Wettability Characterization of Filter Media using Modified Washburn's Equation

By

Prashant Kulkarni

The University of Akron

PRODUCED WATER SOCIETY - JAN 2009

Acknowledgements

- Dr. George Chase
- Chan Shin and Kavitha Moorthy (Previous Graduate Students)
- Coalescence Filtration Nanomaterials Research Consortium
  - Parker Hannifin Corporation
  - Ahlstrom Paper Group
  - Cummins Filtration
  - MemPro Ceramic
  - Donaldson Company
- Produced Water Society

Outline

- Motivation
- Wettability- In liquid-liquid coalescence
- Research background
- Problem Statement
- Hypothesis
- Wettability Characterization
- Materials and Filter Media Preparation
- Results
- Summary
- Future work

Motivation

Fuel filtration

- Liquid fuel contains both solids and water as contaminants.
- Effect of water is more insidious than solids.
- Water is present in fuels as Primary emulsions (>100μm) and as Secondary emulsions (<100μm).
- Water combines with chemicals in fuels, such as sulfur and form corrosive compounds which corrode engine parts.
- Surfactants- reduce interfacial tension.

Oil-in-water emulsion separation

- Plugging of lines, orifices and valves due to deposition of hydrocarbons.
- Degradation of process water quality.

Industrial Importance

- Dewatering of Crude oil.
- Water haze removal from Aviation fuels.
- Separation of oil from process water.

Coalescence Filters

Important factors

- Fluid velocity, fiber structure, fiber geometry, surface properties, fluid properties etc.
- Bed length (determines the filter efficiency)

In liquid-liquid coalescence

Wettability of filter media is known to have effect on filter performance, especially when interfacial tension between liquid phases is low.

Wettability-In liquid-liquid coalescence

- Wettability of filter media can be defined as ability of filter media to hold water.

- Wettability of filter media depends on surface properties of fibers and porosity of filter media.

- Surface properties of fibers could be based on hydrophilic and hydrophobic nature of fibers.

Effect on filter performance

- The hydrophilic fibers can hold water inside the filter media and leads to higher saturation.
- Higher saturation reduces porosity and permeability and low porosity leads to excessive pressure drop.
- If fibers are hydrophobic then there will be no coalescence.
- Intermediate wettability gives best performance.

