Prospects of and Problems in Using Natural Gas for Motor Transport in RUSSIA

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Abstract. This article is devoted to increasing the use of natural gas in Russia as a measure to decrease the negative influence of motor transport on the environment. A brief analysis of the global fleet of natural gas vehicles is provided above. The documents accepted in Russia to promote public awareness of compressed natural gas in transport are submitted. The basic reasons keeping the growth of natural gas vehicle fleets in Russia consist of weak branching of refuelling stations; difficulty in determining the actual amount of compressed natural gas required; and control methods of the consumption of gas fuel. The offers promoting the growth of the fleet of natural gas vehicles are given.

1. Introduction

The rapid growth of global motor transport is having an increasingly negative impact on the environment. Against this background, addressing the problems of replacing traditional motor fuels, such as gasoline and diesel, with alternatives are all the more real. There is a set of options to do so, beginning from electric cars and finishing with hydrogen fuel. But for Russia, it is more appropriate and logical to use natural gas (NG), as the country possesses 30% of the world’s NG deposits.

There is a world-wide successful transportation industry that operates on NG, which shows the best ecological indicators in comparison with both gasoline and diesel fuel [1-4].

According to the NGV journal [5] global leaders in terms of the number of natural gas vehicles (NGV) and natural gas refuelling stations (NGV RS) are Argentina, Brazil, Germany, India, Iran, Italy, China, Colombia, Pakistan, the United States, Thailand, and others. In total, in the world, there are about 22 million methane NGVs (2% of the total global vehicle fleet) (figure 1). According to NGV journal [5] the global vehicle fleet operating on gaseous fuel annually increases by 30%.

Today, Russia holds a fairly modest position in terms of number of NGVs (90050) and NGV RSs (250). In comparison, Iran has about 4 million NGVs, and China, 6500 NGV RSs (table 1).

However recently at the legislative level, several attempts of widespread use of NG on the motor transport have been made that includes the:

- The order of the Deputy Prime Minister of the Russian Federation I.I. Sechin № IS P9-5878 of 25 August 2010 on the establishment of a permanent working group to develop proposals for an increase in the demand for liquefied petroleum and NG as a motor fuel.
• The order of the President of the Russian Federation № 1923 from 27.06.2011 on the organization of stage-by-stage replacement of public motor transport by NGVs and on the expansion of a network of NGV RSs.

Table 1. Global leaders in number of NGV, fuelled with compressed natural gas and the amount of NGV RS according to NGV journal

| Country  | N/m³ monthly sales average | Number of NGV, units | Amount of NGV RS, units |
|----------|---------------------------|----------------------|------------------------|
| Iran     | 630000000                 | 4068632              | 2268                   |
| China    | no data                   | 3994350              | 6502                   |
| Pakistan | 245750000                 | 3700000              | 2997                   |
| Thailand | 184200000                 | 462454               | 497                    |
| Argentina| 239815000                 | 2487349              | 1939                   |
| India    | 163210000                 | 1800000              | 936                    |
| Brazil   | 144535636                 | 1781102              | 1805                   |
| Bangladesh| 91550000                 | 2200000              | 585                    |
| USA      | 77520000                  | 150000               | 1615                   |
| Italy    | 75000000                  | 885300               | 1060                   |
| Colombia | 45000000                  | 500000               | 800                    |
| Germany  | 23000000                  | 98172                | 921                    |
| Uzbekistan| no data                  | 4500000              | 213                    |
| Russia   | 33750000                  | 90050                | 253                    |

• The order the Prime Minister of the Russian Federation D.A. Medvedev № 767-r "On regulation of the relations in the sphere of the use of gas motor fuel" (from 13.05.2013).
• The comprehensive plan of actions for expansion of use of NG as motor fuel from November 14, 2013 № 6819p-P9 (it is approved as the Deputy Prime Minister of the Russian Federation A.V. Dvorkovich).
On the basis of the submitted documents of PJSC "Gazprom" and LLC "Gazprom gas fuel" program for the construction of compressed natural gas refuelling stations CNG RSs and liquefied natural gas refuelling stations (LNG RS)s was developed. According to a related document submitted for Russia with a plan of action until 2030, more than 2600 NGV RS will be established. It is also noted that the servicing of NGV at each NGV RS must be planned post maintenance and warranty period. This action plan also includes transferring 524 thousand vehicles to NG.

