Separation of liquid-liquid emulsions using hydrophilic/hydrophobic coalescing media

Prashant Kulkarni, Shagufta Patel,
George Chase

The University of Akron

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Topics

- Motivation
- Coalescence filters & wettability
- Research background
- Materials and filter media preparation
- Wettability characterization
- Liquid-liquid coalescence experiment results
- Summary
- Future work

REMOVAL OF WATER DROPS FROM FUEL HAS SIMILARITIES TO REMOVAL OF OIL DROPS FROM WATER

Motivation

Industrial Importance

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

Water is a problem in fuels

- Water combines with chemicals in fuels, such as sulfur and form corrosive compounds which corrode engine parts.
- Water promotes microbial growth – plugs fuel filters.
- Water degrades fuel quality and burning efficiency.

Effect of wettability on silane coated glass rods

Flow of petroleum ether + water

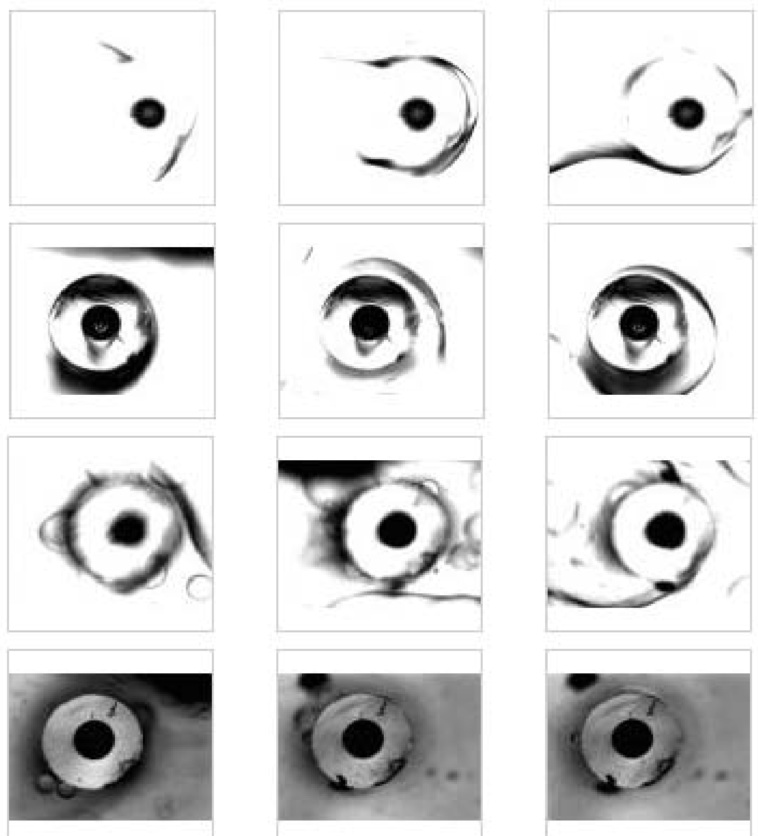
Contact Angle

0 deg — High water-wetting

39 deg

62 deg

104 deg — Low water-wetting



(a) Untreated glass rod – Thick water film

(b) APTS – Thin water film (3-aminopropyltriethoxysilane)

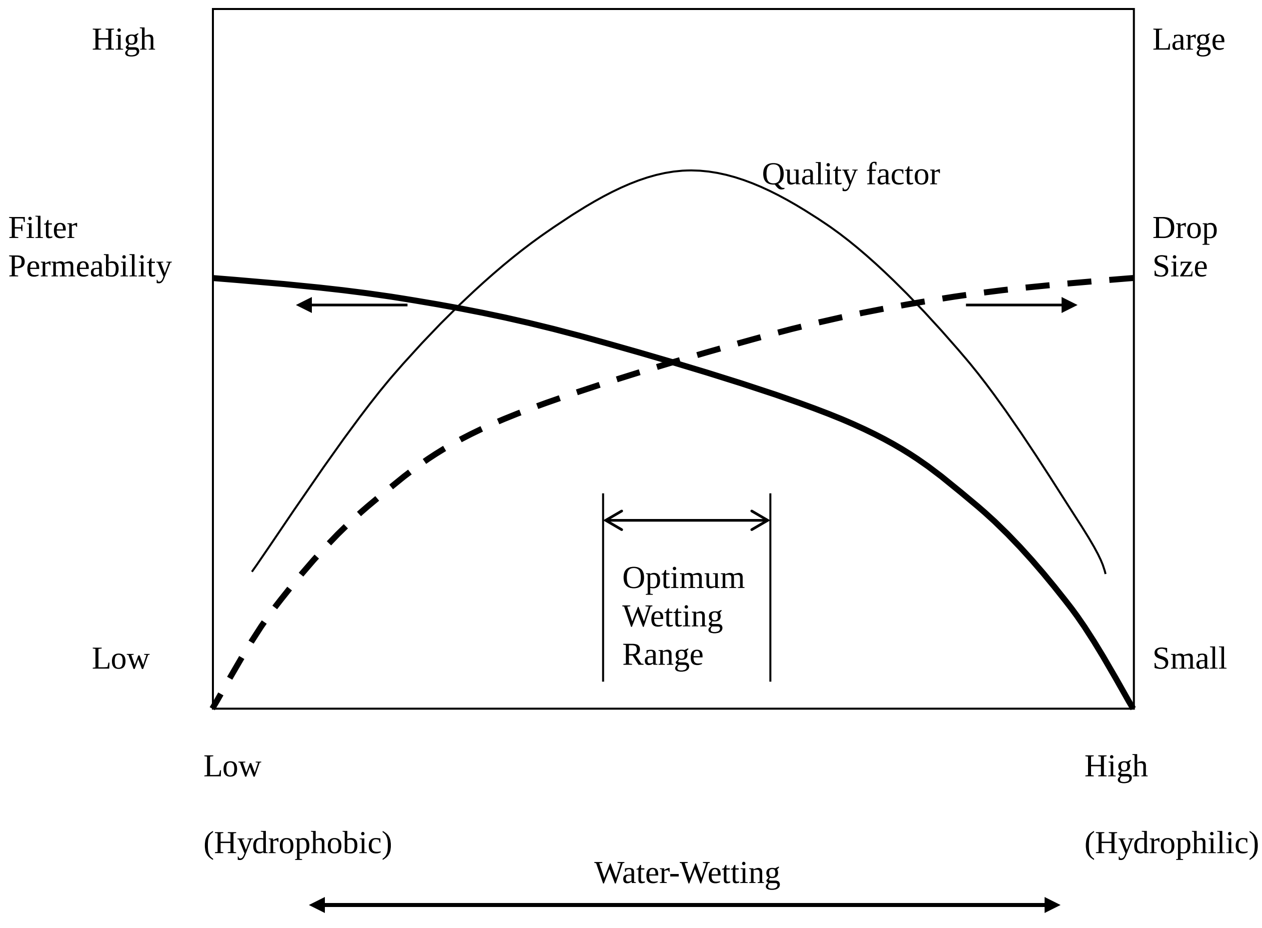
(c) CES - some drops attach and coalesce but easily pulled off of the surface (2-(carboxymethylthio)ethyl-trimethylsilane)

(d) FTS – no drop attachment, no coalescence ((heptadecafluoro-1,1,2,2-tetra-hydrodecyl) -trichlorosilane)

(Shin, 2004)

