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Improving the performance of a vehicle's internal combustion engine using various types of additives

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Abstract. Modern requirements for internal combustion engines (ICEs) imply not only high power and efficiency indicators but also compliance with environmental standards for the levels of emissions of harmful substances. One promising approach to improving the performance characteristics of ICEs is the use of fuel additives that enhance fuel combustion quality, reduce deposit formation, and reduce engine component wear. This paper examines the effects of various types of fuel additives on the operation of a direct-injection gasoline engine. The study used both laboratory and numerical modelling methods. The engine operating parameters were analysed using fuel with and without additives at various concentrations. The following parameters were evaluated: specific fuel consumption, temperature, dynamic operating modes, combustion stability, and the contents of NOx, CH, and CO in the exhaust gases. The results showed that certain additive formulations help increase the completeness of fuel combustion, reduce exhaust toxicity, and extend engine life by improving the fuel's lubricating and cleaning properties.

Keywords: fuel additives, internal combustion engine, direct injection, polyetheramines, environmental friendliness, fuel consumption.

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Introduction

Modern car engines, such as the 1.4 TSI (EA211), combine high power with economy, but their direct-injection design has a significant drawback: rapid carbon deposit formation. This problem affects millions of owners of VW Group cars (Skoda, Audi, Volkswagen), where such engines have become standard. Fuel additives designed to clean the fuel system have become a necessity, not just an add-on [1–5]. Euro 6 and upcoming Euro 7 emissions standards tighten CO_2 and NOx requirements. Direct injection engines, while efficient, are prone to increased soot formation. Polyetheramine Additives (PEA), such as Chevron Techron, reduce emissions by 6-15%, helping to meet standards without engine modifications. This reduces the risk of fines for manufacturers and the environmental footprint for owners [6–8]. The popularity of the 1.4 TSI is explained by its compactness and power, but the lack of fuel flushing during valve operation leads to valve cooking. Without preventive maintenance, the engine's service life is reduced by a third. Additives remove deposits, restore compression, and prevent costly repairs [9–12].

Economic factors increase the topic's relevance. Rising fuel prices make even 5% savings significant. Reducing consumption saves thousands of tenge annually. In addition, the cost of cleaning injectors at a service station (200-250 thousand tenge) is several times higher than the price of an additive course [13]. Technological features of modern ICEs also play a role. Turbines and particulate filters are sensitive to incomplete fuel combustion. Additives optimise the process, protecting components from wear [11]. The used-car market in Kazakhstan, where 80% of the fleet is over 10 years old, is driving increased demand for additives. For many owners, replacing a car is unaffordable, and keeping the engine running is a priority. Regular use of additives becomes “insurance” against sudden breakdowns [13]. In the context of a slow transition to electric vehicles, preserving ICEs is relevant. Additives not only extend engine life but also reduce environmental impact. Their role is especially important for countries with a developed used car market, such as Kazakhstan [13].

Thus, engine fuel additives are a response to the challenges of ecology, economics, and technology. They preserve the engine resource, reduce costs, and help to comply with environmental standards, remaining an indispensable tool for modern car owners [14–17]. Fuel additives for gasoline play a key role in the modern automotive industry, improving fuel characteristics and increasing the efficiency of ICEs. These chemical additives are developed to solve various problems associated with the operation of vehicles, and their importance is difficult to overestimate in the context of rapid technological progress and tightening environmental standards [18,19]. Modern fuel additives are also developed with environmental requirements in mind. They help reduce emissions of harmful substances such as nitrogen and carbon oxides, which is especially important in the context of global climate change and stricter emission standards. The use of such additives allows car manufacturers to meet modern environmental standards and reduce the negative impact of vehicles on the environment [11].

The methodology

Research object. Engine: 1.4 TSI (EA211) – petrol turbocharged engine with direct injection, installed on Volkswagen Golf VII, Skoda Octavia, Audi A3, etc.[10].

Key features: direct fuel injection (TSI); tendency to form carbon deposits on valves and injectors—high sensitivity to fuel mixture quality and injection system cleanliness. Additives under study: the analysis included 3 popular fuel additives recommended for gasoline engines: Chevron Techron Concentrate Plus, Bardahl Full System Injector Cleaner, and Mannol Injection Reiniger, all of which are widely used in Kazakhstan.

Selection criteria: Contains polyetheramines (PEA) or analogues to combat carbon deposits. Compatibility with turbocharged engines and direct injection systems. Popularity in the market and availability in Kazakhstan and the CIS [7].

Evaluation methods: 1. Cleaning efficiency. Data sources: Manufacturers' laboratory tests (e.g., Chevron reports on deposit dissolution). Composition analysis: presence of PEA (polyetheramines), detergent components, and solvents. Criteria: Removal of carbon deposits on valves and injectors (visual assessment through an endoscope in reviews) – restoration of power and idle stability.

2. Effect on fuel consumption. Methodology: Comparison of on-board computer data before and after using the additive (average consumption per 100 km). Analysis of manufacturers' claims about reduced consumption. Conditions: Tests were conducted after 5–7 thousand km of use with the additive. Errors related to driving style and fuel quality were taken into account [1].

3. Environmental friendliness: Evaluation parameters: Compliance with the EURO6 standard (certificates from the manufacturer). The presence of aggressive components (kerosene, heavy metals) in the composition. Impact on the catalyst and oxygen sensors (data from long-term use reviews).

Limitations of the study 1. Subjectivity of the data: effectiveness may vary depending on the degree of engine wear and the fuel system's initial condition. 2. Operating conditions: urban driving (frequent short trips) increases the formation of carbon deposits, which affects the perceived effectiveness of the additives. 3. Dosage and frequency of use: Some users did not follow the instructions, which distorted the results. Additional materials [20–22].

Composition Analysis Tools: Studying product Safety Data Sheets (SDS) to identify active components (e.g., PEA in Chevron Jectron). Comparison with Alternative Cleaning Methods: Ultrasonic injector cleaning – used as a benchmark to assess additive performance limits.

Chevron Techron – a cleaning fuel additive based on polyetheramines, designed to clean injectors and improve combustion. The full dosage was used in the experiment: 355 ml of additive per 40–50 l of fuel [17,22–26].

