

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Surfactant Adsorption Isotherms

The adsorption of surfactant is strongly influenced by a number of factors: 1) the nature of the structural groups on the solid surface; 2) the molecular structure of the surfactant being adsorbed - whether it is ionic or nonionic, and whether the hydrophobic group is long or short, straight chained or branched, aliphatic or aromatic; 3) the environment of the aqueous phase - pH, electrolyte content, the presence of any additives, such as short-chain polar solutes, and temperature. However, in this experiment, the pH of the aqueous phase was of most interest.

4.1.1 Adsorption Isotherm of SDS on Carbon Black

Figure 4.1 shows the adsorption isotherm of SDS on carbon black at different solution values. The amount of surfactant adsorbed on carbon black was calculated from the difference between the initial concentration and the residual concentration in the supernatant after the system reached equilibrium. The adsorption isotherms of SDS on the surface of carbon black is the Langmuir type. The Langmuir adsorption isotherm is based on the assumption of the formation of a monolayer of adsorbent on the adsorbate.

Table 4.1 The surface area of sample as determined from BET with nitrogen

Sample	Specific surface area (m ² /g)
Polyester fiber	2.500
Cotton fiber	4.326
Carbon black	96.000

The surface area of sample as determined from BET with nitrogen was shown in table 4.1 Thus knowing the accessible surface area of sample, the Adsorption density ($\mu\text{mole}/\text{m}^2$) occupied by surfactant molecule can be calculate.

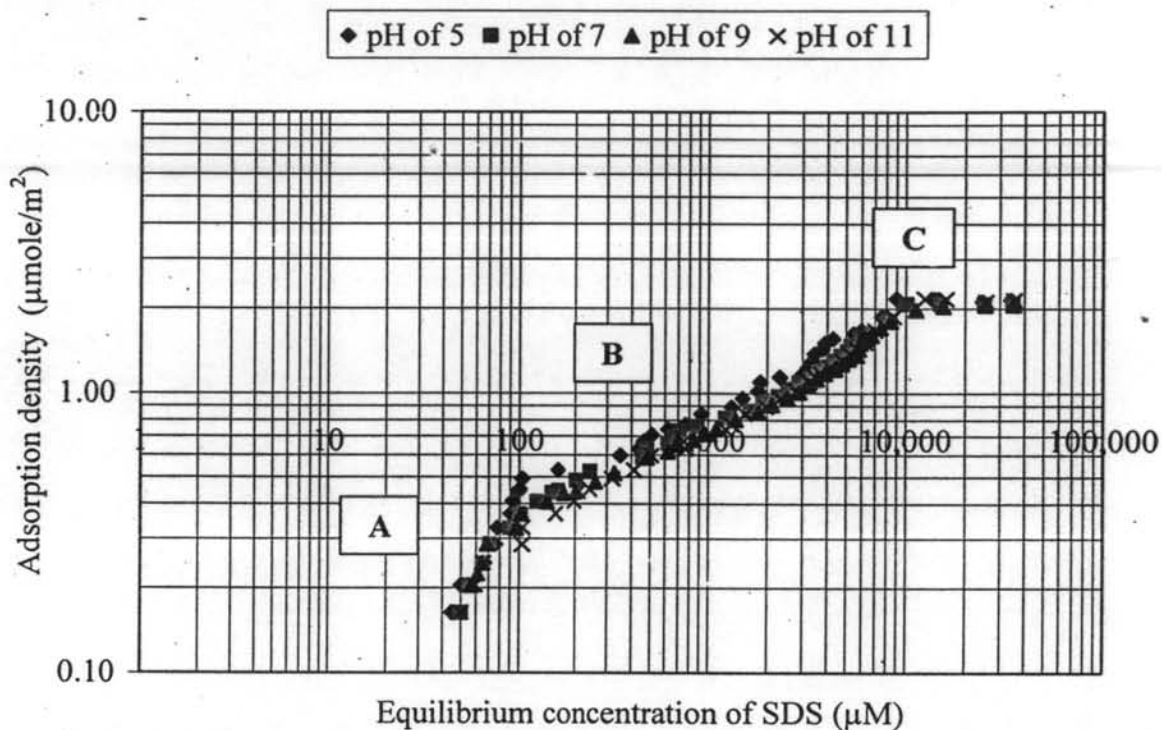


Figure 4.1 Adsorption Isotherm of SDS on Carbon Black at various pH levels.

The slope of the isotherm of Region A was linear. It was shown that the alkyl chain of the anionic surfactant is adsorbed parallel to the surface at low surfactant concentrations, presumably to maximize the favored condition by the hydrophobic interaction between alkyl chains and the hydrophobic surface. The interaction at the adsorption site is a hydrophobic chain/surface interaction (Region A) and occurred in small amount of SDS concentration. The adsorption isotherm shows a strong increase until the monolayer surface is complete (Region B). Beyond this stage is referred to as the plateau adsorption region where adsorption is complete. Continuing interaction in this region are hydrophobic chain/chain interactions. Saturation was reached near the CMC $9,000 \mu\text{M}$ of SDS of $2.1 \mu\text{mole}/\text{m}^2$ and represents the maximum amount of SDS surfactant adsorbed per unit area of carbon black, which is near the CMC of SDS, of $8,300 \mu\text{M}$ reported by

Mukerjee and Mysel, 1970. From the adsorption isotherm, the adsorption at pH 11 was slightly lower than the adsorption at pH of 9, 7, or 5 in all regions. This usually causes marked changes in the adsorption of ionic surfactants onto the charged solid substrates. As the pH of the aqueous phase is lowered, a solid surface will usually become less negative, because of the adsorption onto the charged sites of protons from the solution, with a consequent increase in the adsorption of anionic surfactants and a decrease in the adsorption of cationics. But in the plateau region it was found that at pH 11, the adsorption isotherm was slightly higher other pH.