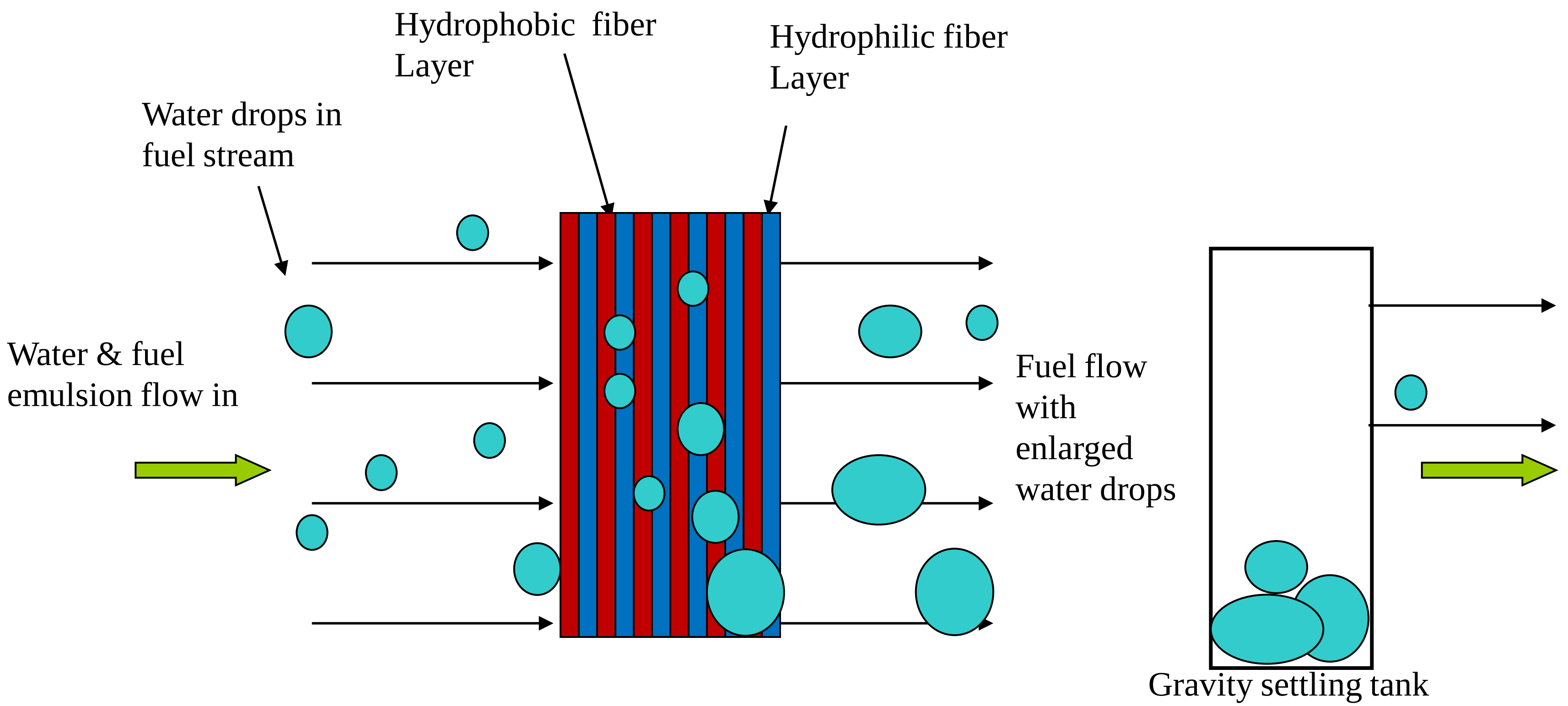
Working Hypothesis

INTERMEDIATE WETTABILITY GIVES BEST PERFORMANCE



(Shin, 2004 & Moorthy,2007)

Approach- Layered Hydrophilic/Hydrophobic fiber media



✓10 layers of each fiber - Microglass and Polypropylene (pp) or Polyester
✓ Layer thickness varies with fiber composition.
✓Filter thickness slightly varies with amount of Polymeric fibers (~ 0.44 to 0.48 inch)

Materials For Filter Preparation

Fiber Material	Fiber size (um)	Melting point (^{0}C)	Surface nature	Manufacturer
Microglass 0 deg	2-5	600	Hydrophilic	H&V
Polypropylene short cut ~ 100 deg	~7	166	Hydrophobic	Minifibers Inc.
Polyester short cut ~ 65 deg	~7	247	Hydrophobic	Minifibers Inc.

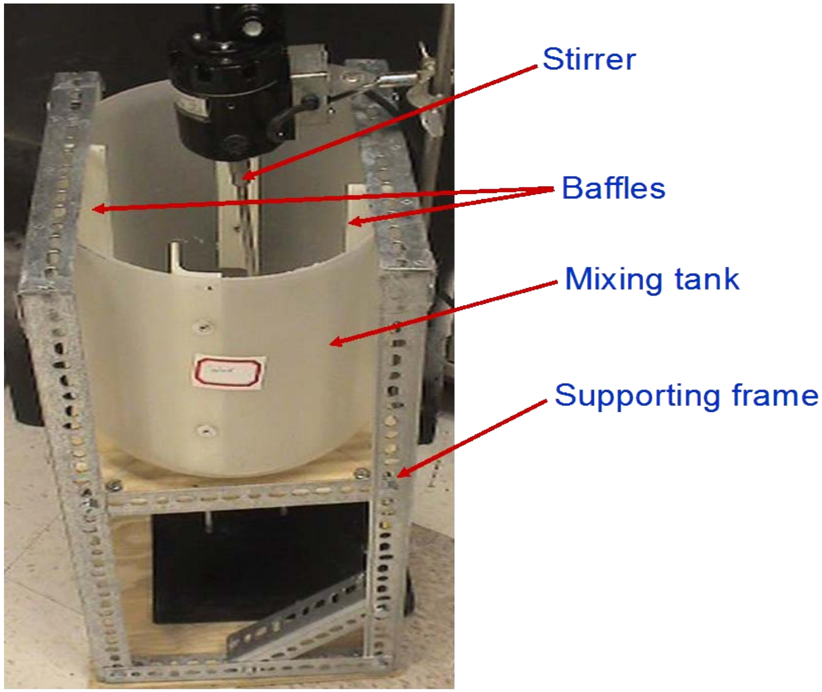
- Megasol S50 binder
- Polyethylene fibers synthetic pulp (thermal binder) (MP – $126^{0}C$)

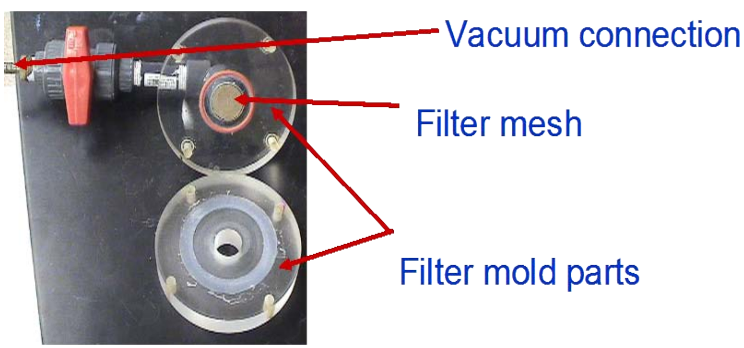
Filters Samples

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

Glass: PET (80:20, 60:40, 50:50, 40:60, 20:80)

Filter Media Preparation





Vacuum Molding Set-up

Filter preparation

Dilute slurries of Glass and polypropylene or polyester in 2.5 L of water with binder.

Vacuum molding in 2.25 cm filter molds.

Apply binder on outside edge .

Heating at 125 ^{0}C for 3-4 min.

Heating at 120^{0}C for 2 hrs.

Modified Washburn Equation

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

Based on capillary rise, Washburn Equation

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

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

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

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

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

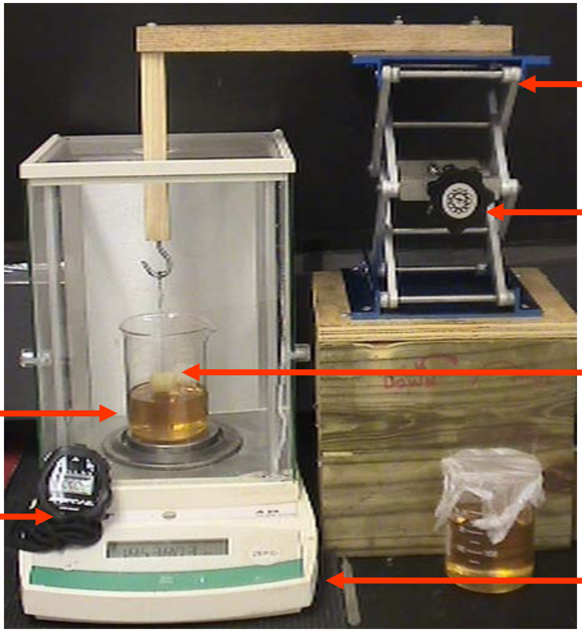
Initial Slope of Kinetic data by

Modified Washburn Equation

Liquid uptake method

Test liquids-

- Viscor -1487
- water



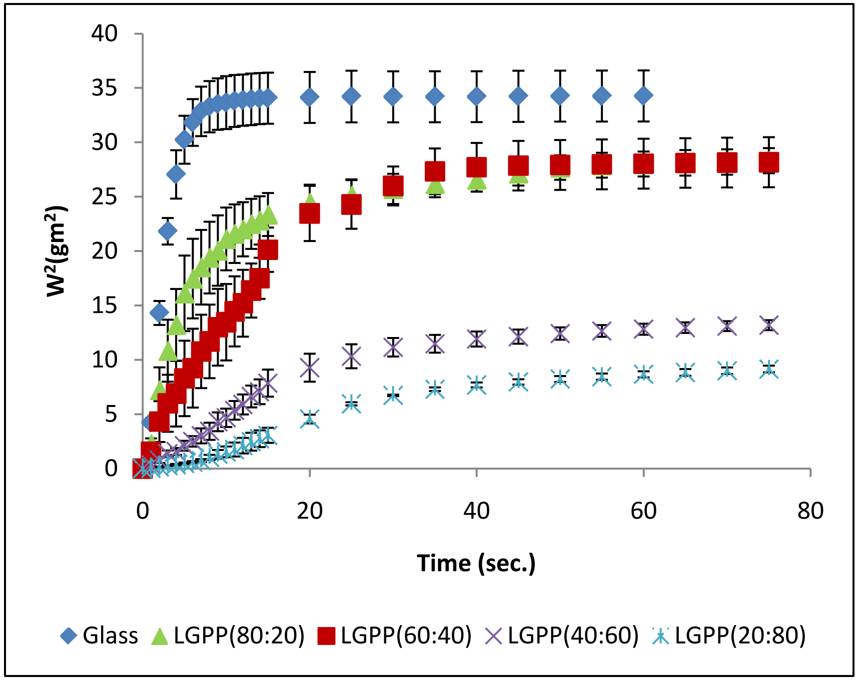
$$\frac{L}{H} = \frac{S_o \eta_o c_w \rho_w^{\ 2} \gamma_w}{S_w \eta_w c_o \rho_o^{\ 2} \gamma_o} = \frac{\cos\theta_o}{\cos\theta_w}$$

