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# Quantitative Analysis of Particulate Matter in Diesel Using a Microfiltration System and a Laser Particle Counter

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Diesel is one of the most widely used fuels in Ecuador due to its availability and relatively low cost. However, its extensive use poses significant challenges related to pollution and engine efficiency. This study addresses diesel microfiltration as a technique to improve fuel quality by reducing the amount of contaminant particles present. The results were evaluated using cleanliness codes according to ISO 4406, which provide a standard framework for assessing diesel quality before and after the microfiltration process. It is demonstrated that microfiltration can significantly improve diesel quality according to the parameters established in the Worldwide Fuel Charter (WWFC), meeting the cleanliness requirements specified by ISO 4406, thereby having a positive impact on diesel engine efficiency and lifespan.
**Keywords:** Diesel, cleanliness code, microfiltration, contaminating particles.

## 1. Introduction

Diesel engines are widely used due to their high performance, durability, lower fuel consumption and lower $CO_2$ generation, which makes them a preferred choice in various applications, including heavy and public transport (Tan et al., 2020). In Ecuador, diesel fuel accounts for a significant portion of total fuel consumption. According to the Ministry of Energy and Mines of Ecuador, in 2022 diesel consumption was 42.7% of total fuel consumption in the country (Ministry of Energy and Mines, 2023).

However, diesel combustion generates a variety of harmful pollutants, such as nitrogen oxides ($NO_x$), carbon oxides ($CO_x$), sulfur oxides ($SO_x$), PM2.5 and PM10 particles, among others. Not only do these contaminants contribute to environmental pollution, but they also pose significant risks to human health and can cause corrosion problems in engine parts and catalytic converter poisoning. Therefore, the durability and performance of diesel engines depend to a large extent on the quality of the fuel used (Stępień & Żółty, 2020). In Ecuador, diesel is classified according to its sulfur content according to the NTE INEN 1489-2012 standard as: Diesel 1 (3000 ppm), Diesel 2 (7000 ppm) and Premium Diesel (500 ppm) (Toro et al., 2023), (Ecuadorian Institute for Standardization, 2012), the latter being used exclusively in vehicle engines. In 2022, premium diesel delivered an average of 51 ppm of sulfur, demonstrating a significant improvement in fuel quality (Ministry of Energy and Mines, 2022).

According to the World Fuel Charter (WWFC), the presence of metal particles such as lead, copper, zinc, sodium and potassium in diesel causes significant fouling of engine injectors, generating a decrease in power and greater production of polluting gases. In addition, the use of high pressures in engines, approximately 2000 bar, and the presence of hard particles in the fuel generate abrasion in the engine parts, being a main cause of engine failures and damage. Thus, to determine the levels of diesel pollution, the ISO 4406 Standard is used, which allows the number of particles greater than the sizes 4, 6 and 14 μm per milliliter, respectively, to be coded (Worldwide Fuel Charter Committee, 2019).

To achieve adequate levels of contamination in diesel, several strategies have been implemented including pre-treatment methods, modifications to engine design and after-treatment technologies (Kurien et al., 2020). Among these, filtration stands out as one of the most effective for the reduction of polluting particles in diesel (Kurien et al., 2020). The objective of this study is to perform a quantitative analysis of particles in diesel, before and after the implementation of a filtration system, using a laser particle counter. This analysis seeks to provide accurate data on the reduction of polluting particles through the use of the filtration system, thus contributing to the development of more effective strategies to improve quality of diesel that enters internal combustion engines and increase their useful life.

## 2. Methodology

### *2.1 Fuel analysis prior to the implementation of the microfiltration system*

The fuel analyzed in this study is diesel, whose importance is fundamental for the transport sector and industry in Ecuador. The investigation was carried out in a diesel storage tank located in the city of Quito, which was undergoing maintenance and cleaning.

Sampling points were established on the diesel distribution line, specifically between the storage tank and the various equipment. Using a vacuum pump and new hoses, samples of the fuel were taken in bottles intended for this purpose, thus guaranteeing the integrity of the samples that were subsequently sealed and labeled so that they could be clearly identified.

Qualitative analysis

To perform the qualitative analysis of the particles present in the diesel, a PTK1 test kit was used (Hy-Pro, 2024b) the information is presented in Table 1. This kit allows you to visualize the type and size of the particles in the diesel sample being analyzed.