4.1.2 Adsorption Isotherm of CTAB on Carbon Black

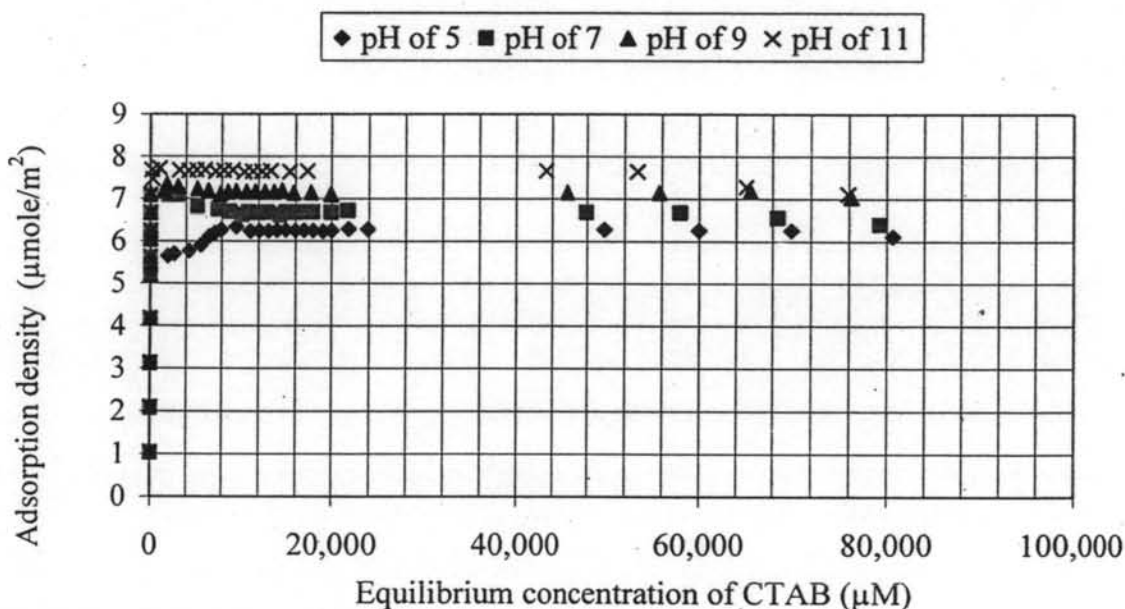


Figure 4.2 Adsorption isotherm of CTAB on carbon black at various pH levels.

The adsorption isotherm of CTAB on carbon black was significantly different from that of the previous anionic surfactant. But it also followed an L-shaped or Langmuirian pattern. The cationic surfactant molecules were adsorbed in a partial monolayer on the carbon surface by carbon chain attachment to the surface by hydrophobic bonding. The plateau adsorption from the CTAB isotherm was reached at about $9 \mu\text{mol}/\text{l}$ while the referred CMC was $980 \mu\text{mol}/\text{l}$. This result implies that

there is very favorable adsorption of CTAB on the carbon black surface leading to saturation of the available surface below the CMC. The maximum adsorption capacity is about $8 \mu\text{mole per m}^2$ of carbon black which is much higher than the adsorption of SDS at about $2 \mu\text{mole per m}^2$ of carbon black. However, the effect of charge between the surface and the surfactant should be remembered. As the pH of the aqueous phase is lowered, a solid surface will usually become more positive, or less negative, because of the adsorption onto the charged sites of the protons from the solution, with a consequent increase in the adsorption of anionic surfactants and a decrease in the adsorption of cationics. At pH 11, then, there is the highest adsorption.

4.1.3 Adsorption Isotherm of SDS on Polyester Fiber

The adsorption isotherm of an ionic surfactant on Polyester fabric is described in this work. Studies of the sorption of an ionic surfactant on textile fabrics show that the charge of surfactant and surface charge density of the fibers can influence the adsorption isotherm. The adsorption isotherms on Polyester fiber at pH 5, 7, 9 and 11 were observed in three regions. (Figure 4.3)

