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Research Article

Preliminary Studies of New Water Removal Element in Purification Applications of Diesel Fuels

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To effectively and efficiently remove water contamination dispersed in petrodiesel fuels, a new water removal element with both coalescence and separation features is studied in this paper. The unique droplet coalescence and separation mechanism occurring in the new water removal element is proposed. The conceptual design of this filter element is presented and the basic features of FCP filtration systems are briefly introduced. A laboratory test stand and fuel analysis procedure are described. The results from preliminary water removal tests with number 2 petrodiesel fuel demonstrate the filtration performance of the new water removal element. For example, within one single fuel flow pass through FCP filtration system equipped with the new water removal element and running at 2 GPM flow rate, the water content in 80°F, number 2 petrodiesel fuel stream can be reduced from up to 40,000 ppm upstream to 64.8 ppm or less downstream.

1. Introduction

Removal of water contamination is a particularly stringent requirement for petrodiesel fuels, since the presence of even a very small amount of water in fuels can cause numerous serious problems. Issues related to fuel thermal oxidation stability, fuel filterability, fuel lubricity, promotion of soluble and insoluble gum growth, development of particulate matter, fuel filter plugging, fuel injector clogging, and fuel combustion efficiency degradation all may be related to water contamination in fuels [1–3]. The maximum water contamination level in fuels is strictly limited in worldwide fuel quality standards. For example, fuel quality standard ASTM D975 recommends a maximum water contamination level in petrodiesel fuels to be less than 500 ppm per volume (ppm: parts per million). The European standard EN590 calls that for less than 200 ppm per mass.

Gravity separation, centrifugal separation, absorbent polymer separation, coalescing-based filtration, and vacuum dehydration are well-known water decontamination techniques in the quality maintenance of petrodiesel fuels. Among them, coalescing-based filtration is the most cost-effective technique for removing free and emulsified water from petrodiesel fuels at constant flow rates. It is mainly achieved by a two-stage filtration system consisting of fuel-water coalescer (FWC) at the first stage and fuel-water separator (FWS) at the second stage. That is, contaminant water dispersion in petrodiesel fuel flow is coalesced into large droplets by fibrous coalescing media of FWC, and then those enlarged droplets are deflected from fuel flow by separation mesh screen of FWS. Hydrophobic barrier fibre media are one type of traditional nonwoven coalescing media, and other new fibrous coalescing media have been successfully developed [4–7]. Precisely woven polymer mesh fabric with hydrophobic-coating and stainless steel wire mesh screen with PTFE-coating are common separation mesh media. To varying degrees, filtration performances of both FWC and FWS are adversely affected by the presence of additives that lower interfacial tension, reduce droplet size, slow down the rate of coalescence, stabilize emulsions, and may absorb onto media and render it less effective. To solve these challenging problems, filtration performance of a new water removal element is investigated in this paper. A unique droplet coalescence and separation mechanism occurring in the new water removal element is proposed. The conceptual design of the above filter element and the basic features of