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

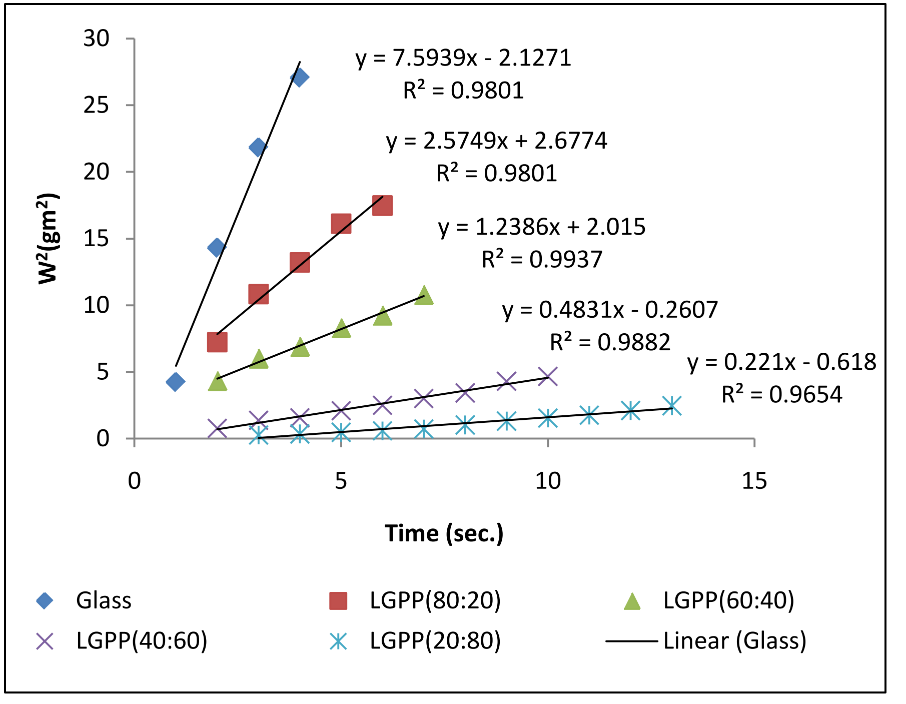
L/H = Small (means the filter is preferentially water wetting)

Results- Layered Glass:PP filter media

Wetting Kinetics – WATER as test liquid



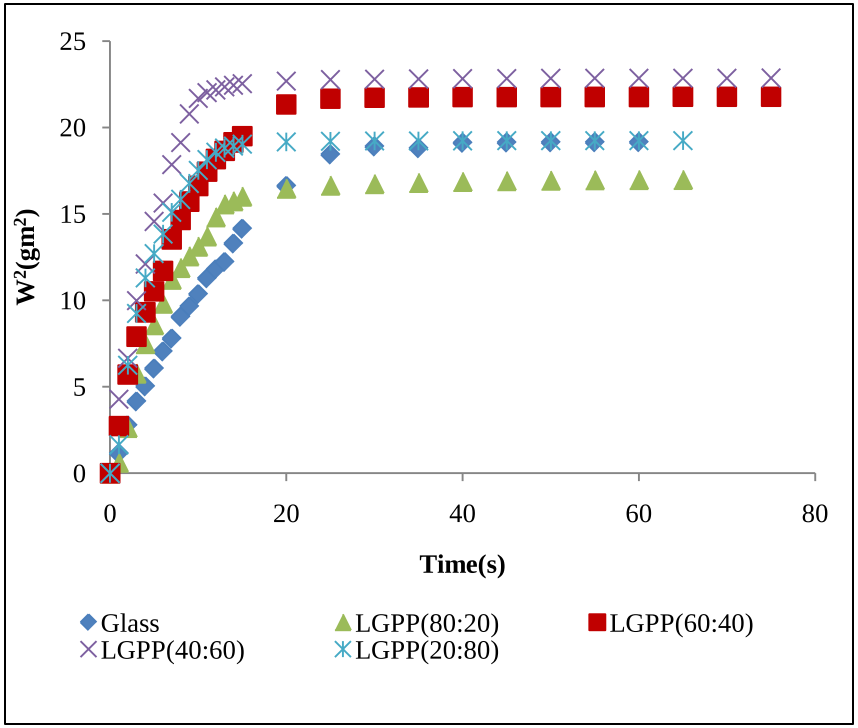
Wetting kinetics for different glass: PP filter media with water as test liquid

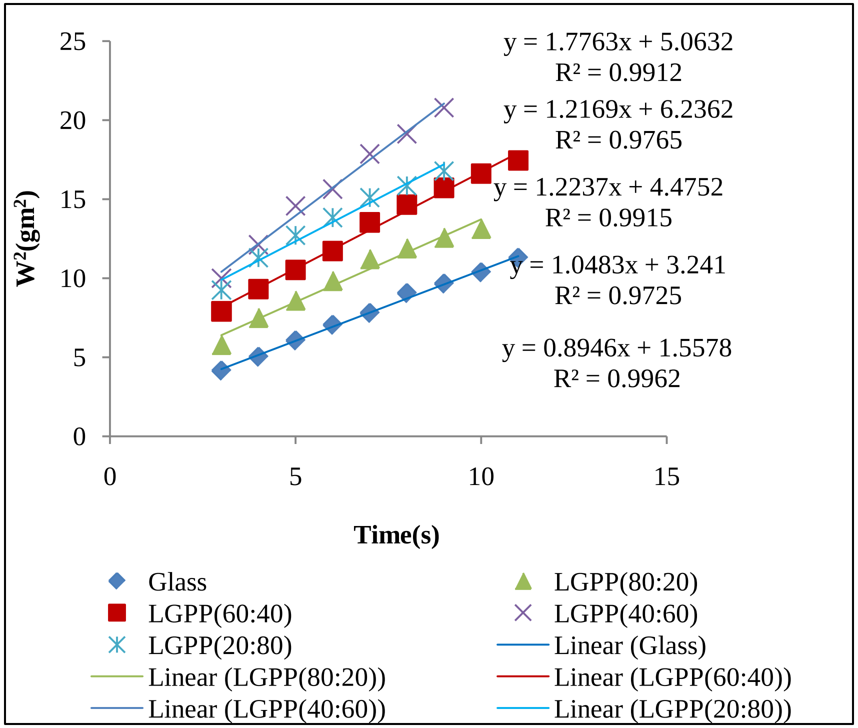


Initial Wetting kinetics for different glass: PP filter media with water as test liquid

Results- Layered Glass:PP filter media

Wetting Kinetics – VISCOR OIL-1487 as test liquid



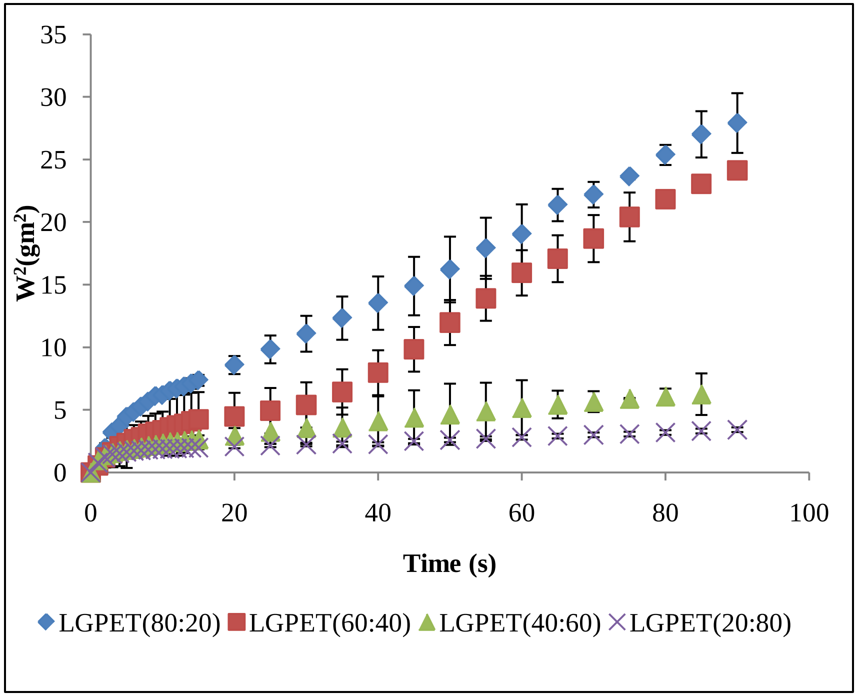


Wetting kinetics for different glass: PP filter media with Viscor Oil as test liquid

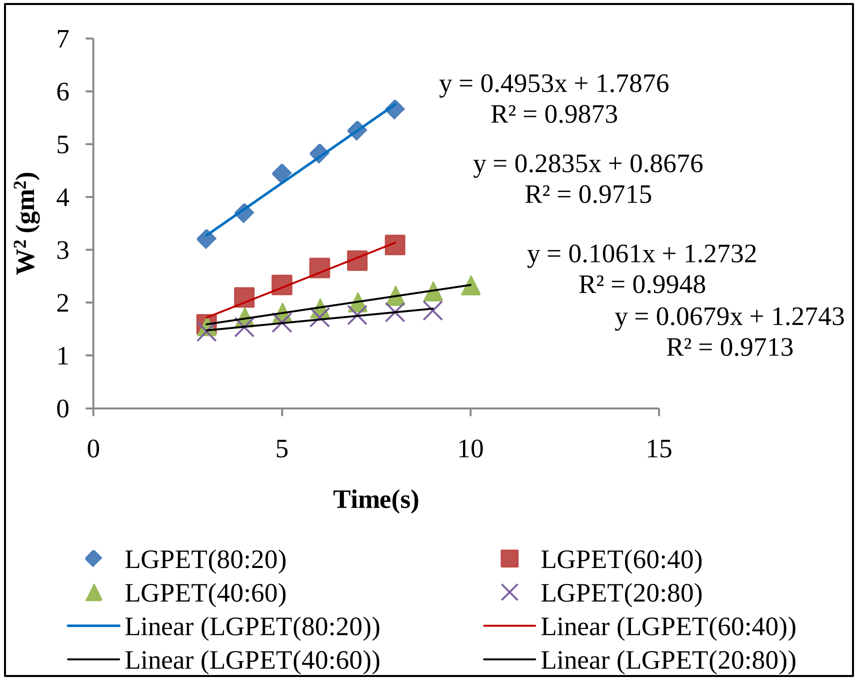
Initial Wetting kinetics for different glass: PP filter media with Viscor Oil as test liquid

