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DEVELOPMENT OF TECHNOLOGIES FOR NATURAL GAS AND BIOGAS UTILIZATION IN TRANSPORT

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Popularity of methane-containing gaseous fuels has slowly been growing since their appearance, especially in the last decades. Occasional non-availability of liquid fossil fuels, the necessity to reduce the transportation costs and to improve the air quality are the basic factors which stimulated development of gas utilization technologies – from accumulation, compression and deflation of gas to its usage in internal combustion engines. Since then different solutions have been offered, and the authors are reviewing them – from the first use of natural gas to nowadays.

Keywords: *natural gas, fuelling, compressing*.

1. INTRODUCTION

Nowadays, the transport sector plays an important role in every country's development; at the same time, it consumes a significant amount of energy. Ever increasing prices on crude oil in the last few years have shown the need for alternative fuels, and one of the perspectives is methane. Fuels containing methane as the base component are well known owing to their use in power generation, home heating, etc.. The most well-known gaseous fuel containing methane (~85-95%) is natural gas, which can be produced from oil fields and natural gas fields [1]. Like oil, this gas is found worldwide, which makes it attractive for users. Besides, the combustion of this fuel is cleaner than that of other fossil fuels (diesel or gasoline). As any other fuel, it also has disadvantages which make the use of natural gas not as global as diesel oil or gasoline. Transportation (as well as other related problems) restricts its use in remote areas where the network of gas pipelines is absent. Although such networks have grown over many decades and are now covering most of the territories in developed countries, the possibility to supply gas to every industrial object or fuelling station is very problematic. In the last years this problem is being solved by creation of technologies which would make the transportation of gas cheaper and more effective. Such technologies are required also in the agricultural sector, where implementation of biogas production capacities allows producing biogas by anaerobic digestion, and, after cleaning and upgrading, also biomethane, which has almost the same characteristics as natural gas. Due to intensive development in this area, partial substitution of biogas for non-renewable natural gas is quite realistic, which will result in increased number of users. This will require flexible transportation of gas from each local producer to the costumer, while using the network of gas pipelines will be problematic.

This paper gives an outlook on the development of natural gas as fuel for vehicles since the dawn, and reviews the main technologies created in the last decade for transportation of natural gas and biogas.

2. HISTORY

Natural gas has long been in use – already in Persia, China, India and Greece the people found it a very useful substance. The Chinese discovered that this gas can be used to heat water; later, they utilized it for evaporation of seawater to obtain salt [1]. Natural gas was also well known in Europe, mainly in England, from 17th century, but it was not used due to the popularity of coal gas as the main energy source in those times. Most popular usage area of this gas was lighting of streets and houses, and Britain was the first country to commercialize this usage. Quite a low efficiency of this type of gas contributed to starting up the production of natural gas from underground: in 1800s such gas was used to power cities in U.S. Despite that, natural gas was then produced from coal. Without a pipeline infrastructure, the possibility to use gas for cooking or heating was limited; therefore, it was formed as an exclusive source of light in streets or houses. This usage of natural gas became unlimited as electricity was invented at the end of 19th century and the gas manufacturers started to look for other gas utilization areas. In that time some solutions arose for gas transportation by pipelines; however, realized constructions were so inefficient and rudimentary that they did not become popular. Without efficient way of transporting gas, till World War 2 (WW2), it was left in the ground or burnt. After WW2, development of the metallurgical industry stimulated construction of natural gas network and creation of suitable pipelines.

Before that, between WW1 and WW2, various interesting solutions for gas (”town gas” – a by-product of the coking process) utilization emerged the majority of which were connected with successfully started development of automotive industry. Besides, the use of natural gas was stimulated by limited availability and still higher price of gasoline. As the engine for gas utilization was invented before, the main engineering problem was that of gas storage on vehicle. The simplest solution was a gas tank of silk (or other fabrics) soaked in rubber [2]. The choice of this material was done based on variety of reasons: cheap; easy usable for tank building; easy repairable; very simple fixing on the roof of a vehicle. Besides, some vehicles had an option to switch engine from one fuel to another (currently – from gas to gasoline). Although such constructions were basically created for automobiles and only later adapted for trucks and buses, more suited for them were precisely buses. This only allowed placing the tank of required capacity on the roof, at the same time maintaining streamline of the vehicle (Fig. 1). In case of automobiles, wooden framework was required which was fastened to the roof (Fig. 2) and also secured to the bumpers of vehicle [2].