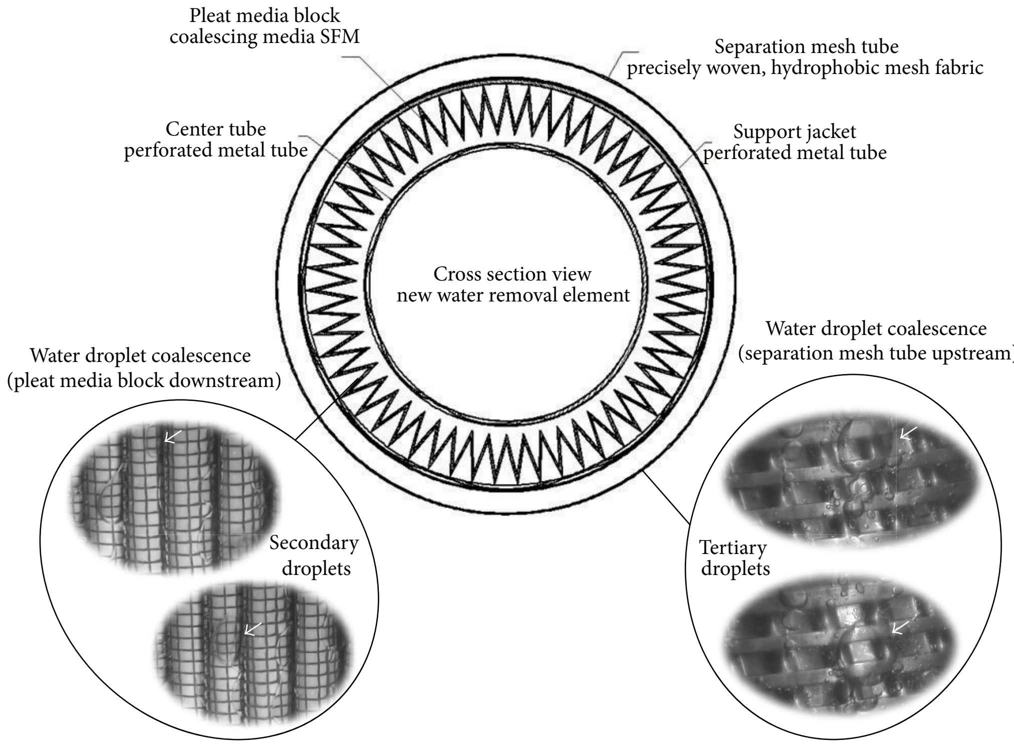

Figure 1: Cross section sketch of new water removal element.

FCP filtration systems are briefly presented. A laboratory test stand and fuel analysis procedure are also outlined. Finally, preliminary experimental results are presented to illustrate the filtration performance of the new water removal element in purification application of number 2 petrodiesel fuel.

2. New Water Removal Element

New water removal element is an innovative filter element capable of removing water contamination from a through diesel fuel flow effectively and efficiently [8]. It integrates both coalescence and separation functions together in one compact element profile. As shown in a cross section scheme in Figure 1, it consists of pleat filter media block, center tube, support jacket, and separation mesh tube. Pleat media block is made of patented filter media SFM, consisting of two different types of fibrous filter media restrained between two layers of wire mesh screen [9]. Facing the upstream flow are multiple layers of partially hydrophilic, nonwoven fibrous filter media. Another type of filter media layer facing the downstream comprises at least one sheet of high hydrophilic, precisely woven monofilament mesh fabric. Separation mesh tube is made of substantially completely hydrophobic monofilament mesh fabric. Both center tube and support jacket are made of perforated metal tubes. The pleat media block is restrained between center tube and support jacket to prevent it from overdeforming due to hydrodynamic interactions of a through fuel flow. Furthermore, the above described element components are assembled together with gaskets and two endcaps by epoxy glue as depicted in Figure 2. Element profile is 4.30$''$ outer element diameter and 12$''$ element length. The nominal direction of a through fuel flow is from inside to outside. The specific flow rate with respect to 8 GPM through fuel flow is designed to be 2.1 GPM/FT^2, where specific flow rate is defined as the ratio of through fuel flow rate to flow-exposed coalescence media surface on one media layer (GPM: gallons per minute; FT: foot).

3. Droplet Coalescence and Separation Mechanism

A two-mode droplet coalescence and separation mechanism is proposed to systematically describe the droplet coalescence and separation process occurring in new water removal element. The first mode mainly describes the water droplet coalescence process in the pleat media block. The fibrous nonwoven medium captures contaminant water dispersion in a through fuel flow. These collected water droplets coalesce into primary water droplets with sizes larger than the minimum opening size of the woven fabric while they migrate through the nonwoven medium. The migrated primary droplets attach onto the sheets of the woven fabric at the downstream in a generally uniform droplet pattern. The strong wetting force of the woven fabric drives those attached droplets to move in a neighbourly fashion on the fabric surface at the downstream and adjacent droplets merge together into the secondary droplets of relatively large size. Meanwhile, hydrodynamic interactions of the through fuel flow drive primary water droplets onto those attached secondary droplets for further droplet coalescence.