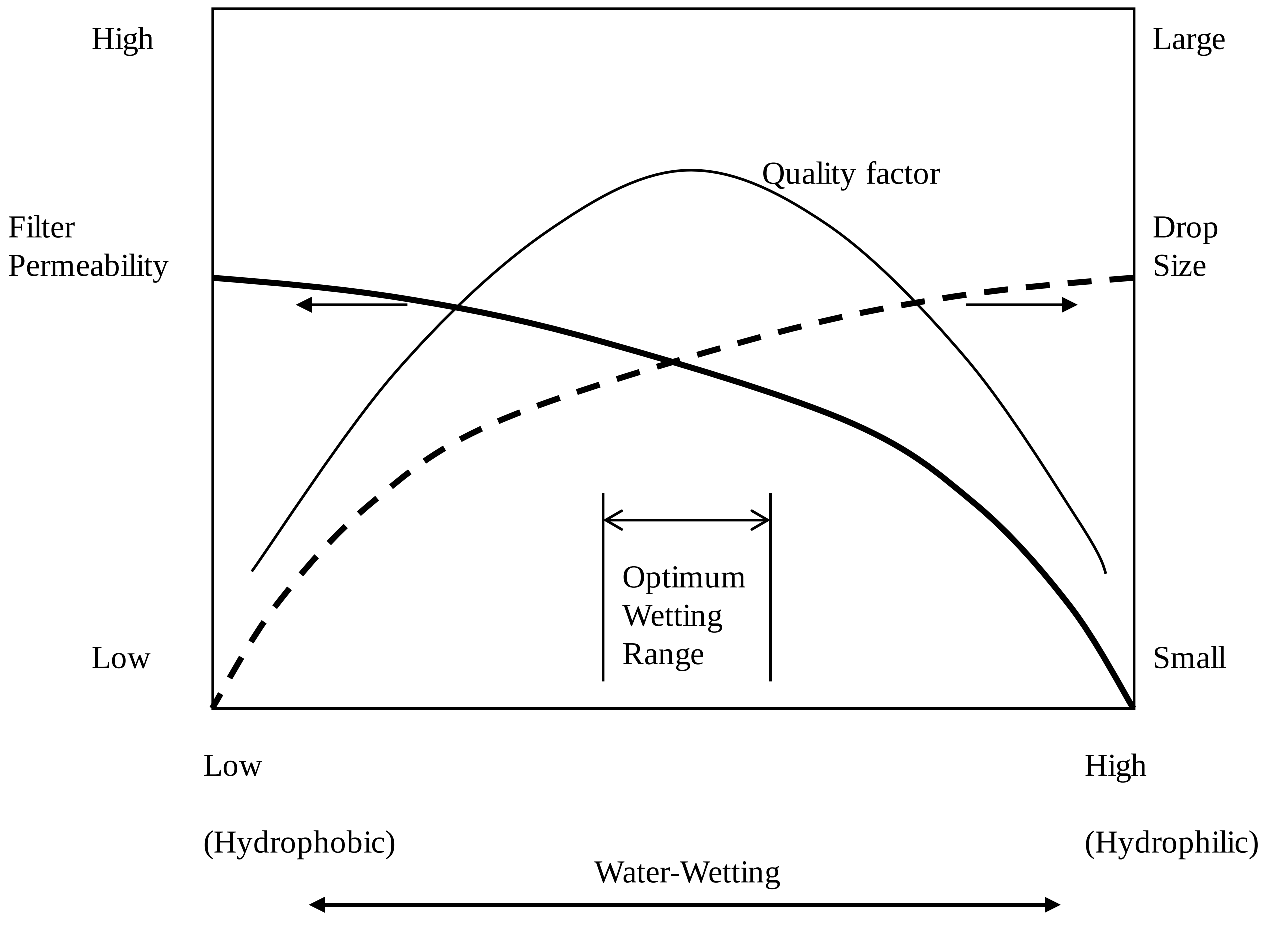
Research Background

- Experiments with silane coated glass rods (Shin, 2004)
  - Study of attachment of water drops on silane coated cylindrical surfaces (glass rods)
- Coalescence experiments with silane coated filter media (Moorthy, 2007)
  - Study of effect of surface energy on liquid-liquid coalescence (silane coated filter media)
  - Characterization of wettability (Washburn Equation)

Silanes

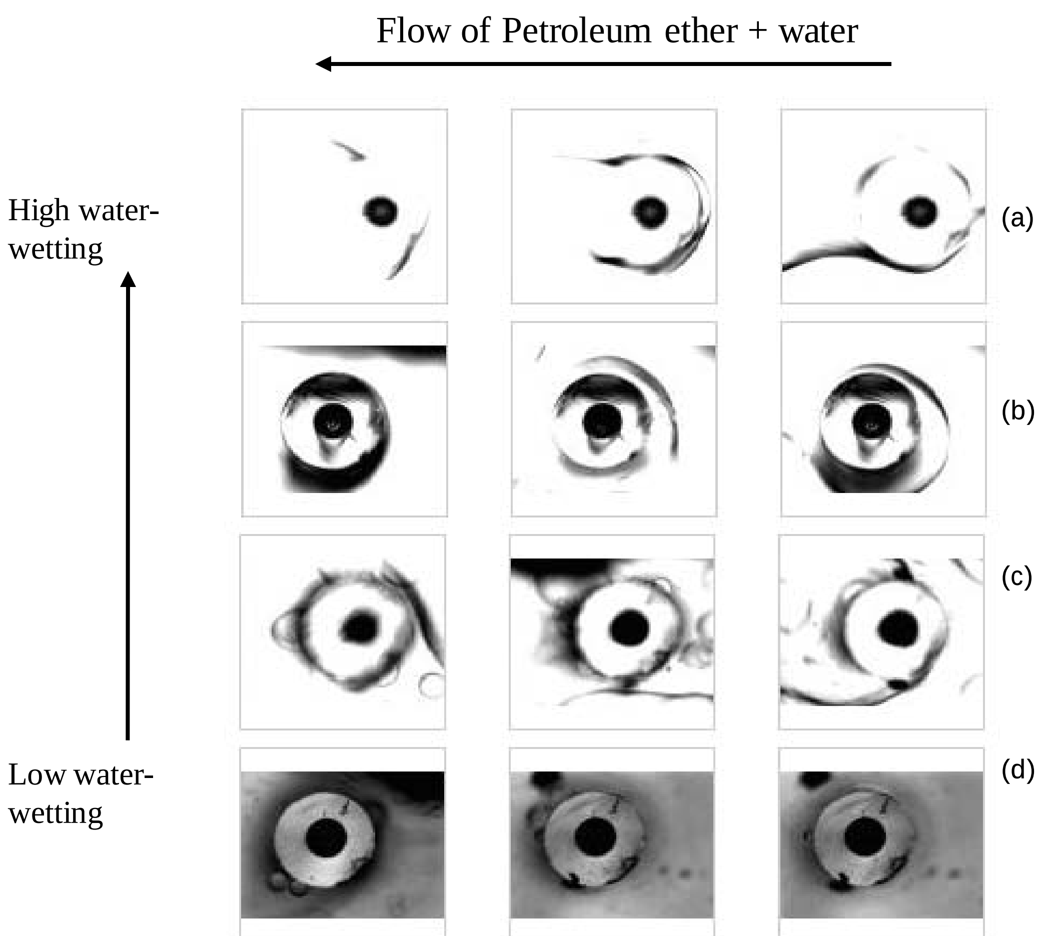
Silane Coating	Water contact angle on flat surfaces
Uncoated Glass	~0^0
FTS **((heptadecafluoro-1,1,2,2-tetra-hydrodecyl) trichlorosilane)**	104^0
CES **(2-(carboxymethylthio)ethyltrimethylsilane)**	62^0
APTS **(3-aminopropyltriethoxysilane)**	39^0

