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Problems of filtration and standardization on parameter conformity of diesel fuels containing decarbonization components and processing impurities

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The use of alternative fuels and fuel components derived from organic and inorganic waste enables progress toward the goals set by decarbonization policies and environmental protection, but on the other hand, it presents a number of challenges related to maintaining the operational quality of these fuels. This primarily involves achieving normative physico-chemical parameters for newly formulated blends intended for powering automotive engines, as well as identifying and effectively removing both solid and liquid contaminants specific to each fraction (component). Information concerning the chemical composition and purity of individual fuel components is essential in the context of formulating substitute fuels. This article presents the results of comparative studies on the amount of contaminants found in substitute fuel components such as hydrotreated vegetable oil (HVO), tire pyrolysis oil (TPO), and plastic-derived pyrolysis oils – polypropylene pyrolytic oil (PPO) and polystyrene oil (PSO). For diesel fuel and substitute fuels, microfiltration was carried out using membrane filters to determine the quantity of solid impurities. The aim of the study was to assess the feasibility of using these types of fuels either on their own or in blends with diesel fuel, under the assumption that they would be used directly after processing to power compression ignition engines. The research showed that the distillation process of pyrolytic oils significantly reduces the content of process-related impurities. The greatest reduction was observed for PPO, where after filtering a 50 ml sample the level of contaminants after distillation and ashing decreased from approximately 23 mg to a value close to zero.

Key words: *process contaminants, filtration, diesel fuel, hydrotreated vegetable oil (HVO), waste-based pyrolytic oils*

1. Introduction

The absence of contaminants in fuels used to power internal combustion engines is one of the most critical requirements that such fuels must meet. This is particularly important for compression ignition engines due to their high operating pressures and the extremely precise tolerances of fuel system components. Fuel injection systems used today are built to extremely precise standards and operate under very high pressure. Because of that, they are easily affected by even tiny traces of contaminants – whether solid particles or liquid residues. When such impurities get into the system, they can cause wear and tear much faster than expected, damage delicate parts, or block narrow channels. This can end up lowering engine performance, raising emissions, and leading to more frequent or expensive repairs. In this context, the presence of any foreign substances – whether particulate, chemical, or microbiological – poses a significant risk to engine reliability and durability. Therefore, these factors necessitate effective fuel filtration – not only to remove solid and microbiological contaminants but also to eliminate water, which can cause corrosion, irregular combustion, accelerated microbial growth, and degradation of fuel quality during storage and operation [24]. Effective filtration becomes even more crucial when dealing with alternative or waste-derived fuels, which may contain unique contaminants resulting from their specific production processes.

Fuel contamination is not just a problem once the fuel reaches the engine – it can start much earlier, right at the point of delivery. Tanks, pipes, and even fuel nozzles at stations are not always perfectly clean. Over time, tiny bits of rust, moisture, or grit can build up, and during refueling, some of that stuff can easily get into the vehicle's tank. It might not seem like much, but it can cause real trouble down the line. Modern injection systems, especially common rail types running at over 2000 bar, are incredibly sensitive. They are built with extreme precision, and unfortunately, that means even the smallest particles can do damage. Tests and field data have shown that one of the biggest threats to these systems comes from very small, hard particles – often inorganic. They are sharp enough to gradually wear out injectors, valves, and other precision components. As wear adds up, fuel delivery becomes inconsistent. That throws off combustion, leads to more emissions, and overall, the engine just does not perform like it should.

These days, there is growing pressure to cut down on harmful emissions like nitrogen oxides (NO_x), carbon monoxide (CO), unburned hydrocarbons (HC), particulate matter (PM), and carbon dioxide (CO_2) – which is widely recognized as a major contributor to climate change [16]. With environmental rules getting tougher and the public demanding cleaner solutions, researchers and engineers have been turning more and more to renewable fuels and bio-based additives. What makes this option appealing is that it does not require overhauling existing engines. In most cases, only small changes to things like injection timing, air-fuel ratio, or exhaust gas recirculation are needed [19]. So, instead of replacing entire systems, we can work with what we already have. This makes renewable fuels a realistic way to lower emissions in transportation without massive costs or disruptions to current infrastructure.

