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Enhanced water/fuel coalescing filter media for diesel engines: overview and future directions

Enhanced water/fuel coalescing filter media for diesel engines: *overview and future directions*
Enhanced water/fuel coalescing filter media for diesel engines: overview and future directions

Outline

❖ Introduction
Fuelling systems and challenging fuel filtration

❖ Design of water/fuel separation system
Emulsion, coalescence, fibrous structure

❖ Future trends
Structure-property relationship and Future trends
Enhanced water/fuel coalescing filter media - *Introduction*

**Four Stroke Diesel Engine Operation**

- **Air Intake Stroke**
- **Air Compression**
- **Injection**
- **Power Stroke**
- **Exhaust Stroke**

Combustion due to injection of fuel into compressed hot air

⚠️ Compression-ignition engines are sensitive to any fuel contaminations
Common fuel contaminations

Water:
- rain
- air humidity

Solid particles:
- Dirt
- Fuel impurity
- Other contaminants

Sensitivity is intensified when High-pressure Common Rail fuelling systems (HPCR) is operating on new fuel components (NFCs)
Enhanced water/fuel coalescing filter media - *Introduction*

**HPCR/NFCs fuelling systems**

- **Fuel Tank**
- **Fuel Transfer/supply Pump**
- **Fuel Filter**
- **Injection Pump**
- **Distribution Rail**
- **Injector**

- Temperature: up to 100 °C
- Pressure: up to 5 bar

**Properties of Fuel**

- **Conventional Diesel fuel**
- **Ultra-Low Sulphur Diesel (ULSD) and Bio-diesel blends**

- Solid contaminant
- Water droplet + surfactants
- Surfactants

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HPCR/NFCs fuelling systems - Challenging filtration

- HPCR is highly sensitive to both water and solid contaminants, as such the fuel introduce to the system should be pure.
- Presence of surfactants disarms conventional filter media to separate emulsified water from the fuel.
Enhanced water/fuel coalescing filter media - Introduction

Quality fuel filtration

- Efficiency (e)
  \[ e = \frac{M_{dU} - M_{dD}}{M_{dU}} \times 100 \]

- Capacity

- Flow rate/Pressure drop (\(\Delta P\))

- Quality Factor
  \[ QF = \frac{-\ln(1 - e)}{\Delta P} \]

\(M_{dU}\): Upstream particle count/amount for particles of diameter \(d\) or greater

\(M_{dD}\): Downstream particle count/amount for particles of diameter \(d\) or greater
Enhanced water/fuel coalescing filter media – *Filter Design*

- Fuel/water emulsion
- Coalescence process
- Fibrous filter media

Design of Water/fuel Separation System

[Image of a diagram showing Diesel and the separation system components]
Fuel (ULSD/bio-diesel) – water emulsion

- High pressure fuel pump (high input energy)
- Low interfacial tension (IFT)
- Easy rupture of bigger droplets
- Low kinetic for fine and stabilised dispersed phase
Coalescence process

- The time two droplets stay together
- Intermolecular forces along with external forces

Film Drainage model

- Velocity difference between two droplets (external forces dominate intermolecular forces)

Critical Approach Velocity model
Enhanced water/fuel coalescing filter media – Filter Design

Factors in successful droplet coalescence

Control on movement of droplets

Control on velocity of droplets

Sufficient impact/residence time
Enhanced water/fuel coalescing filter media – *Filter Design*

Fibrous filter media: Media configuration

- **Dirt separator media:**
  - Single/composite layer
  - Multilayer

- **Water separator media:**
  - Coalescer element
    - Single/composite layer
    - Multilayer
  - Hydrophobic barrier element
    - Woven mesh/nonwoven
Enhanced water/fuel coalescing filter media – Filter Design

Fibrous filter media: Filtration mechanism

Particle capture:
- inertial impaction (mainly large particles, >1 μm)
- interception (>0.1 μm)
- diffusion
- electrostatic attraction

Particle separation:
- Holding solid particles
- Enlarging droplets by coalescence and let them to be drained out

Inertial impaction
Interception
Diffusion
Electrostatic attraction

Dirt Separator
Coalescer element
Enhanced water/fuel coalescing filter media – *Filter Design*

Role of fibrous media in successful droplet coalescence

Increase control on free-moving droplet by capturing them

- $W_{sl} > 0$; $\gamma_{lv} + \gamma_{sv} > \gamma_{sl}$
  - $\gamma_{lv}$: liquid surface tension
  - $\gamma_{sv}$: solid surface tension
  - $\gamma_{sl}$: solid-liquid interfacial tension
Role of fibrous media in successful droplet coalescence

- Increase control on captured droplets by managing their movement

- $W_s > 0; \gamma_{sv} > \gamma_{lv} + \gamma_{sl}$

- $P_c = \frac{2\gamma_{lv} \cos \theta_a}{r_e}$
  
  $r_e$: effective capillary radius

Contribute to induce surface tension gradient on the surface of droplets

- $Pl = \gamma \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$
  
  R1 and R2: radiiuses of the curved interface
Design of water/fuel coalescing media

Operational Requirements
- Coalescing water droplets
- Structural stability
- Tolerable pressure drop
- Inexpensive and universal application

Required Properties
- Managing water droplet movement
- Proper flex resistance
- Proper fluid permeability
- Material and production process

Technical Factors
- Surface area
- Wettability
- Porosity, pore size, pore size distribution
- Physical, chemical, and thermal properties of material
Surface area, wettability, pore structure, thickness, and macrostructure of the fibrous structure are being considered as the main properties of coalescing filter media.

Inversely interrelated factors such as pressure drop versus pore-size, surface area, and wettability have made the media design very challenging and comprehensive study is needed to provide a clear profile for the factors.

Single layer and multilayer media are two main structural configurations for coalescing media.

The future trend in this area might be focused on proper configuration and selection of materials in fibrous coalescing media to manage fibrous material properties to maximise fulfilment of the end-use requirements.
Enhanced water/fuel coalescing filter media

Our Facilities in Leeds to study, model, and design water/fuel separation systems

Water coalescence test rig

Water coalescence simulation

Water droplets

Fibres
Thank you...

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