CHAPTER 38

KENAF AS AN ABSORBENT, A BODY-FEED FILTER AID, AND A COALESCENCE AID

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ABSTRACT

This study investigated the potential of kenaf fiber as an oil absorbent, a body-feed filter aid in cake filtration, and a coalescing agent for dispersed oil. Oil absorption capacity (paraffin oil) increased with porosity and decreased particle size. In the body-feed filter aid filtration of kaolin slurry, the filtrate quality was good and the rate of filtration was low (75-80%) compared to that of the commercial products. As a coalescing agent, kenaf was better than diatomaceous earth and perlite, but not as good as solka floc and cotton. Kenaf showed an excellent coalescing efficiency for unstable dispersions. Coalescing efficiency increased with decreased particle size, increased thickness, and increased density of the medium. For the surfactant-stabilized emulsions, coalescence efficiency was only moderate. The cationic surfactant resulted in the best coalescence followed by nonionic and anionic, in that order. Emulsion pH had no effect on the performance for the anionic surfactant, while for the nonionic, better coalescence was obtained at lower pH.

INTRODUCTION

Kenaf (*Hibiscus cannabinus*) is an annual plant cultivated in North America (in states such as Mississippi, Texas, Arizona, Louisiana) as well as in Asia and Africa. The kenaf stalk is composed of a bast (bark) of long fibers and a center (core) of shorter fibers. Kenaf core has commercial applications as an absorbent, drilling mud additive, raw materials for paper, and thermoplastic filler. Kenaf bast is used in the textile and paper industries.

Kenaf is preferentially wetted by organic solvents like acetone and alcohol, and by oils. Kenaf can absorb and hold four to fifteen times its weight in oil, depending on the kenaf fiber size and the nature of the oil. These properties make kenaf a potential absorbent in oil spill clean-ups. Borazjani and Diehl (1994) demonstrated that the use of kenaf enhanced bioremediation of oil-contaminated soils. Kenaf is combustible with a caloric value of about 16.282 mJ•kg^{-1} (7,000 btu/lb) and an ash content of about 1.6%. Like most fine particles, kenaf particles exhibit a negative surface charge.

Filter aids are materials used to increase the permeability of filter cake in cake filtration so that a higher rate of filtration and a longer cycle time can be achieved. Use of filter aids reduces the overall filtration cost. Filter aids are also used in cases where a sparkling clarity is required for the product, like in beer and wine filtration (Cain 1984). In most filter aid filtrations, the filtrate is recovered and the solids are disposed. Thermal and biological degradation are not possible with the mineral-based commercial filter aids, diatomaceous earth and perlite.

Finely-dispersed organic phase in water is a common problem in the oil industry. Produced water from oil drilling operations, bilge water from tankers, aircraft and automobile wash, industrial laundry, and cooling and lubricating emulsions used in machine shops contain considerable amounts of dispersed oil. Separation of the dispersed phase, especially when the dispersion is a stabilized emulsion, is very difficult. Coalescence filtration is a common technique used in the separation of liquid dispersions. Synthetic-based and cellulose-based media are used for coalescence. Kenaf, with very high intrinsic porosity and a surface charge is a potential coalescing agent.

This paper describes details and results of proof-of-principle experiments using kenaf as an oil absorbent, a body-feed filter aid, and a coalescence medium.

MATERIALS AND METHODS

Oil

Light paraffin oil with a density of 0.845 to 0.86 g/cc and a Saybolt viscosity of 80-90 at 25°C was used for the preparation of emulsions. The paraffin oil used in the study had a volatiles weight loss of 3.1% at 85°C.

Kenaf

Whole kenaf ground to 5- to 20-mm particles from Kenaf International, Louisiana was further ground to smaller particles using a laboratory grinding mill from Glen Mills, Inc. The different size ranges used in the experiments were the following: (1) particles passing through a 200-μm sieve (Kenaf 200), (2) particles passing through a 500-μm sieve (Kenaf 500), (3) particles passing through a 1000-μm sieve (Kenaf 1000), (4) particles passing through a 2000-μm sieve (Kenaf 2000), and (5) particles passing through a 3000-μm sieve (Kenaf 3000).

Surfactants and Kaolin

Three types of surfactants were used in the preparation of stabilized emulsions: Triton X-100, a nonionic surfactant with a critical micelle concentration (CMC) value of 140 mg/L; sodium dodecyl sulfate (SDS), an anionic surfactant with a CMC value of 2.38 g/L; and cetyl pyridinium chloride (CPC), a cationic surfactant with a CMC value of 306 mg/L. Kaolin was used for the slurry preparation in the filter aid experiments.

Oil Absorption Capacity

Absorption capacity is determined by field-saturating a weighed sample of kenaf. The difference in weight between the saturated kenaf and the dry kenaf gives the weight of oil absorbed. This weight divided by the weight of dry kenaf is the absorption capacity. The apparatus used to measure the absorption capacity is a cylindrical glass tube with a wire mesh clipped to the lower end of the tube. The glass tube with kenaf is kept in contact with oil/water, so as to just touch the surface of oil/water. Due to capillary effect the oil/water rises in the tube, until the kenaf is field-saturated.