Mixing bio-components into fuel can change how it behaves in more ways than one. The fuel might get thicker, and water can behave differently – sometimes staying suspended longer or forming larger droplets. How much this happens depends a lot on how the liquids interact on a surface level, like their tension [2]. These changes can be subtle but still affect how the fuel performs. People working with engines – especially in real-world settings – have noticed that biodiesel tends to plug up filters sooner than regular diesel. That seems to happen more often when there's more water involved. The way biodiesel flows and how it moves through filter media probably has something to do with it [11].

Moreover**,** the degradation process of biodiesel leads to the formation of soft particles that negatively impact filtration efficiency [4, 5, 8]. Reports from users regarding clogged fuel filters [12] and damaged engine components have prompted the development of solutions aimed at mitigating the adverse effects of biocomponent usage. One such solution is the implementation of multi-stage filtration systems, which can significantly extend filter service life [9].

Despite ongoing research, the impact of biodiesel on the filtration process remains insufficiently understood [20]. Even less is known about the behavior of newer fuel additives containing decarbonizing components such as hydrotreated vegetable oil (HVO), pyrolytic oils from used tires (TPO), and plastic-derived oils, including polypropylene pyrolytic oil (PPO) and polystyrene oil (PSO), along with the process-related contaminants associated with their production.

Some newer approaches to removing water from fuel include filters made with graphene-based materials – which are also known for their ability to kill bacteria [7]. Another solution uses filters built from fine polypropylene (PP) and polyamide (PA6) fibers. These are made using co-extrusion and delamination methods. In lab tests, they have shown better water separation than standard commercial filters, with results ranging from about 62% to 85% under the same testing conditions [22, 23].

One of the other problems that can come up when using biodiesel is contamination from glycerides – these can end up clogging fuel filters. Even a small amount of monoglycerides in the fuel can cause buildup, especially when temperatures drop [17]. Some tests [14, 15] using filters with different pore sizes – along with a modified version of the CSFT method (ASTM D7501) – showed that filters with bigger pores tend to collect fewer deposits.

At the same time, researchers have looked into whether certain materials can help improve biodiesel filterability. One study [1] tested several common adsorbents – including activated carbon, silica, and sand. Out of those, activated carbon worked best.

But monoglycerides aren't the only issue. Other substances, like sodium soaps and free sterol glycosides, also play a role in shortening filter life. According to another study [3], current fuel standards don't fully cover these problems, and there is a growing case for updating regulations to better protect fuel systems running on biodiesel.

Some studies have explored how less conventional plant oils – like karanja or palm – perform when used in fuel blends [13]. Since these oils usually come from non-edible sources, they are often seen as a good option for scaling up biofuel production without cutting into the food supply. Still, their chemical makeup is different from what is used in more common feedstocks, and that can bring up new issues with fuel cleanliness. For karanja oil in particular, research shows that doing things like esterification, transesterification, or degumming can help. These treatments reduce the amount of sticky compounds – like gums, polar residues, or heavier materials – that tend to block filters [21]. These refining steps improve fuel stability and mitigate the formation of deposits that can obstruct fuel flow under operational conditions. For example, study [20] observed that the tendency to clog the FBT filter increased exponentially with higher biodiesel content in the blend, emphasizing the sensitivity of filtration systems to biodiesel-induced contamination. Tests showed that filters used with biodiesel had about 35% more pressure drop than those with regular diesel. In simple terms – the fuel had a harder time flowing, and filters wore out quicker. That might not matter much everywhere, but in places with high biodiesel use or seasonal blends, it could turn into a real issue. On the other hand, research [13] showed that diesel locomotives running on a 20% biodiesel–palm oil mix were still filtering well after 125 hours of generator use or even after three months of traction service. So, with the right blending and processing, biodiesel can hold up well – even in tough, long-running conditions. It all comes down to making sure that processing steps match the type of feedstock used. When that is done right, it is possible to get both good engine performance and real environmental gains.