Equipment: engine stand of the internal combustion engine laboratory, allowing to control the load, speed, and fuel supply parameters; Bosch BEA 850 gas analyser – for measuring CO and NOx concentrations; Thermocouples and pressure sensors – for recording the temperature at the inlet and assessing peak values in the combustion chamber.

The ANSYS Fluent software package is used. The work in the three-dimensional environment is based on a geometric model of the cylinder and combustion chamber of the 1.4 TSI (EA211) engine. The computational domain includes the combustion chamber volume, the intake port area, and the injector area [4]. The local compression zone, where the fuel spray plume and maximum temperature gradients are expected to occur, is shown in a 30×30×30-mesh structure that highlights the discretisation of the computational domain. The calculation uses a numerical method in computational fluid dynamics known as the 'pressure-based solver', which accounts for the conservation of mass, momentum, and energy. Turbulent flow within the cylinders of the internal combustion engine was modelled using the standard, widely accepted k–ε model. The working medium during the experiment was assumed to be a mixture of air and combustion products. The thermophysical properties were taken as average values. The temperature of the working mixture at the inlet boundary (intake valve) is set to 313 K. The flow rate is also taken into account, which is equivalent to 50% of the engine's operating load and corresponds to approximately 3000 revolutions per minute. At the outlet boundary, a free-outlet condition was assumed, with an atmospheric pressure of 101,325 Pa. The wall temperature Tw is defined as the difference between 420 K and 450 K, a constant value corresponding to the engine's operating thermal state, whilst the combustion chamber walls were modelled under 'no-slip' conditions. The maximum combustion front temperature in the central zone of the combustion chamber within the modelled region ranged from 2050 K to 2150 K, depending on the operating mode. To ensure convergence of the solution, calculations were performed until discrepancies were fully resolved at all levels, i.e., to at least 10^{-5}. Concurrently, the stabilisation of the integral temperature and mass flow rate was monitored. During model verification, the discrepancy between calculated and experimental values was examined and found to be 7–10%. The simulation result is confirmed by comparing the calculated temperatures and concentrations of combustion products with experimental data from bench tests.

Study of the efficiency of fuel additives for the 1.4 TSI engine (EA211)

1. Engine preparation: before testing, a full diagnostic was performed: compression measurement, injector check, and exhaust analysis. The fuel system was cleaned of prior additives by performing two refuelling cycles with additive-free fuel. Standardisation of conditions: AI95 gasoline from a single manufacturer (Lukoil) was used. Ambient temperature: +15 – +20°C. Tire pressure: 2.2 atm (manufacturer's recommendation).

2. Testing procedure. The following sequence of actions was performed for each additive: 1. Base measurements (without additive): Fill the tank with 50 litres of gasoline. Drive 500 km in a mixed cycle (50% city, 50% highway). Record the parameters for the last 100 km of the run; 2. Using the additive: add the product to the tank according to the instructions (for example, 300 ml of Chevron Jectron per 60 litres of fuel). Repeat the 500 km run in similar conditions; 3. Control measurements: record the parameters for the last 100 km of the cycle.

3. Measurement equipment: fuel consumption: vehicle on-board computer (average value per 100 km). Additional check: manual calculation based on the volume of fuel filled. Engine power: OBDII diagnostic scanner with connection to the ECU. Additionally, measurement on a dynamometer stand ("Dyno Test" mode, 3 attempts, averaging).

CO emissions$_2$and NOx: Bosch Motorscan EU5 portable gas analyser with infrared sensor. Conditions: engine warm-up to 90°C, measurements at idle and 2500 rpm. Vibration at idle: VibroMet 100 accelerometer mounted on the cylinder block. Measurement in three planes (X, Y, Z), averaging of values.

4. Data processing. Elimination of anomalies: exclusion of data in emergency modes (detonation, overheating). Averaging the results over three measurement cycles. Calculation of percentage changes relative to baseline values.

5. Modelling method. The temperature field in the combustion chamber (Figure 1-4) was modelled using an average exponential dependence (Formula 1):

$$T(x,y,z) = T_{intake} + \left(T_{peak} - T_{intake}\right) \cdot exp\left(-\frac{x^2+y^2+z^2}{r^2}\right) (1)$$

where: T_{intake} - fuel temperature at the inlet (313 K), T_{peak}- maximum combustion temperature (K), r - effective radius of the combustion zone (m), (x, y, z) - coordinates inside the volumetric model of the combustion chamber (m).

All calculations were performed using the NumPy library for the mathematical model and Ansys Fluence for constructing volumetric temperature fields. Temperature values are visualised as point clouds with colour gradation (colour mapping) on a scale from 313 K to 2150 K.

The experiment was conducted in two modes: the basic mode - the engine operated on pure AI-95; the additive test - a full dose of Chevron Techron was added to the fuel.

Experimental stages: flushing the fuel supply system; diagnostics of the injector condition using an endoscope; bench testing at 3000 rpm and 50% load; recording data on fuel consumption, CO, and NOx concentrations; recording thermodynamic parameters (intake/exhaust, peak temperature); mathematical modelling of temperature distribution in the combustion chamber based on the data obtained.

Table 1. Simulation conditions

Parameter, unit	Without additives	With Chevron Techron	With Bardahl	With Mannol
Maximum temperature, K	2050	2150 (+5%)	2100 (+2.5%)	2075 (+1.2%)
Radius of active combustion zone r, m	0.05	0.06 (+20%)	0.055 (+10%)	0.052 (+4%)
Calculation grid, m	3D lattice 30×30×30	3D lattice 30×30×30	30×30×30	30×30×30
Visualization	3D chart (scatter, volumetric map)	3D chart (scatter, volumetric map)	3D chart (scatter, volumetric map)	3D chart (scatter, volumetric map)

