristics of pipeline transportation, pressure regulating equipment, demand/supply adjusting equipment, and operational procedures.

1. Introduction

Hydrogen exists as a gaseous substance under ordinary temperature and pressure conditions, and at present it is also produced as a gaseous substance by various hydrogen production methods. Hydrogen transportation methods include transport by pipeline, the method generally used for transporting gaseous substances, and the batch transportation method using containers (Because the density of hydrogen is low, hydrogen is often handled as compressed hydrogen or liquid hydrogen.) described elsewhere. Here, however, the transporting of hydrogen by pipeline is compared with natural gas transportation, of which there are now many actual examples demonstrating the pipeline transportation of gaseous substances.

Figure 1 shows an example of hydrogen network in Europe and North America.

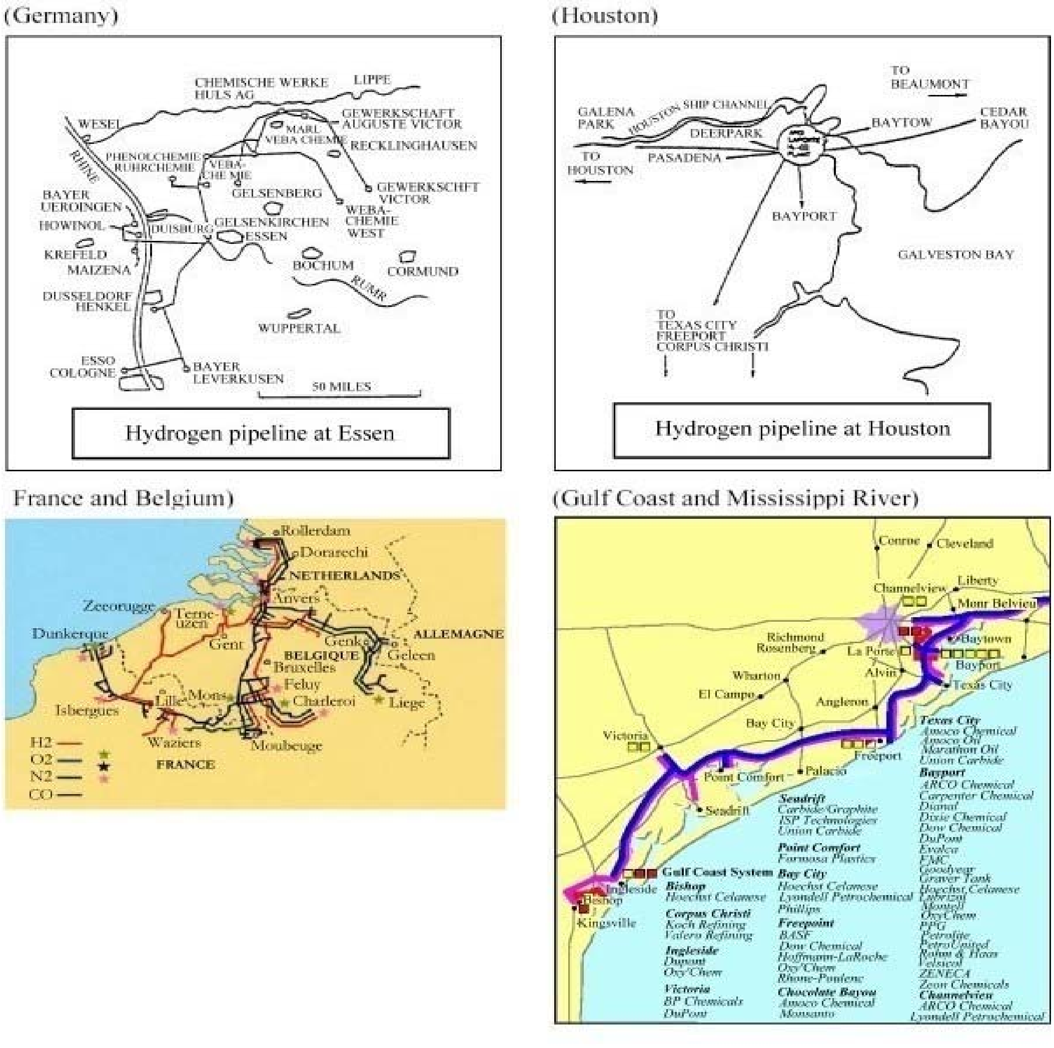

Figure 1. Hydrogen Pipelines in Europe and the U.S.A.

In addition to transporting gaseous hydrogen by pipeline, it may also be possible to transport hydrogen as liquid hydrogen and slush hydrogen. However, many themes remain to be solved prior to practical use of the liquid and slush hydrogen transportation methods, because hydrogen exists in the liquid and slush states only at extremely low temperatures (boiling point of liquid hydrogen: 20.4 K, at atmospheric pressure), and latent heat of vaporization of liquid hydrogen is extremely small (0.45 MJ/kg), so it evaporates easily. Therefore, in addition to the enormous amount of energy needed to make gaseous hydrogen into liquid hydrogen or slush hydrogen, at the level of insulation technology now in use, heat input during hydrogen transportation is extremely great, so that liquid hydrogen partially vaporizes and its volume increases during transportation, resulting in extreme decrease of transportation efficiency. The actual current examples of liquid hydrogen transportation are the liquid hydrogen transport line at the Kennedy Space Center and French Guiana etc., where the use of hydrogen in its liquid state is essential. There is almost no long-distance transportation of liquid hydrogen or slush hydrogen by pipeline. Therefore, this article describes only the transportation of gaseous hydrogen by pipeline.