Figure 2: New water removal element.

The attached secondary water droplets continue to grow in size by the droplet mergence processes to such an extent that they can be released from their attachment sites by the hydrodynamic interactions. The second mode primarily describes the droplet coalescence and separation process occurring in gap between support jacket and separation mesh tube. After passing through the support jacket, those released secondary droplets attach on the separation mesh tube at the upstream. Due to gravity, large attached droplets move along the upstream surface of the separation mesh tube in a downward direction and merge with other attached droplets on moving paths together into the tertiary droplets of relatively large size. In the meantime, the hydrodynamic interactions drive released secondary water droplets onto those tertiary droplets for further droplet coalescence. Those enlarged tertiary droplets continue to grow up in sizes by those types of droplet mergence processes to such an extent that they contact with both support jacket at the system downstream and separation mesh tube at the upstream. Hydrophilically wetting contact of those enlarged tertiary droplets with the support jacket at the downstream prevents them from being broken down. Finally those enlarged droplets are released out of the new water removal element from drain holes on the bottom side surface of the woven mesh tube. To further demonstrate typical modes of droplet coalescence processes on the pleat media block at the downstream and the separation mesh tube at the upstream, four pictures taken in fuel-water separation experiments are presented in corners in Figure 1. Two pictures at the left corner in the figure illustrate coalescence process of a water droplet, appointed with a white arrow, on the pleat media block at the downstream. In those two pictures, the appointed droplet mainly moves to the tip of the pleat media block in the inside-to-outside direction. Other two pictures at the right corner demonstrate coalescence process of a water droplet, appointed with a white arrow, in the gap between support jacket and separation mesh tube. In those two pictures, the appointed droplet primarily moves along the gap in the downward direction.

3.1. FCP Filtration Systems. Schemes of FCP fuel filtration systems are illustrated in Figure 3. FCP series are next-generation fuel purification products initially designed based on a US patented coalescence filtration technology [9]. All FCP systems share one FCP vessel system design but have three different types of mounting configuration. Among them, each FCP system is equipped with one prefilter filter and one water removal element. Installation configuration of those two filter elements in FCP vessel is schemed in the partial cross section view in Figure 3. Contaminated fuel flow passes first through the prefilter filter to remove particle contamination and then through water removal element to coalesce contaminant water dispersion into large water droplets. Those large water droplets finally settle down inside water accumulation sump surrounded by 360° view sight window, through which cleanness of both fuel and water can be visually examined. Fuel samples can be taken from two sample valves at system upstream and downstream for further analyses of fuel quality. Nominal flow rate of FCP systems is 6 GPM. Different system flow rates are optional. In this paper, a portable FCP vessel system is modified to study the filtration performance of new water removal element.

4. Laboratory Fuel Test Stand and Fuel Analysis Procedure

Water removal capability of new water removal element is studied by a series of fuel-water separation tests on a laboratory fuel test stand as schemed in Figure 4. Number 2 petrodiesel fuel is used as working fluid cycling in the laboratory fuel test stand. Clean tap water stream at a predetermined flow rate is continuously injected into fuel flow at the system downstream of fuel reservoir. Gear pump equipped with FCP systems is used to well mix those two fluid flows into one fuel-water blend flow with very fine water droplet distribution. Rotation speed of the pump-driven motor is controlled by a variable frequency drive (VFD) to increase fuel flow rate through new water removal element up to 8 GPM. The prefilter element, equipped with the FCP system, and the new water removal element are installed in the FCP vessel as shown in the partial cross section view in Figure 3. The new water removal element coalesces contaminant water dispersion in fuel flow into large water droplets. Those enlarged droplets finally settle down into water accumulation sump surrounded by 360° view sight window, whence bulk water there is manually drained out. Clean fuel flow returns back to the fuel reservoir.