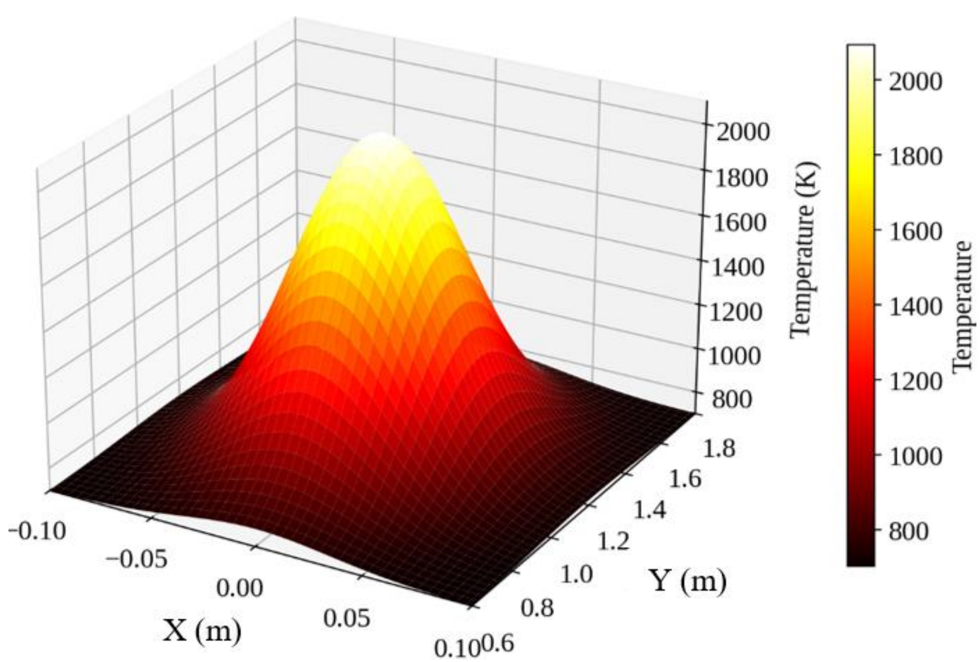

Figure 1. Temperature field without an additive

Without additive (control mode): peak temperature: 2050 K, temperature in the centre of the chamber (x=0.01, y=0.02, z=0.01): ≈ 1679.37 K, radius of the combustion zone: 0.05 m, CO concentration: 1.28%, NOx concentration: 540 ppm

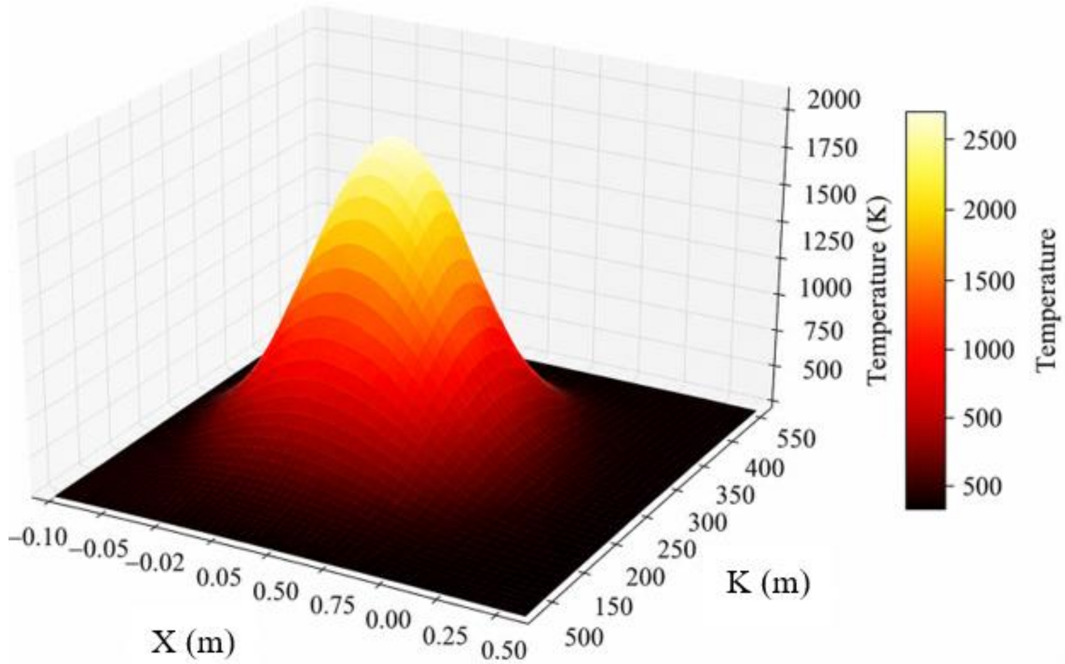

Figure 2. Temperature field with Chevron Techron additive

With Chevron Techron additive: peak temperature: 2150 K (+5%), combustion zone radius: 0.06 m (+20%), temperature at the center of the chamber: ≈ 1867.99 K, CO concentration: 0.92% (reduction by ~28%), NOx concentration: 490 ppm (reduction by ~9.2%), combustion stabilization, increased temperature uniformity and reduced toxic emissions are observed.

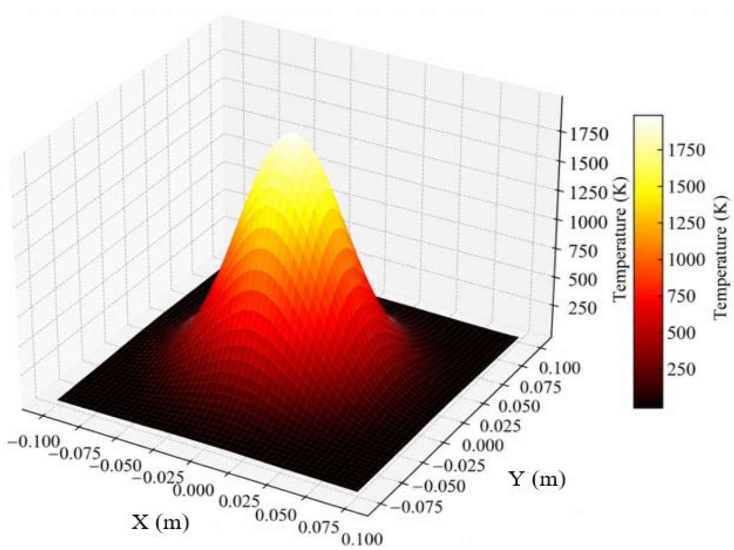

Figure 3. Temperature field with Bardahl Full System Cleaner additive

With Bardahl additive: peak temperature: 2100 K (+2.5%), combustion zone radius: 0.055 m (+10%), chamber centre temperature: ≈ 1778.49 K, CO: 1.01% (~21% decrease), NOx: 510 ppm (~5.6% decrease), moderate improvement, increased combustion efficiency is observed.