To quantitatively evaluate how effectively fuel filters retain contaminants, researchers employ a variety of analytical techniques. These include gas chromatography–mass spectrometry (GC-MS), X-ray fluorescence spectroscopy (XRF), Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM/EDX). Thermogravimetric analysis (TGA) is also commonly used for this purpose [4, 5].

Lab tests are useful, no doubt, but they can not always show what is really going on inside the filter. So, in a lot of cases, researchers build math-based models to help them get closer to the actual behavior [6]. These tools let them try out different combinations – fuel blends, particle size, filter material – to see what happens when everything interacts. Not under perfect conditions, but more like what would be got in the real world. It is not always exact, but it is enough to find weak spots or make early design changes that would take a lot longer to test in practice. By accounting for factors such as fluid flow dynamics, particle size distribution, mechanisms of pore blockage, and pressure drop evolution, these models support the development of filtration systems that are both more efficient and more durable. Furthermore, predictive modeling helps reduce the time and cost of empirical testing by narrowing the range of design options before physical prototypes are constructed and validated. Nevertheless, despite these advancements, the filtration of fuels containing a wide range of additives remains a poorly understood issue that requires further detailed investigation. The growing diversity of renewable and waste-derived fuel components introduces an array of contaminant types with distinct physical and chemical properties, which may behave differently from those encountered in conventional fossil-based fuels. Some of these contaminants come from leftover by-products, materials that break down during processing, or particles that get in from raw materials or equipment. The way they interact with filter materials is still not fully understood, which makes it hard to reliably predict how well a filter will perform when different types of alternative fuels are used.

The primary objective of this study is to conduct a comparative analysis of contaminants present in selected waste-derived substitute fuels, namely hydrotreated vegetable oil (HVO), polypropylene pyrolysis oil (PPO), polystyrene pyrolysis oil (PSO), and waste tire pyrolysis oil (TPO) – in relation to conventional diesel fuel. Too many contaminants in fuel can shorten the service life of filters – both in fueling equipment at stations and inside engine systems. This not only drives up maintenance costs but also puts long-term equipment reliability at risk. In more serious cases, especially where high-precision fuel injection is used, heavy contamination may lead to unexpected breakdowns or even major engine damage. Since this area is still not well understood, and considering how strongly fuel quality affects engine performance, there is a clear need for more detailed research. Solid, real-world data are necessary – not just to help shape fuel blending guidelines, but also to support better design of filtration systems. That kind of knowledge will be key to safely and effectively including waste-based fuels in today’s fuel distribution networks.

2. Research methodology

The first stage of the study focused on determining the mass of solid contaminants. Mass measurements were performed using a RADWAG WAA40/160/X/1 analytical laboratory balance, characterized by a readability of 0.01 mg and repeatability of 0.02 mg. Each fuel sample was tested in duplicate, and the results for mass and filtration time were averaged. A proprietary testing methodology was developed based on the ISO 4020 procedure.

The determination of solid impurities involved forced filtration of 50 ml of fuel through an ashless cellulose acetate (CA) membrane filter with a diameter of 47 mm and a pore size of 0.8 μm, under a vacuum of 80 kPa ±1 kPa. A standard laboratory vacuum filtration setup was used (Fig. 1), following the procedure below.

Measurement of the mass of a porcelain crucible used to hold the filter membrane:

- measurement of the crucible with the membrane prior to filtration
- placement of the membrane on the sintered disc of the vacuum filtration apparatus
- filling the glass filtration funnel with 50 ml of the test fuel
- activation of the vacuum pump and adjustment of the vacuum pressure to 80 kPa ±1 kPa
- initiation of the filtration process with simultaneous timing of the filtration duration
- transfer of the membrane into the porcelain crucible post-filtration
- measurement of the crucible mass with the membrane after filtration
- drying the crucible with the membrane at 100°C for 1 hour
- cooling of the crucible in a desiccator
- measurement of the crucible mass after drying
- placement of both the post-filtration and clean membranes in crucibles onto a hot plate heated to 550°C ±5°C for preliminary ashing
- transfer of the crucibles to a muffle furnace at 800°C ±20°C for 2 hours
- removal of the crucibles from the furnace and cooling in a desiccator for 1 hour
- measurement of the crucible masses with the ash residues
- calculation of the mass of solid contaminants based on the difference in mass before and after ashing.