In the JSC "Oil Company "Rosneft," one of three main marketing strategy priorities of gas business is active participation in federal programs of development of the market of gas motor fuel, including creation of a corporate network of the NGV RS. Thus, the expansion of NG usage in the motor transport is a real prospect of the upcoming future of Russia. And the questions connected with operation of NGV are actual.

NG can be transported in compressed (CNG; at compression to 25 MPa) or liquefied (LNG; when cooled to -162 °C) states. This requires installing the corresponding gas equipment at the same time. When using CNG, vehicles refuel at CNG RSs. The NGVs using a LNG gas need a refueling procedure based on cryogenic gas stations (LNG RSs). In this article we will focus on NGV running on CNG and, respectively about the CNG RSs.

Objective of this research is studying of prospects of large-scale use of NG on the motor transport in Russia and identification of limiting factors.

2. Factors affecting the growth of the NGV fleet in Russia

2.1 Locations of CNG RSs

The primary issue interfering with the full-scale transfer of vehicles to gaseous fuel in a number of the countries, including Russia, is the necessity of establishing appropriate infrastructure and in particular CNG RSs [6-7].

The network of CNGRSs is distributed in the following federal districts of Russia (the real number of CNGRSs may slightly differ from the submitted data): 1. Volga Federal District (FD) – 62; 2. Central FD – 54; 3. Ural FD – 42; 4. Southern FD – 35; 5. North Caucasus FD – 24.

From a technical point of view, the small number of CNG RSs in other FDs can be attributed to several factors, most importantly:

1. Weak branching (or total absence) of gas pipelines in Eastern Siberia and the Far East. It is known that the main part of Russia’s gas transmission system is located in the western, central and southern parts, as well as in the Urals. Supplying fuelling stations with NG requires a gas pipeline.

2. The significant extent of the specified FDs territory and the resulting problematic nature of the creation of so-called "blue corridors" (i.e., vehicles moving in different settlements and using NG only). As noted by professor Ya. S. Mkrtchyanch, the distance between CNG RSs should be in the range of 70–250 km. Between Tyumen (Urals FD) and Novosibirsk (Siberian FD) (i.e., a distance of 1278 km; federal highway R402–R254), there are no CNG RSs. Furthermore, in the Siberian and Far Eastern FD one cannot count more than 20 gas stations.

3. The problematic nature of NGV operation on NG given low ambient temperatures. The majority of Russian is in a cold climate zone (about 70% - northern parts of Russia, Western Siberia, Eastern Siberia and the Far East) and is accordingly subject to low ambient temperatures. Such conditions can lead to unstable operation of transport. However, research [8] has noted that such temperature changes can affect NGV output parameters; even so, the operation of vehicles, with appropriate preparation, is possible.

2.2 Determination of the actual quantity of NG

There are a number of organisations in Russian currently involved in the design, construction, and refurbishment of old CNG RSs using the latest technologies. However, there is a complexity of determination of actually released gas to vehicle owners.

The quantity and consumption of NG is typically determined by reference tables presented in RD 3112199-1095-03 [9]. Therefore, the owner of a vehicle, knowing the cylinder volume, the gas
pressure in it (measured according to indications of the manometer installed with the gas equipment in kgf/cm² or MPa) and the ambient temperature can determine the quantity of CNG in m³.

However, determining exactly how much gas is in the cylinders after refuelling is difficult. Volumetric accounting of methane fuel in this case may not be sufficiently reliable because the volume of a gaseous product depends on both the gas pressure and temperature. In RD 3112199-1095-03 [9], it is indicated ambient temperature. However, the gas temperature is not always equal to the ambient temperature.

It is likely for this reason that CNG RSs are sometimes faced with the problem of selling gas to vehicle owners that differs slightly from the volume of gas received at the station.

To determine a solution to this problem, organisations engaged in construction and reconstruction of CNG RSs have developed and certified a measuring and control system for refuelling NGVs. This system, which is based on a mass meter for measuring the mass flow of liquids and gases, is constructed on the principle of a Coriolis flow sensor. This method yields the most objective data for determining the air volumes of gaseous fuel. Nevertheless, at the present time, not all CNG RSs possess this equipment.

