

Influence of High Injection Pressure on Diesel Fuel Stability: A Study of Resultant Deposits

Jim Barker, Paul Richards, Mark Goodwin and Jonathan Wooler

Innospec Limited

Copyright © 2009 SAE International

ABSTRACT

Recent developments in diesel engines and fuel injection equipment together with the move to ULSD and bio-blends have seen an increase in reports regarding deposits in both injectors and filters.

Historically deposits have been generated from a number of sources: bio-contamination, both aerobic and non-aerobic, water contamination, lube oil adulteration, additives, dirt, metals in fuel, and biodiesel degradation. These may be ascribed to "poor housekeeping," incorrect additivation, deliberate adulteration or some combination.

However the recently observed deposits differ from these. The deposits are described and indicate possible precursor molecules that support proposed mechanisms and their ability to form filter deposits.

INTRODUCTION

Since the industrial revolution in the late 18th and 19th century there has been a period of evolution. The rate of evolution has not been constant with periods of rapid change, interspersed with more gradual development. The automotive world is a prime example. In the later part of the 20th century many of these periods of rapid evolution have been driven by the need to meet forthcoming legislation.

For engine technology the desire for more power and efficiency has been a constant driver and has been

behind the gradual evolution of the internal combustion engine. Superimposed on this has been successive tightening of emission standards. But as these engines require fuel then in general the fuel has evolved in line with the engine.

Considering diesel fuel, the topic of this paper, there has been an evolutionary rise in the cetane number of the fuel as this allows engines to be designed for greater specific power output. Because there is usually a cost penalty associated with increasing the cetane number of the fuel, the required cetane number of the fuel varies from region to region and country to country. However, there is a trend towards convergence of specification.

Emissions legislation is also driving fuel specification towards convergence on permissible levels of sulphur in the fuel. Whilst sulphur emissions are not themselves regulated, sulphates contribute to particulate matter emissions, and more importantly sulphur can contribute to the reduction in efficacy of exhaust after-treatment devices (1-4).

To achieve these low sulphur levels the refinery usually employs a hydro-treatment process whereby the hydrocarbon stream is mixed with a hydrogen rich gas, the mixture then passing over a catalyst. The hydrogen then reacts with the sulphur compounds to produce hydrogen sulphide gas, which is then separated from the liquid hydrocarbon. This process also removes excess nitrogen, metals, and halides from the fuel (5, 6). An additional consequence of this process is that it tends to

convert unsaturated hydrocarbons, such as olefins, and particularly di-olefins, to saturated paraffins (7).

With recent concern over the so called 'Greenhouse Effect' and security of supply, there is increasing pressure to replace petroleum derived fuels with renewable or sustainable sourced products. For diesel fuel this has predominantly resulted in the inclusion of fatty acid methyl esters (FAME) as a blending component for finished diesel fuel (8). The FAME, also known as bio-diesel has many properties that are very close to those of diesel fuel.

Blends of petroleum diesel fuel and bio-diesel are denoted as Bxx, where xx represents the percentage by volume of the FAME in the finished blend. Thus a B20 is 80% volume petroleum diesel fuel, plus 20% volume FAME. B0 is pure petroleum diesel fuel, and B100 is 100% FAME. Whilst some engines can run without modification on B100 it is considered that the legacy fleet is best served with blends of no higher than B5. Cost and availability of the FAME are often the limiting factors to the uptake of these blends (9-13).

The recent change in the US diesel fuel specification to limit fuel sulphur to 15 mg/kg (14) has coincided with the inclusion of bio-diesel into the blending pool.

Over a similar time frame there has been an increase in the reported incidences of severe fouling of diesel fuel filters, and of diesel fuel injectors. These deposits appear to be more carbon like and more granular than deposits seen previously. Historically, deposits have been generated from a number of sources: bio-contamination, both aerobic and non-aerobic, water contamination, lube oil adulteration, additives, dirt, metals in fuel, and biodiesel degradation. These may be ascribed to "poor housekeeping," incorrect additivation, deliberate adulteration or some combination (15, 16). As yet there is no clear correlation between these incidences of severe fouling, and engine type, fuel injection equipment, fuel filter type or fuel supply source. However, newer technology engines e.g. those with high pressure fuel injection (HPFI) equipment, do seem more prone to problems compared with older technology.