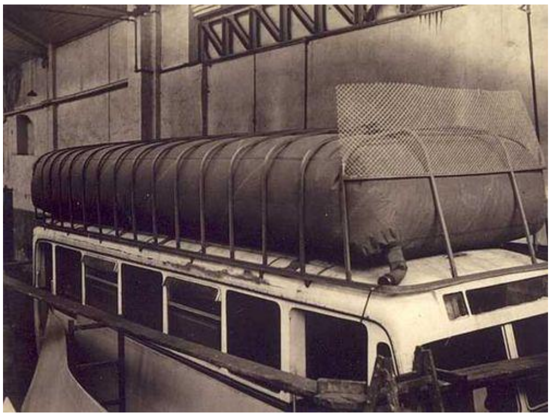


Fig. 1. Construction for the gas bag placement on a bus [2].

Fig. 2. Construction for the gas bag placement on an automobile [2].

Initially, gas in the bags was not compressed, and, due to its lower energy density as compared with gasoline, the driving range was also limited. To overcome this problem it was necessary to compress the gas and thus increase its amount in a bag. Since ”town gas” was technically difficult to compress, more attention was turned to natural gas, and after some time first constructions of compressing equipment were observed on the streets of the largest European cities. The fuelling stations seen in Fig. 3 resemble typical pipelines of a modern gas network.

Fig. 3. Natural gas fuelling station.

Apart from that, also a need arose for special solutions of compressed natural gas (CNG) storage, and steel gas vessels were found to be the most suitable in that case (Fig. 4). These could be successfully placed on the roof of a car, which allowed reducing the total space as compared with previously used gas bags.

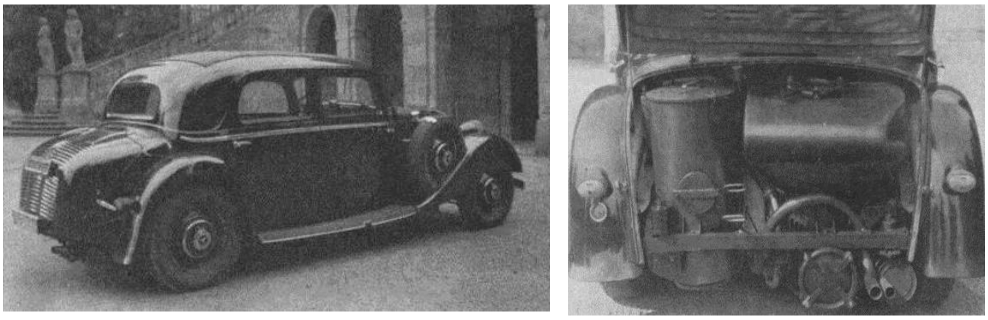
Fig. 4. A vehicle converted for CNG use with steel gas vessels on the roof [2].

During WW2, when fossil energy resources were very limited, more interest was shown in the ”wood gas” cars. The technology of such gasification was well-known as German engineer Georges Imbert developed a wood gas generator for mobile use in the 1920s [2]. Its working principles were very simple – wood residues were gasified there in oxygen-limited environment and, as a result, combustible gas mixture was produced for powering cars with ordinary internal combustion engines. The main drawback of the technology was the necessity to equip a car or a truck with a gasifier. Usually, this was placed behind a vehicle (Fig. 5), but later vehicle models became available with built-in gasification units (Fig. 6) mass-produced at car factories. As these systems were mostly installed by amateur engineers while the cars were not designed to drive on ”wood gas”, various drawbacks limited their operation; this was then compensated by possibility to drive.

This technology became so popular that in Germany at the end of WW2 there were ~0.5 million vehicles and a network of 3000 ”fuel stations” [2]. With these gasification units not only private cars were equipped, but also buses, tractors and trains. The use of such vehicles started also in France, Sweden, Finland, etc., so by the end of WW2 ~ 2 millions of them could be found in Europe. Their number rapidly decreased after WW2 when gasoline became more available. Rapid development of manufacture demanded for more stable transport with definite technical and economical characteristics; therefore, the use of gasoline or diesel in conventional internal combustion engines was understandable.