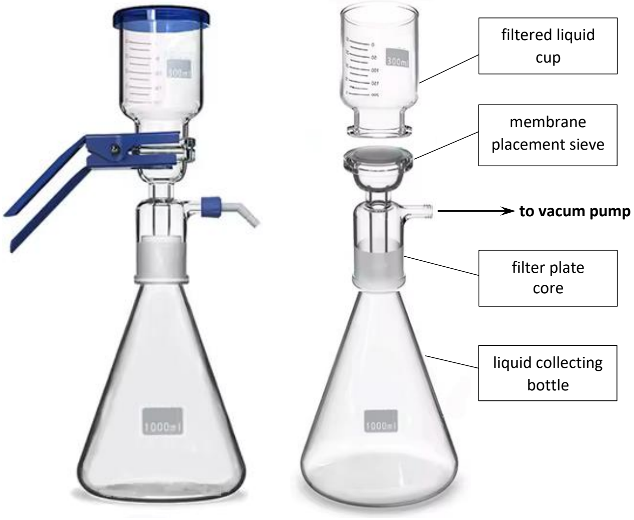

Fig. 1. A standard laboratory vacuum filtration setup used to sedimentation tests; assembled view (at left); component view (at right)

Comparative testing was performed for conventional diesel fuel and selected waste-derived substitute fuels: HVO, PPO, PSO, and TPO.

This selection of fuels represents a broad spectrum of chemical compositions and production technologies, each associated with distinct impurity profiles. Hydrotreated vegetable oil (HVO), produced via catalytic hydrotreatment, typically contains minimal contaminants due to extensive processing steps. In contrast, pyrolysis-derived oils such as PPO, PSO, and TPO generated through thermal decomposition of plastic waste or end-of-life tires can retain significant amounts of process-related impurities, including unconverted feedstock residues, oligomers, char particles, and various organic compounds. The physico-chemical properties of the tested fuels, as well as the production technologies of the waste-derived fuels, were previously reported by the authors [10, 18], providing a comprehensive basis for understanding their behavior in filtration processes.

In the second stage of the study, atmospheric distillation was performed in accordance with the standard PN-EN ISO 3405, Petroleum and related products of synthetic or natural origin – Determination of distillation characteristics at atmospheric pressure, for PSO, TPO, and PPO. The application of this distillation process was aimed at simulating industrial-level purification steps to assess the potential of reducing contaminant loads in these fuels through relatively simple thermal separation methods. By removing the most volatile and heavy fractions, the distillation process was expected to concentrate residual contaminants and allow for a more accurate quantification of the solid impurity content remaining in the fuel.

The measurements were carried out using an OptiDist distillation apparatus (Fig. 2), which was configured according to Group 4-a configuration representative of diesel fuel – thus maintaining consistent instrument settings across all fuel samples. This standardized configuration ensured that variations in distillation behavior and residual contamination could be attributed solely to the intrinsic properties of the fuels themselves rather than to differences in test methodology. The ability to apply identical distillation parameters to both conventional and substitute fuels allowed for direct comparability and provided an objective basis for evaluating the efficacy of distillation as a contaminant-reduction technique.

Fig. 2. OptiDist distillation apparatus used to perform atmospheric distillation tests

Following the distillation process, the mass of residual contaminants in the waste-derived fuels was determined. The visual assessment of the post-distillation samples (Fig. 3) revealed notable differences in clarity and sediment content, which were indicative of the varying efficiency of impurity removal across the different fuel types. The distilled fuels were designated as follows: PSO-D, TPO-D, and PPO-D, each representing the respective distillate fraction after thermal processing. This nomenclature was adopted to distinguish between the raw and purified forms of each substitute fuel throughout the subsequent filtration analyses.