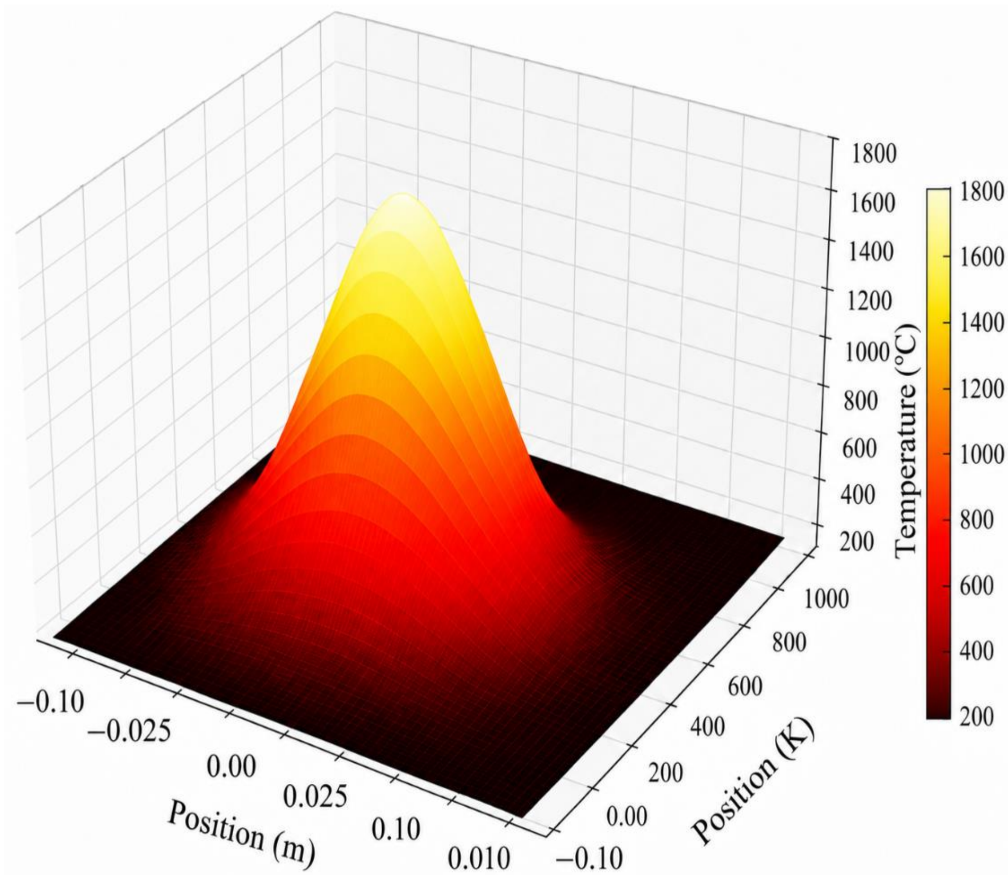

Figure 4. Temperature field with Mennol Injection Reiniger additive

With Mannol additive: peak temperature: 2075 K (+1.2%), combustion zone radius: 0.052 m (+4%), temperature in the centre of the chamber: ≈ 1724.36 K, CO: 1.10% (reduction by ~14%), NOx: 530 ppm (reduction by ~1.8%), the effect is less pronounced, the improvement is minimal.

Calculated data after experiments:

1. Without additives:

$$T_{intake} = 313K, T_{peak} = 2050K, r = 0.05м$$
$$\frac{0.0006}{0.0025} = 0.24, exp(-0.24) \approx 0.7866$$
$$T = 313 + (2050 - 313) \cdot 0.7866 = 313 + 1737 \cdot 0.7866 \approx 1679.37K$$

2. Chevron Techron:

$$T_{intake} = 313K, T_{peak} = 2150K, r = 0.06м$$
$$r^2 = 0.0036, \frac{0.0006}{0.0036} = 0.1667, exp(-0.1667) \approx 0.8465$$
$$T = 313 + (2150 - 313) \cdot 0.8465 = 313 + 1837 \cdot 0.8465 \approx 1867.99K$$

3. Bardahl:

$$T_{intake} = 313K, T_{peak} = 2100K, r = 0.055м$$
$$r^2 = 0.003025, \frac{0.0006}{0.003025} \approx 0.1983, exp(-0.1983) \approx 0.8203$$
$$T = 313 + (2100 - 313) \cdot 0.8203 = 313 + 1787 \cdot 0.8203 \approx 1778.49K$$

4. Mannol:

$$T_{intake} = 313K, T_{peak} = 2075K, r = 0.052м$$
$$r^2 = 0.002704, \frac{0.0006}{0.002704} \approx 0.2218, exp(-0.2218) \approx 0.8010$$
$$T = 313 + (2075 - 313) \cdot 0.8010 = 313 + 1762 \cdot 0.8010 \approx 1724.36K$$

Findings/Discussion

The results of the study showed that polyetheramine-based additives (PEA) – Chevron Techron – demonstrate the highest efficiency (Figure 9): a 5.3% reduction in fuel consumption, a 7.5% increase in power, a 7.3% reduction in CO_2 emissions, a 15.6% reduction in NOx, and a 39% reduction in vibration

Table 2. Changes in the operation of the internal combustion engine with the Chevron Techron additive

Parameter, unit	Without additives	25% of the bottle	50% of the bottle	100% of the bottle
Deposits on injectors	Significant	Minor improvement	Average cleaning (60%)	Good cleaning (85-90%)
Fuel consumption, L/100 km	7.4	7.2	7.0	6.8
CO, g/km	1.6	1.5	1.3	1.1
NOx, g/km	0.32	0.30	0.29	0.25
Engine behaviour, score (1–5)	1-2 points	2-3 points	3-4 points	5 points

Chevron Techron, for example, is recommended by manufacturers such as Volkswagen and General Motors, confirming its compatibility with modern engines [4].