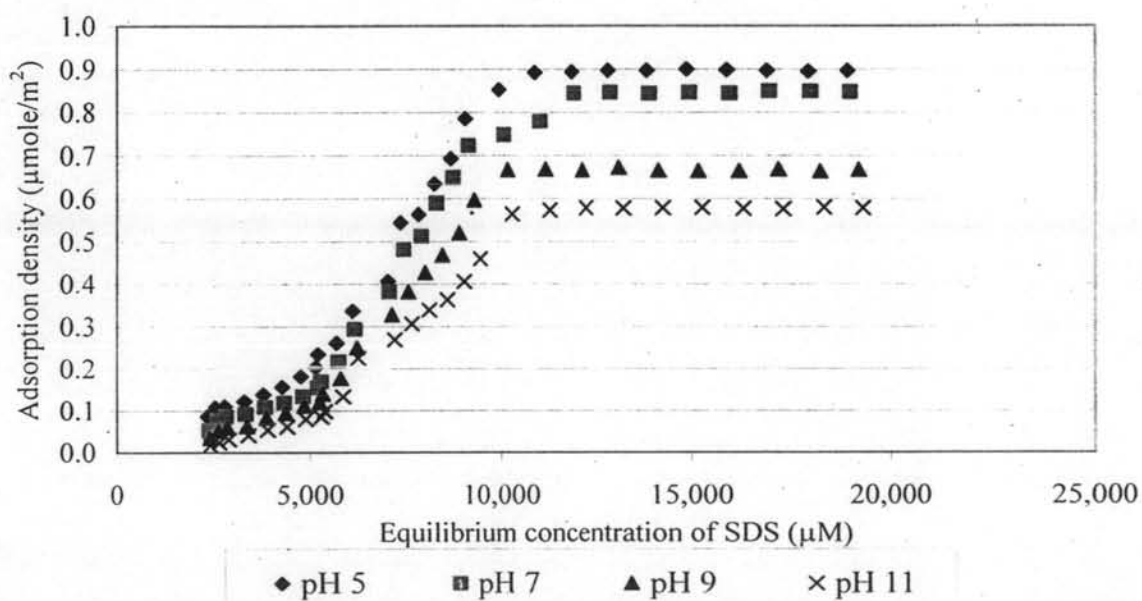


Figure 4.3 Adsorption isotherms of SDS on polyester fiber at various pH levels.

Adsorption isotherm curves, relating the amount of surfactant adsorbed by the dry fiber in ($\mu\text{mole}/\text{m}^2$) to the equilibrium concentration of surfactant, are often used to investigate the adsorption characteristics of fibers. Adsorption of anionic surfactant levels decrease with increasing charge density on the polyester fiber surface (the PZC of polyester fiber is about 3.4). Theoretically, isotherms show the characteristic three regions. From figure 4.3 we can observe for every equilibrium concentration, SDS adsorption on polyester fiber at pH 5 was higher than at pH 7, 9 or 11. From the plateau region the maximum SDS on polyester fiber at pH 5, 7, 9 and 11 are 0.89, 0.84, 0.67 and 0.57 $\mu\text{mole}/\text{m}^2$ respectively. From this it can be expected that the surface of the polyester is becoming more negatively charged. From this experiment, at pH 11 there is the highest negative charge, so the SDS adsorption is the lowest. On the other hand, at pH 5 there is the lowest negative charge, so SDS adsorption is the highest.

4.1.4 Adsorption Isotherm of CTAB on Polyester Fiber

As seen in Figure 4.4 2 distinct adsorption regions exist when a cationic surfactant (CTAB) adsorbs on a negatively charged polyester fiber. The adsorption remains nearly constant with a CMC around 950 μM which is near the reported CMC of CTAB, 1000 μM (Rosen, 1989). The trend of the adsorption isotherm at pH 11 was greater than at pH 5, 7, or 9 because the PZC of Polyester fiber is 3.4. Then at pH 5 the polyester fiber has the lowest negative charge, and at pH 11 it has the highest negative charge. CTAB (cationic surfactant) had the highest adsorption on the polyester fiber at pH 11 from the ion exchange between the polyester fiber and the cationic surfactant. From the plateau region the maximum CTAB on polyester fiber at pH 5, 7, 9 and 11 are 2.3332, 2.8669, 3.1868 and 3.3036 $\mu\text{mole}/\text{m}^2$ respectively.

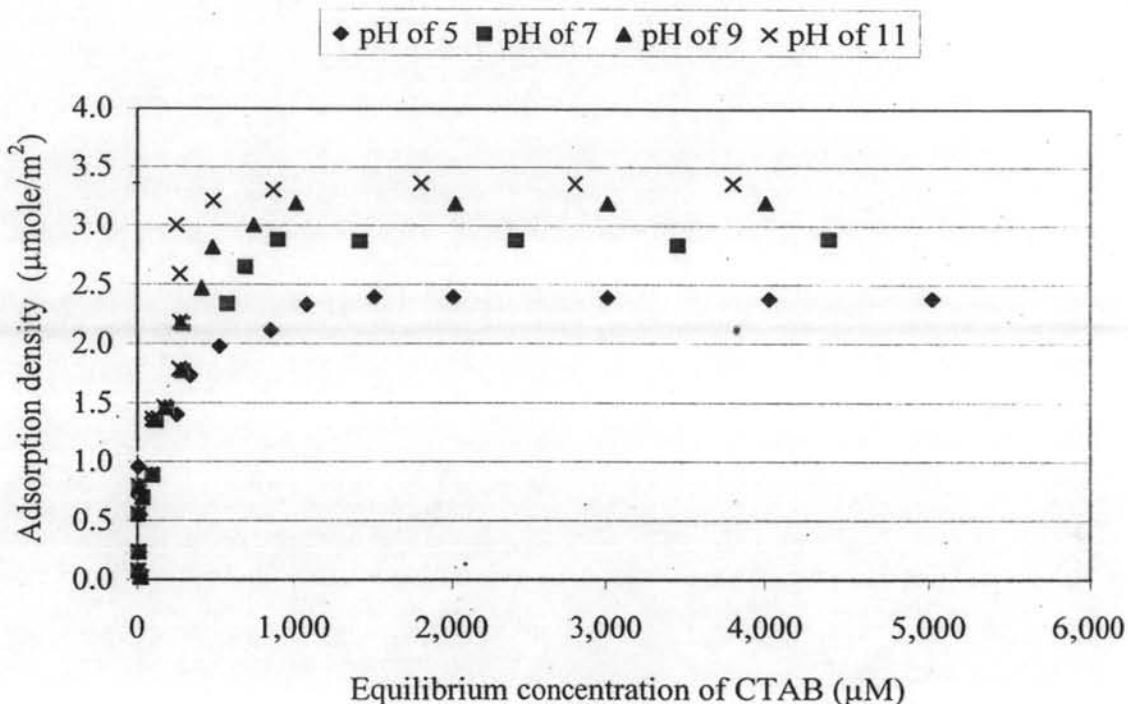


Figure 4.4 Adsorption isotherms of CTAB on polyester fiber at various pH levels.