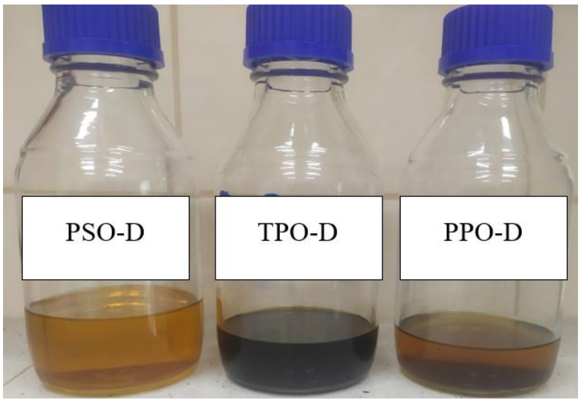

Fig. 3. Fuel samples after distillation, for which the mass of contaminants was determined

3. Analysis of research results

The objective of the study was to conduct a comparative analysis of contaminant levels in waste-derived substitute fuels relative to conventional diesel fuel, using a vacuum-assisted filtration system designed to quantify solid impurities. This method enabled a direct evaluation of the filtration load imposed by each fuel type, reflecting their respective purity levels and potential operational risks for fuel systems. Figure 4 presents the appearance of the filtration membranes following the filtration process for diesel fuel and the analyzed substitute fuels. The degree of membrane darkening serves as a visual indicator of contaminant concentration, with progressively darker membranes suggesting greater amounts of retained particulate matter. Among the tested fuels, the membrane corresponding to PPO displayed the most pronounced darkening, indicating the highest concentration of solid contaminants in this fuel. This qualitative observation was fully consistent with the quantitative results obtained from mass measurements of the retained impurities (Fig. 5), confirming PPO as the most heavily contaminated among the tested samples. Furthermore, these results were corroborated by the recorded filtration times (Fig. 6), which serve as an additional proxy for filter loading and flow resistance. Fuels with higher contaminant content exhibited longer filtration durations, reflecting increased membrane fouling and reduced permeability under the applied vacuum conditions.

As illustrated in Fig. 5, PPO resulted in the most substantial deposit on the membrane, with a recorded mass of 1.4310 g. This considerable buildup indicates a high impurity load in pyrolysis oil derived from polypropylene. The likely sources of these residues include incomplete breakdown of feedstock, carryover of solid particles, or condensation of heavier organic compounds during the thermal process. Supporting this, the filtration of PPO required over two hours to complete, as shown in Fig. 6, highlighting severe membrane obstruction and restricted flow. In real-world systems, such conditions would likely lead to rapid filter clogging in engines and fuel dispensers.