Working Hypothesis



(Moorthy,2007)

Experiments with silane coated glass rods



Untreated glass rod-water forms film around glass rod

APTS - water forms a thick film around the rod.

CES - some drops attach and coalesce on the rod surface but are easily pulled off of the surface

FTS - drops do not attach and are quickly removed before coalescence can occur

(Shin, 2004)

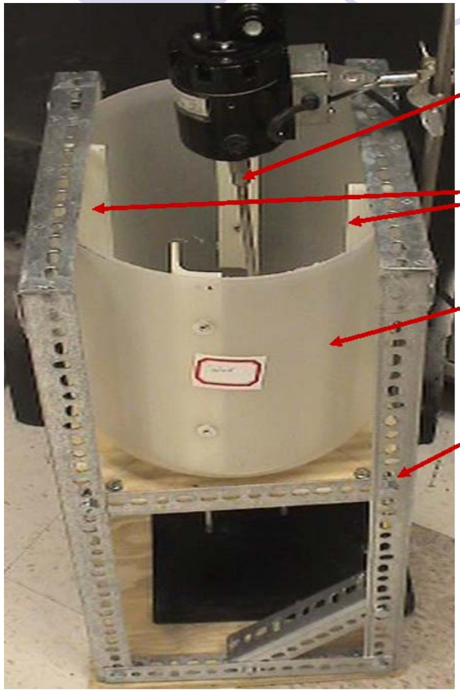
Problem Statement

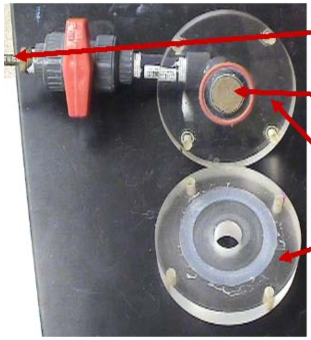
- Wettability of filter media has an effect on filter performance.
- Effect of wettability on filter performance is not well understood, especially when interfacial tensions are low.
- Dearth of literature and useful data is limited.
- Wettability characterization techniques are not widely applied.

Hypothesis of this work

- Filter media can be made by mixing hydrophilic and hydrophobic fibers.
- If fiber is hydrophilic, larger drops form on fiber as drops stay on fiber surface for extended period of time.
- Hydrophobic fibers aid in drop migration and drainage and therefore, reduces saturation and increases permeability.
- In Mixed filter media hydrophobic fibers can aid in drop migration towards the hydrophilic fibers and larger drops get formed. Larger drops are good for coalescence.

Materials and Filter Media Preparation





Vacuum Molding Set-up

Materials

Polypropylene fibers (Minifibers Inc.)

Microglass fibers (Hollingsworth & Vose)

Filter preparation

Dilute slurry of Glass and polypropylene in 7 L of water

Vacuum molding in 2.54 cm filter molds

Heating and drying at 100 ^{0}C for 2 hrs.

Samples

Glass: PP (100:0, 80:20, 60:40, 50:50, 40:60)

Modified Washburn Equation

The method of contact angle cannot be used to characterize wettability of filter media.

