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Fuel Additive Strategies for Petrol: A Comparative Review of Antioxidants, Corrosion Inhibitors, Ethanol Additives and Octane Boosters

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ABSTRACT

Petrol is a chemically complex fuel whose storage stability, combustion quality, material compatibility and emissions are strongly influenced by fuel composition and additives. This paper presents an integrated literature-based assessment of four important additive strategies: antioxidants, corrosion inhibitors, ethanol-based fuel additives and octane boosters. Forty supplied studies were reorganized into a common framework so that these technologies can be considered as interacting parts of fuel formulation rather than isolated topics. The literature indicates that fuel quality is multidimensional. Ethanol can improve octane quality while increasing the importance of water management and corrosion control; alternative blendstocks can offer attractive combustion properties while requiring stabilization against oxidation; and octane boosters must be assessed by actual RON/MON response rather than additive concentration alone. Antioxidants mainly suppress radical oxidation and the formation of degradation products, whereas corrosion inhibitors protect metallic surfaces through adsorption, passivation and related chemical effects. Recent research also shows growing interest in renewable or biomass-derived additives. On the basis of the combined evidence, this paper proposes an experimental framework in which oxidation stability, corrosion protection, octane response, engine performance and emissions are evaluated together. The main research opportunity is the development of a compatible multifunctional additive package that provides a balanced improvement in fuel quality without unacceptable trade-offs.

Keywords: *petrol; gasoline; fuel additives; antioxidants; corrosion inhibitors; ethanol; octane boosters; oxidation stability; corrosion; RON; MON.*

1. INTRODUCTION

Modern petrol must satisfy several requirements simultaneously: reliable ignition, resistance to abnormal combustion, storage stability, compatibility with fuel-system materials and acceptable emissions. These requirements become more complex as oxygenated and renewable blendstocks are introduced. Fuel additives are therefore better viewed as functional tools for controlling fuel chemistry than as simple performance enhancers.

The literature supplied for this study covers four connected functions. Antioxidants address chemical deterioration during storage. Corrosion inhibitors protect tanks, lines, pumps and other metallic components. Ethanol and related oxygenates influence octane quality, combustion and emissions. Octane boosters are used to increase resistance to knock. In real fuel formulations these functions overlap. An additive that improves one property may affect another.

Christensen et al. showed that alkylated furans such as 2-methylfuran and 2,5-dimethylfuran can have attractive fuel properties but poor oxidative stability, producing oxidation products and gums [1]. This illustrates why high-octane or renewable blendstocks cannot be evaluated only by their combustion value. Similarly, studies of ethanol-gasoline systems show that corrosion and octane response depend on blend composition and contaminants [28,37,39,40].

The purpose of this paper is to combine the supplied evidence into an original, publication-oriented analysis. The wording and organization are newly developed for this paper; the cited studies are used as supporting literature rather than reproduced text.

2. OBJECTIVES

- To synthesize the 40 supplied papers on antioxidants, corrosion inhibitors, ethanol additives and octane boosters.
- To explain the chemical and engineering mechanisms behind the reported fuel-additive effects.
- To compare benefits, limitations and experimental approaches across additive classes.

- To identify interactions between oxidation stability, corrosion protection, octane quality and engine performance.
- To identify research gaps suitable for a future experimental publication.
- To propose a practical methodology for testing a multifunctional petrol additive package.

3. LITERATURE REVIEW METHODOLOGY

This work is a structured narrative synthesis, not a report of new laboratory measurements. The 40 supplied references were classified into antioxidant/oxidation studies [1–5,32–34], corrosion-inhibition studies [6–10,35–40], ethanol and gasoline-blend studies [11–15,21–25,28–31], and octane/fuel-additive studies [16–20,26–30].

For each paper, the analysis considered the fuel system, additive type, principal measured property, experimental approach and practical implication. Because the studies use different fuels, concentrations, temperatures, engines and test standards, their numerical values should not be combined as though they came from one experiment. The present paper therefore emphasizes mechanisms, trends, compatibility and research design.

Before journal submission, every bibliographic record should be checked against the final publisher version, especially entries supplied with abbreviated journal information or incomplete page details.

4. ANTIOXIDANTS AND OXIDATION STABILITY OF PETROL

4.1 Oxidative degradation

Petrol can slowly react with oxygen during storage. Radical reactions may produce hydroperoxides and secondary oxygenated compounds, followed by acids, aldehydes, ketones and high-molecular-weight material. The practical consequences can include gum formation, deposits and changes in fuel quality. Reactive alternative blendstocks can increase this risk.

