Natural Gas Use On Minibuses, Engaged In The Carriage Of Passengers And Baggage On The Regular Routes, As A Measure For Decrease In Harmful Environment Effects

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Abstract. The paper deals with an option of increase the compressed natural gas use as a motor fuel for diesel minibuses to reduce emissions of harmful substances with exhaust gases. In terms of the Russian company LTD "WTC Automobilist", carrying passengers and baggage on regular routes by minibuses, the calculation of the park's natural gas needs is promoted. A mini CNG RS with optimal performance is suggested. The approximate payback period of the natural gas equipment installation on all buses of company and introduction into service period of mini CNG RS are calculated.

1. Introduction
Development of a street road network doesn't get on well at the majority of the countries behind rapid growth of the motor transport on roads. Congestions on the roads became a commonplace. This is particularly evident in cities with a population of over 500 thousand people. At the same time transport releases a huge amount of harmful substances into the atmosphere that causes an irreparable loss to the environment. Therefore many countries promptly expand the use of more environmental friendly alternative energy sources, reducing consumption of traditional oil motor fuels.

For Russia the most perspective is use of natural gas (NG) as the country possesses a great amount of the world’s NG deposits (24.6%). It ranked second after the US for its production (18%). Today at state and regional levels taken a number of legislative initiatives, which will soon have to increase the consumption of natural gas by motor transport in compressed (CNG) and liquefied (LNG) states.

Countrywide construction of natural gas refuelling stations (CNG RSs) has to play a leading role in increase of this hydrocarbon consumption. In [1-6] it is noted that weak network of gas stations contains growth of the GBA fleet. In [3] it is noted that the rapid development of natural gas takes place in those countries where there are significant internal reserves in the given hydrocarbon.

At the same time the set of experiments carried out confirms that at combustion of NG in automobile engines less harmful substances emitted with the exhaust gases in comparison with both traditional gasoline and diesel fuel (DF) [7-20, etc]. Besides in all countries gaseous fuel is much cheaper in comparison with gasoline and diesel (as a rule, by 2-3 times). For example, in Russia this price proportion was regulated until recently by the Resolution of the Government of the Russian Federation of 15.01.93 № 31 "On urgent measures to expand the replacement of motor fuels with
natural gas”. However since 21.04.2015 this Resolution is repealed according to the Resolution of the Government of the Russian Federation of 10.04.2015 № 338 [21]. However, the upward trend in NG prices are not observed.

In the world, there are about 20 million natural gas vehicles (NGVs) (2% of the total global vehicle fleet) operating on NG. According to [22] the global NGVs fleet annually increases by 30%. A considerable part of them constitute the buses running on public transport routes. Therefore, research on the NG use by buses are relevant [15, 23, 24].

By the use of NG on motor transport in general and on buses in particular, Russia lags behind many countries. Recently, however, positive change in this direction are seen. Especially it is noticeable in such megalopolises as Yekaterinburg, Kazan, Moscow, Nizhny Novgorod and St. Petersburg. Nevertheless, even in these cities, the number of CNG RSs does not exceed 4 units. It is associated with some problems in the operation of natural gas buses (NGB), the main ones are significant zero runs to gas station and back and costs of time for them. One solution to this problem is to build a mini CNG RS in the territory of motor transport enterprise.

2. Methodology

2.1 Choice of the research object

In this paper the method of the efficiency increase of buses usage on the example of the entity of LTD "WTC Automobilist" (Tyumen) by transfer of its fleet to CNG and a construction of mini CNG RS in the territory of enterprise is offered. The choice of Tyumen is caused by the fact that since 2016, the city is included in the “Reduction of greenhouse gas emissions from motor transport in the cities of Russia” project. The project is directed to decrease in emissions in the atmosphere of greenhouse gases by means of improvement of planning and management of an urban transportation by creation of effective systems of monitoring and promotion of environmentally friendly transport modes. Project implementation will be enabled at the expense of the Ministry of transport of the Russian Federation and the United Nations Development Programme with the assistance of the Global Environment Facility.