4.1.5 Adsorption Isotherm of SDS on Cotton Fiber

It can be seen that the adsorption of SDS on cotton fabric conforms to S-shaped adsorption isotherm for an ionic surfactant. The amount of SDS adsorbed on cotton fabric was found to initially increase sharply with an increase in SDS concentration. As the SDS concentration increases further, the slope started to decline, leading eventually to a constant value. The trend of adsorption isotherm on cotton is higher than that of polyester reported by Wurster 1987 because cotton has higher surface area than polyester. The trend of the adsorption isotherm at pH 5 was greater than at pH 7, 9, or 11. From the plateau region the maximum SDS on cotton fiber at pH 5, 7, 9 and 11 are 5.5426, 4.3383, 3.1977 and 1.8638 $\mu\text{mole/m}^2$ respectively.

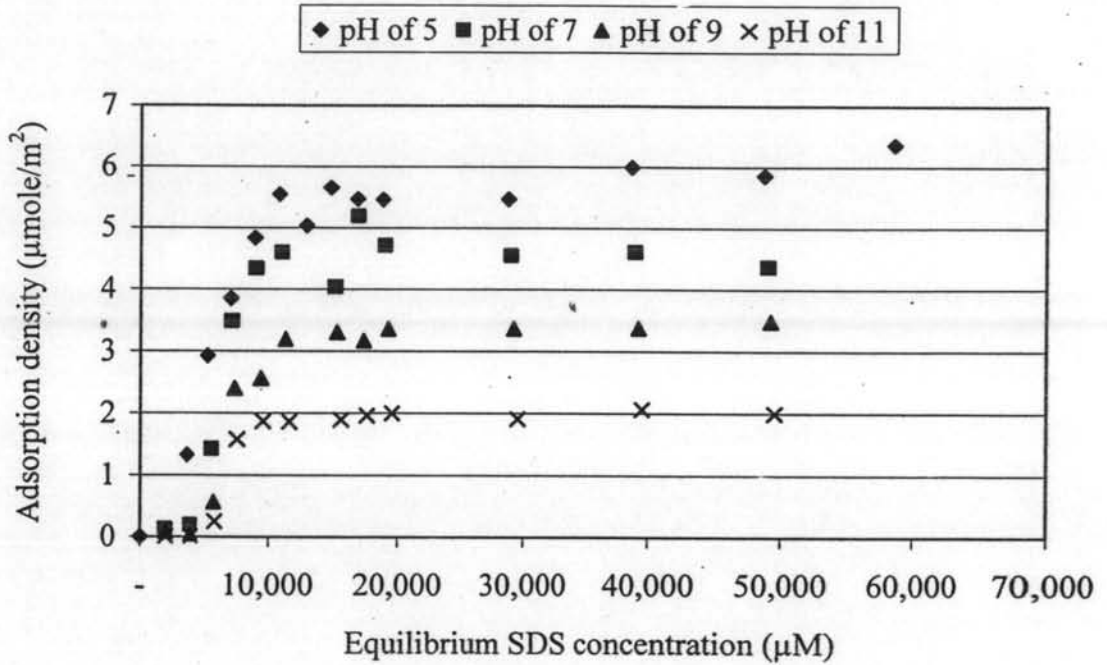


Figure 4.5 Adsorption isotherms of SDS on cotton fiber at various pH levels.

4.1.6 Adsorption Isotherm of CTAB on Cotton Fiber

Figure 4.6 shows the CTAB adsorption isotherm on cotton fabric. It has been suggested that at highest pH (pH11) cotton surface is highest negatively charged, the electrostatic attraction with the cationic CTAB is dominant at low CTAB concentration. CTAB adsorbs through hydrocarbon chain-chain interaction with neighboring CTAB. The trend of the adsorption isotherm at pH 11 was greater than at pH 5, 7, or 9. From the plateau region the maximum CTAB on cotton fiber at pH5, 7, 9 and 11 are 4.9489, 6.6611, 8.491 and 8.9752 $\mu\text{mole/m}^2$ respectively.

