# SEARCHING FOR NEW TECHNOLOGIES IN METALLURGY AND MECHANICAL ENGINEERING DIRECTLY RELATED TO THE USE OF ALTERNATIVE PROPULSION SYSTEMS IN AUTOMOTIVE INDUSTRY

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**Abstract**

Many years of ongoing development of the world's largest car manufacturers in the area of construction of new alternative propulsion systems of motor vehicles and their gradual practical application in operation must clearly receive a positive appraisal. Running such vehicles significantly reduces the impact of their operation on the environment and it also addresses the threat of depletion of the reserves of traditional raw materials, in this case of oil. Along with the positive features, however, the use of alternative propulsion systems in transportation also presents a number of technical problems. The most crucial issues, according to the type of used fuel, include where to store the fuel in the vehicle itself, where every kilogram of weight carried in addition to the normal weight means higher consumption, lower range and a significant change in the handling characteristics of the vehicle, with consequent impact on the continuity and safety of traffic. Designers have been struggling with higher weight and its distribution in the vehicle in most green vehicles. In the case of electromobiles, the issues include capacity, size and location of batteries, while in vehicles powered by natural gas (CNG, LNG) or hydrogen, the problems include the size, number and location of the pressure vessels and similar issues. The search for new suitable materials and their processing technology is therefore a major requirement and condition of further development and use of alternative fuels. A necessary condition of a further increase in the number of green vehicles in operation is to achieve the prices of vehicles comparable to vehicles burning conventional fossil fuels, or their tax or other advantages, so that the acquisition and operation of such a vehicle is also economically interesting for the owner.

**Keywords:** motor vehicles, alternative fuels, production technologies

## 1. INTRODUCTION

Transport and the means of transport have received a lot of attention all over the world in recent years. The number of motor vehicles in operation has been continuously increasing and the fuel consumption has been increasing as well, as the result of that. A substantial part of these fuels are still oil products (automotive gasoline and diesel). It is clear that with declining global stocks, the prices of fossil fuels will continue to increase and their combustion will bring further negative impacts on the environment. These are sufficient reasons why all major car manufacturers have been intensively working on the development of alternative propulsion systems for many years. At present, there are a number of new technical solutions for propulsion of motor vehicles. Some of them have seen successful practical application; others are still in their development and testing stages. A common limiting factor of the use of new technologies is the issue of the production of suitable fuel (e.g. hydrogen), the method of storage in the vehicle, and also the final price that cannot be a limiting factor for the customers. In terms of the assessment of the advantages and shortcomings of the individual technical options, the most widely used vehicles nowadays are those powered by electricity, the so-called electromobiles, hybrid vehicles, combining the use of conventional internal combustion engine and an electric motor, and vehicles powered by gas, mostly LPG (Liquefied Petroleum Gas), CNG (Compressed Natural Gas) and LNG (Liquefied Natural Gas). Vehicles powered by natural gas (CNG) have

probably seen the largest utilization in recent years. The advantage of this power is especially the low price of CNG, lower impact on the environment and the level of world reserves of natural gas [3].

## 2. THE USE OF CNG IN TRANSPORTATION - CURRENT SITUATION AND THE FUTURE

### 2.1 The use of CNG in transportation in the world and in the EU

Natural gas has been used in transportation all over the world for many years. The proof is in the number of vehicles and the number of registered filling stations. According to the statistics of NGVA (Natural Gas Vehicles for America) organization [1] published on the 23rd September 2013, there were17.7 million CNG powered vehicles in operation and more than 22,000 CNG filling stations. The record holders in the number of vehicles are Iran, Pakistan, Brazil, China and India.

Europe is lagging behind in this field and over 93% of the means of transport use oil-based fuels. In practice, this means that transport is Europe's second largest source of environmental pollution, immediately after industry. A number of measures have been introduced to fix this problem, but their implementation is mostly spread out until 2020, when, for example, 10% share of CNG fuel consumption in transport should be achieved. The European branch of NGVA Europe organization states, in its statistics published by the same date (September 2013) [2], that there are about 1.1 million CNG vehicles in Europe and almost 3,000 filling stations. Europe's leaders are Italy (850,000 vehicles), Germany (100,000 vehicles) and, perhaps surprisingly, Bulgaria (62,000 vehicles).