Table 1 – Test Kit for Qualitative Analysis PTK1

| Elements | Specific data |
|---|---|
| Brand | Hy-Pro |
| Microscope | 100x magnification. |
| Briefcase | Water-resistant, shockproof and dustproof case. |
| Patches | 1.2 µm and 5.0 µm test patches with patch mounting cards and adhesive covers to protect samples from environmental contamination and preserve them for future reference. |
| Manual Vacuum Pump | Vacuum pump to extract fluid samples from the system and process 25 mL of sample through a patch. |
| Reference Photographs | Visual correlation photographs to determine the approximate ISO cleanliness code of the test kit sample. |
| Accessories | Stainless steel funnel and tweezers, booklet for analysis, sample bottles. |

For each of the diesel samples, the equipment was pre-prepared by placing an airtight patch between the stainless steel funnel and the manual vacuum pump that was screwed onto each sample bottle. With the help of the vacuum pump, the diesel was extracted to pass it through the patch of the test kit, after that the funnel was removed and with the help of tweezers, the patch was removed and placed on a slide and covered with a plastic sheet. The sample was analyzed with a microscope with 100x magnification and visually compared with reference photographs in correlation to the approximate ISO cleaning code, in this way the type of contaminant, the concentration and the size of the particles were identified.

With this visual analysis, it was possible to obtain previous results on the contamination present in diesel.

Quantitative analysis

For the quantitative analysis of particles present in diesel, the portable online laboratory was used, which has a laser particle counter with PFM75 code (Hy-Pro, 2024a), the specifications of which are shown in Table 2. With the help of this equipment, it was possible to obtain real-time results on the particles present in the diesel.

Table 2 – PFM75 Laser Particle Counter Specifications

| Characteristics | Specific data |
|---|---|
| Brand | Hy-Pro |
| Operating Pressure | With high-pressure connection (5 – 320 bar)<br>With pump operation (0 bar) |
| Operating conditions | Fluid temperature (0°C to 60°C)<br>Ambient temperature (-10°C to 80°C)<br>Relative humidity (0% to 95%) non-condensing |
| Fluid viscosity | 5 – 1000 cSt |
| Power source | Power source 24 V d.c.<br>Power Consumption 8 A |
| Power Source Power Adapter | Power adapter (100 – 240 V d.c. 50 – 60 Hz)<br>Power Consumption 4 A |
| Battery | Rated capacity (7500 mAh) |
| Particle measurement visualization | ISO 4406; SAE AS 4059E; NAS 1638\|<br>Measurement sizes (4 µm, 6 µm, 14 µm, 21 µm) |
| Accessories | Control panel with digital display, printer, internal pump for suction line, high and low pressure hose sets |

For quantitative analysis, the PFM75 portable laboratory was located near the online sampling port that was used in the qualitative analysis. The respective couplings and the inlet and outlet hoses were installed. Once the diesel entered the equipment hose, the control panel was turned on and the in-line particle count was performed.

The PFM75 portable laboratory features an internal pump that is used in case the fuel line does not have suction pressure. However, in this fuel distribution line, the necessary pressure was obtained for the diesel to circulate properly through the equipment.

On the control panel, the ISO 4406 cleanliness code was selected for particle count in the sizes of 4 µm, 6 µm, and 14 µm. This process was carried out for 30 minutes, obtaining real-time data on the size and number of particles according to the configured cleaning code.

Once the particle counter was stabilized, the results obtained were printed. These results made it possible to corroborate the data obtained from the PTK1 test kit for analysis and to relate the cleaning code obtained with the one recommended according to the World Fuel Charter (WWFC).

### *2.2 Microfiltration System Implementation*

Since the diesel fuel did not meet the required cleaning parameters, an in-line microfiltration system was installed, based on the evaluations carried out and prior to the analysis carried out based on the filtration efficiency. The characteristics of this system are detailed in Table 3.

Table 3 – Microfiltration System Features

| Characteristics | Specific data |
|---|---|
| Brand | Hy-Pro |
| Model | Spin-On S75 |
| Pre-filter | β22[c] filtration efficiency = 1000 |
| Filter | Filtration efficiency β5[c] = 1000 |
| Filter element | Item Material: Dualglass |
| Housing | Base Material: Aluminum<br>Container Material: Steel<br>Differential pressure gauge |
| Flow Range | Flow (373 bpm max) |
| Operating Pressure | Pressure (14 bar max) |
| Safety factor | 2.5 : 1 |
| Bypass valve | Bypass valve calibration (1.77 bar) |
| Temperature range | Viton (-26°C~135°C) |
| Compatible Fluids | Compatible with all petroleum-based oils, diesel, oil/emulsified water, synthetic fluids. |

For the installation in the distribution line of diesel to the equipment, a bypass with valves was placed at the inlet and outlet of the microfiltration system, which was made up of a double base to place the prefilter and filter.