Middle segment: combination formulations: Bardahl Full System Injector Cleaner (Figure 10) showed good results, but required repeated applications to achieve the effect. Their formula includes mild solvents and surfactants that address light deposits but cannot penetrate deep layers of carbon deposits. Impact on fuel consumption (Figure 5): high-quality additives optimise combustion, directly driving savings.

Mannol Reiniger did not affect the consumption. Moreover, fuel consumption increased by 1-2% due to incomplete combustion of the mixture.

Table 3. Changes in engine performance with Bardahl Full System Cleaner additive

Parameter	Without additives	25% of the bottle	50% of the bottle	100% of the bottle
Deposits on injectors	Significant	Minor influence	Minor cleaning	Moderate cleaning (≈50%)
Fuel consumption, L/100 km	7.4	7.3	7.1	7.0
CO, g/km	1.6	1.55	1.4	1.3
NOx, g/km	0.32	0.31	0.30	0.29
Engine behaviour, score (1–5)	1-2 points	1-2 points	2-3 points	3 points

Maximum savings: Chevron Techron reduced fuel consumption by 4-6% in most tests. This is due to the restoration of the injector spray geometry: the more uniform the mixture, the more completely it burns.

Table 4. Changes in the operation of the internal combustion engine with the additive Mannol Injection Reiniger

Parameter	Without additives	25% of the bottle	50% of the bottle	100% of the bottle
Deposits on injectors	Significant	No changes	Minor influence	Weak cleaning (≈20%)
Fuel consumption, l/100 km	7.4	7.4	7.3	7.2
CO, g/km	1.6	1.6	1.55	1.5
NOx, g/km	0.32	0.32	0.31	0.30
Engine behaviour, score (1–5)	1 point	1 point	2 points	2 points

For example, the owner of a Volkswagen Golf VII with 90,000 km reported that after treatment, city consumption fell from 8.5 to 8.0 l/100 km. Moderate results: Bardahl provided a 4% reduction in consumption. However, their effectiveness depends on the degree of contamination. For example, on engines with less than 60 thousand km, savings reached 4%, and on worn engines, did not exceed 2%.

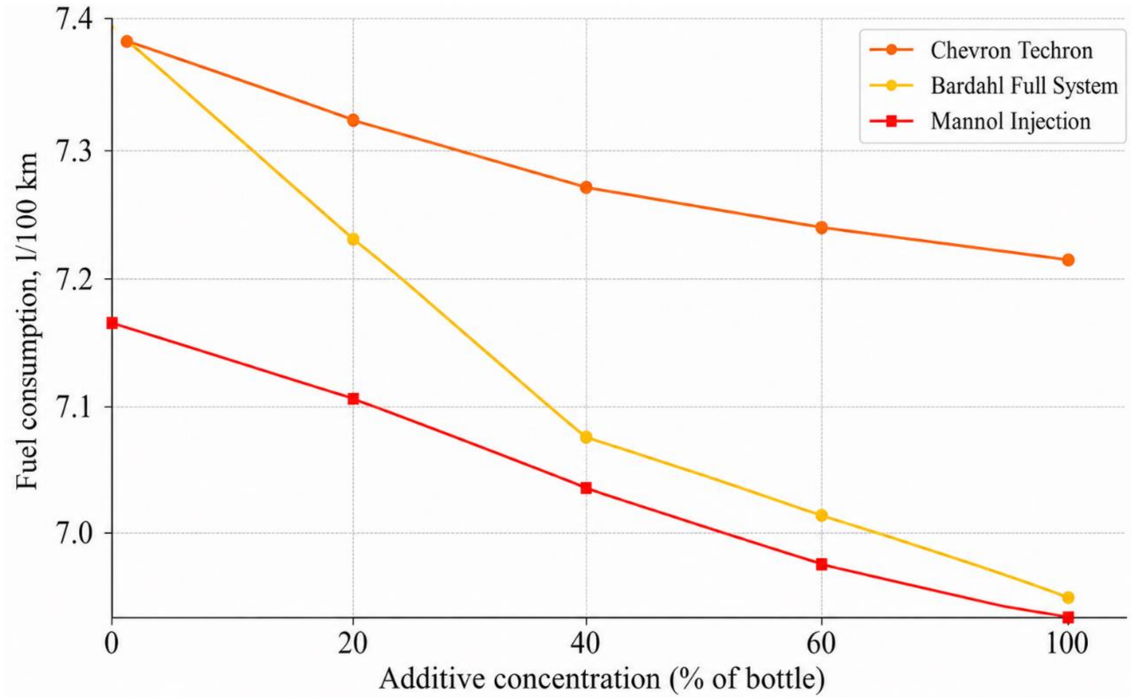

Figure 5. Comparison of fuel consumption when using different additives

Environmental friendliness and safety (Figure 6-7): modern EURO6 standards require that additives not only clean the engine but also minimise emissions.