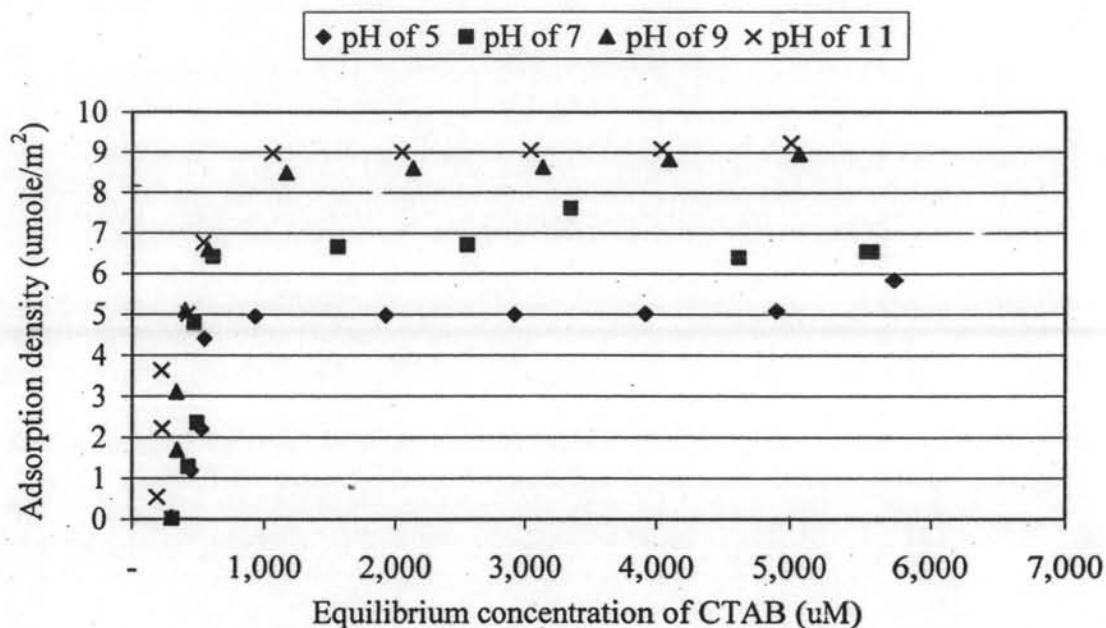


Figure 4.6 Adsorption isotherms of CTAB on cotton fiber at various pH levels.

4.2 Zeta Potential Measurement

Zeta Potential is an approximation of surface potential. It is the electrical potential at the shear plane between the Stern layer and the diffuse layer. It is an important feature because zeta potential can be measured in a fairly simple manner, while the surface potential cannot. Zeta potential is an effective tool for coagulation control because of changes in the repulsive force between colloids.

4.2.1 Zeta Potential of Carbon Black versus SDS

Figure 4.7 shows the zeta potential of carbon black in the SDS surfactant as a function of pH level. In this experiment, the concept of point of zero charge (PZC) which is a point or range of pH of solution which makes the charge at the solid surface become zero was used. The PZC for the carbon black particles was found at a pH level of about 2.3. In contrast they showed a negative charge when the $\text{pH} > 2.3$. From the PZC theory, the charge of the carbon black particles becomes more negative at higher pH. The carbon black particles have the highest negative charge at pH 11 and are lowest negative charge at pH 5. At constant equilibrium SDS

concentration, the absolute zeta potential of carbon black at pH of 11 was slightly greater than both at pH 9 and 7. Because the effect of pH between 7 and 9 was not significant to the SDS adsorption on the carbon black surface, the negative charge on the carbon black surface at pH 11 remained higher than at other pH levels.

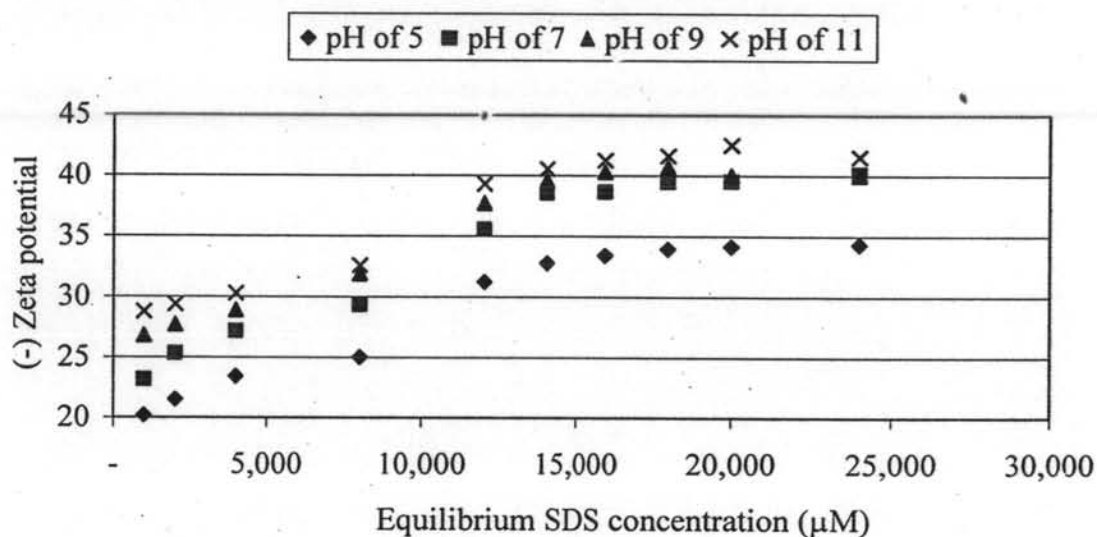


Figure 4.7 SDS adsorption and zeta potential of carbon at various pH levels.

4.2.2 Zeta Potential of Carbon Black versus CTAB

Figure 4.8 shows, the zeta-potential of cationic CTAB surfactants solution on carbon black at various pH, the sign of the zeta-potential of the carbon black surface changed from negative to positive. In the CTAB solutions, the zeta-potential of the CTAB concentration reaches a constant value around 50mv for concentrations of the bulk CMC and higher. The PZC of the carbon black is around 2.3 and had the lowest negative charge at pH 5 and the highest negative charge at pH 11. At pH 11, then, the CTAB (cationic) had the highest adsorption on the carbon black, and at pH of 11 has the highest value of zeta potential. On the other hand at pH 5, the CTAB had the lowest adsorption on the carbon black, and the lowest value of zeta potential.