In Tyumen operates only one CNG RS, located in 12 km from the downtown. It is impractical to use this CNG RS bus fleet. Thus, today in the city a real alternative is development of the mini CNG RSs network which shall be located in close proximity or in the territory of the bus enterprises. At the same time one of the main installation criteria is availability of the gas pipeline as the mini CNG RS is connected to a gas distribution network.

Across the territory of the Tyumen region (autonomous regions and Khanty-Mansi Autonomous Dietrict (KMAD) and Yamalo-Nenets Autonomous Okrug (YNAD)) in general, and in particular the city of Tyumen there passes a huge kilometers amount of transmission and distribution pipelines. This is due to the fact that in YNAD produces 85% of Russian gas and practically in all settlements NG is used as fuel in many industries.

Within the borders of the city of Tyumen length of gas pipelines of various capacity is about 1000 km. Therefore installation of CNG RS is possible practically in any point of the can city. And pressure on the part from gas control points (GCP) to the consumer usually 0.05-0.3 MPas (0.5-3 bars) which is sufficient for the operation of mini CNG RS.

2.2 Transportation of passengers and baggage by bus of LTD "WTC Automobilist"

The kind of activity of LTD "WTC Automobilist" is rather extensive, however one of the main is to provide services in transportation of passengers and baggage on regular city routes. As of August, 2016 the organization has about 48 minibuses (15-26 places) are registered. These buses are mostly owned by individual carriers and the other entities which signed the contract for the organization and implementation of regular transportations of passengers and baggage on municipal Tyumen routes with LTD "WTC Automobilist". The bus fleet is constituted by the brands presented in the table 1.
Table 1 - Bus fleet of LTD "WTC Automobilist"

| №  | Bus brand                 | Busload, pearson | Year of manufacture |
|----|--------------------------|------------------|--------------------|
| 1  | Fiat Ducato              | 15-18            | 2009-2011          |
| 2  | Fiat FST613              | 22               | 2012               |
| 3  | Peugeot Boxer (modifications) | 22          | 2010-2013          |
| 4  | GAZ 3302                 | 22               | 2012               |
| 5  | Citroen L4H2 and modifications | 16-22      | 2013               |
| 6  | Renault (modifications)  | 22-25            | 2013-2015          |
| 7  | Ford (modifications)     | 25-26            | 2012-2014          |

All buses are equipped with diesel engines. They work on three regular routes of public transport:
1. Loop route № 52. Route: the square of Nemtsov – air-port Plekhanovo. Headway: on weekdays: 4-14 min., on weekends: 6-21 min. The length (distance) of a route in the direct direction: 5.94 km, in the return: 5.54 km. Quantity of stops in direct direction: 10, in the return: 9. On average the running time is from 06:20 till 21:39.
2. Loop route № 57. Route: the 1st residential district – the residential district "Moskovsky dvorik"). Headway: on weekdays: 1-20 min., on weekends: 5-14 min. The length (distance) of a route in the direct direction: 12.92 km, in the return: 15.25 km. Quantity of stops in direct direction: 27, in the return: 27. On average the running time is from 06:12 till 21:55.
3. Loop route № 68. Route: the Mys settlement– Bakinskikh Komissarov St.). Headway: on weekdays: 6-17 min., on weekends: 8-30 min. The length (distance) of a route in the direct direction: 14.04 km, in the return: 17.08 km. Quantity of stops in direct direction: 25, in the return: 33. On average the running time is from 06:11 till 21:48.

2.3 Calculation part

On brands of vehicles which are operated by the enterprise the gas equipment (for work on a gas-diesel cycle) and 3 ballons volume of 50 l everyone can be installed. Therefore, under standard operating conditions (air temperature of 20 °C, atmospheric pressure of 760 mm Hg) in these capacities, according to RD 03112194-1095-03 [25], 37.5 m³ of methane can be filled (with a pressure in cylinders of 19.6 MPas). It should be noted that at vehicles operation on a gas-diesel cycle in country conditions fuel is spent in the ratio 70% of NG and 30% of DF. In city conditions this ratio is typically 50% to 50%. Consequently, the composition of the fuel-air mixture depends upon a number of factors (the driving style, engine wear, and road and climatic conditions, traffic intensity, frequency of acceleration and braking, etc.) and calculated by electronic vehicle control unit.