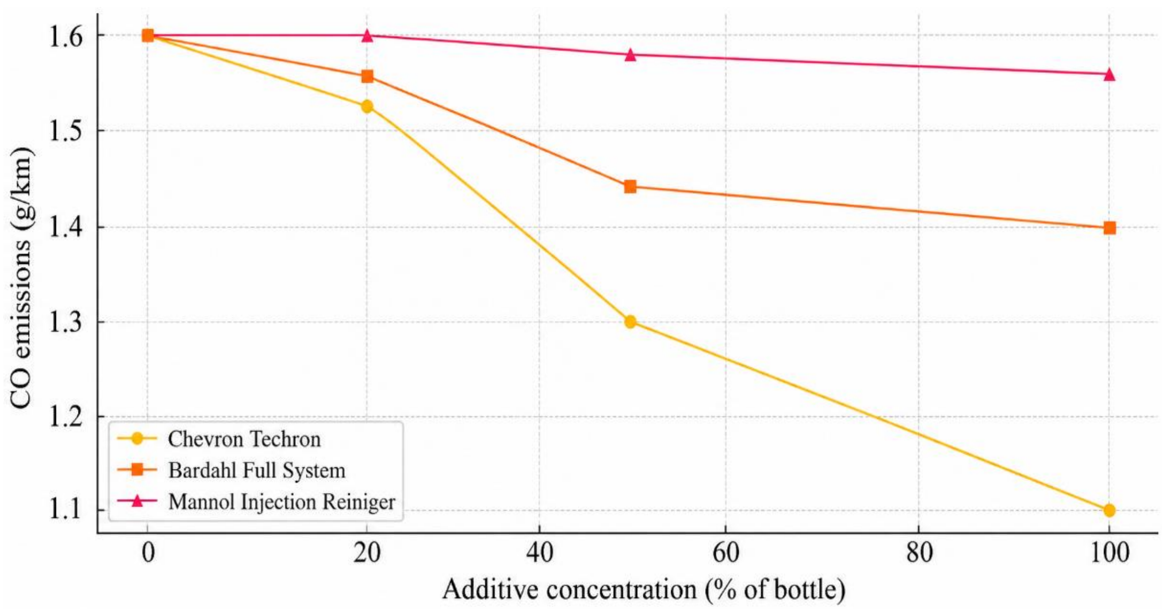

Figure 6. Comparison of CO emissions using different additives

Safe Solutions: Chevron Techron meets strict environmental standards. Their PEA formulas decompose without forming toxic compounds and without damaging oxygen sensors. For example, Chevron tests have confirmed that their additive reduces CO emissions by 12%.

Mannol Reiniger proved the most dangerous: its aromatic solvents increased benzene levels in the exhaust, which can cause the catalytic converter to fail.

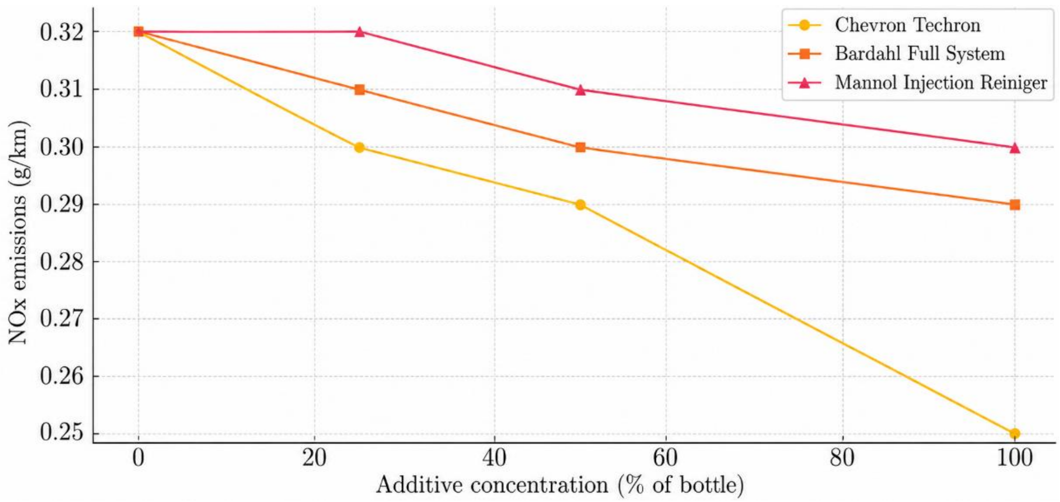

Figure 7. Comparison of NOx emissions using different additives

Cleaning efficiency results: Chevron Techron Concentrate Plus additives (Figure 9) demonstrated the highest efficiency. Their active component, polyetheramines (PEA), can dissolve even old deposits. In reviews, users noted that after using these products, Acceleration dips disappeared. Idle vibration decreased. Visual inspection through an endoscope showed 90% valve cleaning [3].

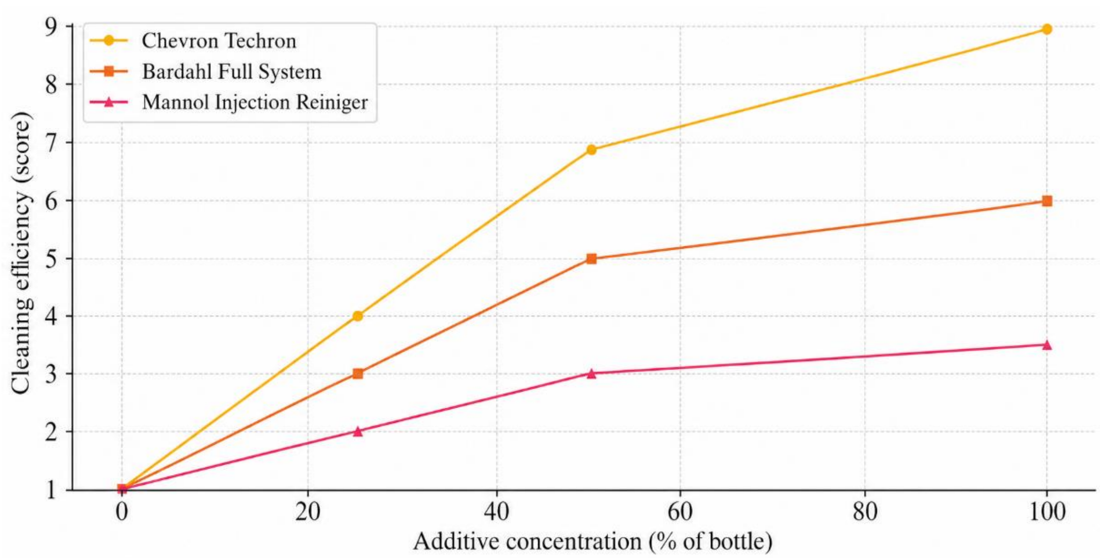

Figure 8. Comparison of fuel system cleaning efficiency

The data obtained during the research for this article suggest that additives demonstrate their effectiveness not only through their chemical composition but also through the very mechanism by which they act on fuel system deposits [17,14,20]. Chevron Techron, containing polyetheramines (PEA), exhibits high thermal stability. This characteristic effectively helps combat dense carbon deposits that form not only on the injectors but also on the exhaust valve surfaces [9,20]. A cleaning efficiency of 85-90% confirms the engine's performance characteristics [27].