Based on capillary rise, Washburn Equation

$$h = \sqrt{\frac{r_{eff}\ \mathbf{cos}\,\theta_a \gamma_{lv}}{2\eta} t}$$

η =viscosity of liquid,

γ =surface tension of liquid,

r_{eff}=effective capillary radius,

θ_a= advancing contact angle.

ε = porosity of medium

w = weight of liquid taken by filter

t = time

$$w = \varepsilon \rho \pi R^2 h$$

$$c = \frac{\varepsilon^2 \pi^2 R^4 r_{eff}}{2}$$

$$\frac{dw^2}{dt} = S = \frac{c\rho^2 \gamma_{lv}\ \mathbf{cos}\,\theta_a}{\eta}$$

Initial Slope of Kinetic data by

Modified Washburn Equation

Liquid uptake method

Timer

Scissor Stand

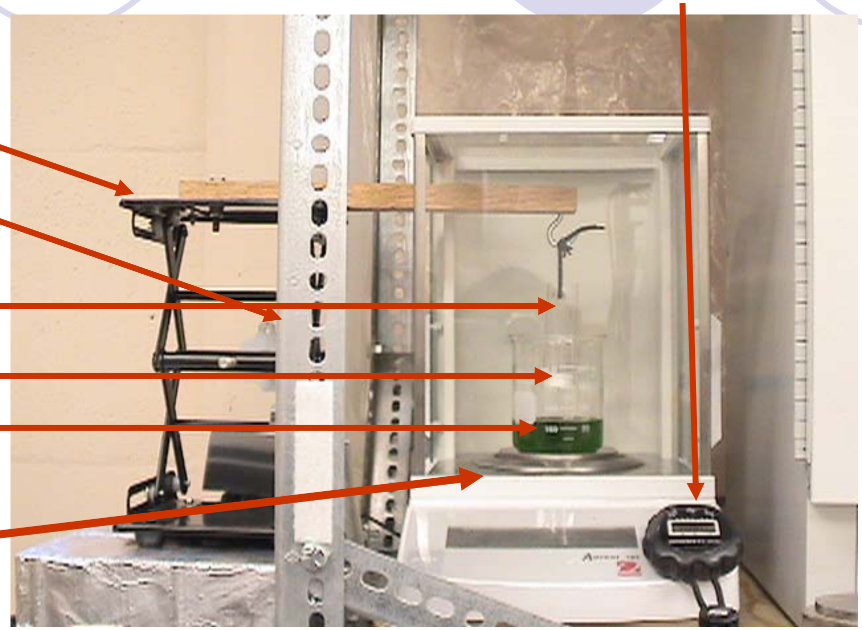
Knob

Glass Tube

Filter Medium

Reference Liquid

Balance



Reference Liquids-

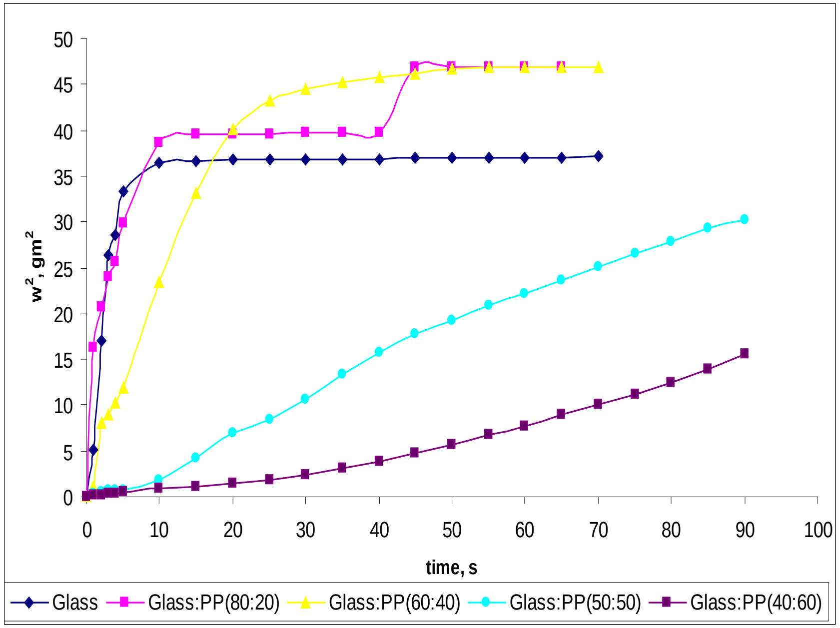
Viscor oil -1487 and water

$$\frac{L}{H} = \frac{S_o \eta_o c_w \rho_w^{\,2} \gamma_w}{S_w \eta_w c_o \rho_o^{\,2} \gamma_o} = \frac{\cos \theta_o}{\cos \theta_w}$$