### 2.2 The use of CNG in transportation in the Czech Republic

At the time when this article was elaborated, there were 3,732 registered vehicles running on CNG and 52 public CNG filling stations, according to the statistics of the NGV o.s. Association [3], in the Czech Republic. If we add the filling stations operated by companies, we get the total number of about 75 stations. With regard to a voluntary agreement concluded between the state and the gas companies in 2006 on promoting natural gas, expanding the network of filling stations, purchasing CNG vehicles for the state administration and the tax advantages of CNG as a fuel used for transportation, these numbers are surprisingly low. It is clear that the content of the agreement is not being fulfilled, neither have the conditions been significantly improved by the Decision of the Government od the CR no. 1592 of 2008 on the implementation of the Programme of Replacement of the Vehicle Fleet of Public Administration for "environmentally friendly" vehicles. The only organization from state-controlled firms and institutions that deserves credit is Česká pošta a.s. with 692 CNG vehicles operating at the beginning of 2014, and this company expects to expand the number of CNG vehicles to 2,200 by the end of the year. The last activity of the state is the call of the Ministry of Environment issued within the framework of the Operational Program of Environment of the 29th January 2014. This should divide one billion crowns among the Moravian-Silesian, South Moravian and Ústecký regions for the purchase of about 10 CNG filling stations and approximately 154 CNG city buses.

Vítkovice a.s. significantly contributes to the development of CNG in transportation in the Czech Republic through its subsidiaries VÍTKOVICE CYLINDERS a.s. (offering a range of products and services in the area of CNG) and VÍTKOVICE Doprava a.s. (offering conversion of spark ignition vehicles to CNG power). The activities of the company in the field of CNG are presented and offered under the registered trademark of CNG vitall. One of the recent major activities is the construction of 25 new CNG filling stations, which should cover large part of motorways and main roads in the Czech Republic by the end of 2014 [1, 2, 3].

## 3. PRESSURE CYLINDERS AS THE BASIS OF CNG VEHICLE PROPULSION SYSTEM

The crucial question in the use of compressed natural gas to drive a motor vehicle is the issue of the installation of gas storage pressure cylinders. Regardless of whether it is an original or additional installation, the critical

parameters include the so-called water capacity, the external dimensions and especially the weight of the cylinders. The task of a designer is to find some kind of compromise between the desired range of the vehicle using CNG and the limitations of the existing utility and handling characteristics.

Pressure tanks as reservoirs of natural gas used in transportation vehicles have exclusively cylindrical shape. They have most often been produced from thick-walled pressure vessels made of steel, especially due to their favorable price (an example is shown in **Fig. 1**). Their disadvantage is their higher weight, which significantly affects the handling characteristics of the car. Higher weight means worse acceleration, longer braking distances, change of the centre of gravity of the vehicle and the effect of centrifugal forces, as well as higher fuel consumption. It also means the possibility of taking less fuel, not to exceed the permitted vehicle weight.


**Fig. 1** Seamless steel cylinder for CNG vehicles CNG - VÍTKOVICE CYLINDERS a.s. [4]

This is the reason why new materials have been searched for and steel cylinders are being replaced with tanks made of composite materials (see **Fig. 2**), especially in personal vehicles. The common types of pressure CNG tanks used nowadays are clearly summarized in **Table 1**, including their weight indicators and destructive pressures.

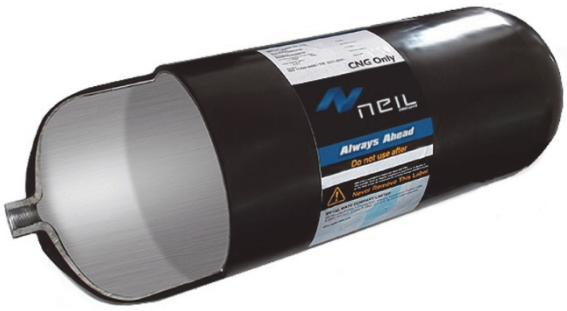


**Fig. 2** Cross-section of type 3 composite tank for CNG vehicles - produced by VÍTKOVICE CYLINDERS a.s. [5]

Using CNG pressure tank type 3 and 4, i.e., tanks with significantly lower weight volume indicator enables the designers to install more tanks into vehicles. This increases the total water capacity of the tanks and extends of the range of the vehicle on one tank filled with natural gas. A great benefit of lighter composite tanks also includes the possibility of their installation on the roof of the vehicle, where the limiting factor is represented by the roof construction load capacity and lower vehicle stability when turning. The disadvantage is the cost of the composite tanks, which is generally 1.5 times (type 2) to 2.5 times (type 4) higher than in case of steel cylinders (type 1).