Filter Aid Filtration

Constant pressure, batch filtrations were carried out in a simple filter shown in Figure 38.1. Samples were prepared by mixing the filter aid (Kenaf 200 or Kenaf 500) with a slurry of 2 g of kaolin in 200 mL tap water. Filtrate was collected in two batches: (1) up to 30 seconds, and (2) after 30 seconds; and analyzed for solids content. Filtrations were filtered three times for all samples.

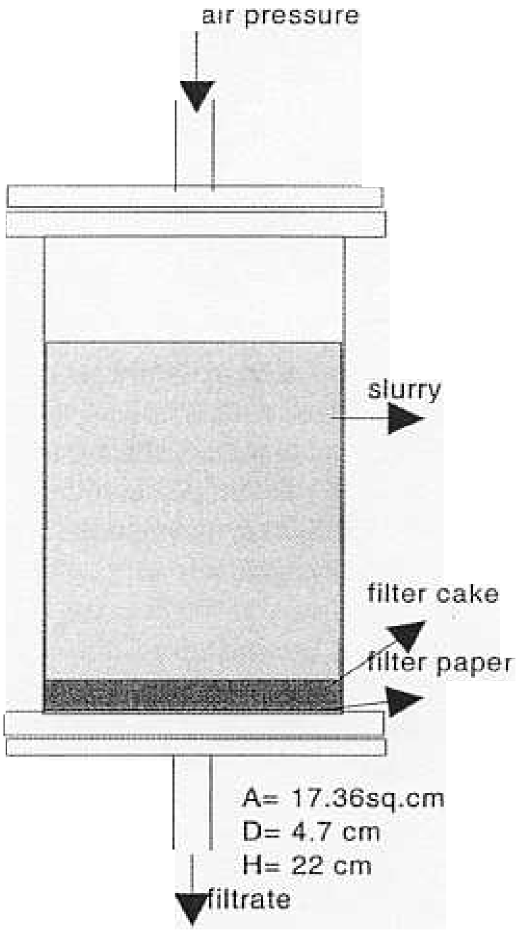

Figure 38.1. Set up used for filter-aid filtrations.

Emulsion Preparation

An oil-in-water emulsion was used in the experiments to simulate produced water. The emulsions were prepared by two methods: mechanical mixing using a high-shear mixer and ultrasonic dispersion using a Tekmar 250 Sonic Disrupter. In these experiments, paraffin oil was used as the dispersed phase and tap water was used as the continuous phase. Emulsions without surfactants were produced by mechanical mixing, and emulsions with surfactants were produced by ultrasonic dispersion.

Coalescence Filtration

Coalescence filtrations were carried out using the simple coalescence filter set up (Figure 38.2) developed by Tiller et al. (1993). In this up-flow arrangement, a pump supplied the emulsion samples from the feed tank. The kenaf bed is supported by a wire mesh and a perforated disc. The coalesced oil drops rise to the surface and form a layer that was collected and measured to determine the percent recovery. Water, with any uncoalesced oil was discharged over a weir outlet and samples were analyzed for oil at prescribed time intervals.

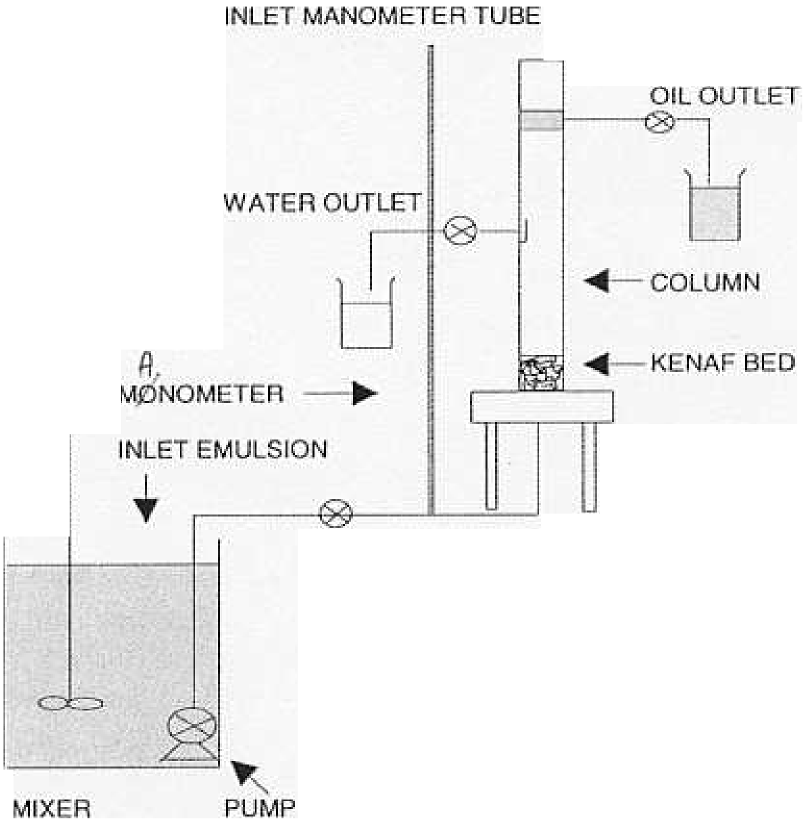

Figure 38.2. Set up used for coalescence.