Let's determine what amount of natural gas it is necessary to fill all buses of the enterprise:

$$Q_{m^3} = A_b \times V,$$

(1)

Where $Q_{m^3}$ – the number of the cubic meters of gas necessary for operation of all enterprise buses, m³; $A_b$ – the quantity of buss on duty, units; $V$ – the total volume of gas ballons for one bus, m³.

Let's say that the enterprise operates 48 buses which will be transferred to CNG and 3 ballons with total capacity of 37.5 m³ will be established on all buses. Then, having added these data in a formula 1 we will obtain the following value:

$$Q_{m^3} = 48 \times 37.5 = 1800 \text{ m}^3.$$
is 10.7 l per 100 km \[26\]. According to \[27\] let's accept that 1 m³ of NG is equivalent to 1 l of liquid fuel.

2. The length of buses runs on routes. The length of one turnover of each route is equal:

- №52: \( L_{m} = 5.94 + 5.54 = 11.48 \) km
- №57: \( L_{m} = 12.92 + 15.25 = 28.17 \) km
- №68: \( L_{m} = 14.04 + 17.08 = 31.12 \) km.

Further we will determine run length for the working day. According to operations control of LTD "WTC Automobilist" on weekdays it is:

- a. №52 – Each bus carries out 16 turns a day. The total mileage of 1 bus \( (L_{O}) \) is:
  \[ L_{O}(\text{№52}) = 11.48 \times 16 = 183.68 \text{ km}. \]
- b. №57 – Each bus carries out 7 turns a day. The total mileage of 1 bus is:
  \[ L_{O}(\text{№57}) = 28.17 \times 7 = 197.19 \text{ km}. \]
- c. №68 – Each bus carries out 6 turns a day. The total mileage of 1 bus is:
  \[ L_{O}(\text{№68}) = 31.12 \times 6 = 186.72 \text{ km}. \]

Further we will determine the total daily mileage \( (L_{OM}) \) for all buses fleet by routes:

- \( L_{OM}(\text{№52}) = 183.68 \times 16 = 2938.88 \text{ km}. \)
- \( L_{OM}(\text{№57}) = 197.19 \times 16 = 3155.04 \text{ km}. \)
- \( L_{OM}(\text{№68}) = 186.72 \times 16 = 2987.52 \text{ km}. \)

The total daily mileage for all routes is:

\[ L_{OM} = 2938.88 + 3155.04 + 2987.52 = 9081.44 \text{ km}. \]

On the basis of the data of the total daily mileage by all routes we will determine day need of the fleet in fuel:

\[ Q_{O} = 0.01 \times H_{s} \times L_{OM}, \quad (2) \]

Where \( H_{s} \) – basic fuel consumption norm for the vehicle milage, l/100 km; \( Q_{O} \) – day need of the fleet in fuel, l(m³).

Having substituted values in a formula 2 we will receive the following:

\[ Q_{O} = 0.01 \times 10.7 \times 9081.44 = 971.71 \text{ l(m³)}. \]

As buses are operated within the city, a ratio of an CNG-DF consumption is accepted 50% to 50%. Let's determine, the day need in CNG \( (Q_{O(CNG)}) \) and DF \( (Q_{O(DF)}) \) during the work of buses on a gas-diesel cycle:

\[ Q_{O(CNG)} = \frac{971.7 \times 50}{100} = 485.85 \text{ m³} \quad Q_{O(DF)} = \frac{971.7 \times 50}{100} = 485.85 \text{ l} \]

Calculations are presented without the idle run and other factors causing increase in fuel consumption (climatic and road conditions, technical condition of the vehicle, driver skills etc.). The number of working days on one full CNG refueling \( (37.5 \text{ m³}) \), will determine by the following formula:

\[ D_{w} = \frac{Q_{M}^{3}}{Q_{O(CNG)}}, \quad (3) \]

where \( D_{w} \) – The number of working days on one full CNG refueling, days.