**Table 1** Types of CNG tanks used in construction of motor vehicles - basic overview [6]

| Type no. | Material construction | Weight volume indicator [kg.l$^{-1}$] | Destructive pressure [MPa] |
|---|---|---|---|
| 1. | all-metal steel tank<br>all-metal aluminum tank | 0.9 ÷ 1.2<br>0.9 ÷ 1.0 | 45 |
| 2. | tank with metal sleeve (steel, aluminum), partly braided with carbon fibre impregnated in epoxy bitumen | 0.6 ÷ 0.8 | 47 ÷ 50 |
| 3. | tank with metal sleeve (steel, aluminum), entirely braided with carbon fibre or fibreglass and impregnated in epoxy bitumen | 0.3 ÷ 0.4 | 47 ÷ 70 |
| 4. | tank with non-metallic sleeve, entirely braided with carbon fibre or fibreglass and impregnated in epoxy bitumen | 0.3 ÷ 0.4 | 47 ÷ 73 |

As far as the design is concerned, all CNG pressure cylinders must be designed in such a way to meet the conditions of operation, given in particular by the filling pressure (operating, maximum) and of withstanding all kinds of damage during their operational use. The minimum requirements applied to gas cylinders designed exclusively to store natural gas as a fuel for motor vehicles and compressed by high pressure are defined by the ISO 11439 standard - Gas cylinders - High pressure cylinders for on-board storage of natural gas as a fuel for automotive vehicles (ČSN EN ISO 11439 - Gas cylinders - High pressure cylinders for natural gas used as fuel in motor vehicles) [4].

### 3.1 CNG in transportation does not involve only the vehicles themselves

However, using vehicles powered by compressed natural gas in practice does not mean only to manufacture and install glass cylinders intended for installation in motor vehicles. From the perspective of operation, it is equally important to build a system of filling stations. The possibility of building a CNG station supplied directly from the gas transmission line would be an ideal solution. In other cases, it is necessary to build filling stations with their own storage tanks that are supplied from the so-called virtual pipelines. The storage and transportation of compressed gas take advantage of bundles of pressure cylinders (stationary or mobile), container bundles and trailers. Small filling stations (the so-called boosters) are an interesting alternative. The gas can be filled and also stored in a trailer with a total volume of up to 20,000 water litres and, according to gas pressure (20 ÷ 30 MPa), with a capacity of up to 5,500 Nm$^3$ of gas. All cases of storage and transportation of compressed gas generally use conventional thick-walled steel cylinders [1, 2, 4].

## 4. THE TECHNOLOGIES IN PRODUCTION PROCESS OF NATURAL GAS PRESSURE CYLINDERS

The production of steel pressure cylinders has been based on two production technologies, according to the input semi-finished product - billets or seamless tubes. You could say that both production processes do not bring anything new, but the requirements on the quality of the final products force manufacturers to innovate these technologies, use new materials, types of surface treatments and to test the quality of their products.

The first production method of pressure cylinders uses billets as the input semi-finished product, which acquires the basic shape of the future cylinder after heating using the method of backward extrusion and subsequent stretching. The free end is closed and the neck is created by means of the rotational molding technology. The following procedures include heat treatment and a number of mechanical working procedures, cleaning and surface treatments. The final stage of production is the application of different types of tests to

verify the regulations required by the applicable standards and customer requirements. The gradual development of this technology has made it possible to produce pressure cylinders of excellent quality and lower weight, particularly thanks to the use of lightweight high-pressure steel.

The second traditional method of production of steel cylinders uses seamless tube as the input semi-finished product. The sealing of both ends (making bottom and neck) is performed using the technology of swaging, together with induction heating. To ensure the final product quality, it is necessary to use tubes with identical wall thickness. The gradual development of this technology has also revealed that heat treatment leads to a loss of up to 0.3 mm of wall thickness of the pressure cylinders. This must be taken into consideration when choosing the input semi-finished product. The problem of this technology is the quality of the bottom, where small defects may occur in the middle, once the cylinders have been sealed. That is why the future development follows this direction.

In the case of production of composite cylinders (type 3 and 4) braided with carbon and glass fibre, impregnated with epoxy resin, the development is focused especially on the materials of these surface layers. They are, together with high quality of the used metallic or non-metallic sleeves, the basic elements necessary to achieve high quality CNG tanks. The appearance and properties of the resulting surface are also affected by the used hardening device that can prevent the loss of resin during hardening. This brings improved resistance against aging (resistance to direct sunlight, high temperatures, and acidic pollutants) and extends the life time, but also ensures higher surface smoothness as an important safety feature for workers handling the cylinders.