To meet successive tightening of emission standards, diesel engine manufacturers have striven to improve the combustion process within the engine. This has called for better mixing of the fuel and air to reduce the amount of combustion that takes place in fuel rich regimes. Generally, this can be achieved by improving fuel atomisation and penetration into the cylinder from the fuel injectors (17, 18). Reduction in fuel injector hole size, and an increased fuel pressure at the point of injection, has been fundamental in this progression (19, 20). It has been suggested that these engineering improvements, and the resultant high pressures and concomitant high temperatures, contribute to the observed fouling problem by accelerating the aging of the fuel.

This paper describes preliminary work carried out to try and characterise the deposits currently being encountered in the field, and to identify possible deposit precursors.

EXAMPLES FROM THE FIELD

In the US the incidence of fouled fuel filters is quite widespread. A number of samples were therefore collected, covering a variety of geographic locations, as well as equipment type.

A typical example of a fouled filter is shown in the upper part of Figure 1. The lower part of the figure shows a used filter that still exhibits acceptable performance.

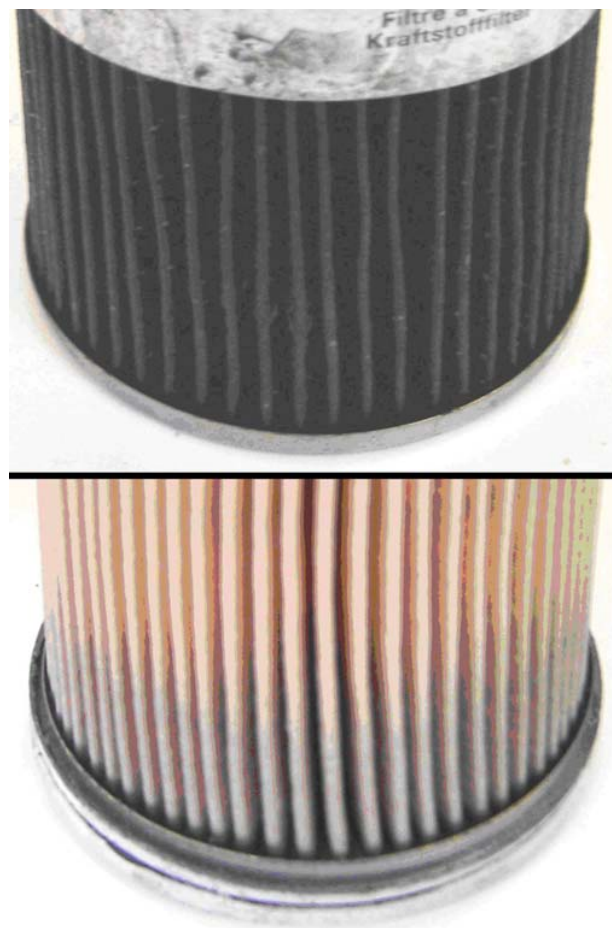


Figure 1. Typical filters taken from the field. Fouled filter above and acceptable filter below.

As can be seen from the above figure, the acceptable filter is still of a pale colour closely matching an unused filter whilst the fouled filter element is uniformly covered in a black deposit. This is further illustrated in Figure 2 which shows a section of the filter element that has been removed for analysis.

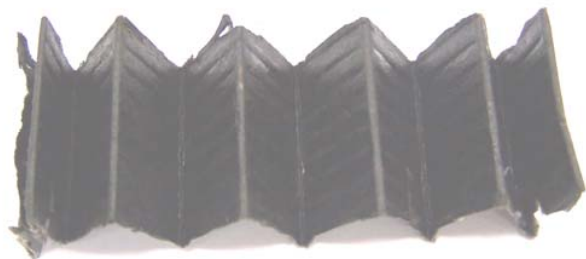


Figure 2. Typical example of a section of fuel filter

A number of fuel injectors were also analysed. A typical example of the deposits formed around the injection holes is shown in Figure 3. Although there is clearly a significant accumulation of deposit around the hole, the topography suggests that at some time there was an even greater amount of deposit. This accumulation has then become detached and fresh deposit has begun to accumulate in the cleared area adjacent to the hole.