During fuel-water separation tests, fuel flow at system downstream is sampled at a 30-minute rate while operational parameters of the laboratory test stand are stable. Total water contents of those fuel samples are measured with Karl Fisher Coulometer Mettler Toledo DL32 per water analysis procedure developed per ASTM D6304 [10]. Water content in fuel-water blend flow at system upstream is calculated based on flow rate ratio of injected clean water stream to pumped

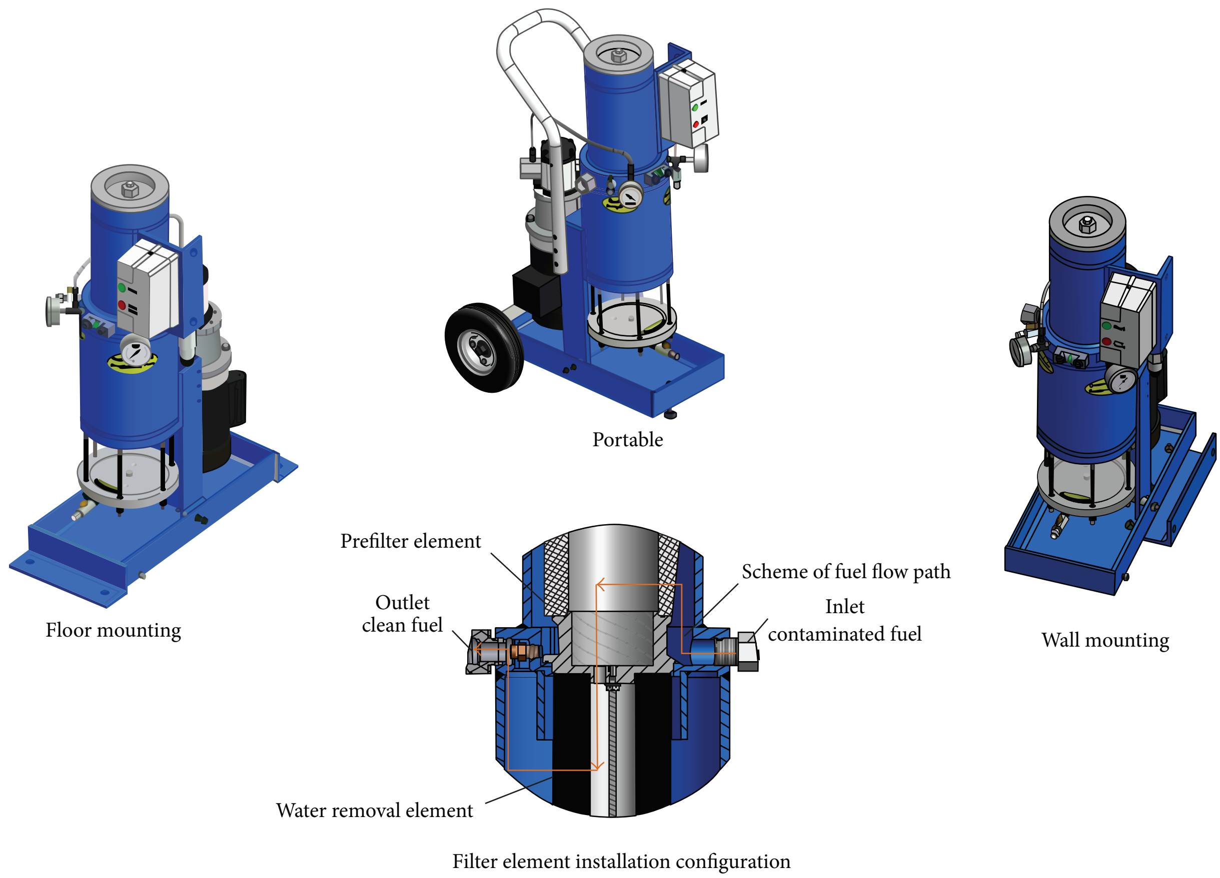

FIGURE 3: Schemes of FCP filtration systems.