The work of Christensen et al. is important because it connects molecular structure with storage behavior. Their investigation of alkylated furans found substantially poorer oxidation stability than conventional gasoline and identified pathways leading to polar products, dimers and higher polymers [1]. The study also showed that antioxidant treatment can reduce oxidation, although the concentration required may be higher than for conventional gasoline components.

4.2 Antioxidant mechanism

Many fuel antioxidants interrupt radical chain reactions. Phenolic antioxidants can donate hydrogen to reactive radicals and form comparatively stable antioxidant-derived radicals, thereby slowing propagation. Performance depends on molecular structure, concentration, temperature, oxygen availability and the rest of the fuel formulation.

Le et al. investigated 2,4-xylenol and reported a strong antioxidant effect in liquid-phase fuel-surrogate experiments at low additive levels, while the tested additive did not substantially alter the principal gas-phase combustion characteristics [32]. Veliyeva et al. studied new fuel-antioxidant candidates, while Radoykova et al. investigated lignin-derived methoxyphenols [33,34]. These studies support interest in renewable-origin antioxidant chemistry.

4.3 Practical formulation

Antioxidant performance should be treated as a property of the complete fuel rather than the additive alone. A compound effective in a model fuel may behave differently in commercial petrol containing olefins, aromatics, oxygenates and trace contaminants. The practical target is the minimum effective concentration that provides an adequate storage margin without causing incompatibility or unnecessary cost.

5. CORROSION INHIBITORS FOR PETROL AND ETHANOL-GASOLINE BLENDS

5.1 Corrosion problem

Fuel-system corrosion can affect tanks, fuel lines, pumps, injectors and fittings. Ethanol-containing fuels deserve particular attention because ethanol changes the polarity and water-management behavior of the fuel. Acetic acid, chloride and dissolved oxygen can intensify electrochemical attack. Even a small corrosive aqueous phase can become important at the metal-fuel interface.

The supplied corrosion literature includes conventional mild-steel systems [6–10] and more application-oriented ethanol-gasoline studies [35,37,39,40]. Conventional corrosion studies help explain adsorption and surface protection, while ethanol-gasoline work shows how these mechanisms behave in low-conductivity fuel environments.

5.2 Inhibition mechanisms

Organic inhibitors can adsorb on metal surfaces and block active corrosion sites. Nitrogen-, oxygen- and sulfur-containing molecules can interact with the surface, while molecular structure and charge influence adsorption. Some inhibitors also modify the local chemical environment or promote a protective passive layer.

Parveen et al. demonstrated a sustainable L-proline/sodium-benzoate approach for mild steel in acidic solution [6]. Other supplied studies examine polymers, pharmaceutical molecules and designed organic inhibitors [7–10]. These studies collectively show that inhibition efficiency depends on both molecular structure and corrosive medium.

5.3 Ethanol-gasoline corrosion

Matějovský and co-workers provide particularly relevant evidence for ethanol-gasoline blends. Their work evaluated several amines and showed that molecular structure strongly affects corrosion inhibition [39]. A broader study combined electrochemical impedance, polarization, surface analysis and long-duration immersion testing, demonstrating the value of using multiple methods rather than a single short-term measurement [37].

A practical corrosion inhibitor must remain soluble, protect relevant metals under realistic water/acid/chloride contamination, remain effective during storage, and avoid deposits or adverse interactions with other additives.

6. ETHANOL AS A PETROL ADDITIVE

6.1 Fuel and combustion role

Ethanol is widely investigated because of its high octane quality and renewable production potential. Engine studies in the supplied literature report changes in performance and exhaust emissions with ethanol blending [11–15,21–25]. The magnitude and direction of these changes depend on blend ratio, engine design, speed, load, compression ratio and calibration.

Efemwenkiekie et al. compared local ethanol-gasoline blends in a four-stroke spark-ignition engine [11]. Abdullah et al. examined engine performance and emissions [12], while Gupta et al. investigated bioethanol produced from Salvinia molesta [13]. More recent studies extend the analysis to prediction models and fuel-jet effects [14,15].