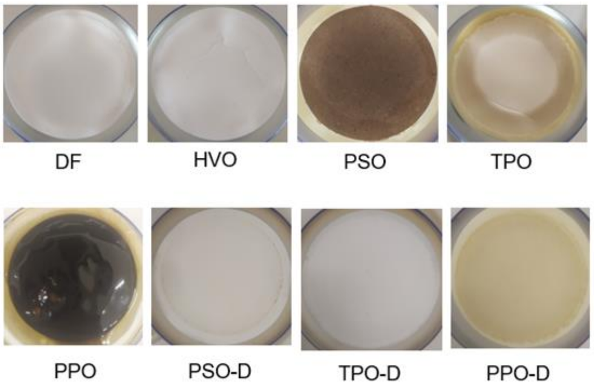

Fig. 4. Filtration membranes after the filtration process

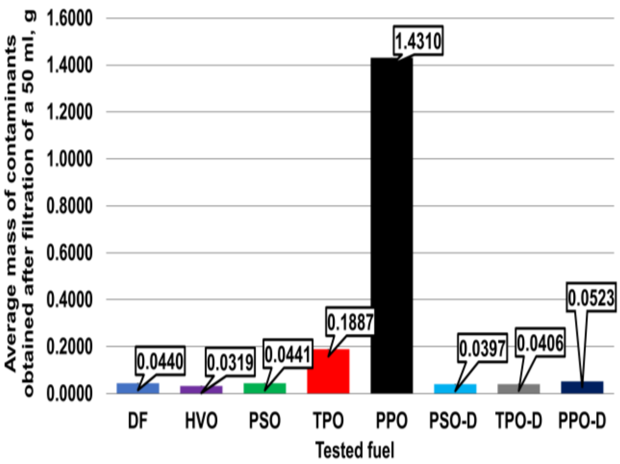

Fig. 5. Average mass of contaminants after filtration

When compared with diesel, PPO left behind a significantly larger amount of solid residues – 1.3870 g more – indicating a clearly higher filtration burden. For TPO, the retained contaminant mass reached 0.1890 g, which is 0.1450 g above the diesel benchmark. Although pyrolysis oil derived from used tires still contains a notable level of impurities, the overall load remains much lower than that associated with PPO. This difference is likely tied to variations in feedstock composition as well as operational settings during thermal conversion. The filtration process for TPO also took longer than for diesel, by approximately 1.0 ±0.1 s, pointing to a moderate increase in membrane resistance. In contrast, HVO demonstrated the cleanest profile. The amount of material deposited on the membrane for this fuel averaged 0.0319 g, which is 0.0121 g less than the value observed for diesel. This aligns with the high purity typically achieved during hydrotreatment. With such a low contaminant load, HVO can be regarded as a clean, low-risk fuel in terms of filtration system wear and performance.

In the following stage of the study, attention was turned to the distilled fuel samples – PSO-D, TPO-D, and PPO-D. After undergoing atmospheric distillation, all three fuels showed a clear drop in the amount of contaminants collected on the filtration membranes. For PSO-D and TPO-D, the measured deposit levels were similar to those found for conventional diesel, which indicates that distillation removed a large share of the particulate and processing-related impurities present in the original feedstocks. This is most likely due to the fact that the distillation process separates lighter compounds, which tend to contain fewer heavy residues or particles. While PPO-D also benefited from the distillation step, the total amount of filtered material was still slightly above that observed for diesel – by around 0.0083 g – possibly due to the persistence of trace heavier fractions in the final product. A slight difference in retained mass between PPO-D and diesel fuel was still observed, which may point to the partial persistence of high-boiling residues from the polypropylene pyrolysis process. Alongside this, notable improvements in filtration behavior were also recorded for the distilled samples. All distillates passed through the membrane faster than diesel, suggesting smoother flow and reduced membrane resistance under vacuum-assisted conditions. Among them, PPO-D had the longest filtration time at 10.3 ±0.1 seconds – still a considerable improvement compared to the much longer filtration duration seen for untreated PPO. In contrast, PSO-D showed the fastest filtration time at 4.1 ±0.1 seconds, indicating a particularly clean fraction. These results collectively confirm that atmospheric distillation has a strong positive effect on the filtration performance of fuels derived from waste, especially those obtained from plastic feedstocks.

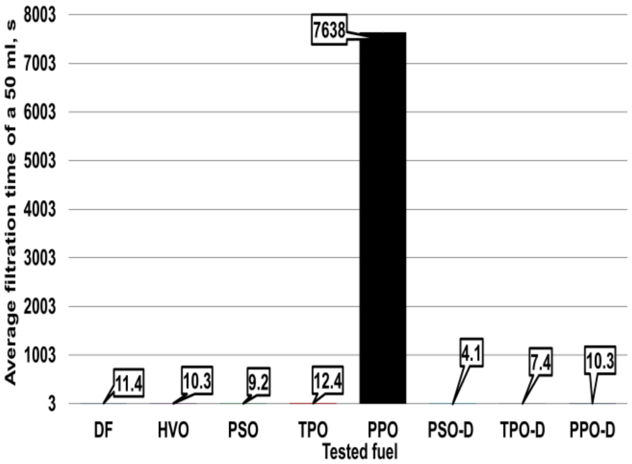

Fig. 6. Average filtration time

The graph presented in Fig. 7 illustrates the average mass of contaminants retained on the filtration membrane after filtering various fuels and their distilled fractions, followed by thermal treatment of the membranes in a muffle furnace at 100°C for 1 hour. This process allowed for the evaporation of volatile compounds.