Analytical Methods

The oil in the feed and filtrate were measured using the United States Environmental Protection Agency (USEPA) method 1664 for hexane extractable materials (HEM). The method initially designed for a 1000-mL sample (USEPA 1995) was modified for a 100-mL sample. Solids content in the filtrate for filter aid filtration experiments were done using a HACH ratio turbidity meter. Particle size analyses were done using a Malvern Mastersizer with a size range of 0.5 μm to 900 μm. Microscopic analysis was used as confirmatory test.

RESULTS AND DISCUSSION

Oil Absorption

Oil absorption capacity and rates were tested for three samples: Kenaf 200, Kenaf 500, and Kenaf 1000. The absorption capacity increased with porosity which, in turn, increased with decreasd particle size (Table 38.1).

Table 38.1. Oil absorption capacities for different kenaf samples.

Sample	Bulk density (g/cc)	Porosity (mL/mL)	Oil Absorption[a] (g/g)
Kenaf 200	0.133	0.900	3.93
Kenaf 500	0.125	0.906	4.90
Kenaf 1000	0.100	0.920	5.29

[a] For paraffin oil at room temperature, g oil/g kenaf.

Body-Feed Filter Aid

Filtrations were carried out using a kaolin slurry with different concentrations of the three commercial filter aids, the Kenaf 200, and the Kenaf 500.

Clarity of the Filtrate

Turbidity measurements showed that clarity of the filtrate in the first 30 seconds was the best for diatomaceous earth and perlite. Clarity for solka floc, Kenaf 200, and Kenaf 500 were in the same range and higher compared to the other two. The common practice in cake filtration is to recycle the initial filtrate until the required clarity is achieved. Therefore, the high solids content in the initial filtrate is not of much concern. The solids content in the filtrate for the various filtration runs show that kenaf filter aids can give the same filtrate clarity as the commercial ones (Table 38.2).

Table 38.2. Turbidity readings for the filtrates collected after 30 seconds.

Filter Aid %	Diatomite NTU[a]	Perlite NTU	Solkafloc NTU	Kenaf 200μm NTU	Kenaf 500 μm NTU
0.5	3.70	2.00	4.90	5.20	5.70
1.0	2.00	1.50	1.80	7.50	4.50
1.5	4.30	2.60	12.20	5.60	4.90
2.0	4.60	4.10	2.45	7.90	14.00
2.5	1.90	3.60	9.00	3.60	5.10
3.0	2.50	3.40		5.50	6.60

[a] NTU = Nephelometric Turbidity Unit; 10 NTU ≈ 12.5 mg/L solids.

Rate of Filtration, Cake Thickness, and Cycle Analysis

Overall rates of filtration for the various filter aids at various concentrations are plotted in Figure 38.3. The plots indicate that the rate of filtration is low for the kenaf samples compared to the commercial ones. This result does not necessarily mean that kenaf is not competitive as a filter aid. In practical applications, the thickness of the cake formed is very important because of the limitation to the possible thickness in any filter design. The formation of a thick cake in a short filtration time would mean that the filter unit has to be stopped for cake removal and put back to service again completing the filtration cycle. The rate achieved over a cycle time (total time including filtration and clean up) is the important criterion in assessing the feasibility of a material as a filter aid. Therefore, cycle analysis was done for all the filter aids based on a cake thickness of 1 cm.