6.2 Octane response

Ethanol does not have a universally linear octane blending response. AlRamadan et al. measured RON and MON for ethanol with several gasoline surrogate compositions and found synergistic, near-linear or antagonistic behavior depending on the base fuel [28]. Badra et al. similarly investigated optimization of the octane response [29]. This means ethanol concentration should be selected with reference to the chemistry of the base gasoline.

6.3 Engine performance and emissions

Because ethanol has different energy content and physical properties from gasoline, blending can alter fuel consumption and engine output. At the same time, increased knock resistance can create opportunities for different engine operating strategies. Iodice and Cardone reviewed CO and HC behavior, while Kozak et al. investigated high-ethanol gasoline in a direct-injection SI engine [23,24]. The practical response therefore depends on both fuel chemistry and engine control.

6.4 Limitations

Ethanol should not be evaluated only as an octane enhancer. Water sensitivity, corrosion, phase behavior, material compatibility, storage stability and emissions must be considered together.

7. OCTANE BOOSTERS AND ANTI-KNOCK PERFORMANCE

Octane number represents resistance to knock under standardized conditions. RON and MON represent different test conditions, while octane sensitivity describes the difference between them. An additive should therefore be evaluated by the actual octane response of the selected base fuel.

The supplied literature includes iso-octane-assisted ethanol blends, locally developed octane enhancers and broader fuel-additive studies [16–20]. Delvi et al. examined ethanol-gasoline blends with iso-octane, while Sheet reported an octane-enhancer study in an SI engine [16,17]. Muhaisen and Hokoma linked fuel additives with spark-ignition engine performance [19].

The main lesson is that a high laboratory octane value is not sufficient by itself. The preferred additive should improve anti-knock quality while maintaining acceptable stability, emissions, deposits, corrosion behavior and cost.

8. INTEGRATED ANALYSIS

The four additive functions are connected in an actual petrol formulation. Antioxidants address storage chemistry; corrosion inhibitors address material protection; ethanol can contribute octane and renewable content; and octane boosters target knock resistance. These effects can interact.

Antioxidant–ethanol interaction: reactive oxygenated blendstocks can require additional stability control, so oxidation testing should be performed on the final blend rather than on each ingredient alone [1,32].

Corrosion inhibitor–ethanol interaction: ethanol-gasoline blends can become aggressive under contamination, while suitable amines can substantially reduce corrosion [37,39,40].

Octane booster–antioxidant interaction: a blendstock selected for high octane should also be evaluated for storage stability. An anti-knock benefit is less useful if the component forms degradation products during storage.

Additive compatibility is therefore a central issue. Individual additive results cannot automatically be added together. The combined package must be tested directly.

9. COMPARATIVE LITERATURE SYNTHESIS

The supplied studies show a progression from single-property testing toward more integrated fuel research. Antioxidant studies emphasize molecular stability and storage. Corrosion studies emphasize adsorption, passivation and contamination. Ethanol studies connect fuel chemistry with engine performance and emissions. Octane studies demonstrate that blending behavior depends strongly on base-fuel composition.

Another important pattern is the use of complementary methods. Chemical analysis identifies oxidation products; electrochemical tests quantify corrosion behavior; RON/MON tests quantify anti-knock quality; and engine tests reveal practical performance. A strong future publication should connect these scales instead of relying on one measurement.

The literature also points toward renewable additive candidates, including bioethanol, lignin-derived antioxidants and alternative blendstocks [13,32–34]. Renewable origin, however, should be considered together with toxicity, storage, volatility, materials compatibility and overall environmental impact.

10. PROPOSED EXPERIMENTAL METHODOLOGY

The following framework is proposed for future experimental validation. It is not claimed as new experimental data in the present review.

10.1 Fuel formulation

Select a well-characterized commercial petrol as the base fuel. Prepare controlled ethanol blends and then evaluate an antioxidant and corrosion inhibitor individually and together. A candidate octane booster can be introduced as a second-stage variable. Prepare duplicate or triplicate samples using calibrated equipment.

10.2 Oxidation stability

Measure oxidation stability using an appropriate standardized accelerated method, such as a PetroOxy-type procedure. Test fresh samples and controlled-aged samples. Where possible, monitor gum formation, acidity or peroxide-related indicators to identify the nature of degradation.

10.3 Corrosion testing

Expose mild steel and, where available, representative fuel-system metals to each formulation. Use electrochemical impedance spectroscopy and polarization for mechanistic information, followed by immersion testing, mass-loss measurement and surface characterization. The combination is supported by the ethanol-gasoline corrosion literature [37,39].