For the majority of CNG RSs in Russia, the information board resembles what is shown in figure 2. However, the only constant parameter of a gaseous substance is its weight. Transitioning to directly measuring the mass of the fuelled NG makes it possible to not only avoid the influence of various factors affecting the measurement accuracy but also simplifies the organisation of the account when refuelling at the compressor station.

Considering this fact, some CNG RSs offer refuelling with methane not in volume sizes (m³) but in mass (kg). This refuelling scheme is shown in figure 3. Some CNG RSs offer refills in m³ and some offer refills in kg, depending on the choice of the vehicle owner.

In standard climatic conditions, converting from the volume of methane to mass is rather simple: 1 m³ corresponds to 0.717 kg.

Therefore, the actual amount of NG in the cylinders of a vehicle can be defined in three ways:
1. According to the manometer indications in kgf/cm² or MPa during vehicle refuelling;
2. According to indications of an information display on the CNG RS in m³ (when refuelling the vehicle);
3. According to indications of an information display on the CNG RS in kg (when refuelling the vehicle).

2.3 Design features of NGV and methods of gaseous fuel consumption control

Internal combustion engines using CNG as a motor fuel can be divided into two categories:

a) dual-fuel engines with a universal power supply system and a spark ignition system that includes two equivalent power supply systems running on gas and liquid oil fuel (gasoline);
b) gas-liquid – engines with power supply system, in which a portion of liquid engine (diesel) fuel during the engine operation on CNG is used as an ignition dose for the ignition of an air-gas mixture in the engine (gas diesel engine);

c) gas – engines, convertible only for work on NG via ignition of an air-gas mixture in the cylinders from an electric spark or a glow plug.

The majority of Russian NGVs are currently dual-fuel, and they possess two equivalent power supply systems running on NG and liquid oil fuel (gasoline or diesel fuel). Furthermore, the majority of these vehicles which do not possess regular gas equipment are petrol (diesel) and are only equipped additionally with such equipment for methane use. However, recent trends both in Russia and worldwide have dictated that more and more vehicles have regular gas equipment installed by the manufacturer. In this case, traditional oil fuel is used as supplemental fuel.

Audi, Chevrolet, Citroen, Daimler-Benz, Fiat, Ford, IvecO, Honda, MAN, Opel, Peugeot, Scania, Toyota, Volkswagen, Volvo, etc. today offer factory vehicles with engines with regular gas equipment that is compatible with CNG. Moreover, the design features of these engines are adapted to work mainly on methane fuel.

In Russia, the most popular producers of NGV on methane are KAMAZ, Liaz, KAvZ, GAZ, VAZ and others. However, compared with foreign automakers, domestic automakers produce very few modifications of such vehicles. Moreover, almost all Russian plants install imported equipment, from the gas equipment to the gas engines.

In Europe, Volkswagen cars are very popular among NGV cars. This company considers constructive decisions that allow it to estimate how useful such vehicles will be in operation.

A summary of the technical characteristics and the dashboards of the considered brands are presented in table 2.

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It should additionally be noted that all of the NGV brands presented in table 2 are started and warmed at low air temperatures (up to the temperature of the cooling liquid plus 10–15 °C) on gasoline and then automatically switched to power with NG.

| Characteristics | Touran EcoFuel | Caddy EcoFuel | Golf Variant Blue Motion | Passat EcoFuel |
|-----------------|----------------|---------------|-------------------------|----------------|
| Engine capacity on CNG and gasoline | 1.4 | 2.0 | 1.4 | 1.4 |
| Power, kW / hp | 80/109 | 80/109 | 81/110 | 110/150 |
| Number of cylinders, pcs. | 4 | 4 | 2 | 3 |
| The total volume of cylinders, l | 115 | 160 | 94 | 132 |
| The mass of gas at 200 bar, kg | 18 | 26 (37 m$^3$) | 15 | 21 (31 m$^3$) |
| Volume of gasoline tank, l | 13 | 13 | 50 | 31 |
| Consumption kg / 100 km | 5.9 | 6.0 | 3.4 H$^a$ | 4.4 H$^a$ |

$^a$NG of group H (high) contains more methane than gas of group L (low). The higher the content of the methane, the better the quality of the gas and the greater the distance that can be driven on the fuel.