The energy crisis of 1973 was the next major factor which stimulated search for alternatives to the existing liquid fossil fuels. Some of the countries turned attention on renewable energy sources, promoting research on solar power; others, e.g. Brazil, focused on the ethanol use in automotive industry, implementing a large project called "Proalcool”. Besides, countries with domestic resources of natural gas decided to reduce their oil dependence by promoting research into technologies which would raise the use of natural gas also in the transport sector.

Fig. 5. Vehicle with a gasification unit placed behind [2].



a b

Fig. 6. Mercedes Benz Type 230 (a) with built-in gasiefier unit (b) [2].

3. ECOLOGICAL PERSPECTIVE

The use of natural gas in transport not only gives economy in the total fuel costs for a vehicle (as cheaper compared with diesel or gasoline), but also could help improve the ecological situation by reducing some compounds in the tailpipe emissions (experimental tests in different countries approve reduction in the carbon dioxide, nitrogen oxide and particulate emissions in the exhaust gases of vehicles depending on the used engine technology).

As the concentration of greenhouse gases in the atmosphere is rising rapidly, reduction in carbon dioxide emissions is very important, and in a long term the use of very low CO_2 sources like biogas would be preferable. Methane-rich biogas can also easily replace the natural gas in transport thus improving the environmental situation. Currently, biogas is mainly utilized in combined heat-and-power plants due to a fixed compensation for electricity, but the interest in its use in transport is also increasing. Before that, gas purification and upgrading is needed to achieve appropriate methane content. Presently, different barriers exist for the biogas utilization in transport, which is mainly connected with non-availability of cheap technologies – not only for biogas upgrading but also for its compressing, storage and deflation. In the next chapter, the most promising technologies that would make these processes cheaper are analyzed.

4. GAS COMPRESSION TECHNOLOGY

Increased number of natural gas users stimulated also development of gas storage and fuelling equipment. Natural gas can be stored and transported in compressed or liquefied form (CNG and LNG, respectively). Both the methods have their advantages and disadvantages, but most widespread is the use of CNG. This is mainly associated with lower costs and simplified technology.

Natural gas cannot be liquefied at ambient temperature; therefore, the energy density of this fuel is very low. Compressing gas up to 20 MPa allows the natural gas density to be raised 230 times relative to normal temperature and pressure, reaching 8.8 MJ/L (at 20°C and 20 MPa), which is 25% of the energy density of gasoline [3]. The equipment used for such high-pressure compression storage systems is very expensive and makes the greatest part of the total investments that are needed for vehicle conversion to the use of such fuel.

Currently, for compressing methane the gas-filling multistage compressors are employed – both with mechanical and with hydraulic drives, which provide the compression of natural gas for its application as a motor vehicle fuel. Complicated construction of compressors with mechanical drive, high energy consumption, generation of large amounts of heat as well as high maintenance costs (compensating the wear of movable parts) resulted in the development of compressors with hydraulic drives.

Different companies are working on the development of gas compression equipment, updating the existing technologies and creating new compressing methods. Among already realized methane compression methods that offered by US Pat. № 5863186 (ECOFUELER Co.) could be marked [4]. According to this method, multistage gas compression is performed in series-connected vessels by under-pressure supply of a hydraulic fluid separated from the compressed gas by pistons moving into the vessels during operation cycles of the compressor. The method has found application in ECOFUELER gas-filling devices, including individual gas-filling appliances of the HRA (Home Refuelling Appliance) type. These devices are intended for residential low-pressure gas network and for the standard residential electric network. The disadvantage of gas-filling devices operated by this method is high price which restricts their use in a private sector. This price is determined by Hitec constructional elements, mainly for precise hydraulic compressing vessels.

A method is proposed for hydraulic compression of gas to fuel a motor vehicle from mobile gas-filling appliances without a dividing piston between the gas and the fluid (RF Pat. № 2128803, [5]). Gas transfer from accumulating vessels to the user's vessels is performed replacing the fluid by gas with the sequential transfer of fluid from the previous vessel to the next ones. This method can be used in mobile gas filling units providing large volumes of compressed gas by connection to a high-pressure gas line having a supply source of sufficient power (industrial electrical network).