10.4 Octane and engine testing

Measure RON and MON where facilities permit. Engine tests should control speed, load and fuel temperature. Record brake power, thermal efficiency, specific fuel consumption and exhaust CO, HC and NOx. Compare the base fuel, ethanol blend, additive-treated fuel and combined package.

10.5 Experimental design and statistics

A factorial or response-surface design is preferable because additive interactions are important. Factors may include ethanol level, antioxidant concentration and inhibitor concentration. Use replicate measurements, report mean and standard deviation, and apply ANOVA or regression to identify significant effects. Predictive models should be independently validated rather than assessed only on the data used to fit them.

11. EXPECTED OUTCOMES AND SCIENTIFIC SIGNIFICANCE

The proposed study should identify whether one formulation can provide a balanced improvement in storage stability, corrosion resistance and anti-knock quality without unacceptable engine or emissions penalties. The optimum formulation should not necessarily be the one with the maximum value for a single property; it should provide the best overall performance.

A second outcome would be identification of additive interactions. A formulation may show excellent octane improvement but poor stability, or strong corrosion protection but undesirable deposit behavior. Quantifying these trade-offs would provide a stronger basis for practical formulation.

The scientific significance lies in connecting fuel chemistry, electrochemical protection and combustion behavior within one experimental framework. This can support development of higher-ethanol fuels and alternative blendstocks while maintaining fuel-system reliability.

12. RESEARCH GAPS

- Few studies evaluate oxidation stability, corrosion inhibition and octane response simultaneously in the same petrol formulation.
- More long-duration corrosion tests are needed with realistic ethanol-gasoline contamination.
- Octane models require broader databases covering different base-fuel compositions.
- Short-term oxidation tests should be linked with longer storage and contamination studies.
- Interactions between antioxidants, corrosion inhibitors, ethanol and octane boosters remain insufficiently characterized.
- Fuel-system component testing should be connected to standardized fuel-property measurements.
- Renewable additives require combined technical, environmental and economic evaluation.
- Engine tests should be linked directly with RON/MON and stability measurements.

13. ENVIRONMENTAL AND PRACTICAL CONSIDERATIONS

An additive should be judged not only by its technical performance but also by dosage, safety, compatibility, cost and environmental consequences. A renewable-origin additive is not automatically preferable if it introduces major toxicity, corrosion or emissions problems. Conversely, a conventional additive may be useful if it achieves the required function at very low concentration and with acceptable environmental behavior.

The practical objective is a stable, compatible and economical additive package. High concentrations should not be assumed to be better. The most useful formulation is generally the lowest concentration that provides a reliable performance margin under the intended storage and engine conditions.

14. LIMITATIONS

This paper is a focused literature synthesis of the 40 supplied references rather than a systematic review of every available publication. The studies differ in fuel composition, experimental scale, standards and operating conditions, so their numerical results should not be pooled directly.

No new experimental results are claimed. The methodology and expected outcomes are proposed for future validation. Before journal submission, each reference should be checked against the publisher record and the final manuscript should be adapted to the target journal's author guidelines.

15. CONCLUSION

Petrol quality is a balance among chemical stability, material compatibility and combustion performance. The 40 studies considered here show that antioxidants, corrosion inhibitors, ethanol and octane boosters address different parts of this problem, but their effects cannot be considered independently.

Antioxidants can protect reactive fuel components from storage deterioration. Corrosion inhibitors become particularly important in ethanol-containing systems exposed to water, acids and chloride. Ethanol provides a useful octane and renewable-blending route, but its response depends on base-fuel chemistry and it increases the importance of corrosion and storage control. Octane boosters can improve anti-knock quality, but their value must be confirmed by standardized octane testing and, where possible, engine experiments.

The strongest research direction emerging from the literature is multifunctional additive-package design. A future experimental study should use a common base petrol, controlled additive concentrations, oxidation testing, electrochemical and immersion corrosion measurements, RON/MON evaluation and engine performance/emission testing. Statistical experimental design should be used to quantify interactions.

Overall, the literature supports development of a balanced petrol additive system that simultaneously improves storage stability, protects fuel-system metals and maintains or improves octane and engine performance. This integrated approach is more practically relevant than optimizing a single fuel property in isolation.

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