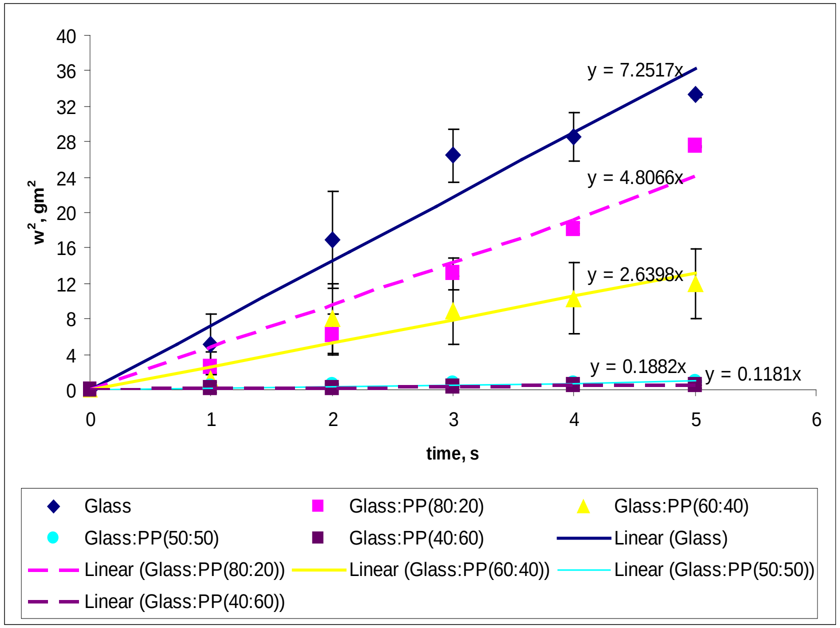
L/H = Large (means the filter is preferentially oil wetting)

L/H = Small (means the filter is preferentially water wetting)

Results
Wetting Kinetics – Water as reference fluid

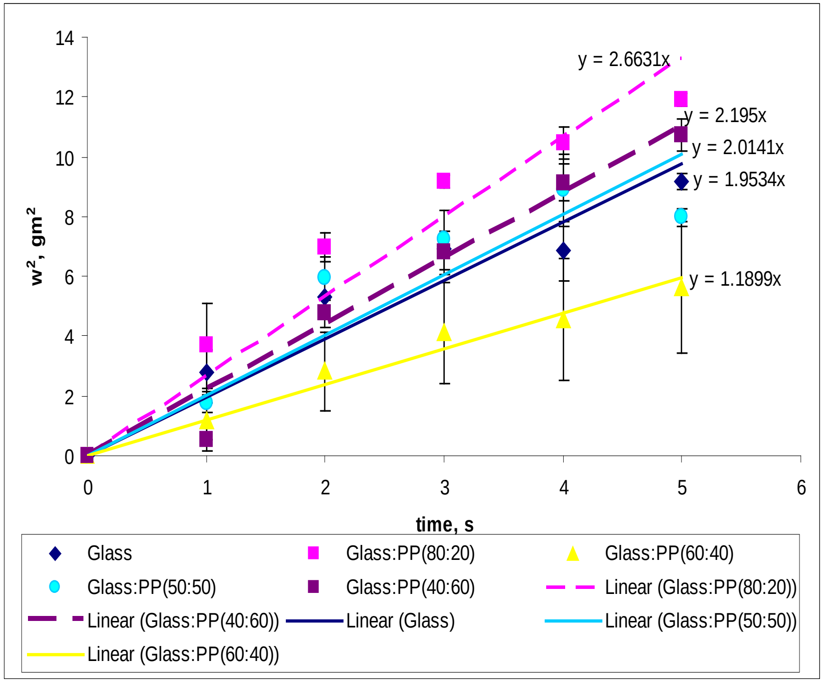


Wetting kinetics for different glass: PP filter media with water as reference liquid



Initial Wetting kinetics for different glass: PP filter media with water as reference liquid