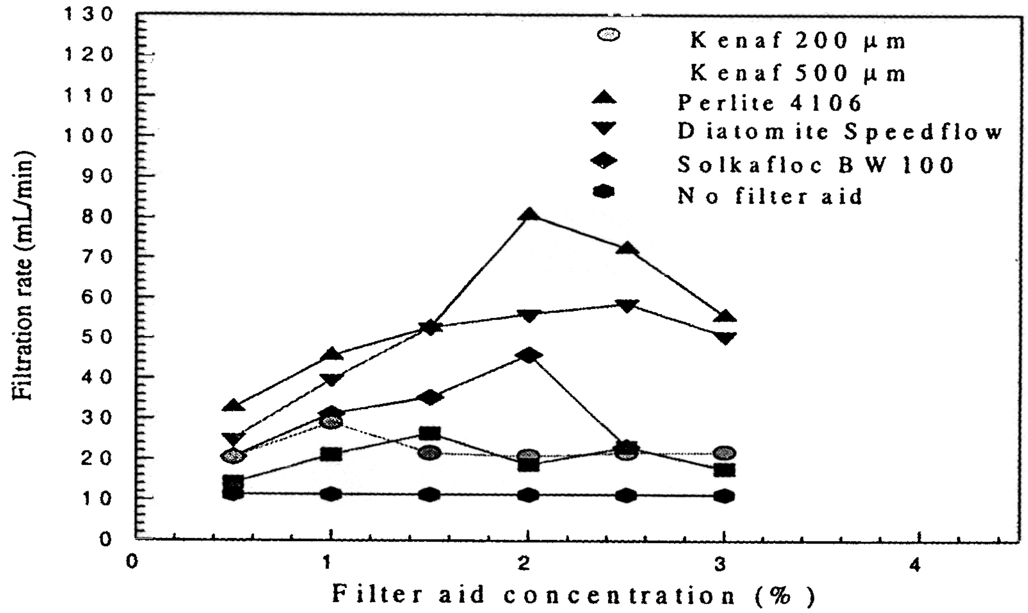

Figure 38.3. Variation in filtration rate with variation in filter aid concentration and type.

Time required to form a 1-cm thick cake was calculated for all the cases. For the cases where the actual thickness (Table 38.3) was equal to or more than 1 cm, time to form a 1-cm cake was directly obtained. For the cases where the actual thickness was less than 1 cm, time to form a 1-cm thick cake was calculated from the filtrate volume, extrapolated from the filtrate volume-filtration time data, and the actual cake thickness measured. See, for example, Figure 38.4.

Table 38.3. Actual, measured cake thickness.

Filter Aid %	Diatomite cm	Perlite cm	Solkafloc cm	Kenaf 200 μm cm	Kenaf 500 μm cm
0.5	0.20	0.30	0.30	0.30	0.30
1.0	0.40	0.55	0.50	0.50	0.50
1.5	0.70	0.75	0.60	0.75	0.70
2.0	0.80	1.00	0.73	0.90	0.90
2.5	0.80	1.30	0.80	1.30	1.30
3.0	1.10	1.55	1.00	1.45	1.50

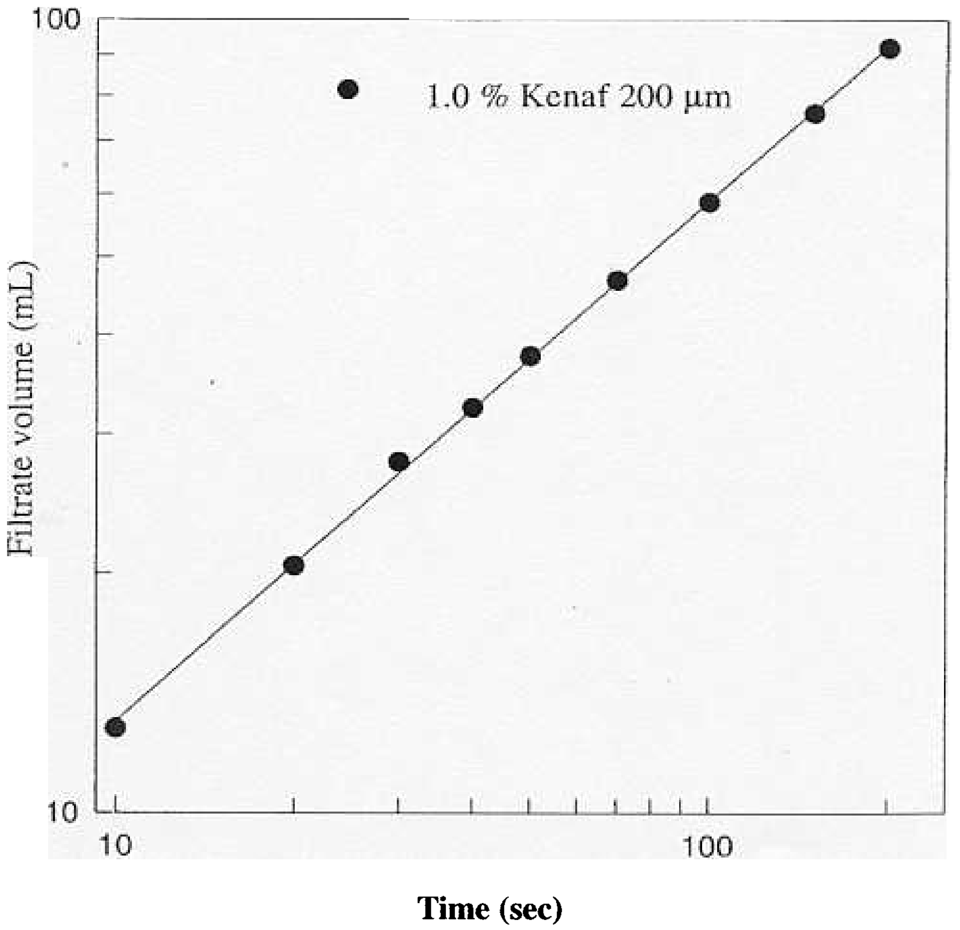

Figure 38.4. Log-log of filtrate volume to filtration time.