### *2.3 Fuel analysis after the implementation of the microfiltration system*

After the implementation of the microfiltration system and using the same previously installed sampling ports, a new in-line particle count was performed, using the PFM75 portable laboratory, in order to determine the ISO 4406 cleaning code. This particle count was performed following the same procedure detailed in the "Quantitative Analysis" section.

To determine the percentage of efficiency of the microfiltration process after a single pass of diesel, equation 1 was used.

$$\% \, Eficiencia = \frac{(partículas\ entrada - partículas\ salida)}{partículas\ entrada} * 100 \qquad (1)$$

## 3. Results

### *3.1 Fuel analysis prior to the implementation of the microfiltration system*

In the qualitative analysis, using the PTK1 test kit for analysis, an ISO 21/19/14 cleaning code was obtained as a result. This result provided a reference on the cleanliness condition of diesel in the distribution line.

In quantitative analysis, with the PFM75 laser particle counter, placed in line; the results presented in Table 4 were obtained.

Table 4 – Results of the quantitative analysis of diesel in the distribution line, using the PFM75 particle counter

| Particle Size | ML/Average Count | Code |
|---|---|---|
| 4µ[c] | 10764,92 | 21 |
| 6µ[c] | 2530,27 | 19 |
| 10µ[c] | 488,30 | 16 |
| 14µ[c] | 149,75 | 14 |
| 21µ[c] | 86,80 | 14 |
| 38µ[c] | 26,20 | 12 |
| 70µ[c] | 17,25 | 11 |

According to the particle count carried out with the PFM75 laser counter, it is corroborated that the diesel cleaning code was ISO 21/19/14. Evidence that the presence of polluting particles exceeded the maximum levels recommended by the World Fuel Charter (WWFC) where it indicates an ISO 18/16/13 cleaning code, observed in Figure 1.

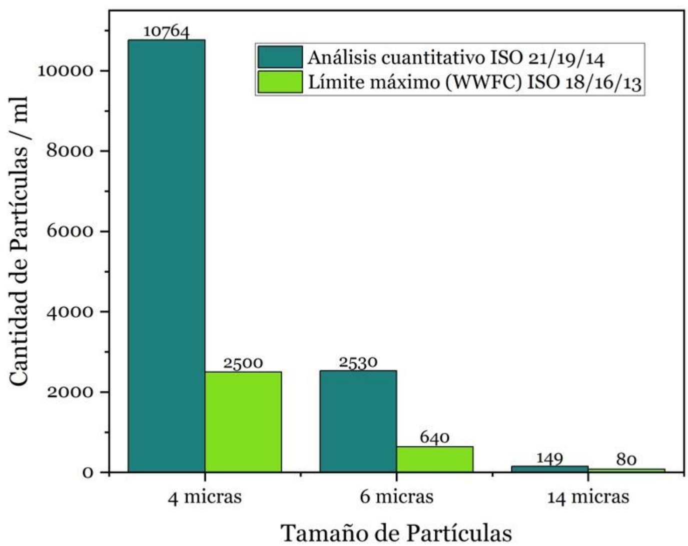


Figure 1 – Comparison of the amount of polluting particles in diesel, prior to the

implementation of the microfiltration system. In original language English

### *3.2 Implementation of the Microfiltration System*

Considering that the WWFC diesel cleanliness code specifies particulate contamination with code 18/16/13 according to ISO 4406 (International Organization for Standardization, 2021), the microfiltration system is selected according to the efficiency presented in the catalogs of these according to Table 3.

### *3.3 Fuel analysis after the implementation of the microfiltration system*

After the implementation of the microfiltration system, a new quantitative analysis was carried out online using the PFM75 laser particle counter, which yielded the ISO 18/16/13 cleaning code according to the results presented in Table 5.

Table 5 – Results of the quantitative analysis of diesel after the microfiltration process, using the PFM75 particulate counter

| Particle Size | ML/Average Count | Code |
|---|---|---|
| 4µ[c] | 1749,00 | 18 |
| 6µ[c] | 356,00 | 16 |
| 10µ[c] | 128,90 | 14 |
| 14µ[c] | 59,00 | 13 |
| 21µ[c] | 27,70 | 12 |
| 38µ[c] | 8,80 | 10 |
| 70µ[c] | 5,80 | 10 |

Figure 3 identifies that the amount of particles, after the microfiltration process, is below the maximum limit recommended by the World Fuel Charter (WWFC).