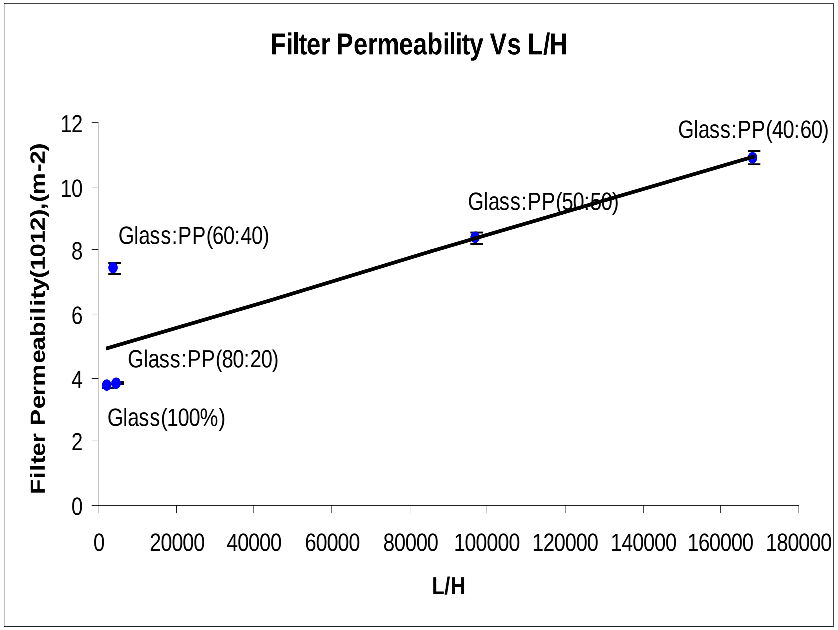
Wetting Kinetics- Viscor Oil 1487 as reference fluid



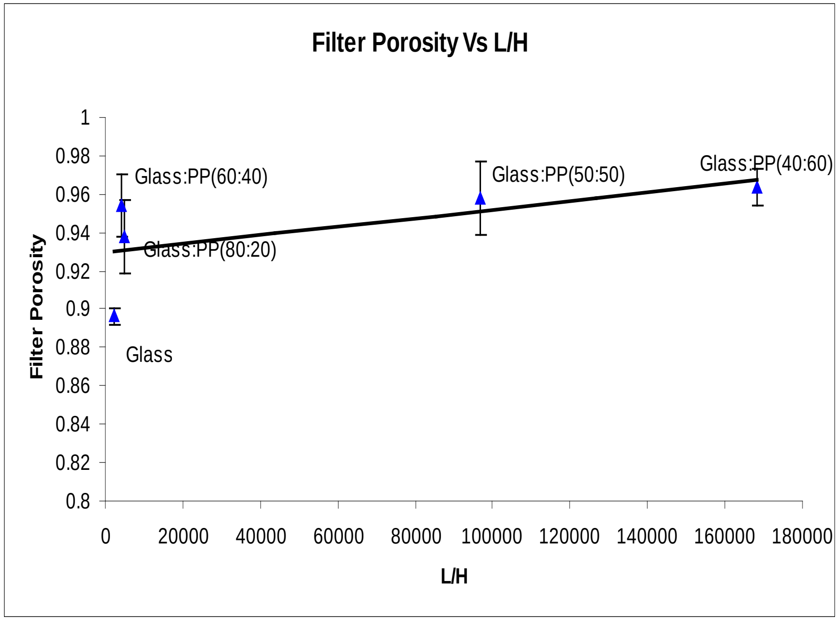
Wetting kinetics for different glass: PP filter media with Viscor oil 1487 as reference liquid

Initial Wetting kinetics for different glass: PP filter media with Viscor oil 1487 as reference liquid

Effect of Filter permeability and Porosity



Filter permeability Vs L/H values for different glass: PP filter media.



Filter porosity Vs L/H values for different glass: PP filter media.

Summary

- Intermediate wettability gives better filter performance.
- Mixing hydrophobic and hydrophilic materials into filter media in appropriate proportions may give optimum wetting range.
- Wettability of filter media can be characterized by Modified Washburn Equation.
- This approach is unique way to design filter media.

Future work

- Perform liquid-liquid coalescence experiments to test the performance of filter media.
- Wettability characterization of developed filter media.
- Analyze results to predict appropriate materials and wettability range for filter media.
- Extend work with different fiber materials like polystyrene, nylon and polyethylene fibers or by with coatings.
- Coalescence experiments for separation of oil from water.

THANK YOU!