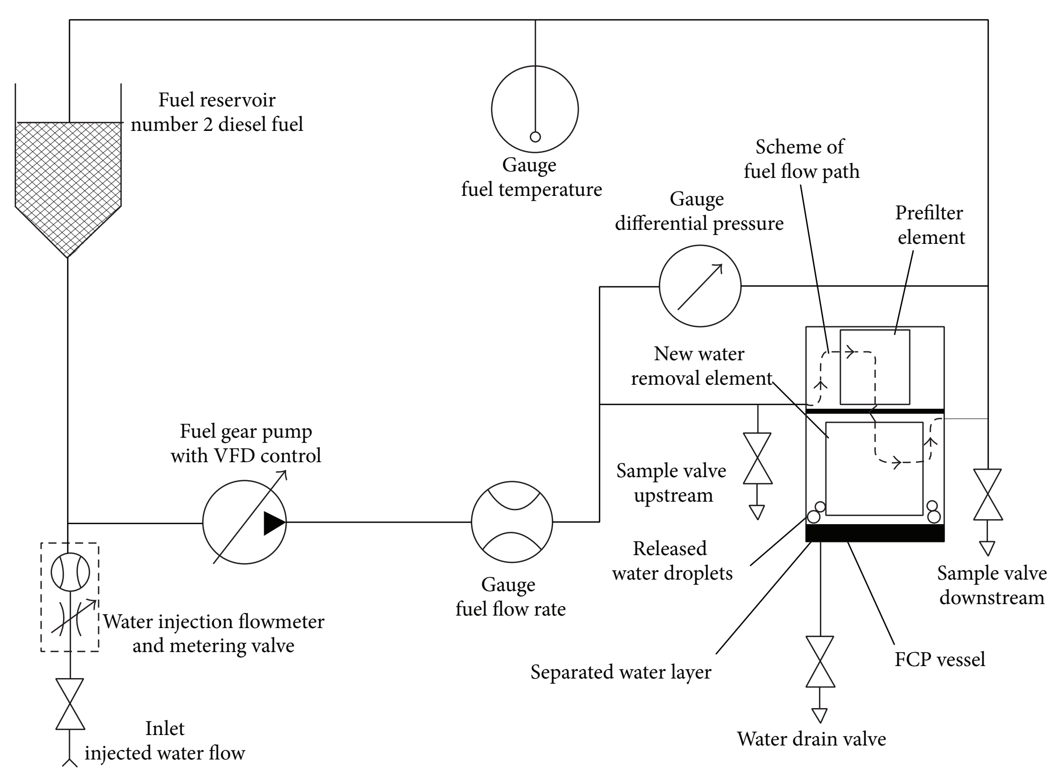

FIGURE 4: Scheme of laboratory fuel test stand.

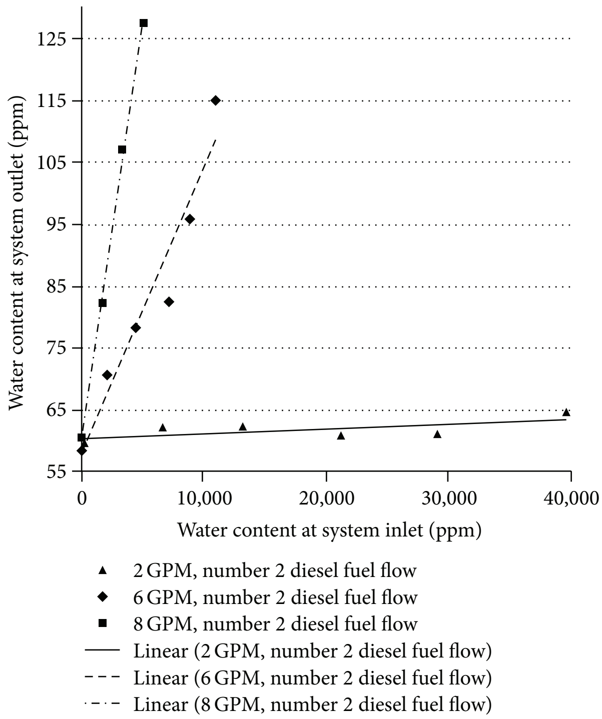

FIGURE 5: Water content changes in fuel-water blend flows.