Results- Layered Glass: PET filter media

Wetting Kinetics – WATER as test fluid



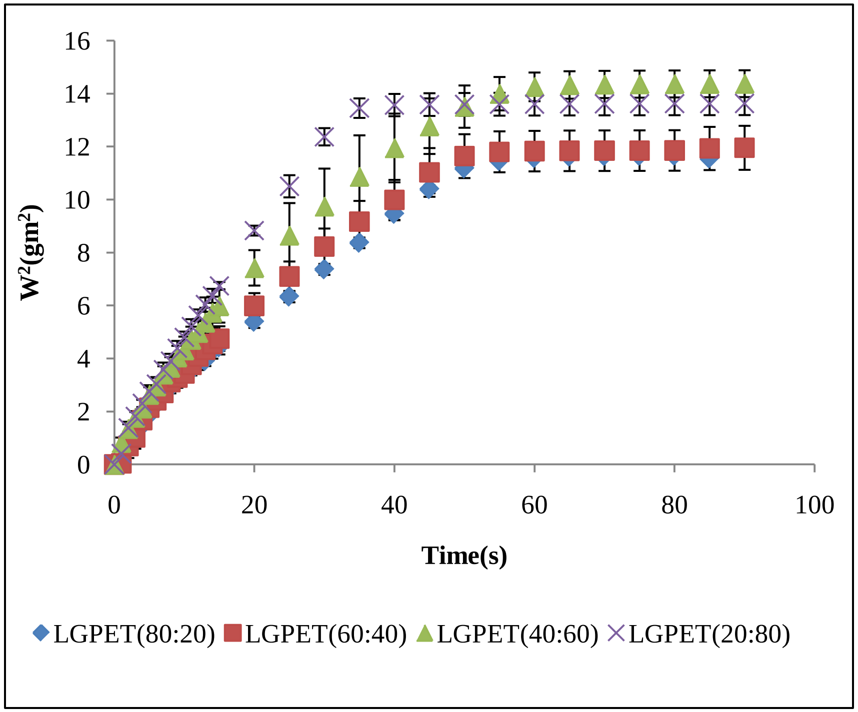
Wetting kinetics for different glass: PET filter media with water as test liquid



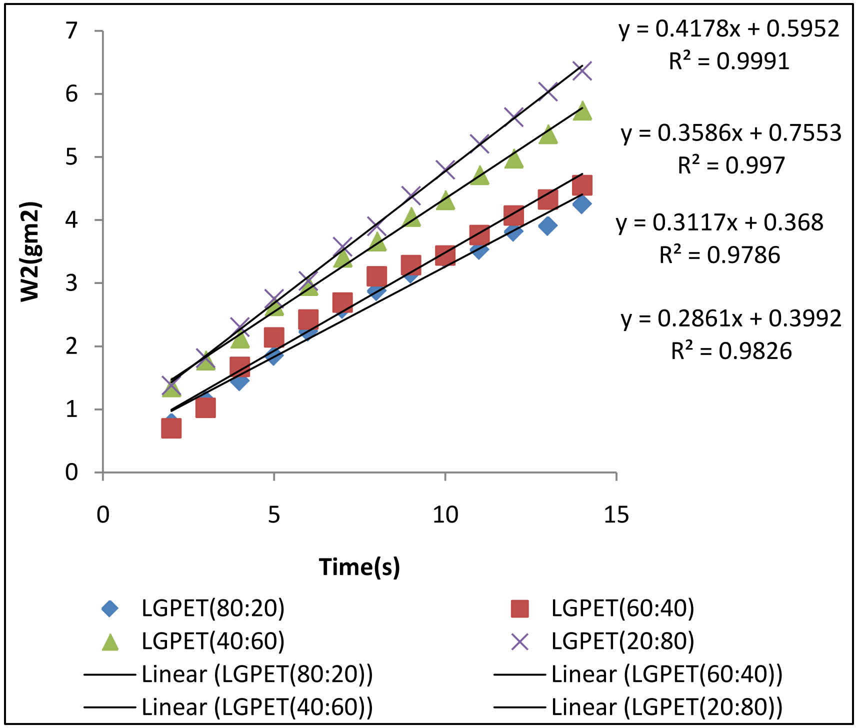
Initial Wetting kinetics for different glass: PET filter media with water as test liquid

Results- Layered Glass: PET filter media

Wetting Kinetics – VISCOR OIL-1487 as test liquid

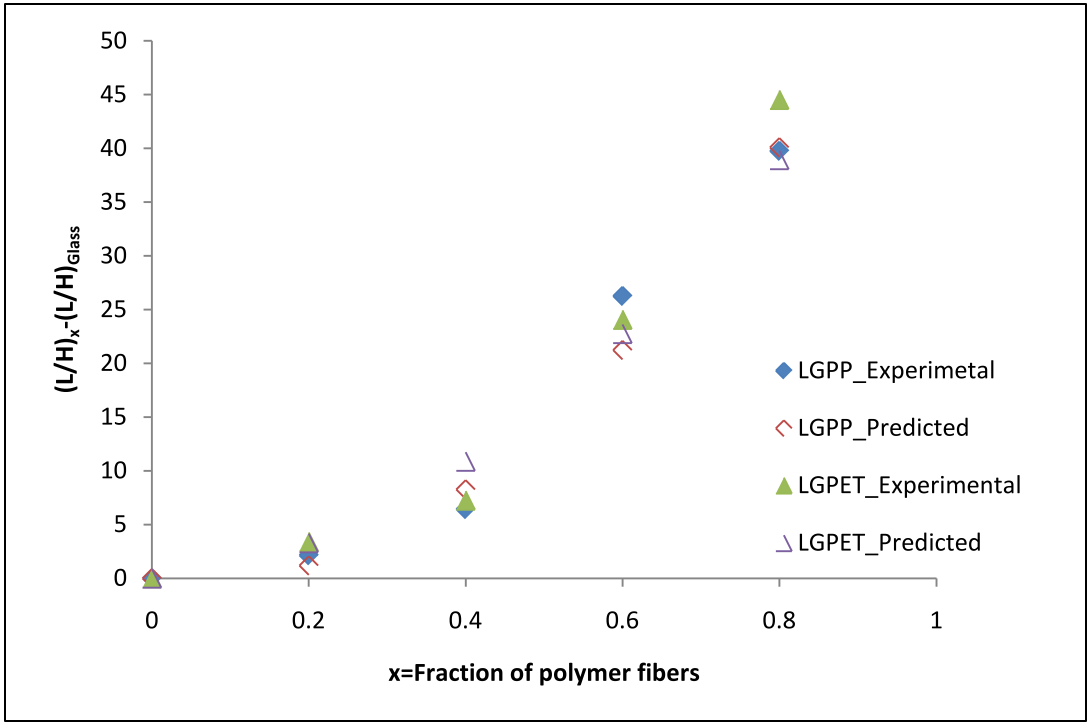


Wetting kinetics for different glass: PET filter media with Viscor Oil as test liquid



Initial Wetting kinetics for different glass: PET filter media with Viscor Oil as test liquid