Assuming a dead time (time from the end of a filtration run to the beginning of the next one) of 30 minutes and the calculated time for the formation of a 1-cm thick cake, cycle time analyses were done for all the filter aids and all the concentrations studied. Results in Table 38.4 show that, for all the materials, cycle rate (rate over an entire cycle) is the highest when the filter aid concentration is 1%. The values also show that the cycle rate for the kenaf samples were 75-80% of that of the commercial materials (Table 38.4). Therefore, to achieve a given rate of filtration using kenaf as a filter aid requires 25-30% more filter area compared to the other commercial filter aids.

Table 38.4. Cycle rates for the various filter-aid materials and concentrations.

Filter Aid %	Diatomite mL/min	Perlite mL/min	Solkafloc mL/min	Kenaf 200 μm mL/min	Kenaf 500 μm mL/min
0.5	2.63	7.52	3.29	4.87	4.33
1.0	7.84	8.55	8.77	6.36	6.30
1.5	7.29	7.10	7.50	4.75	5.43
2.0	6.56	5.42	6.88	4.47	4.33
2.5	6.42	4.09	5.19	3.46	3.64
3.0	4.79	3.37.		3.25	3.05

Kenaf vs. Other Materials

Performance of kenaf as a coalescer was compared to that of cotton, peat moss, solka floc, perlite, and diatomaceous earth by pumping a 2000 mg/L oil dispersion through a 1.8-cm thick bed of each of the materials. Plots in Figure 38.5 show that kenaf is better than perlite and diatomaceous earth, but not as good as solka floc or cotton. Peat moss and kenaf gave the same performance.

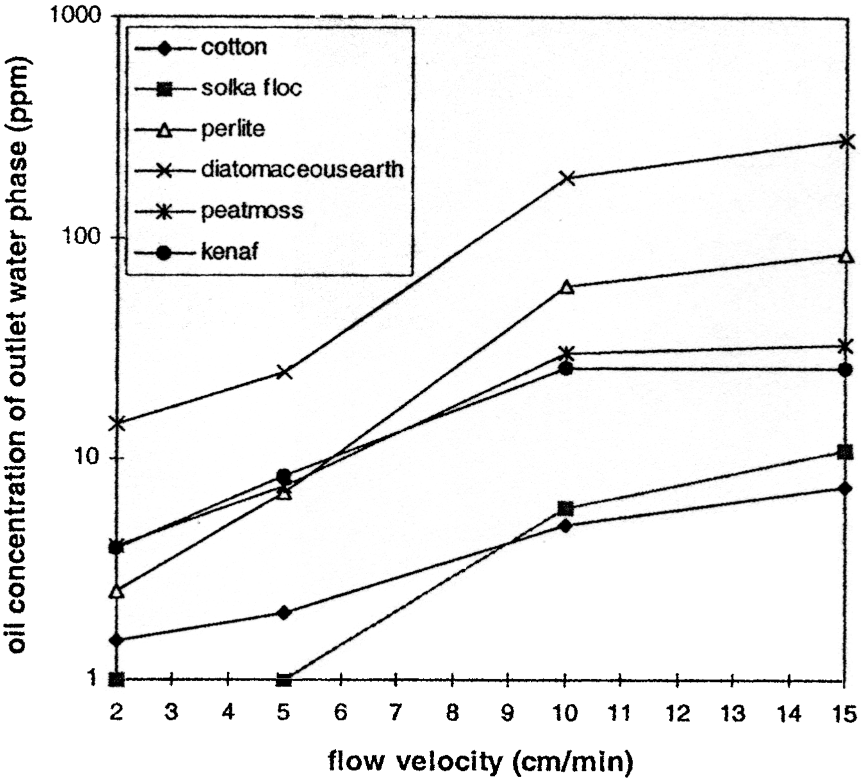

Figure 38.5. Oil concentrations in outlet water for different media.

Effect of Velocity on Oil Recovery

Coalescence experiments were carried out at different flow velocities using a 2000 mg/L oil dispersion and Kenaf 2000 beds of thickness 0.9 cm, 1.8 cm, and 2.7 cm (2, 4, and 6 g, respectively). Plots in Figure 38.6 show that there is an optimum flow velocity for each thickness at which the oil recovery is maximum. Below this velocity, very little oil is brought to the medium and no oil separates out. Beyond the optimum velocity, low contact time and high flow shear reduces the rate of coalescence and the size of the drops formed.