fuel-water blend flow. Ice bags are temporarily placed in the fuel reservoir when fuel temperature is too high. Test parameters displayed by various gauges in the laboratory fuel test stand, such as differential pressure and fuel temperature, are recorded during water-fuel separation tests.

5. Water Removal Performances

Filtration performance of new water removal element was investigated based on three sets of water removal tests by the laboratory fuel test stand in Figure 4. Number 2 diesel fuel purchased from a commercial gas station was used as the working fluid cycling in the laboratory test stand. Fuel-water blend flow rate through the new water removal element and water contamination level at the system upstream are two major test parameters. In the first set of water removal tests, the fuel-water blend flow is set to be 2 GPM, and clean tap water streams were continually injected into the upstream of the fuel gear pump at one of the following flow rates: 0 CCM, 50 CCM, 100 CCM, 160 CCM, 220 CCM, and 300 CCM (CCM: cubic centimetre per minute). In the second set of tests, the fuel-water blend flow rate is set to be 6 GPM, and clean tap water flow streams were injected into the same upstream side at one of the following flow rates: 0 CCM, 50 CCM, 100 CCM, 160 CCM, 200 CCM, and 250 CCM. In the third set of tests, the fuel-water blend flow rate is set to be 8 GPM, and clean tap water flow streams were injected into the same upstream side at one of the following flow rates: 0 CCM, 50 CCM, 100 CCM, and 150 CCM. During those water removal tests, fuel temperature in the fuel reservoir is controlled to be 80°F. The described fuel sampling and analysis procedure was used to measure the experimental results presented in Figure 5, where linear trend lines associated with those test data are also represented. The results show that within one single flow pass through the new water removal element at a fuel-water blend flow rate of 2 GPM 40,000 ppm (4.0 vol%) water content at system upstream was reduced to 64.8 ppm at system downstream. Also, 9,000 ppm (0.9 vol%) water content at system upstream was reduced to 96.1 ppm at the system downstream when a fuel-water blend flow rate was 6 GPM. Furthermore, 5,000 ppm (0.5 vol%) water content at system upstream was reduced to 127.6 ppm at the system downstream when a fuel-water blend flow rate was 8 GPM. In general, it was observed that the fuel-water blend flow rate and the upstream water contamination level have adverse impacts on water-fuel separation performance of the new water removal element. That is, larger fuel-water blend flow rate generally results in higher water content level at system downstream. Larger water contamination level at system upstream generally does in higher one in system downstream.

6. Conclusions

This paper is mainly concerned with the study of the separation performance for an innovative water removal element. The conceptual design of this new water removal element is briefly introduced together with proposal of a unique droplet coalescence and separation mechanism. The separation performance of this new water removal element has been studied in relation to two parameters, that is, through water-fuel blend flow rate and upstream water contamination content. Many unique design features make the described water removal element capable of effectively reducing heavy water contamination in fuel flow to a very clean water content level.

From the investigations of water removal performance in 80°F, number 2 diesel fuel it can be summarised that within one single flow pass through new water removal element

(1) at 2 GPM fuel flow rate, 40,000 ppm (4.0 vol%) upstream water contamination can be effectively reduced to 64.8 ppm water content at system downstream;

(2) at 6 GPM fuel flow rate, 9,000 ppm (0.9 vol%) upstream water contamination can be effectively reduced to 96.1 ppm water content at system downstream;

(3) at 8 GPM fuel flow rate, 5,000 ppm (0.5 vol%) upstream water contamination can be effectively reduced to 127.6 ppm water content at system downstream.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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