An interesting solution was presented by LV Pat. No 13661 B (HYGEN Co.) [6] for compressing gas to fuel vehicles by alternate gas transfer into two vertically arranged compressing vessels, its compression and forcing into high-pressure vessels by filling the compressing vessels with working fluid under pressure using a hydraulic drive. Each cycle of gas compression and forcing out of the compressing vessels is performed until these vessels are fully filled with the working fluid and alternately forced out of one vessel into the other in response to a signal sent by a fluid-level sensor capable of detecting the full filling of the corresponding vessel. This solution could be very promising and now develops intensively in Latvia.

The schematic of this gas-filling device is provided in Fig. 7.

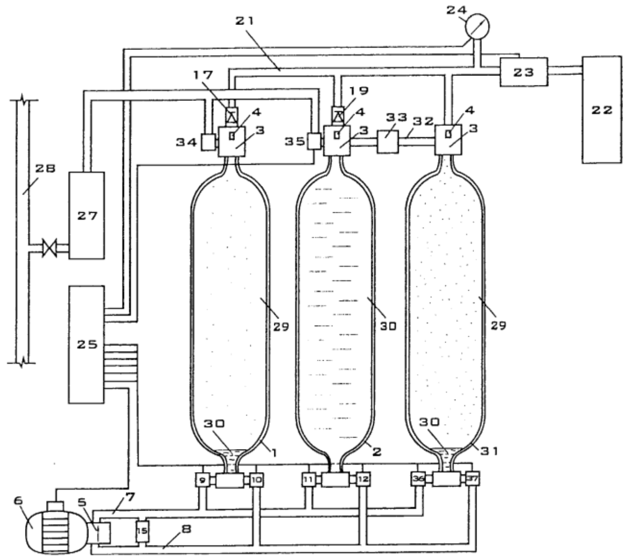


Fig. 7. Schematic of high-pressure compression system for gaseous fuel [6].

1, 2 – compressing vessels; 3 – shut-off device; 4 – fluid level sensor; 5 – hydraulic pump;
6 – electric drive of hydraulic pump; 7 – high-pressure line; 8 – low-pressure line;
9-12 – electromagnetic valves; 15 – bypass valve; 17, 19 – one-way valves;
21 – outlet pipeline; 22 – fuel tank of a vehicle; 23 - connector;
24 – electric contact manometer; 25 – electronic control unit; 27 – filter-drier;
28 – low pressure gas pipeline; 29 – gas; 30 – working fluid; 31 – accumulating vessel;
32 – drain tube; 33 – bypass valve; 34-37 - electromagnetic valves.

5. EXPERIMENTAL

Based on the invention illustrated by Fig. 7 a laboratory model (Fig. 8*a*) was realized, and then the experimental prototype of industrial complex (Fig. 8*b*) was made for further detailed investigations. The laboratory model contains three metal vessels: two compression and one accumulating, while the prototype – ten plastic vessels: two 80 l compression and eight 50 l accumulating. Results of the experimental research have confirmed that the process of filling the vessel with fluid and forcing the gas out can be realized successfully, in compliance with safety measures, and with the necessary technical parameters (pressure 20 MPa, gas compression and accumulation cycles, etc.). During the experimental work it was found that the use of all-metal vessels instead of any type plastic (or combined with plastic) vessels is preferable: due to low thermal conductivity of a plastic vessel's walls the heat exchange with environment is not sufficient to cool such vessels, so at the end of a compressing cycle their temperature exceeded the admissible (65°C). The tested prototype of the gas filling system (Fig.9), which was created in Latvia based on the scheme described above, consists of eight metal vessels with a capacity of 140 l (two compression and six storage vessels); it stood all tests and has successfully been used for *Mercedes Citaro* bus.

a b

Fig. 8. High-pressure compressor for gaseous fuel:
a – model; b – prototype.

Fig. 9. Mobile high-pressure system for gaseous fuel.

Based on different compressing methods and research works in the natural gas area, companies offer consumers not only compressors, but also ”in-box” complete CNG stations (consisting of compressor, control panel, gas cooling and storage systems) thus trying to achieve full utilization of natural gas as economic, efficient and compact as possible.