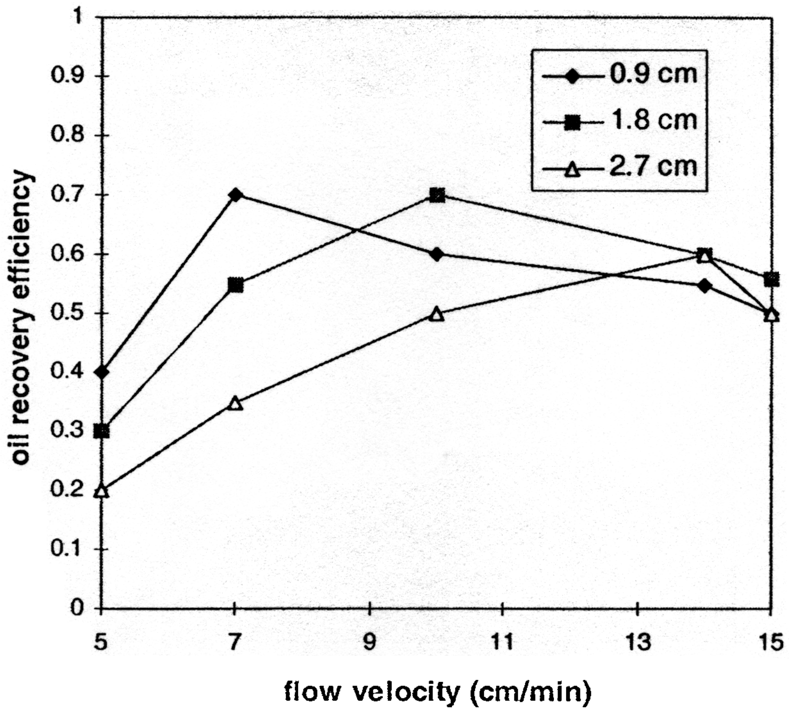

Figure 38.6. Oil recovery efficiency at different bed thickness for Kenaf 2000.

Effect of Fiber Size on Coalescer Performance

Coalescence of a 2000 mg/L oil-in-water dispersion was done with 1.8-cm thick (4-g) beds of Kenaf 1000, Kenaf 2000, and Kenaf 3000. The results plotted in Figure 38.7 show that at low velocities (up to 7 cm/min), the clear-water outlet oil concentrations were almost the same. At a velocity of 10 cm/min, the oil content in the treated water is 67 mg/L oil-in-water for Kenaf 3000, nearly three times the value for Kenaf 1000, with the value for Kenaf 2000 in-between. These results suggest that the coalescing efficiency increased with decreased particle size of the medium.

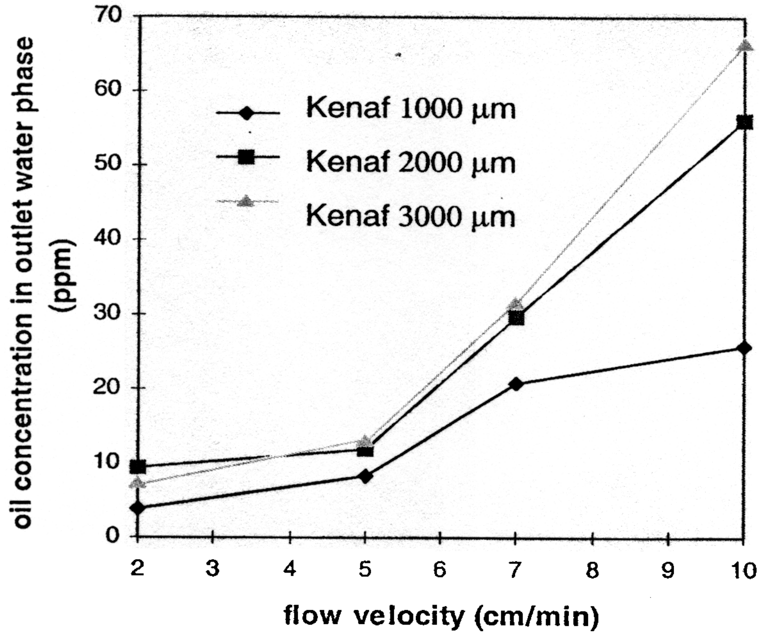

Figure 38.7. Oil concentrations in outlet water for different fiber sizes.

Effect of Bed Thickness on Coalescer Performance

A dispersion with 2000 mg/L of oil-in-water was treated with 0.9-cm, 1.8-cm, and 2.7-cm thick beds of Kenaf 2000. Results in Figure 38.8 show that the oil content in the effluent decreased with increasing bed thickness. A thicker bed provides more surface area for coalescence and longer contact times, both leading to increased coalescence.