The highest amount of contaminants retained on the filtration membrane was recorded for PPO, with a mass of 0.7504 g. Compared to diesel fuel (DF), this represents an increase of approximately 97%, highlighting the significant impurity burden associated with raw polypropylene pyrolysis oil. The substantial contaminant mass suggests that the pyrolysis of polypropylene generates not only condensable hydrocarbons but also considerable amounts of solid residues, char particles, and high-molecular-weight by-products that are difficult to remove without additional refining steps. A lower, though still elevated, contaminant mass was observed for TPO, which exhibited 0.1178 g of retained contaminants, an increase of approximately 83% relative to DF. This elevated level likely reflects the presence of tire-derived inorganic fillers, carbon black, and metallic residues often encountered in waste tire processing streams. PSO presented a considerably lower contaminant mass of 0.0254 g, corresponding to approximately 21% more than diesel fuel, suggesting that the pyrolysis of polystyrene yields a cleaner product in terms of solid impurities compared to other waste-derived feedstocks.

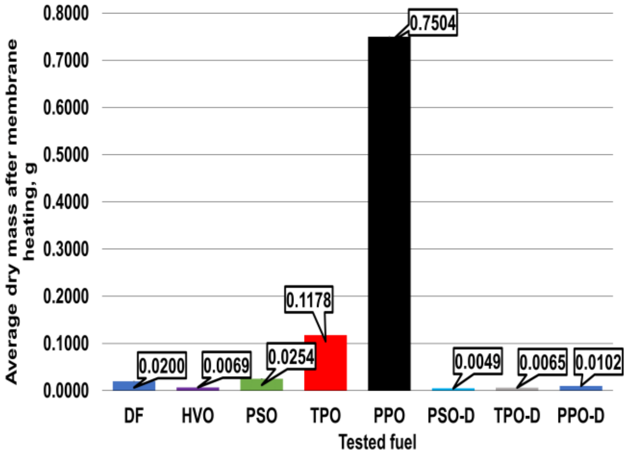

Fig. 7. Average mass of contaminants after heating of the filter membrane

In contrast, the lowest levels of contamination were observed for HVO (0.0069 g), confirming once again the high purity of this hydrotreatment-derived fuel. Among the distilled fuels, contaminant levels were further reduced, with PSO-D (0.0049 g), TPO-D (0.0065 g), and PPO-D (0.0102 g) demonstrating significantly improved filtration cleanliness compared to their raw counterparts. These results reinforce the beneficial role of atmospheric distillation in removing impurities, particularly from pyrolysis-derived fuels, and suggest that simple distillation can serve as an effective initial purification step prior to fuel utilization or blending.

The final stage of the study involved ashing the filtration membranes, followed by thermal treatment of the residue at 800°C ±20°C for 2 hours in a muffle furnace. This high-temperature treatment allowed for the complete combustion of organic matter, isolating only the inorganic solid residues. The mass of these residues serves as a reliable indicator of non-volatile inorganic contaminants, including metals, ash-forming minerals, and refractory compounds that could contribute to long-term engine wear or deposit formation.

Figure 9 summarizes the results concerning the average mass of contaminants remaining after the ashing and heat treatment of the membrane samples, providing a more detailed characterization of the nature and persistence of solid impurities in the tested fuels.

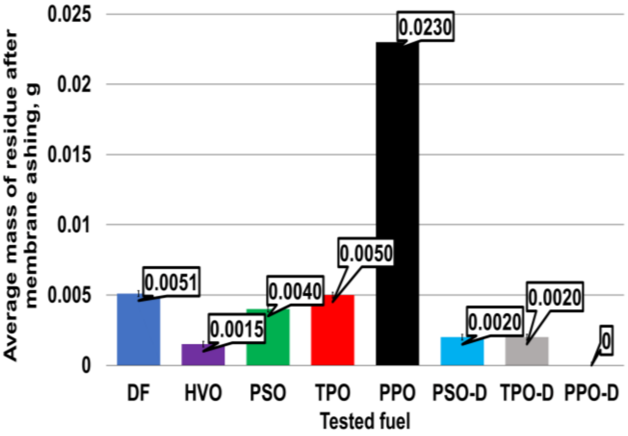

Fig. 8. Average mass of residue after filtration membrane ashing followed by high-temperature drying