On the basis of formula 3 we’ll receive:

\[ D_{w} = \frac{1800}{485.85} = 3.7 \text{ days}. \]

Knowing the day need in NG \( (Q_{O(CNG)}) \) within the given conditions, we will determine optimum, from the presented in the table 2, mini CNG RS for continual activity of the enterprise transport on gaseous fuel:

\[ CNGRS = P_{CNGRS} \times T_{R}. \quad (4) \]

where \( P_{CNGRS} \) – one-hour efficiency of CNG RS, m³/hours; \( T_{R} \) – the bus running time, h.
Table 2 – An example of some mini CNG RSs specifications and their cost

| Model         | Input pressure, bar | Output pressure, bar | Performance, m³/hour | Cost (august 2016), thousand rub. |
|---------------|--------------------|----------------------|----------------------|----------------------------------|
| Coltri MCH-24 | 0.304              | 200/250              | 24                   | 1223                             |
| Coltri MCH-30 | 0.304              | 200/250              | 30                   | 1223                             |
| H8-11         | 2.53               | 200/250              | 40                   | 2592                             |
| H6-11         | 4.053              | 200/250              | 45                   | 2592                             |
| H8-15         | 3.04               | 200/250              | 50                   | 2808                             |
| H6-15         | 6.08               | 200/250              | 60                   | 2808                             |

There are many companies in Russia that offer mini CNG RSs of various modifications: LTD "Elitgaz", LTD "Rademi", LTD "Broadway», «Fornovogas», LTD "Micrometan C" and others.

In view of the fact that 48 minibuses are operated at the LTD "WTC Automobilist", it is necessary to calculate optimum compressor station for such number of vehicles.

Taking into account the working period of a public transport on regular routes in Tyumen from 6:30 till 22:00 (without time spent for a lunch and/or to a shift change) to satisfy the day needs in fuel of the considered enterprise the station capable in 15 hours to refuel about 486 m³ of methane is necessary.

Let’s find an optimum fuel station from the table 2.

\[
\text{CNGRS}_{\text{Coltri MCH-24}} = 24 \times 15 = 360 \text{ m}^3.
\]

\[
\text{CNGRS}_{\text{Coltri MCH-30}} = 30 \times 15 = 450 \text{ m}^3.
\]

\[
\text{CNGRS}_{\text{H8-11}} = 40 \times 15 = 600 \text{ m}^3.
\]

\[
\text{CNGRS}_{\text{H6-11}} = 45 \times 15 = 675 \text{ m}^3.
\]

\[
\text{CNGRS}_{\text{H8-15}} = 50 \times 15 = 750 \text{ m}^3.
\]

\[
\text{CNGRS}_{\text{H6-15}} = 60 \times 15 = 900 \text{ m}^3.
\]

As seen from the calculations mini CNG RSs H8-11, H6-11, H8-15, H6-15 satisfy specified requirements. A CNG RS Coltri MCH-30 has a little smaller performance than necessary. However, the difference in cost between Coltri MCH-30 and, for example, H8-11 is 1,369,000 rub. Therefore, it is economically reasonable to establish Coltri MCH-30.

Further we will calculate the purchase costs of the gas-ballon equipment (GBE). On the bus brands presented in table 1 usually all-metal ballon of the 1st type is established. By data [28] the cost of installation is about 177 thousand rubles (the GBE brand: Tamona Diesel Gas, 3 ballons of the 1st type). Let's calculate GBE purchase costs \( C_p \) for the enterprise:

\[
C_p = 48 \times 177 = 8496 \text{ thousand rub.}
\]

The cost of DF \( C_{DF} \) and CNG \( C_{CNG} \) in Tyumen as of the 2nd quarter 2016 is \( C_{DF} = 37.1 \) rub for 1 liter and \( C_{CNG} = 13.3 \) rub for 1 m³.

Consequently, knowing the total day fuel requirement calculated according to the formula 2 let’s define the overall cost of the bus fleet using diesel cycle (DC) (5) and gas-diesel cycle (GDC) (6), respectively:

\[
C_{\text{GNGRS}} = P_{\text{GNGRS}} \times T_R.
\]

\[
C_{\text{GDC}} = Q_{\text{CNG}} \times C_{\text{CNG}} + Q_{\text{DF}} \times C_{\text{DF}}.
\]

Where \( C_{\text{DC}}, C_{\text{CNG}} \) – total day expenditures during the operation on diesel cycle gas-diesel cycle respectively, rub.