Filter media wettability with variation in fiber composition



Layered Glass-PP

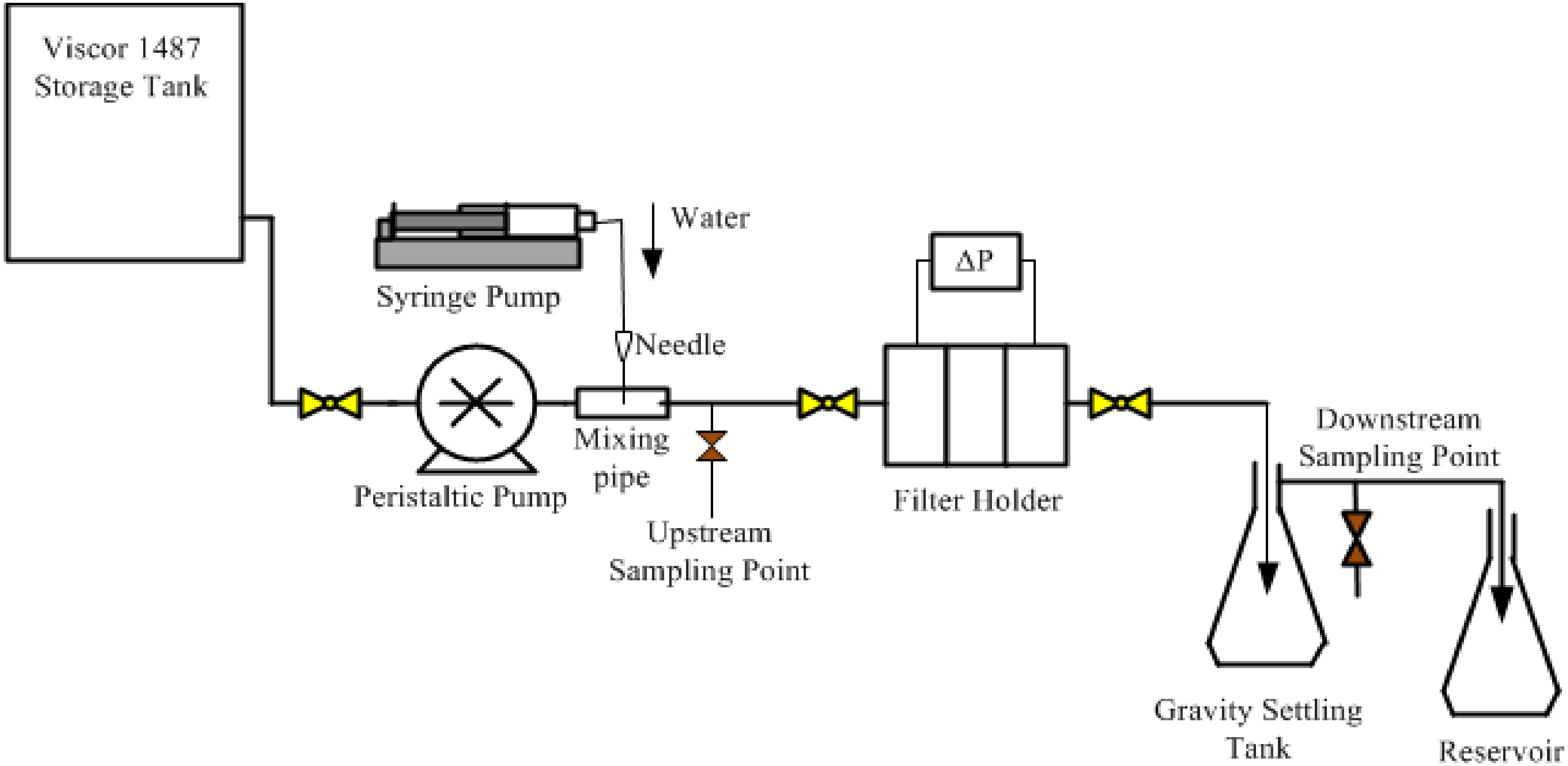
$$\left[\left({}^{L}/_{H}\right)_{x} - \left({}^{L}/_{H}\right)_{Glass}\right] = 73.610x^2 - 8.7795x$$

Layered Glass-PET

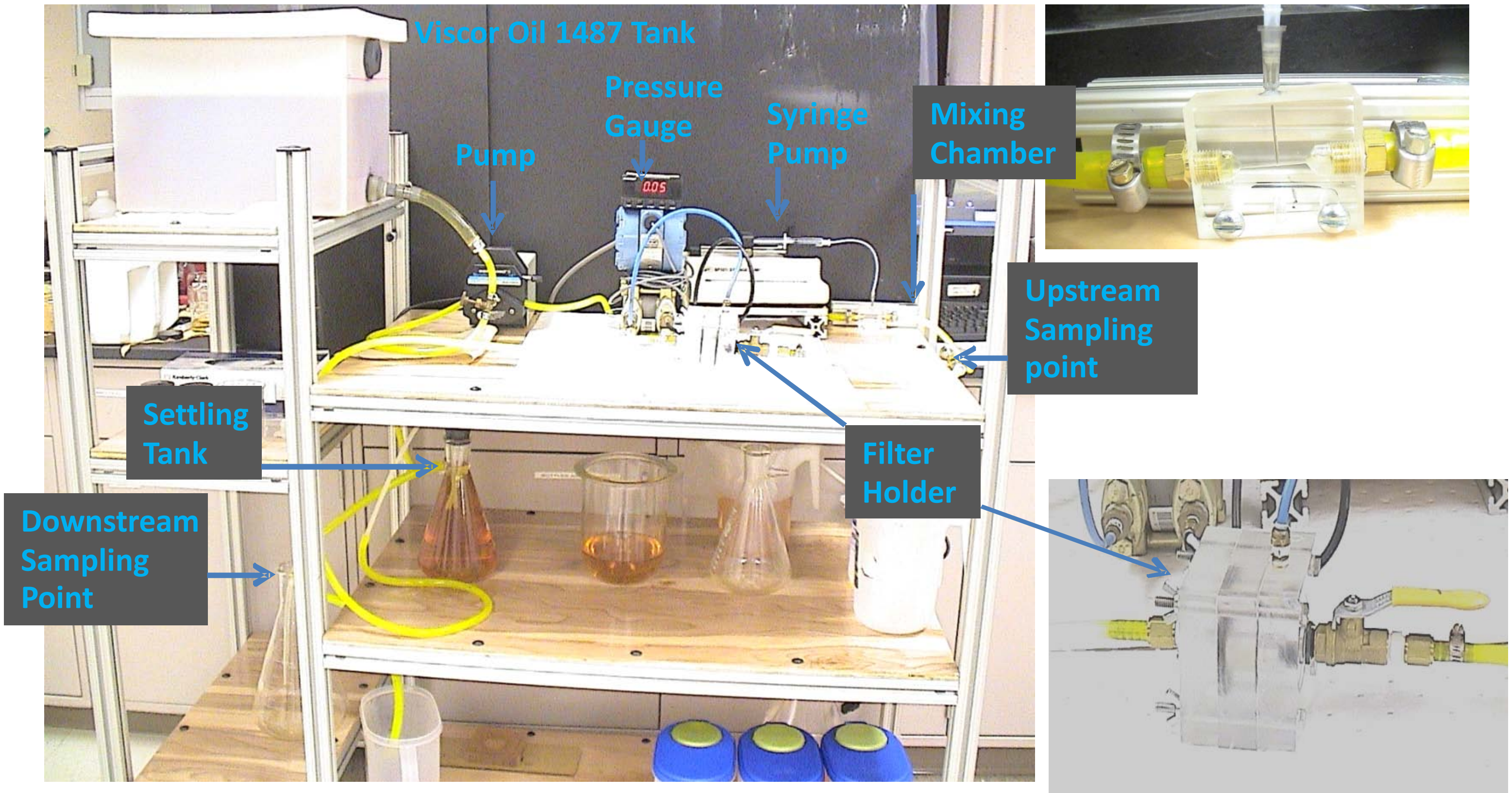
$$\left[\left({}^{L}/_{H}\right)_{x} - \left({}^{L}/_{H}\right)_{Glass}\right] = 53.726x^2 + 5.6912x$$

It is possible to achieve a range of wetting properties by varying the composition of hydrophilic and hydrophobic fiber layers.