PPO stood out among all the tested fuels by leaving the largest quantity of ash after combustion, with 0.0230 g of residue recorded. Compared to diesel fuel (DF), this represents an increase of approximately 360%, indicating that polypropylene pyrolysis oil retains notable amounts of non-volatile inorganic material even after the organic content has been burned off. Such residues are most likely composed of metals, remnants of catalysts, or thermally resistant char substances often formed as by-products during the thermal breakdown of plastic waste. In contrast, HVO samples showed the least contamination, with ash content averaging 80% lower than in diesel, pointing to a much cleaner composition. The results for HVO once again demonstrated its exceptionally high purity. Practically no ash remained after the ashing procedure, which reflects the effectiveness of hydrotreatment in eliminating both organic and inorganic contaminants. Thanks to this high degree of cleanliness, HVO can be considered well suited for use in modern injection systems, with little risk of filter blockage or injector deposits.

In the case of PPO-D, no solid residue was detected after ashing. This indicates that atmospheric distillation was successful in removing almost all non-volatile contaminants from the original pyrolysis fraction. The result further supports the idea that distillation may serve as a straightforward but efficient method for cleaning up plastic-derived pyrolytic oils. For raw PSO, the post-ashing mass was approximately 20% lower than that of diesel, pointing to a naturally low concentration of thermally stable inorganic matter in polystyrene-derived fuels. TPO, in contrast, left behind 0.0050 g of ash, essentially matching the result obtained for diesel. This finding reflects the typical complexity of tire-based fuels, which often contain both carbonaceous residues and mineral-based additives. Distilled versions of these fuels – PSO-D and TPO-D – exhibited significantly improved cleanliness. The amount of residual ash dropped by about 60% compared to diesel. This reduction not only confirms a lower total level of contaminants but also shows that distillation is particularly effective at removing substances that would otherwise remain as ash after combustion. These improvements highlight the potential of distillation to prepare waste-based pyrolysis fuels for use in diesel engines without posing additional operational risks.

4. Conclusions

Based on the conducted research, the following conclusions can be drawn:

- the lowest mass of contaminants was recorded for HVO, confirming the high degree of purification achieved through hydrotreatment, which effectively eliminates both organic and inorganic impurities
- PSO and diesel fuel (DF) exhibited comparable levels of solid contaminants, suggesting that polystyrene-derived pyrolysis oil, even in its raw form, contains relatively few non-volatile residues that could challenge filtration systems
- the filtration time of the tested fuels closely correlated with the mass of retained impurities, demonstrating that increasing contaminant load directly impacts filtration performance and resistance to flow
- the highest contaminant levels were found in PPO and TPO, reflecting the more complex composition and impurity profiles of polypropylene and tire-derived pyrolysis oils, which contain significant solid residues, char particles, and refractory compounds
- distillation proved to be an effective method for reducing process-related contaminants in pyrolytic oils derived from plastics and used car tires; the significant reduction in both organic and inorganic impurities after distillation demonstrates the practical value of this relatively simple purification step in improving the filterability and potential usability of waste-derived fuels.

The results of this study clearly indicate that, due to their high impurity content, raw waste-based pyrolytic oils are not suitable for direct application as fuels in diesel engines, as their use would likely lead to rapid filter clogging, injector fouling, and accelerated wear of precision fuel system components. However, as demonstrated by the experimental data, atmospheric distillation may serve as a viable and technically straightforward method for purifying such fuels. The resulting distillate fractions exhibit substantially improved purity, making them potential candidates for use either as standalone fuels or as blending components with conventional diesel or HVO. Nevertheless, while the reduction of solid contaminants is a crucial step toward the practical application of waste-derived fuels, their full suitability for diesel engine operation requires further comprehensive research. Additional investigations should address other critical fuel parameters, such as lubricity, cetane number, chemical stability, and the formation of combustion deposits, all of which directly influence combustion processes, emissions, long-term engine durability, and ope-rational safety.

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Nomenclature

CA	cellulose acetate membrane
DF	diesel fuel
HVO	hydrotreated vegetable oil
PPO	polypropylene pyrolysis oil
PPO-D	distillated polypropylene pyrolysis oil
PSO	polystyrene pyrolysis oil
PSO-D	distillated polystyrene pyrolysis oil
TPO	waste tire pyrolysis oil
TPO-D	distillated waste tire pyrolysis oil

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