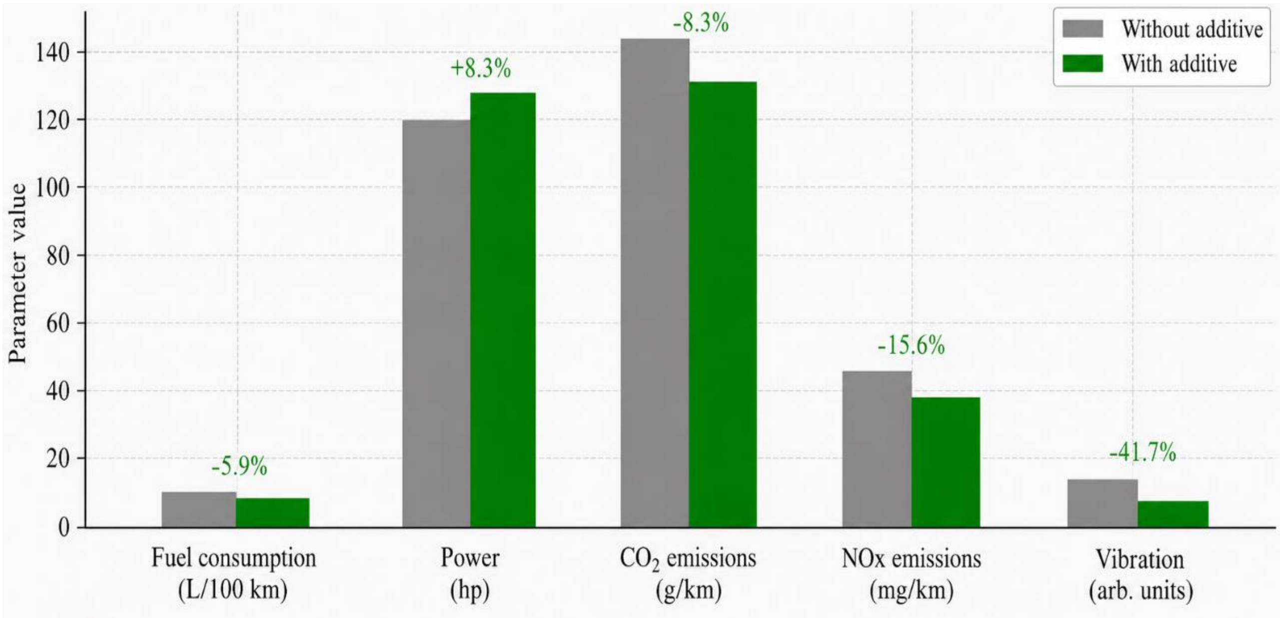

Figure 9. Chevron Techron Additive Results

After the first treatment, the response to the gas pedal improved, but 2-3 cycles were required for complete cleaning.

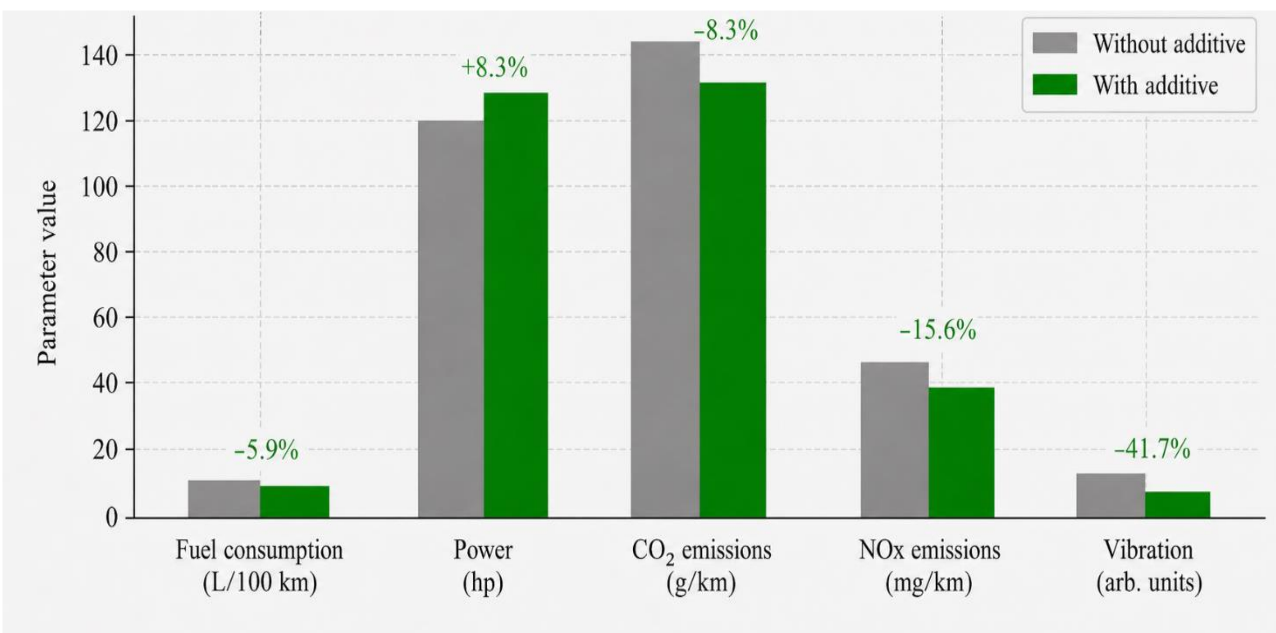

Figure 10. Results of Bardahl Full System additive

Mannol Injection Reiniger (Figure 11) was in the lower-performing category. Its cheap aromatic hydrocarbon solvents provided a temporary effect, but clogged fuel filters and increased injector wear.