Liquid-liquid Coalescence Schematic

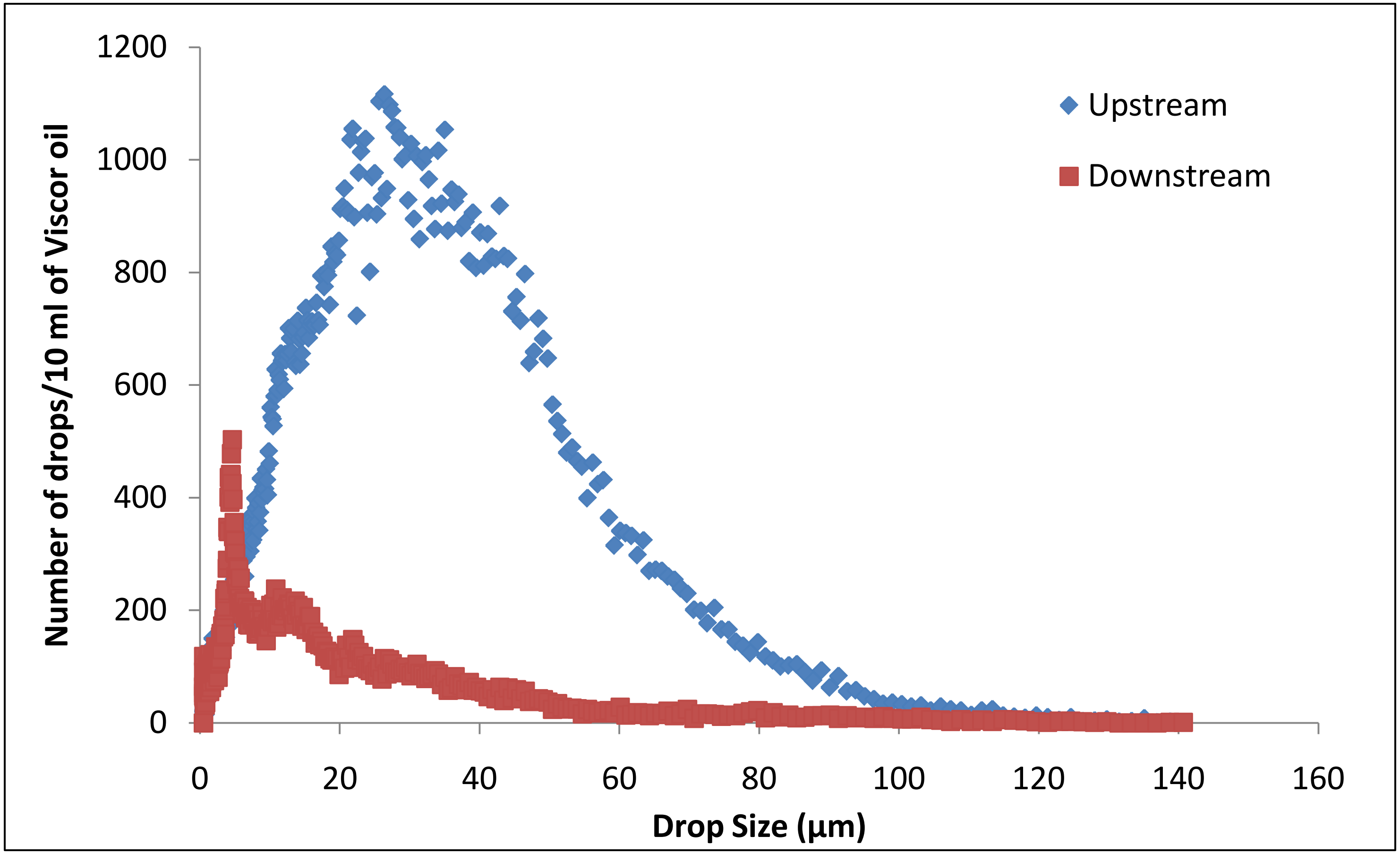


Liquid-liquid Coalescence experiment set-up

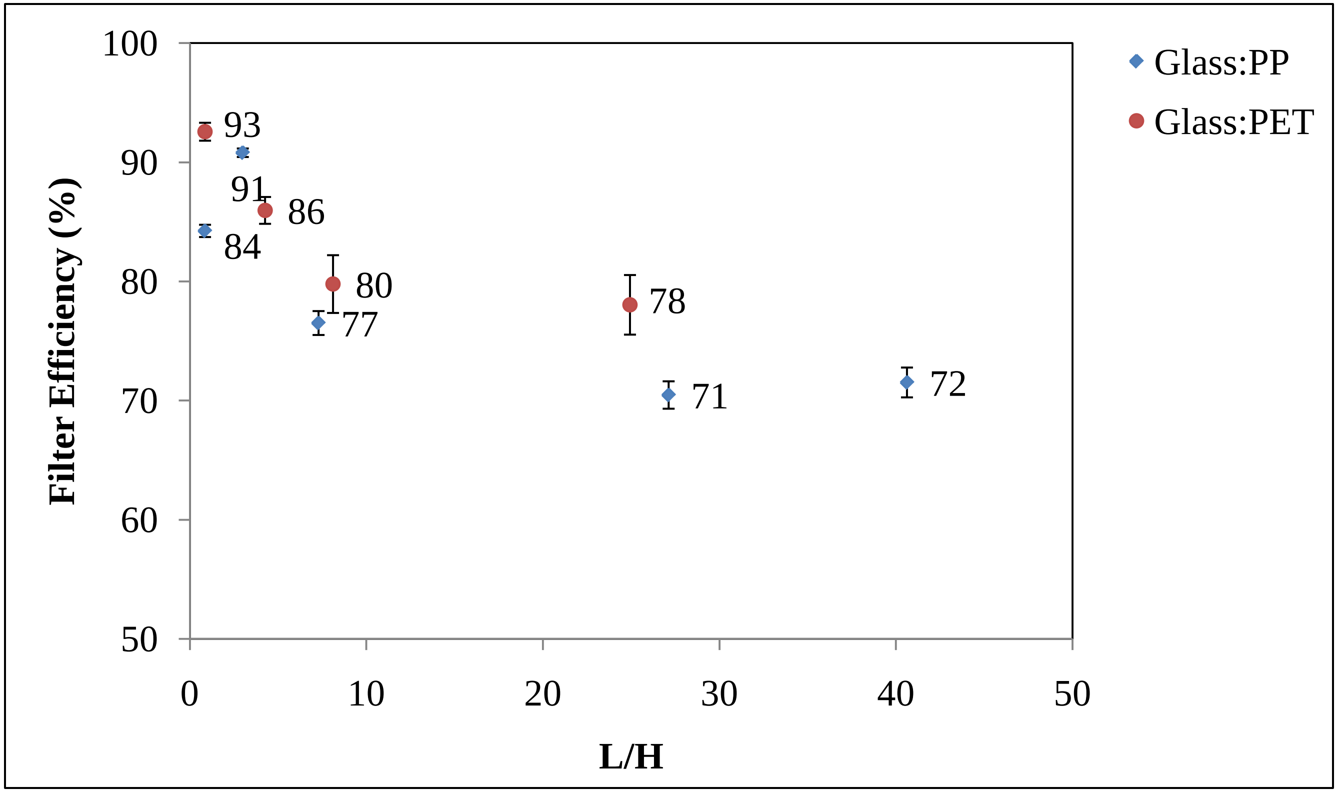


- ✓ Oil Flow rate – 210 ml/min
- ✓ Water flow rate – 80 ul/min
- ✓ IFT – 15 dynes/cm
- ✓ Particle Analysis – Accusizer -780/PALS (0.5 – 500 um sensor)