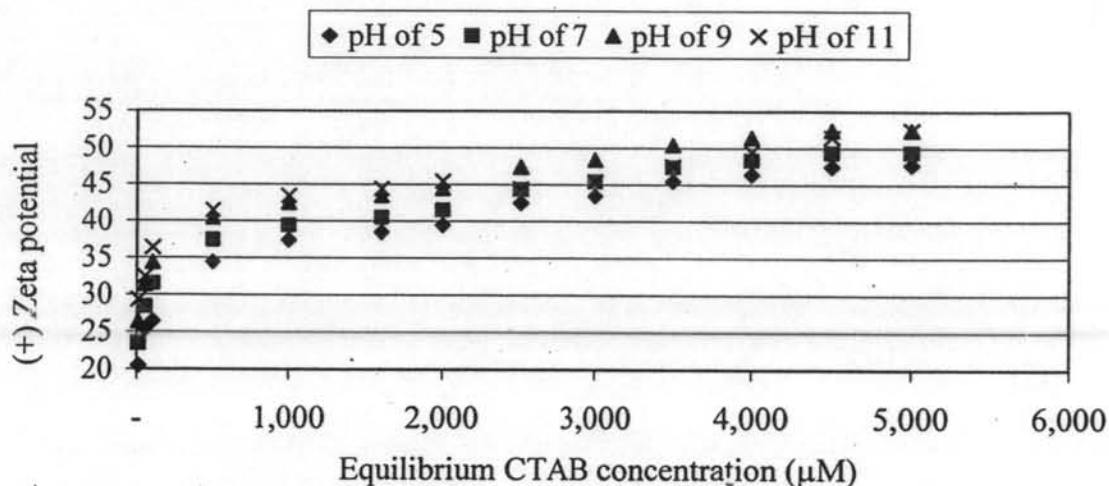


Figure 4.8 CTAB adsorption and zeta potential of carbon at various pH levels.

4.2.3 Zeta Potential of Polyester and Cotton Fiber at vary pH

The zeta potential of polyester and cotton fiber depends on the pH. The zeta potentials of the substances were very different and were dependent on the pH of the solution. From Figure 4.9, it can be seen that the zeta potential of the polyester fiber which showing the highest negative charge was at a pH of 11 (-110mV). But in the case of cotton, it had a lower negative charge (-22mV). The corresponding increase in mutual repulsion between the charges of the surface and the surfactant is responsible for an increase in the washing effect because, based on the electric theory, the amount of energy is sufficient enough to separate a particle from the substrate. The % soil detergency and % soil removal were observed later.

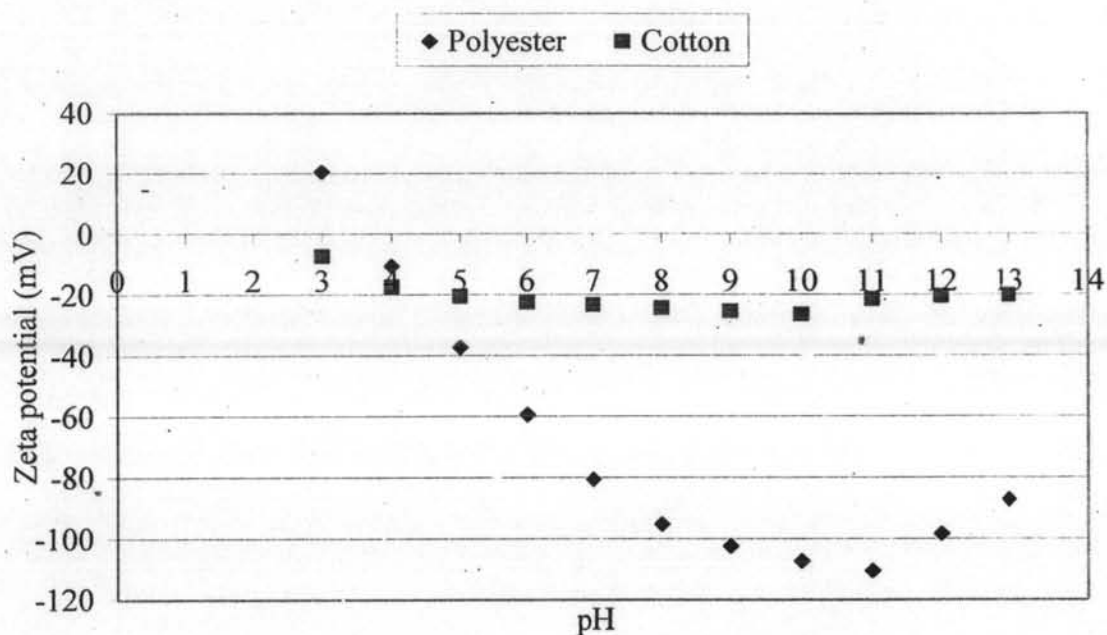


Figure 4.9 Zeta potential of polyester and cotton at various pH levels.

4.3 Detergency Performance

The detergency performance experiment can determine two parameters, % detergency and % soil removal. Moreover the contact angle, zeta potential, surface tension and adsorption isotherm are correlated to detergency performance to more clearly understand the soil removal mechanism in the detergency process. The experimental data part and the calculation methods are provided in the Appendix.

4.3.1 Effect of Surfactant Concentration and pH on Detergency Performance of Polyester Fiber

For this study the total surfactant concentration refers to the weight (%w/v) of the total surfactant solution.