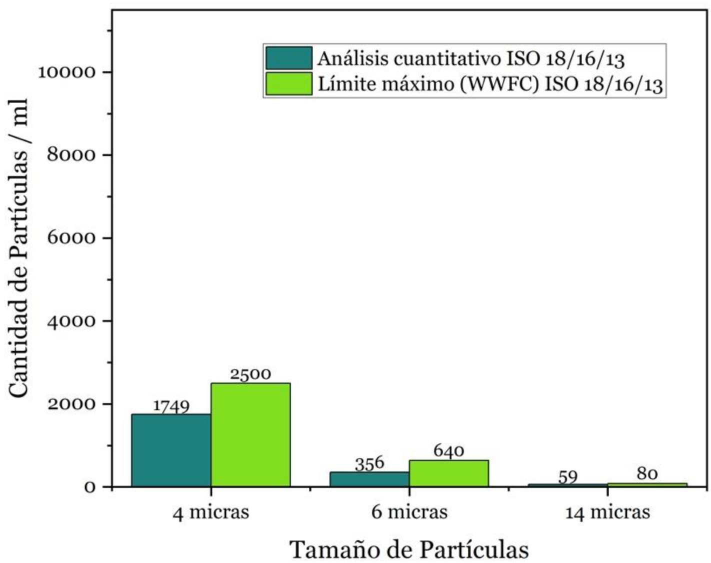


Figure 2 – Amount of polluting particles in diesel, after the implementation of the microfiltration system. In original language English

Quantitative comparison

When comparing the initial and final results, considering the size and amount of pollutant particles present in diesel, it was observed that the most significant decrease in pollution was in 4 and 6 µm particles. Prior to the implementation of the microfiltration system, the number of particles of these two sizes was approximately four times higher than the levels set by the WWFC. This is in line with the study conducted by Stępień (2020), which indicates that diesel pollution for 4 µm particles reaches a maximum amount of 7000 particles, tripling the limit recommended by the WWFC.

After the microfiltration process, the filtration efficiency for each particle size analyzed was 83.75%, 85.93% and 60.40% for 4 µm, 6 µm and 14 µm particles, respectively, with the highest percentage of removal being achieved in the 6 µm particles. However, as shown in Figure 3, the largest initial amount of particles present in diesel corresponds to those of 4 µm, achieving, with the microfiltration process, complying with the ISO 4406 code established by the WWFC for this and the other sizes.

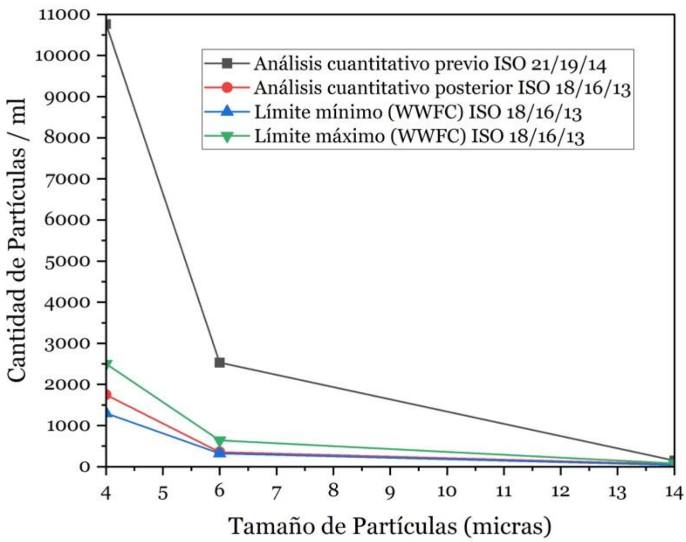


Figure 3 – Comparison of the amount of particulate pollutants in diesel, before and after the implementation of the microfiltration system. In original language English

## 4. Conclusions

The use of the PTK1 qualitative analysis kit, in combination with the PFM75 laser particle counter, proved to be an accurate and reliable methodology for assessing the amount of particulate pollutants in diesel. The elimination of human error and the obtaining of a true count of particles by size confirm the superiority of automated analysis over manual methods.

The significant reduction of pollutant particles, achieved through microfiltration, especially in the 4 and 6 μm particles that are found in greater quantities in diesel, suggests an improvement in the efficiency and durability of the engines. By reducing the amount of harmful particles, wear and tear on engine components can be reduced, resulting in longer life and more reliable performance.

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