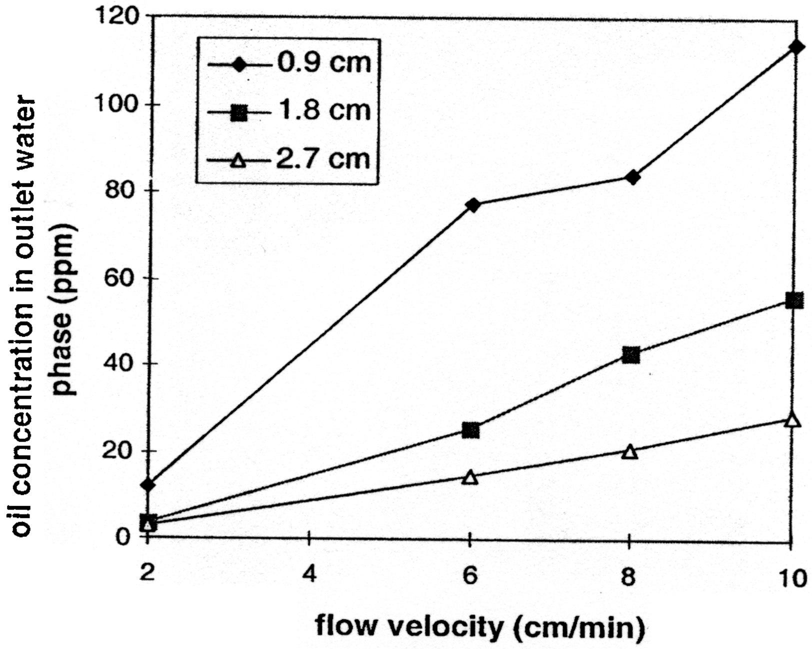

Figure 38.8. Outlet oil concentrations for different bed thicknesses with Kenaf 2000.

Effect of Bed Density on Coalescer Performance

In these experiments, 3.5 g, 5 g and 7 g of Kenaf 1000 were used with a bed thickness of 1.8 cm. Figure 38.9 shows that the lowest bed weight has the highest oil-in-water concentration in the clearwater outlet. At the highest velocities, the light bed produces a water that exceeds a target value of 10 mg/L oil-in-water. When the bed weight is 7 g, the oil concentration is less than 5 mg/L, but the pressure drop is very high, which is not satisfactory. For the, 5-g bed, the oil concentrations are less than 10 mg/L, and the pressure drop is not high. In this case, acceptable effluent quality and good coalescence results.

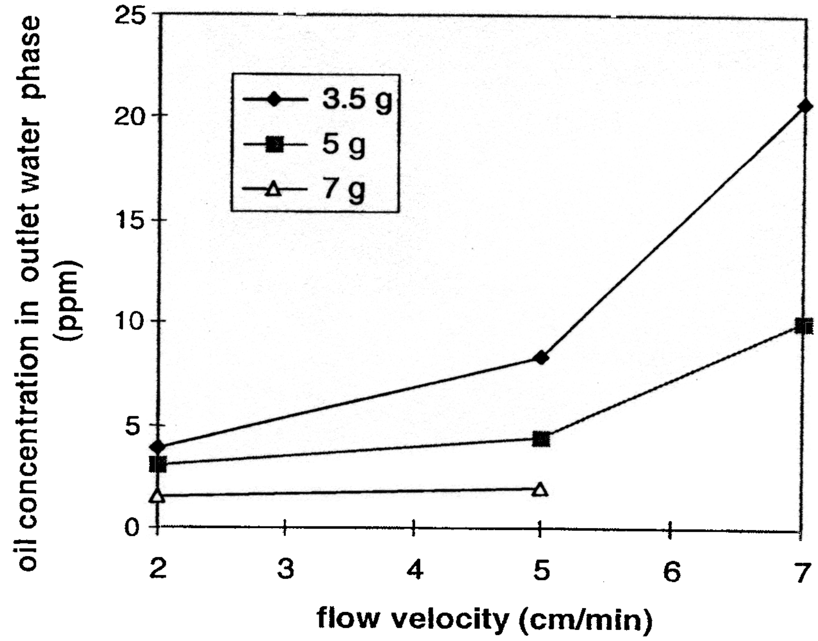

Figure 38.9. Outlet oil contents for different bed densities using Kenaf 2000.

Effect of Surfactant Type and Concentration on Coalescer Performance

Stabilized emulsions were prepared with surfactant concentrations of 0.5 CMC, 1 CMC, and 2 CMC for the surfactants Triton X-100, SDS, and CPC. Coalescence experiments were conducted with the Kenaf 500 bed of 1.8 cm thickness. The results in Figure 38.10 indicate that the coalescence efficiency decreased with increased surfactant concentration for all the surfactants. The increased stability of the emulsion at higher concentration of surfactant explains this observation. Among the three types of surfactants, CPC, the cationic one gave the best results, followed by Triton, the nonionic, and SDS, the anionic surfactant, in that order. The high efficiency for the cationic and the low efficiency for the anionic surfactants are due to the negative charge of the kenaf surface.