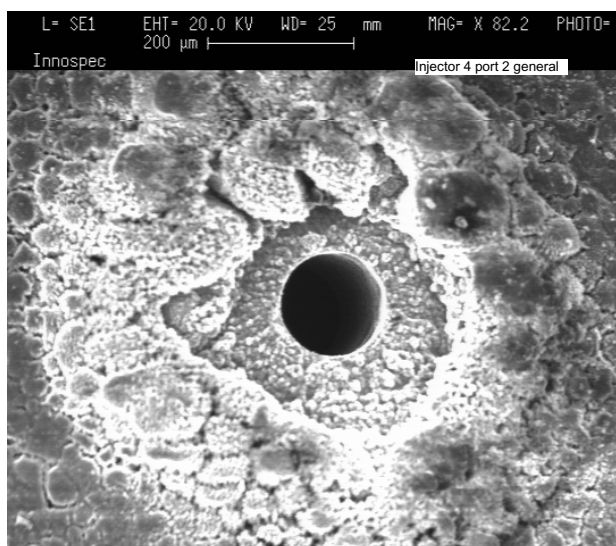


Figure 3. Deposits around injector hole.

EXPERIMENTAL TECHNIQUES

Many of the fuel filters presented for analysis were “fuel wet”, and the following protocol was followed to enable the separation and characterization of both the soluble and insoluble moieties. The protocol is illustrated schematically in Figure 4.

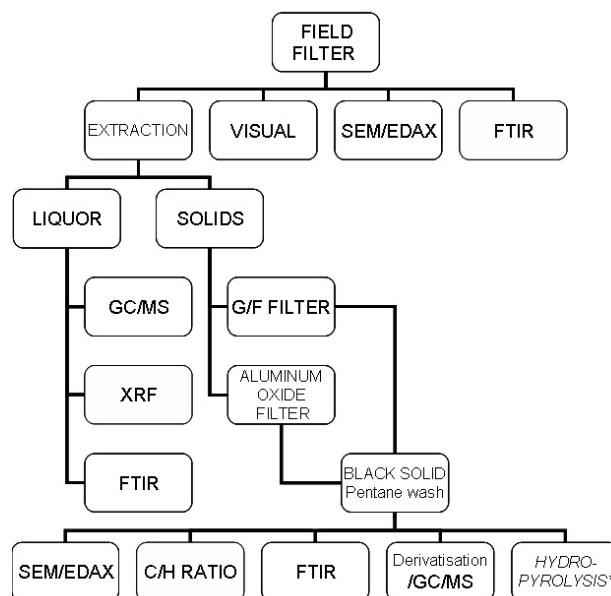


Figure 4. Analytical Separation Protocol.

A 15cm by 3cm section of the filter element was cut from the filter, an example of which is shown in Figure 2. A gravimetric evaluation of this filter section was made, to allow a determination of residue levels. The filter section was then subject to visual analysis, scanning electron microscopy with energy dispersive X-ray analysis (SEM/EDAX), and Fourier Transform Infra-red analysis (FTIR). The deposit was then extracted with 120mL of HPLC (High Pressure Liquid Chromatography) grade tetrahydrofuran, either by 15 minutes in an ultrasonic bath, or an overnight soak. The liquor was then filtered through an 8 micron glass fibre filter, or a 0.2 micron aluminium oxide membrane. The filtrate was washed in pentane to remove any remaining diesel fuel, and subjected to SEM/EDAX, carbon/hydrogen ratio analysis, FTIR, derivatised gas chromatography with mass spectroscopic detection, (GC/MS), and hydrolysis (21). The filtered liquor was then subject to (GC/MS), X-ray fluorescence (XRF) and FTIR.

The results of the various analyses are given in the following sections.

RESULTS OF SEM/EDAX FTIR ANALYSIS

SEM/EDAX ANALYSIS - In order to assess the filter deposits before chemical extraction was carried out, SEM/EDAX analysis was performed on a strip of filter cut from the original filter housing. Figure 5 shows a SEM image that clearly demonstrates the granular deposits adhering to the fibres that make up the filter material.