2. Distinctive Features of Pipeline Transportation System

When a relatively large quantity of gas is used without much fluctuation of amount in a fixed place, and gas transportation continues for a long period of time, a gaseous-substance transportation system using a pipeline is a stable system with higher transporting efficiency than that of batch transportation using ships and vehicles, and is almost unaffected by weather.

The distinctive features of a gaseous-substance transportation system using a pipeline, however, are that the initial investment for the pipeline transportation system is relatively high compared to that for a batch transportation system, and because the gaseous substance production facility and the equipment by which the gaseous substance is used are directly connected through the pipeline, the selection and operation of demand/supply adjusting mechanisms, including those for the production system, to cope with fluctuating production and consumption of gas are important elements controlling the efficiency of the entire system.

3. Equipment Constituting Pipeline Transportation System

A pipeline transportation system consists of boosters installed together with the hydrogen-producing equipment, equipment to remove the impurities in hydrogen gas that could cause pipeline blockage during hydrogen transport, the main body of the pipeline, demand/supply adjustment equipment including gas holders, booster stations installed along the pipeline route, regulators which reduce and regulate the pressure of gas transported to that needed in the place where the gas is used, and systems to monitor and control the pressure and flow rate of gas in various locations along the pipeline.

The main body of the pipeline, pressure-adjusting equipment, and demand/supply adjusting equipment including gas holders, which are distinctive pipeline transportation system equipment items, are described here.

3.1 Main Body of Pipeline

3.1.1 Selection of Pipeline Route and Construction to Lay Pipeline

It is necessary to select an appropriate route along which the pipeline will be laid, with comprehensive consideration of the conditions of land use in its peripheral area, development trends, environmental conditions including ecosystems and geology, etc., and the long-term hydrogen demand trend.
Like conventional oil pipelines and natural gas pipelines, etc., hydrogen pipelines can be installed under any kinds of geological conditions, for example, between continents and across oceans.

Laying pipeline underground, where pipeline is stable and not much affected by the environment, is the general method of installing pipeline on land, but there are some examples of pipeline being laid inside tunnels or on the surface of land in regions where it is difficult to lay pipeline underground, for example, where permafrost is present, so an appropriate pipeline laying method should be selected with consideration of the environment of the region where the pipeline is to be laid.

When pipeline is laid across rivers, lakes and oceans, etc., it is mounted on bridges, or laid in tunnels or under the bottom of water. In case when pipeline is laid under the bottom of water, it is necessary to adjust the pipe's specific gravity by covering it with concrete, etc., with thorough consideration of the effect of buoyancy on the pipe.

Also, to maintain stabilized pipeline transportation for long periods of time, measures such as the use of various anti-corrosion techniques are essential for pipeline longevity. In addition, development of pipeline loops, and installation of valves for gas cutoff and facilities for gas emission, can be considered very effective since they allow pipeline maintenance to be done while still providing stabilized pipeline transportation.

As mentioned above, a pipeline should be constructed with thorough advance consideration of the environment of the area where it is to be installed, selecting a construction method suitable for the environment and for ensuring ease of maintenance, etc.

3.1.2 Material Quality for Pipes, etc.

Various materials of different qualities have already been studied and adopted for the transportation of natural gas, etc.; however, the molecule of hydrogen gas to be transported is very small (the size of a hydrogen molecule is only about 1/100 that of methane, the main component of natural gas.) And hydrogen molecules easily intrude between the crystal lattices of metals such as the iron used as pipe material, and are considered to give bad effects on pipe material including embrittlement, which decreases material strength. Investigation and research already done concerning the influence of hydrogen on various materials have confirmed that hydrogen intrudes between the metal lattices of carbon steel under conditions of high temperature (several hundred K) and high pressure (several MPa), resulting in embrittlement of the metal, but show that there is almost no problem under ordinary pipeline operation conditions (temperature: 373 K or below, and pressure: several MPa).

However, the intrusion of hydrogen molecules into metal lattice accelerates the embrittlement of metal (hydrogen embrittlement), aggravating the influences of impurities and corrosion etc., the thermal stress accompanying welding, and the influences of various other stresses after the pipeline has been installed; therefore sufficient investigation analysis is needed concerning the environment where pipeline is laid, as well as concerning anticorrosive coating, electrical anticorrosion conditions, and welding conditions, etc.

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Bibliography

Pettier J. D. and Blondin E. (1995). *Mass Storage of Hydrogen: Hydrogen Energy System,* edited by Yuma Durum, Lower Academic Publishers, pp. 167–179. [This paper explains the technological and economic problems inherent in storing large quantities of hydrogen gas using underground storage facilities.]

Tsar Y. (1992). Gaseous hydrogen transport, *Energy and Resources*, **13**(6), 561–566. [Methods of transporting gaseous hydrogen are described together with the property of hydrogen and particularly in comparison with natural gas in the case of pipeline transportation (Japanese).]

Biographical Sketch

Kunihiro Takahashi was born 28 January 1942 in Japan; he graduated from Chemical System Engineering Department, Faculty of Engineering, the University of Tokyo; completed master course with major in engineering, the University of Tokyo; joined Tokyo Gas Co., Ltd.; presently general manager of the Center for Supply Control and Disaster Management, Tokyo Gas Co., Ltd. Previous positions: appointed as a member of General Research Laboratory of Tokyo Gas Co., Ltd. (1967–1977); appointed as general manager of Technical Development Department, general manager of Engineering Department, and general manager of System Energy Department of The Japan Gas Association (1994–1997); appointed as a member of Sub-task-1-committee of WE-NET committee of New Energy and Industrial Technology Development Organization (1994–1997); has held present position since June 1997; studied research themes: research on production processes and catalysts for hydrogen-rich gas and methane-rich gas.