When discussing NGV converted from traditional motor fuels to natural gas-powered vehicles, it is possible to note that the determination of the fuel amount in the cylinders can be made via indications of the manometer (in kgf/cm$^2$ or MPa). It causes inconveniences for two reasons:

1. The absence of the information dashboard of the manometer (fuel consumption sensor). The dashboard is, as a rule, located in a location of cylinders.

2. Reading the manometer indications, it is difficult to determine the actual amount of gas in the cylinders. For this purpose, it is necessary to use reference tables [9].
For the Volkswagen vehicles that we consider, the relevant design decisions for this purpose are provided.

Touran EcoFuel and Caddy EcoFuel have the following indicators of a gas operating mode, and these makes also show the mode of emergency work on gasoline on the dashboard:
- the control indicator of the emergency work mode on gasoline;
- a segment indicator of the gasoline level;
- an analogue indicator of the gas level.

There are two various options for a dashboard:
1. Midline cars (figure 3). If the arrow flashes near or over the segment indicator, it means that the car works with gasoline. When the arrow dies out, the car switches to gas. Operation on gas is possible at temperatures exceeded the cooling liquid by +15°C. The engine control unit automatically switches from a gas-operating mode to the emergency work mode on gasoline.
2. Highline cars (figure 4).

Figure 5 shows an optional dashboard for a Volkswagen Passat EcoFuel.

Information about the actual NG consumption (in kg) or gasoline (in litres) per 10 km and a total fuel distance possible when using a particular type of fuel is shown on the multifunction display. In addition, the information about the ambient temperature is located on the display. The green indicator lamp of running on gaseous fuel means that the engine is running on NG.
One of the most modern NGVs is the Volkswagen Golf Variant Blue Motion. The dashboard on this brand of vehicles looks practically identical to that shown in figure 5. However, there is one feature, the multifunction display. Information pertaining to the quality of NG (figure 6) is shown on this feature.

The quality of gaseous fuel is displayed as a percentage, with a step size of 10% between 70% and 100%. After each refuelling, an adjustment to the quantity of NG is carried out. During refuelling, the adaptation of the content of the gaseous fuel of methane, which characterises the quality of NG (heat of combustion), is defined. An indication of 100% means that the content of methane in the gas is higher than 90%, and an indication of 90% means that the content of methane in the gas is higher than 80%. Since the content of methane is not measured directly but rather calculated, an indication of NG quality can differ from the actual content of the methane.

Furthermore, for convenience, all Volkswagen NGVs indicate NG consumption in kg. With regard to domestic producers, it is worth noting that they are also attempting to improve their dashboards with the addition of information about the quantity of NG in the cylinders. Figure 7 shows a bus KAvZ-4238-72 dashboard that indicates the residual amount of NG as a percentage ratio (level sensor).

However, after analysing figures 3–5, one can note that the dashboard on Volkswagen cars is more convenient and informative than the dashboard shown in figure 7.

3. Conclusions
To promote NGVs in Russia operating on CNG, it is necessary to promote the widespread expansion of the CNG RS network. Additionally, it is necessary to:

1. Develop an easy-to-understand system of defining the actual amount of gas in a cylinder. We propose to adopt foreign conventions and measure methane in mass units (i.e., kg).

2. Increase the Russian production of domestic vehicles with regular gas-cylinder equipment and engines. Particular emphasis, in accordance with Government Order № 767 [10], should be placed on buses, transport of road utilities, trucks and the most in-demand brands of domestic cars. At the same time, it is worth paying attention to the dashboard and placing on it the quantity of gas in the cylinder.

3. In view of the intensive gasification of Eastern Siberia and the Far East on the national level, it is necessary to work out the issue of creating a "blue corridor" in these regions.

4. Improve the legislative base pertaining to stimulation of converting transportation to NG via various benefit programs (e.g., providing instalment payments for the installation of gas equipment, lowering interest rates on loans to buy new NGVs, cost reductions on toll roads and parking areas, etc.).

5. Increase the awareness of vehicle owners about the advantages of NG by running television ads, distributing booklets, etc.

Replacing traditional fossil fuels with NG will enable reductions in the general emissions of harmful substances emitted with exhaust gases from vehicles, which will make it possible to improve the ecological situation, particularly in large cities.

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