Droplet size distribution obtained using Accusizer

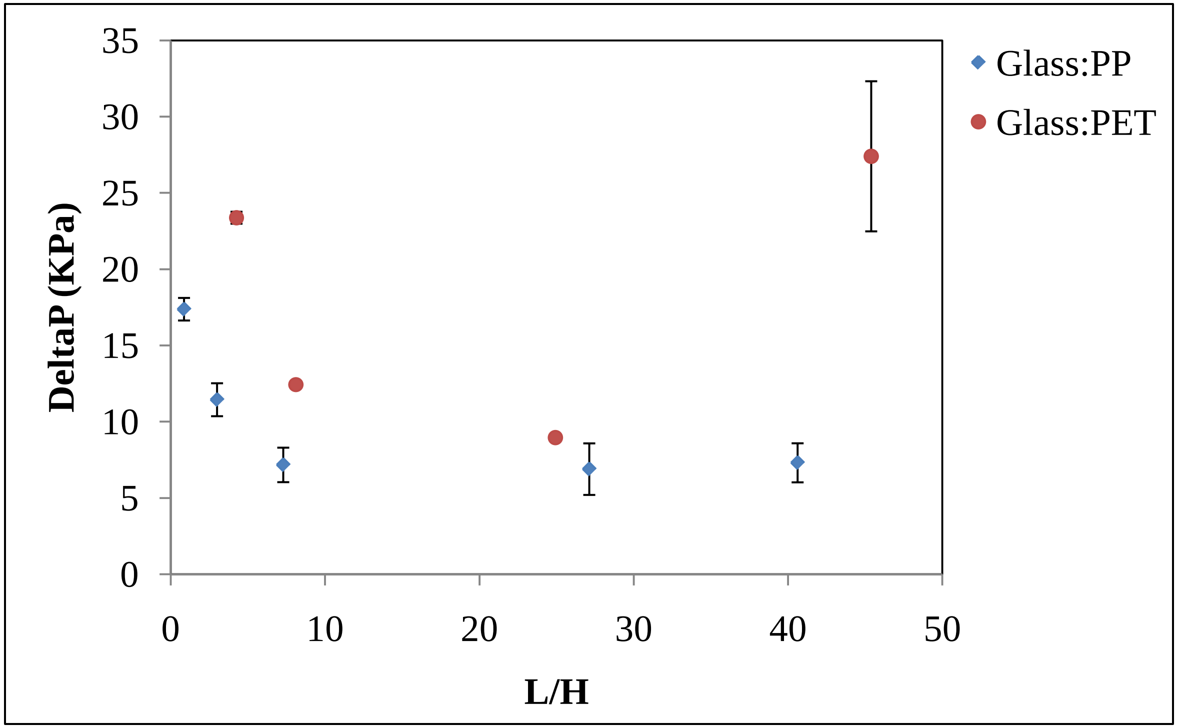


Effect of wettability on separation efficiency



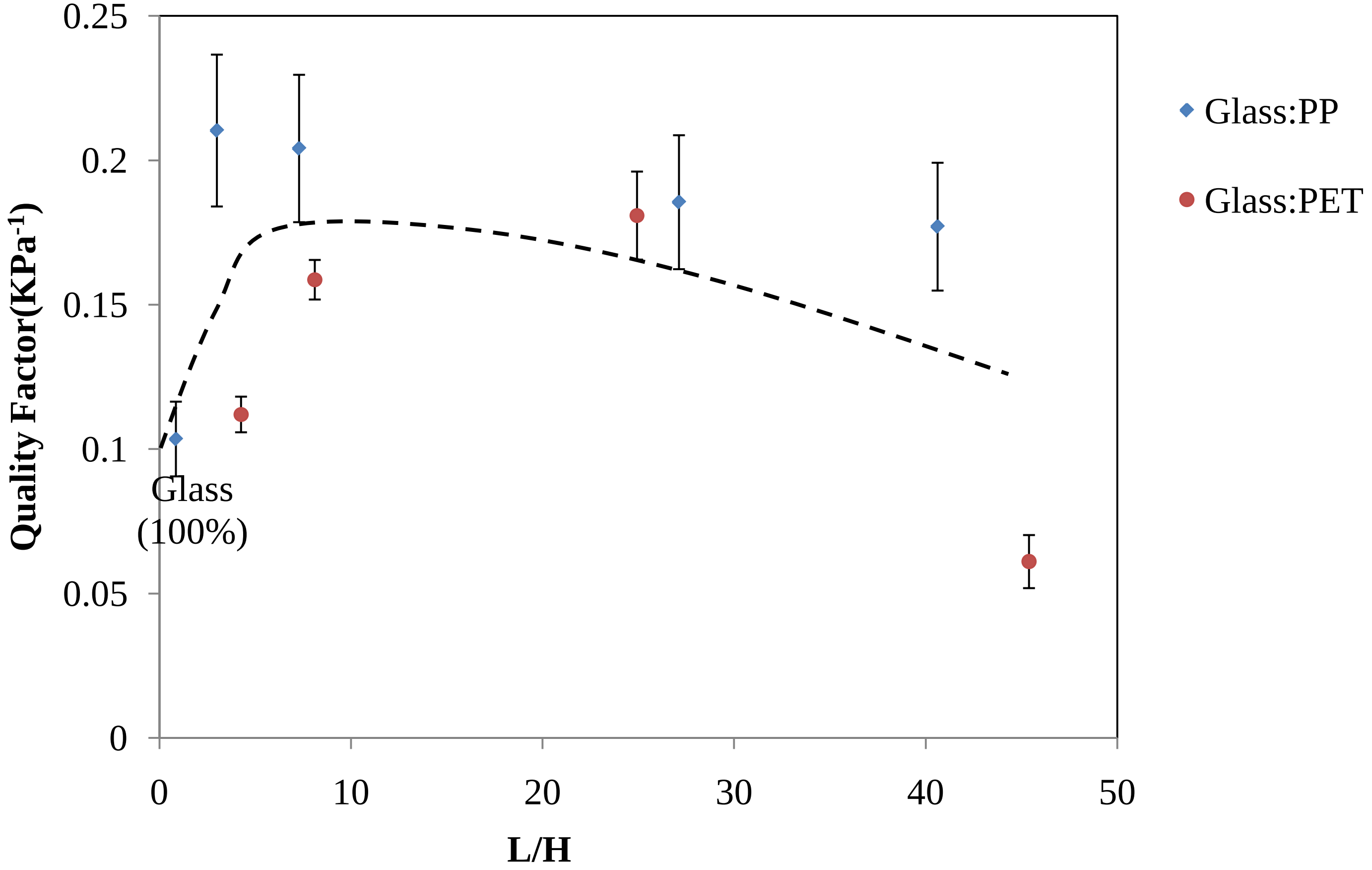
Filter efficiency Vs. L/H values for different layered filter media.

Effect of wettability on pressure drop



Pressure dropVs L/H values for different layered filter media.

Effect of wettability on quality factor

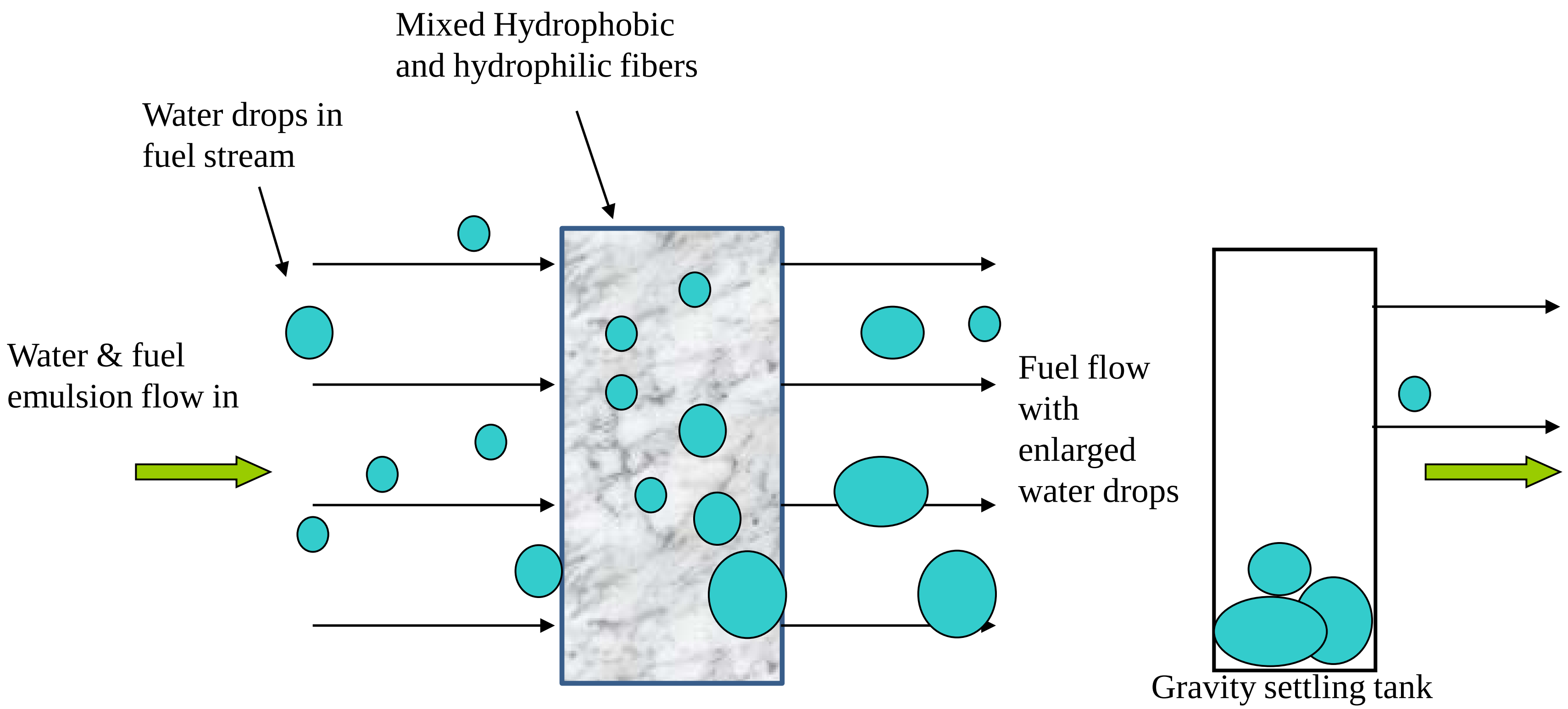


Quality factor Vs. L/H values for different layered filter media.

Summary

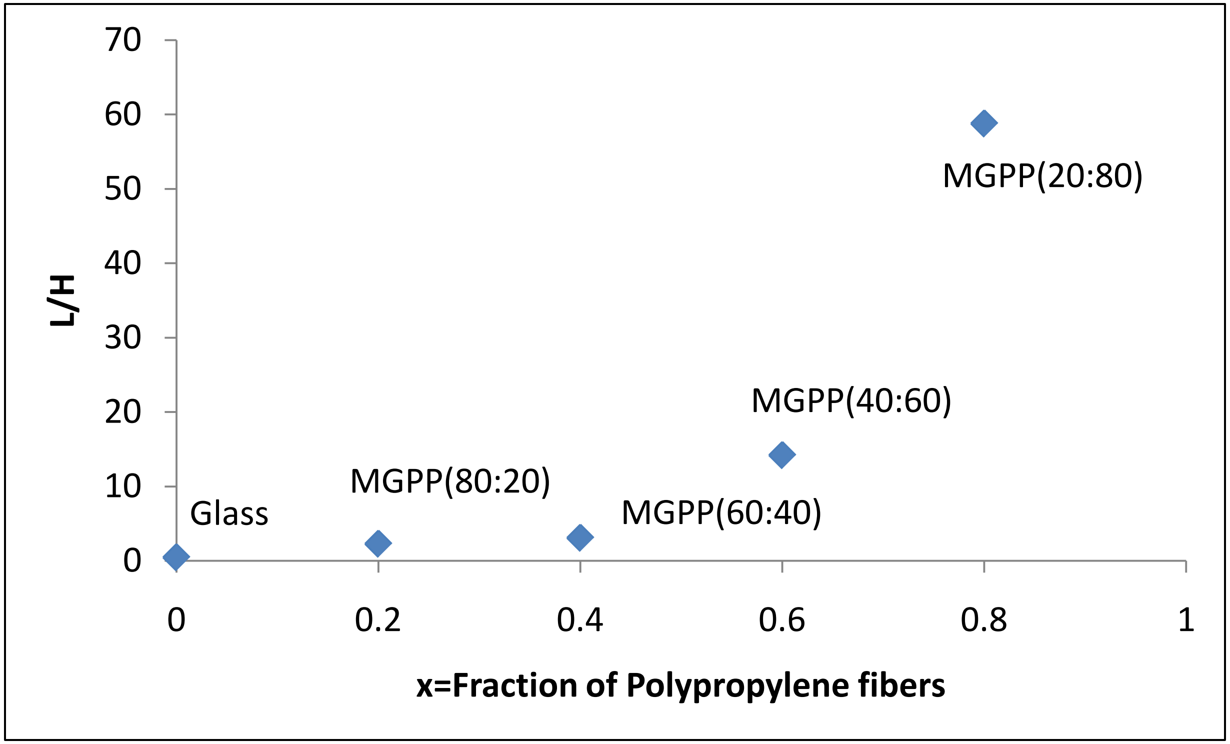
- Filter media can be characterized for wettability using modified Washburn's equation.
- Filter media with range of wetting properties can be prepared by using hydrophilic and hydrophobic fiber materials in different proportions.
- Higher separation efficiency – layered Glass:PET (80:20) i.e. 93% and Glass:PP(80:20) i.e. 90%.
- Quality factor is improved for layered filter media as compare to only glass fiber media.
- Increase in quality factor is primarily due to decrease in pressure drop.