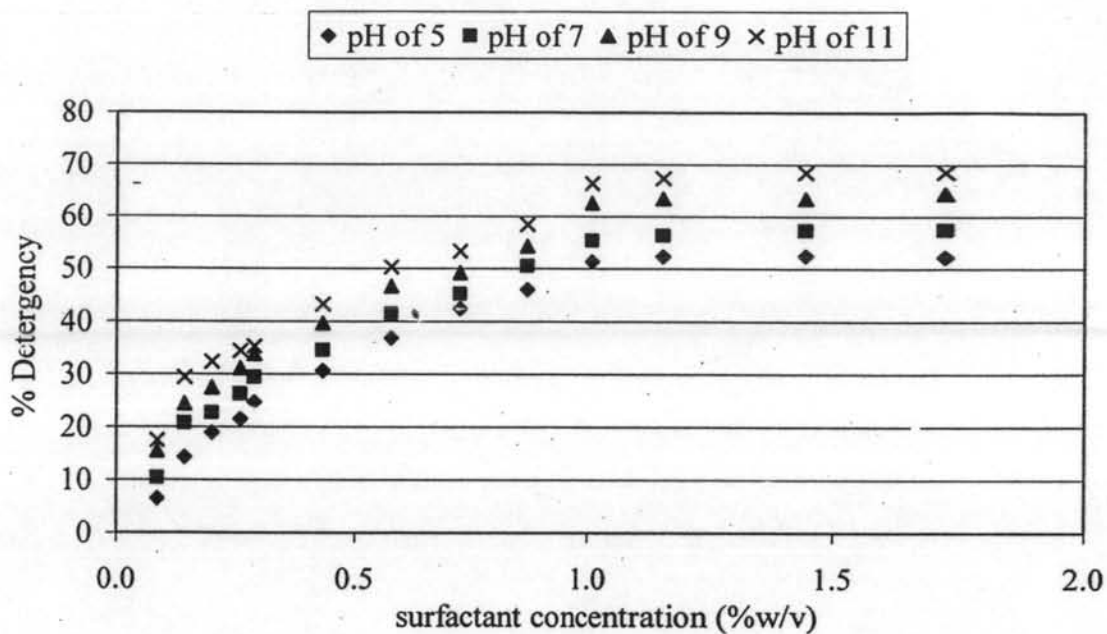


Figure 4.10 % Detergency and effect of active surfactant (SDS) concentration at various pH levels of polyester fiber.

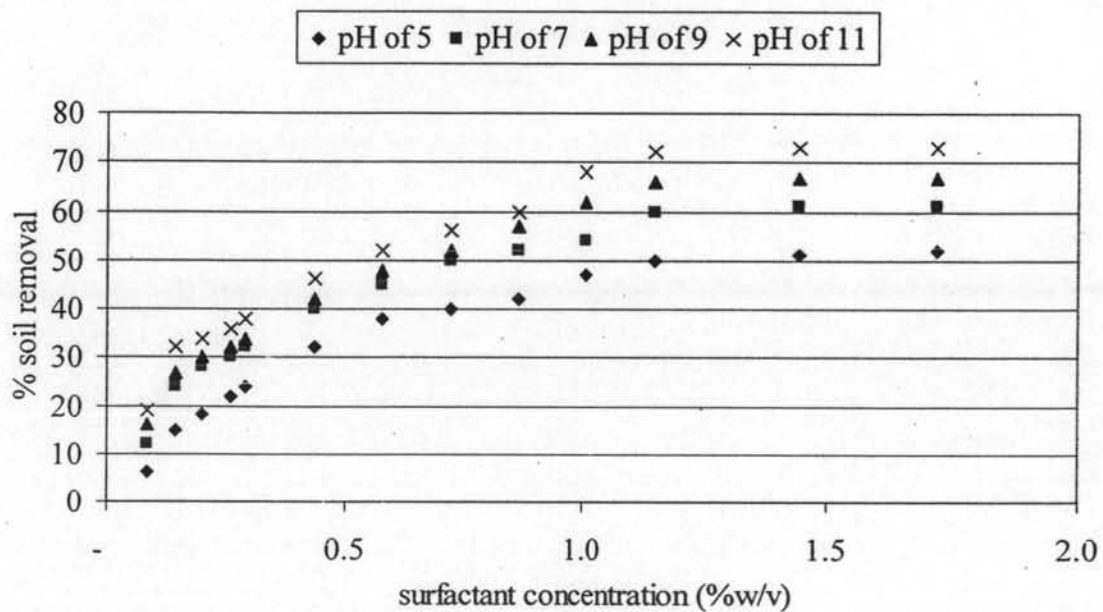


Figure 4.11 % Soil removal and effect of active surfactant (SDS) concentration at various pH levels of polyester fiber.

From this study, it was found that the % detergency increased with increasing surfactant concentration and the % detergency reached the plateau at around 1.1 (%w/v) surfactant concentration for polyester. From this experiment we found that at pH 11 there is highest % detergency at around 69%. Carbon black also acquires a negative charge in water. The negative charge of carbon black and fiber is highest by adsorption of the anionic surfactant at pH 11. The corresponding increase in mutual repulsion is responsible for an increase in the washing effect. The dispersing power for carbon black also increased for the same reason, whereas the redeposition tendency of removed carbon black is diminished. Furthermore this finding correlates with that of Vaeck and Verleye (1973) who found that the redeposition of hydrophobic carbon black decreased rapidly with increasing pH for all fabrics. In the % soil removal experiment, use the method of measuring the weight of the sample before and after washing, and then filtering the remaining soil from the wash water to correlate the sample weight with the remaining carbon black. It was found that at 1.1% of surfactant concentration at pH 11, the % soil removal is around 71%.