The gas filling system created in Latvia (Fig.9) could be installed on any type of truck in a set of 10 similar units with one common control system. Such sets allow conveying considerable amounts of compressed gas to any destination.

6. GAS FUELLING

A CNG station is more difficult to design and build compared with a conventional liquid fossil fuel station, as precise choice of the compressor's size and the storage capacity is required. A proper combination of these factors can impact the number of vehicles that will be fuelled at this station in the future. Besides, it should be noted that the CNG amount to be stored varies depending on such factors as pressure rating, ambient temperature, and fuelling rate [7].

Depending on the number of vehicles to be refuelled and on the fuelling time, two methods exist for this purpose, which are as follows.

”Slow” filling, where the compressor is connected to one or more vehicles at once, and during several hours the pressure is increased to the ultimate filling pressure. The relevant stations usually have large compressors, and the tank of a vehicle is filled directly from compressors. The time of filling the tanks depends on the number of vehicles and compressor size. Despite the fact that such stations are mainly used by bus fleets (large transport companies), small-scale use (filling 1-2 cars) of such stations is also possible, only a gas line should be available at home. Fuelling is usually done in the night time.

”Fast” filling technique consists in filling first an intermediate storage vessel or vessels, one of them under an appreciably higher pressure than desired [8]. The gas storage pressure is ~ 25% higher than required for a vehicle tank, which allows feeding gas to a vehicle faster than it would be done directly from the compressor. Since it is necessary to compress gas to a higher pressure than the ultimate fill pressure in the intermediate storage vessel, a fast-fill system consumes more energy than a slow-fill one [8]. The excessive consumed energy can be minimized using a series of vessels (a cascade), with fuelling a vehicle from each in turn. Such stations are better suited for retail sale, since the fuelling is done fast – in 3-5 min depending on the capacity of a vehicle’s tank.

7. CONCLUSIONS

Due to ever increasing prices of conventional liquid fuels (gasoline, diesel) during the last years the market of natural gas has shown stronger growth tendencies than ever before. The number of vehicles running on natural gas increased up to 15 million at the end of 2011 (i.e. 19.9% greater than in 2010 [9]). Despite rather a fast development, the current natural gas share in transport is still small, mainly due to a limited number of fuelling stations. More than 70% of all NGVs and almost half of all fuelling stations are found in only five countries: Argentina, Brazil, India, Iran and Pakistan; Europe has almost 3 500 stations, of which ~ 900 are located in Germany and 800 – in Italy [10].

At the same time, the equipment needed for utilization of natural gas in transport is widely available, and the relevant technologies continue to improve. For example, natural gas engines emit less pollutions than set by Standard Euro 5. The number of gas vehicles is also increasing, and these are now offered by such manufacturers as Volkswagen, Fiat, Opel, etc.. In overall, potential benefits of using natural gas in transport are: reduction in fuel costs; less GHG emissions; local air quality improvements; noise reduction, etc. Considerable decrease in the carbon emissions from vehicles will also be possible, provided the use of biogas is stimulated by making its price more attractive for users.

The industrial gas filling system for motor vehicles is still in progress in Latvia. First positive results of using the original operational equipment described in the paper allow successful solution of this problem to be expected.

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APSKATS PAR TRANSPORTA SEKTORĀ IZMANTOJAMĀM DABASGĀZES UN BIOGĀZES TEHNOLOĢIJĀM

J. Gelfgats, R. Šmigins

K o p s a v i l k u m s

Metāna saturošo gāzu popularitāte kopš to atklāšanas ir pakāpeniski augusi, jo īpaši pēdējās desmitgadēs. Šķidro fosilo degvielu ierobežotā pieejamība dažādos laika periodos, transporta izdevumu izmaksu samazināšana, nepieciešamība uzlabot gaisa kvalitāti – tie ir pamatfaktori, kas sekmējuši gāzes izmantošanas tehnoloģiju attīstību, sākot no gāzes uzkrāšanas, kompresijas un izplūdes sistēmām, un beidzot ar to izmantošanu iekšdedzes motoru darbināšanai. Šajā laikā ir parādījušies dažādi šo tehnoloģiju risinājumi, un dotais raksts sniedz pārskatu par tiem, sākot no pirmās dabasgāzes izmantošanas līdz pat mūsdienām.

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