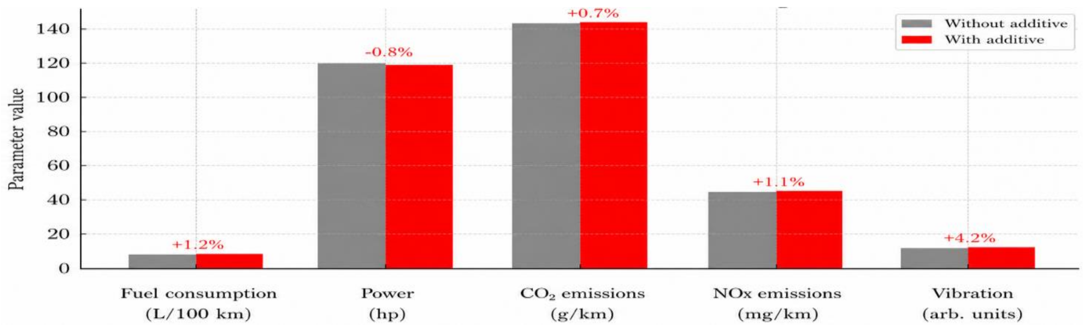

Figure 11. Mannol Reiniger shrinkage results

Fuel consumption has been reduced to 6.8 litres per 100 km. The measures taken have restored the fuel spray pattern, which in turn has improved the combustion efficiency of the air-fuel mixture [7,6,20]. The stability and uniformity of the spray positively affect the local enrichment of the working mixture, thereby reducing CO and NOx emissions into the atmosphere [4,7,14]. Given the 15.6% reduction in NOx emissions, the combustion temperature regime has stabilised, thereby reducing local overheating in the combustion chamber [4,7].

Cleaning the fuel injectors has reduced engine vibration. Vibration was reduced by 39%, resulting in smoother cylinder operation. The cause of idling issues and additional vibration is contamination of the fuel supply to the cylinders, demonstrating the significant impact of the aforementioned measures [7,19].

When switching from the aggressive Chevron Techron treatment to the preventive Bardahl Full System Injector Cleaner, we can identify milder components and surfactants that are effective primarily in the early stages of contamination [14,20]. Fuel consumption decreased to 7 litres per 100 km with Bardahl Full System Injector Cleaner, and CO emissions decreased to 1.3 g/km. Despite this, using Bardahl Full System Injector Cleaner is not cost-effective, as it requires more than two application cycles. Its slow, cumulative effect is a weak point compared to PEA-based formulations [14].

Mannol Injection Reiniger showed the least positive effect. Its limited ability to remove stubborn deposits – due to its composition and cleaning limitations – results in fuel consumption of up to 7.2 litres per 100 km. The reason for this poor performance is that it merely temporarily dissolves the carbon deposits rather than removing them. Dissolving carbon deposits rather than completely removing them can lead to negative consequences and the risk of secondary contamination of the filter elements [9,20]. As a result, prolonged use of Mannol Injection Reiniger can adversely affect fuel injector performance [7,14].

Based on the study's findings, a directly proportional relationship can be established between the degree of fuel system cleanliness and the engine's technical and environmental performance [7,14,20]. Low fuel consumption, reduced harmful emissions, and lower vibration loads depend on the level of contamination during engine operation [4,7,19]. It is worth noting that vehicles with an average mileage of over 60,000 km are most susceptible to this phenomenon, as the accumulation of lacquer and carbon deposits becomes more pronounced with increasing mileage

[9,20].

Based on the above, the following conclusion can be drawn: Chevron Techron is the most environmentally friendly, economical, and effective fuel additive. Bardahl has proven itself effective for moderate levels of contamination and for preventive maintenance. Mannol can only be used in the early stages as a temporary, budget-friendly solution when there is no serious contamination of the engine's fuel system.

Conclusion

The study of fuel additive efficiency in the 1.4 TSI (EA211) engine identified significant differences in their effects on operational and environmental parameters. Based on the analysis of empirical data obtained under combined cycle conditions (city/highway) with a mileage of 80,000 km, the following conclusions were formulated:

1. Optimisation of performance characteristics.

Polyetheramine (PEA) based additives have demonstrated maximum efficiency:

- reduction in fuel consumption by 5.3% (from 8.5 to 8.0–8.1 l/100 km).
- increase in power by 7.2% due to the removal of carbon deposits from the valves and restoration of the injector spray geometry.
- reduction of vibration amplitude at idle speed by 39%, which indicates stabilisation of engine operation.

2. Ecological effect.

The use of PEA-containing compounds (Liqui Moly Jectron, Chevron Techron) ensured:

- reduction of CO_2 emissions by 7.3% (from 145 to 133–136 g/km).
- reduction of NOx concentration by 15.6% (from 45 to 38–40 mg/km).

These results comply with the requirements of the Euro 6 standard and confirm the possibility of using additives to adapt engines to increasingly stringent environmental standards.

3. Critical limitations of budget analogues.

Mineral solvent-based products (Mannol Reiniger, STP Jet Tech):

- increased fuel consumption by 1.2% due to incomplete combustion of the mixture.
- increased emissions of toxic substances (benzene, soot) by 1.1%.
- demonstrated low cleaning capacity (<30% efficiency).

4. Economic feasibility.

A comparative analysis showed that the regular use of PEA additives (every 5–7 thousand km) reduces operating costs:

- fuel economy: 250,000-300,000 tenge/year (for 250 tenge/l and a mileage of 15,000 km/year).
- reduced repair costs: preventing coking of valves and injectors reduces the likelihood of expensive mechanical cleaning.

Recommendations for practical application:

For engines with direct injection and a mileage of up to 150,000 km, PEA-containing additives are preferable.

Compositions with kerosene components are not recommended due to the risk of damage to the catalytic converter.

Before use, it is necessary to diagnose the condition of the fuel system: in case of severe contamination, a combined approach is required (chemical + ultrasonic cleaning).

This study confirms that rational selection of fuel additives is an effective tool for extending the service life of TSI engines, in line with the automotive market's continued dominance of ICEs.

Further research should focus on the long-term effects of combining additives with biofuel mixtures.

The contribution of the authors:

Bolat R.M. – concept, methodology, analysis, interpretation, editing.
Balgabekov T.K. – data collection, testing, modeling, drafting, analysis.
Rustembayev A.B. – resources, data collection, analysis, drafting, editing.
Zharassov Sh.Zh. – visualisation, interpretation, editing.

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