A separate chapter in the manufacturing of pressure cylinders is represented by the development in the sphere of testing and checking, as a necessary prerequisite of complying with a number of existing standards and regulations, high standards of production and safety during practical use. The number of tests is perhaps best visible from many available schemes of cylinder production technological flows. The manufacturing process published by VÍTKOVICE CYLINDERS a.s. [7], where the following checks and tests are gradually applied, may serve as an example: input material control, ultrasonic inspection of semi-finished products after extrusion and stretching, hardness checks and mechanical properties checks after thermal processing, inspection of the neck machining using magnetic methods, continuous testing of cylinders by cyclic pressure, burst pressure, ultrasonic cylinder inspection, visual surface inspection and final visual inspection prior to shipment.

The quality of the final product, especially its life time, in this case represented by the pressure cylinders for compressed natural gas, is also affected by the final surface treatment. The basic prerequisite is always a thorough surface preparation of the cylinder. In case of steel cylinders, it is done by means of blasting, multistage rinsing and proper drying. Only after these procedures, you can follow with the application of powder coatings and the subsequent baking. Intensive development work, focused on meeting the new requirements of resistance against mechanical damage, temperature changes, chemicals substances, and UV radiation, has been taking place in the area of coatings as well. At the same time, they must be environmentally friendly. This last condition can be met by waterborne coatings nowadays [6, 7].

## CONCLUSION

The requirements of the EU regarding permanent reduction of $CO_2$ emissions in transportation, with the new Euro 6 standard in force from 1st January 2014, together with the rising prices of conventional fuels (gasoline and diesel), force the owners of vehicles to consider the possible alternatives of propulsion of their vehicles. There are many possibilities of using alternative fuels in transportation and some of the solutions have already been widely used in practice. However, the satisfaction of the owners with such vehicles varies and depends mainly on the handling characteristics, the operating costs and the purchase price of the vehicle, range with one "fill-up", the availability of "filling" stations or the culture of travelling.

We have been encountering electromobiles, hybrid cars (combining the conventional internal combustion engine and electric motor) on the roads, and a variety of vehicles powered by compressed natural gas (CNG, LNG). Vehicles burning propane - butane (LPG) are not included intentionally, because it is actually a by-product of oil refining. According to previously reported figures, it is clear that the greatest expansion in the world has been achieved by compressed natural gas, not only in car, but also in railway transport and in shipping.

For the Czech Republic, as an export-oriented state, the use of natural gas for transportation can ensure two advantages in terms of competitiveness. The first is, of course, the lower price of natural gas compared to conventional fuels, resulting in a total reduction of production costs and the ability to offer customers an attractive price. The second fact is that the Czech Republic ranks among the industrially developed European countries that have traditionally been able to offer advanced metallurgical technologies, supported by a solid production base, high level of expertise and professional approach of the employees or the corresponding level of research and development base [8], [9]. All this ensures that we can offer product structures meeting the market demand, while supplying them in adequate quality [10].

In case of the production of pressure vessels or pressure cylinders for compressed natural gas (CNG), the space for further innovation is quite significant. The evidence is provided by newer and newer requirements of car manufacturers that are trying to listen to the demands of their customers to increase the kilometric range of CNG vehicles on a single tank refueling. For the manufacturers of pressure cylinders, this means offering products that are significantly lighter, of course, while complying with all legislative requirements and safety criteria. This can be achieved only by further development in the field of materials, metallurgy and manufacturing technologies.

Another important reason behind the search for new materials and technologies is the fact that the production of pressure vessels is quite energy intensive. This forces the manufacturers to invest resources in further development and innovations. Any reduction in production costs will positively influence the price of the final product, which, together with quality, is a crucial factor in the successful application of the product on the market, i.e., its competitiveness. The segment of production of pressure vessels for compressed natural gas for motor vehicles is also one of those fields, where the price is influenced by the supply of large Asian manufacturers. They have built up such a position that they are able to deliver their products to many major car manufacturers.

Because of the global reserves of natural gas resources and minimal impact of the use of motor vehicles powered by CNG on the environment, further dynamic development is this area is to be expected. From the perspective of maintaining or gaining new markets, the investment in the search for new technologies, production processes, new materials of pressure cylinders, materials for the final surface treatment, but also in the existing production infrastructure, are absolutely necessary [8, 9, 10].

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