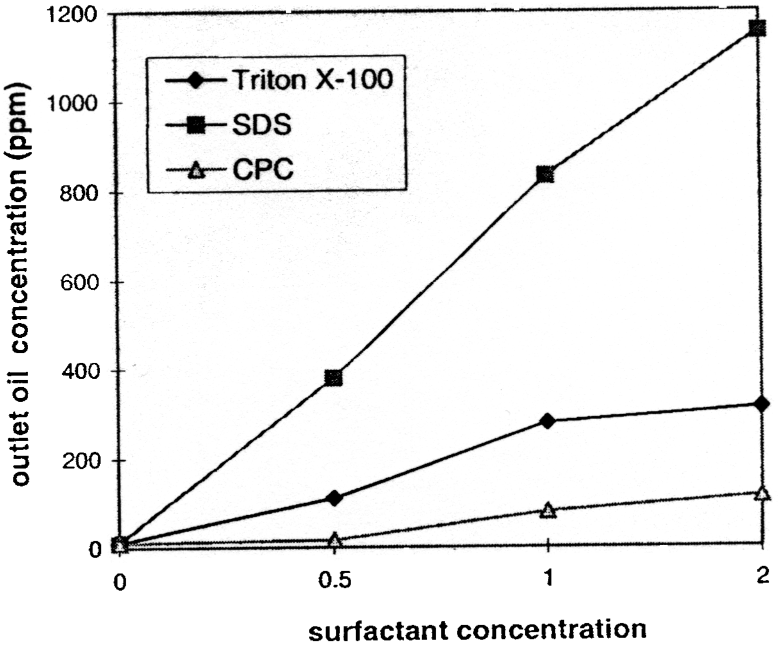

Figure 38.10. Outlet oil contents for emulsions using different surfactants at different concentrations.

Effect of PH on Coalescer Performance

Stable emulsions with SDS and Triton X-100 were prepared at pH values of 3, 5, 7, and 9 adding HCl or NaOH. A 1.8-cm thick bed of Kenaf 500 was used for the study. The plots in Figure 38.11 show that the performance of Triton X-100 was not affected by the change in pH, as expected, because of its nonionic nature. For SDS, an increase in pH reduced the coalescing efficiency drastically. At the lower pH, SDS is mostly in the non-ionized form giving a performance comparable to that of Triton X-100.

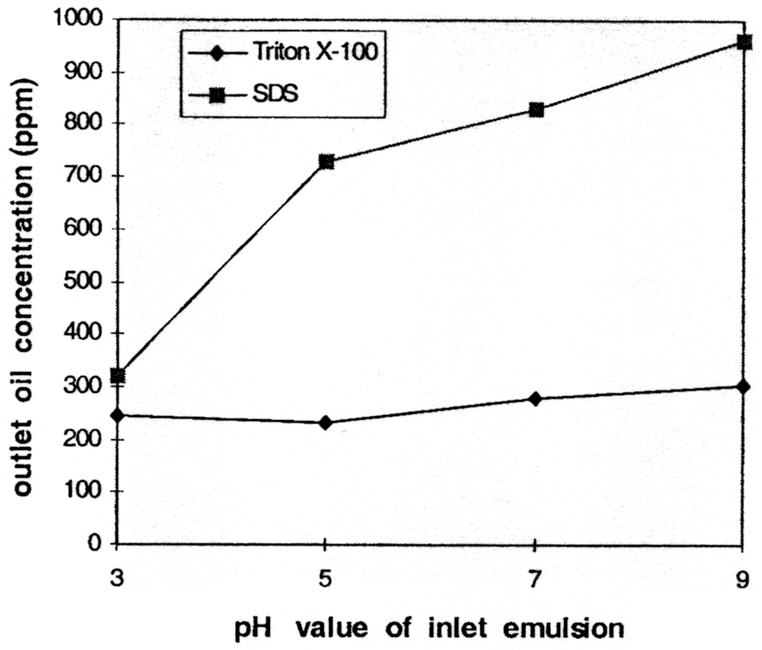

Figure 38.11. Outlet oil concentrations for various surfactants at different inlet pH values.

CONCLUSIONS

The oil absorption experiments showed that finely-ground kenaf is a good oil absorbent and absorption capacity increased with porosity which, in turn, increased with decreasd particle size.

Kenaf is an effective body feed filter aid. Although, compared to the commercial filter aids, kenaf requires about 25% more filter area, the low cost of kenaf and the possible saving on the solid waste (filter cake) disposal could make it commercially competitive.

Kenaf performed better than diatomaceous earth and perlite in coalescing dispersed oil. Although, cotton and solka floc were more efficient than kenaf, they are far more expensive than kenaf. Kenaf has an excellent coalescing efficiency for unstable emulsions with moderate results for surfactant-stabilized emulsions. For the unstable dispersion, an optimum flow velocity at which the oil recovery was the best was observed for each medium. Also, the coalescence efficiency increased with decreased particle size, increased thickness, and increased density of the media. For the surfactant-stabilized emulsions, coalescing efficiency decreased with increased surfactant concentration. Among Triton X-100, SDS, and CPC, the cationic surfactant, CPC resulted in the best coalescence followed by Triton X-100 and SIDS, in that order. The pH had no effect on coalescence for the emulsion stabilized by Triton X-100. Coalescence efficiency increased with the decrease in pH for SDS.

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