Having substituted values in a formula 5 and 6 we will receive the following:

\[
C_{\text{DC}} = 971.7 \times 37.1 = 36050.07 \text{ rub.}
\]

\[
C_{\text{GDC}} = 485.85 \times 13.3 + 485.85 \times 37.1 = 24486.8 \text{ rub.}
\]

Day money economy \( E_D \) from use of a gas-diesel cycle in comparison with diesel are defined:

\[
E_D = C_{\text{DC}} - C_{\text{GDC}}.
\]

Having substituted values in a formula 7 we will receive the following:
To define the payback period of GBE it is used the following formula:

$$P_{b_{GBE}} = \frac{C_p}{E_D}, \quad (8)$$

where $P_{b_{GBE}}$ – payback period from acquisition of the gas-ballon equipment, days.

Having substituted values in a formula 8 we will receive the following:

$$P_{b_{GBE}} = \frac{8496000}{11563.27} = 734.3 \text{ days}.$$ 

Further we will calculate a payback period of mini CNG RS which we will determine by a formula:

$$P_{b_{CNGRS}} = \frac{C_{CNGRS}}{E_D}, \quad (9)$$

where $P_{b_{CNGRS}}$ – payback period from acquisition of the mini CNG RS, days; $C_{CNGRS}$ – cost of mini CNG RS, rub.

According to [29] cost of the Coltri MCH-30 CNG RS is 1223 thousand rubles.

Having substituted values in a formula 9 we will receive the following:

$$P_{b_{Coltri \ MCH-30}} = \frac{1223000}{11563.27} = 105.8 \text{ days}.$$ 

Define total payback periods ($P_{b_{TOTAL}}$) of GBE and mini CNG RS according to the formula:

$$P_{b_{TOTAL}} = P_{b_{GBE}} + P_{b_{CNGRS}} \quad . \quad (10)$$

Having substituted values in a formula 10 we will receive the following:

$$P_{b_{TOTAL}} = 734.3 + 105.8 = 840.1 \text{ days}.$$ 

Thus, costs for re-equipment of the buses fleet for operation on a gas-diesel cycle and acquisition of the mini CNG RS of necessary performance pay off for 2 years and nearly 4 months.

3. Conclusions

Based on calculations it is possible to note that under the given conditions payback periods of transferring diesel minibuses on a gas-diesel cycle and construction the mini CNG RS are rather considerable. The reason is that in urban environments during engine operation on gas diesel cycle, due to the constantly changing speed regime, increasing the proportion of diesel fuel in the fuel-air mixture as compared to operation outside of urban. Therefore, fuel costs increase proportionally. Also the studied routes have rather low day mileage. That also affects the payback time.

Thus, enterprise economy from NG use can be reached in the medium term. However NG transport transport when working on gas-diesel cycle will emit less amount of harmful substances with exhaust gases, compared with diesel cycle. Therefore, to increase the use of NG on the transport and environmental improvement are invited to develop a plan of government (regional) enabling activities, such as:

1. To develop the plan for subsidizing of the bus enterprises. For example, in Tyumen to make changes to the resolution of Tyumen Administration of 29.08.2008 № 117-pk "On approval of the Order of subsidies provision for reimbursement of expenses related to the transport services provision within the organization of transport service for the population of Tyumen". To add point to grant a subsidy of 50% of the costs for the installation of GBE.

2. To reduce, cancel or temporarily not to levy a tax on vehicles using NG as fuel.

3. On the basis of the first two offers to change the requirements to the tender participants when carrying out tender on implementation of regular passengers and baggage transportations on municipal routes of Tyumen. To establish obligatory selection criterion in the form of the minimum quantity of
NG buses in the enterprise fleet to 30% (according to the order of the Government of the Russian Federation № 767-r of 13.05.2013. "On regulation of the relations to the sphere of gaseous motor fuel use, including natural gas as motor fuel").

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