Mixed Glass-Polypropylene media



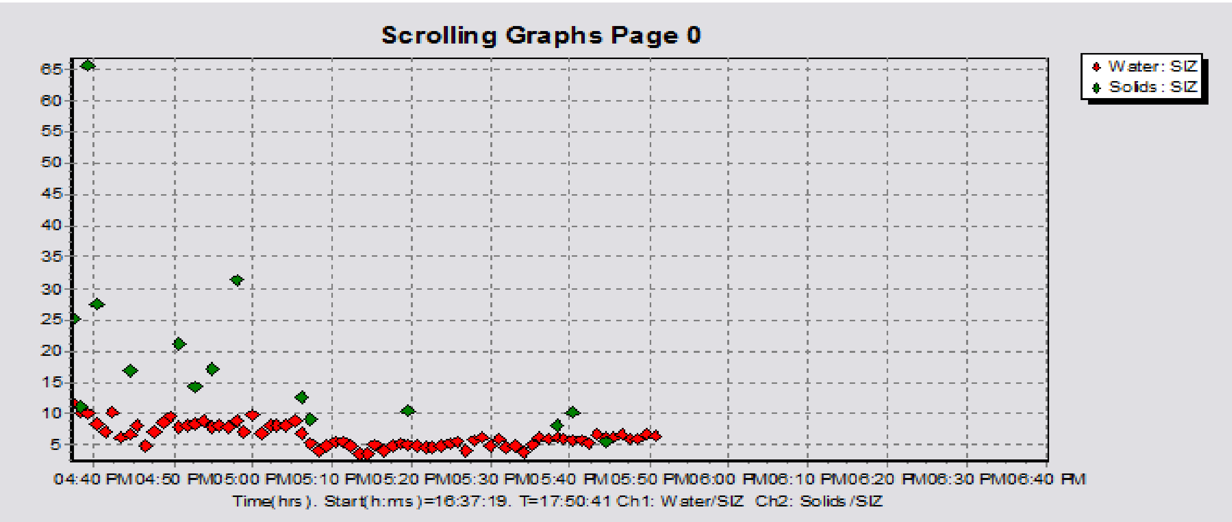
✓Instead of layers, the fibers are blended (mixed)

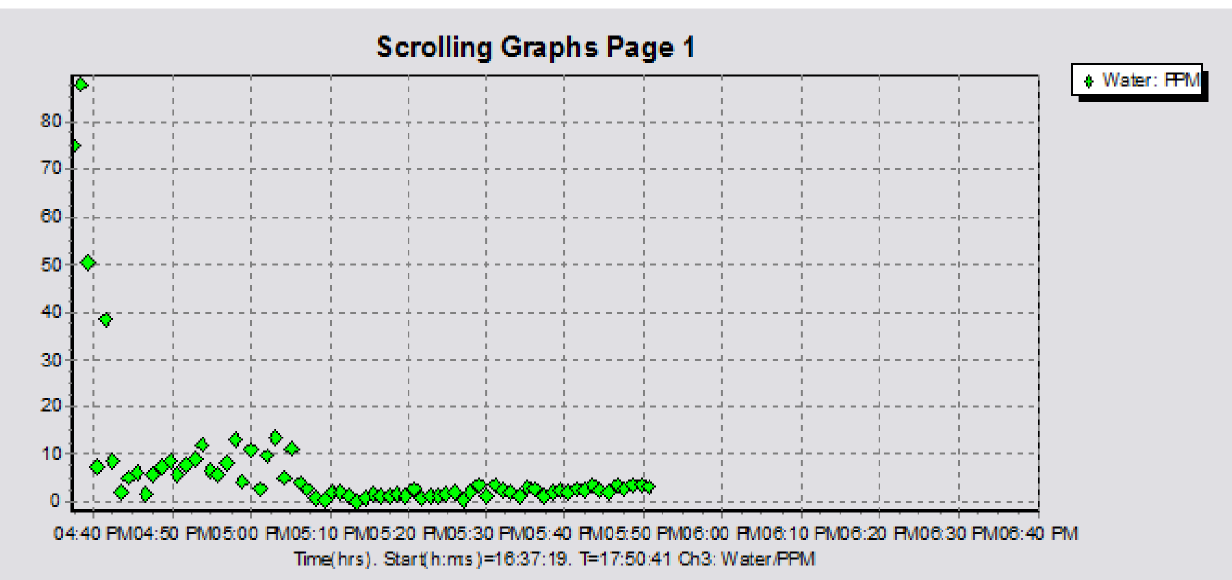
Mixed Glass-Polypropylene media



- Filters were made in varying composition of Glass and Polypropylene fibers.
- Glass and Polypropylene fibers were randomly mixed in filter media
- Filter were characterized for wettability using Modified Washburn's Equation.
- Accusizer and JORIN ViPA were used for sampling in liquid-liquid coalescence experiments

JORIN ViPA Analysis





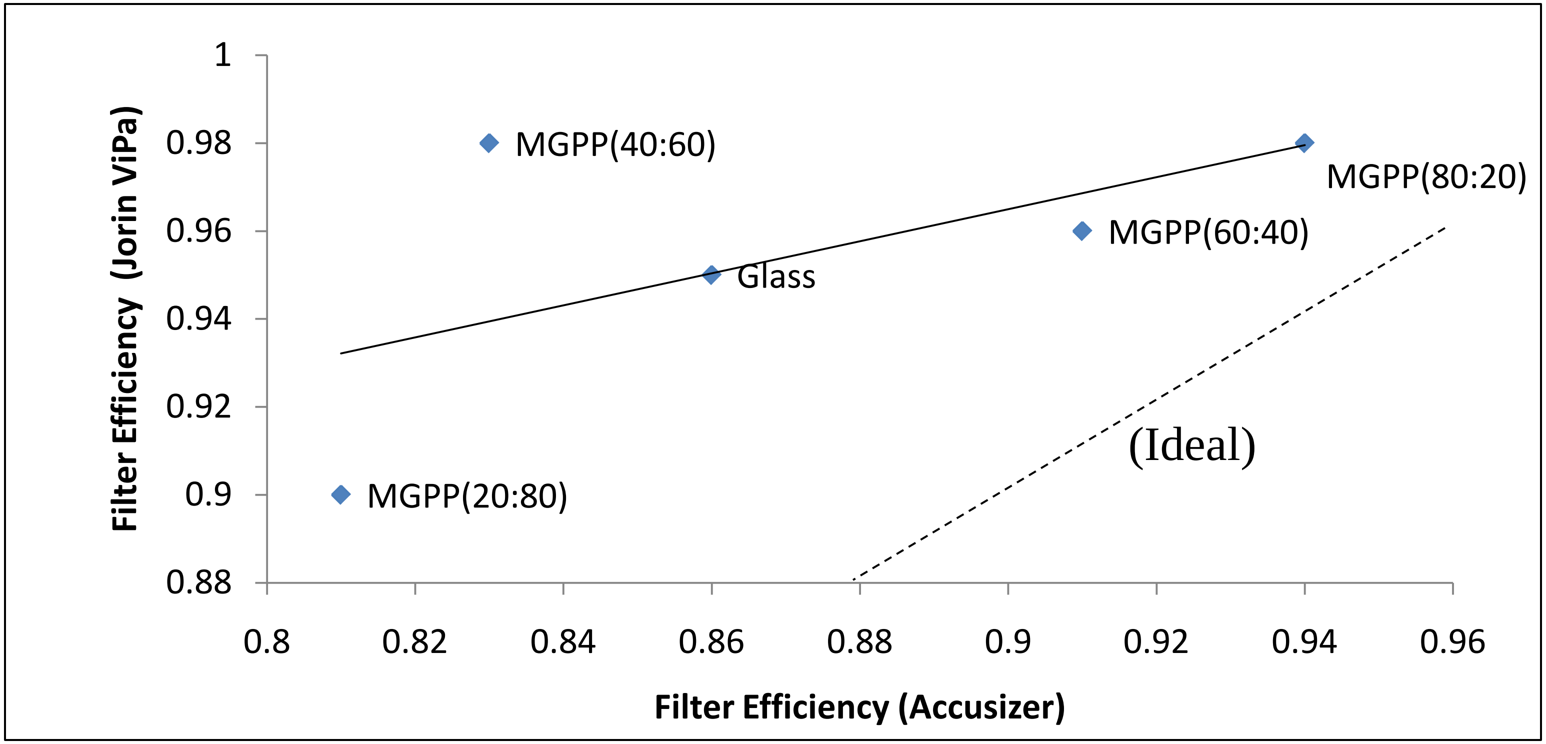
✓Oil flow rate 25ml/min

✓Concentration and mean size measurement of WATER, SOLIDS and AIR

✓First 5 cycles – upstream sampling, then downstream sampling is continuous

✓Filter efficiency is calculated based on average concentration of THREE cycles at upstream and downstream

Comparision of Accusizer and JORIN ViPA



- Results of JORIN ViPA compared with Accusizer
- More work is needed for comparison between both instruments.

Future work

- Use Jorin and Accusizer to compliment each other.
- Develop different filter geometries to achieve filter media with different wetting properties and their performance evaluation.
- Evaluate different fiber materials like polystyrene, nylon, PTFE, polyethylene etc.
- Experiments with varying IFT values.
- Analyze results to predict appropriate materials and wettability range for filter media.

Acknowledgements

- ✓ Coalescence Filtration Nanofibers Consortium

- ✓ Produced Water Society
- ✓ JORIN Limited, UK
- ✓ Minifibers Incorporated, TN (Fiber supplier)