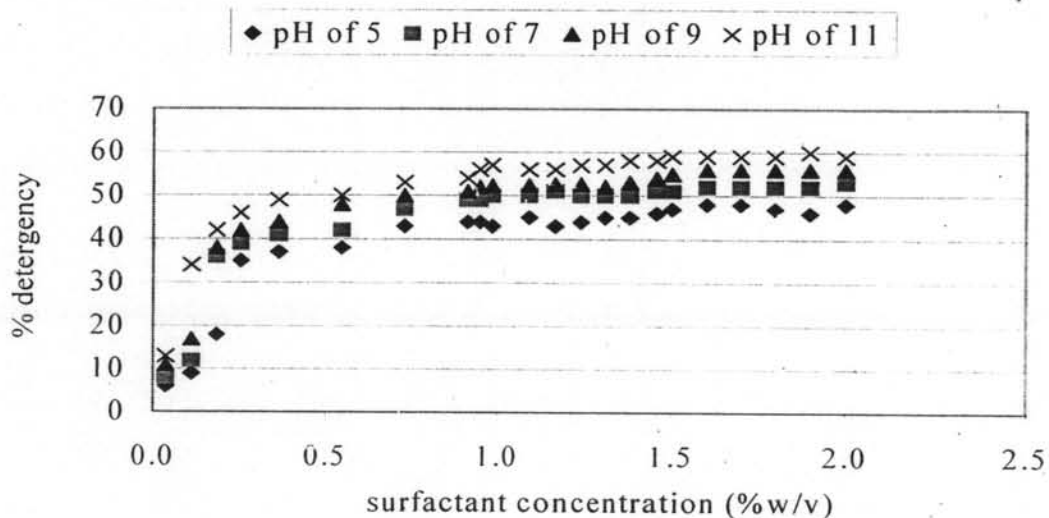


Figure 4.12 % Detergency as a function of active surfactant (CTAB) concentration at various pH levels of polyester fabric.

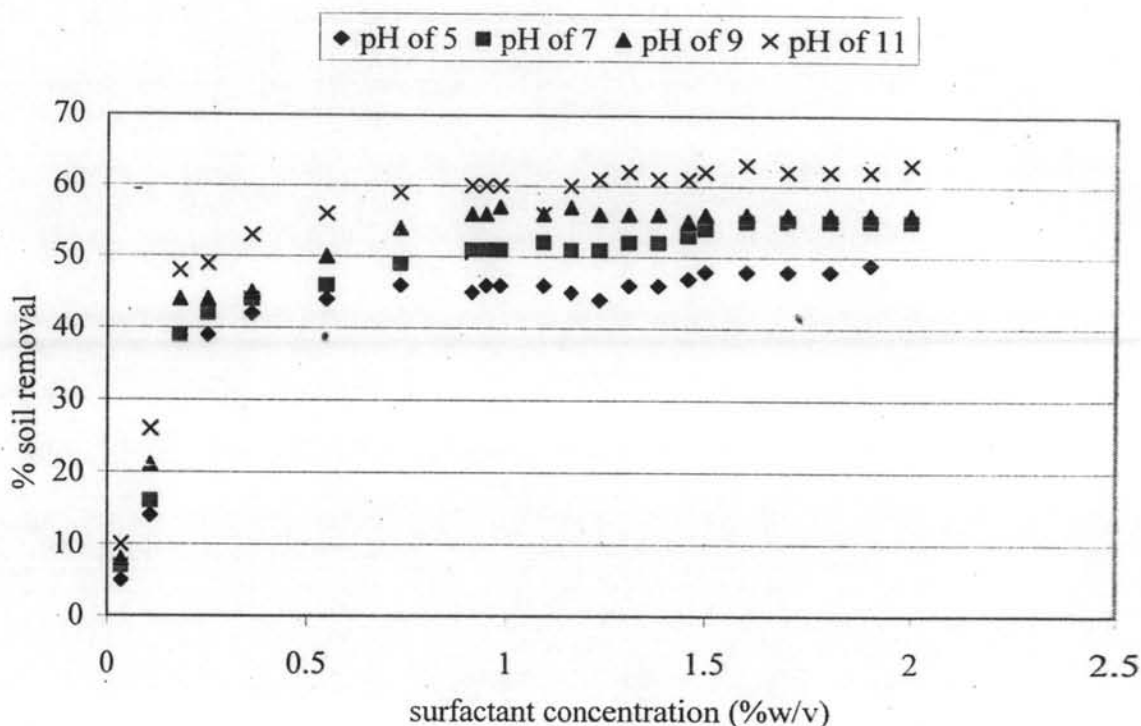


Figure 4.13 % Soil removal as a function of active surfactant (CTAB) concentration at various pH levels of polyester fabric.

From this study, It was found that the % detergency is highest around 60% at pH 11 and the % soil removal is highest around 61 %, and from the graph we found that CTAB amount is higher than SDS around 1.5(%w/v). The mechanism will be shown later. Long chain cationic surfactants of CTAB exhibited extraordinarily high sorption to a carbon black and fiber surface. Adsorption rises steeply at low surfactant concentrations, followed by rapid saturation as the concentration increased. This behavior suggested complete coverage of boundary surfaces.

At the same time, cationic surfactants display behavior opposite that of anionic surfactants as regards to the charge relationship on solids. Since the surfactant molecules bear a positive charge, their adsorption reduces the negative zeta potential of solids present in the aqueous solution, thereby reducing mutual repulsions, including that between soil and fibers. Use of higher surfactant concentrations causes a charge reversal; thus solid and fiber become positively charged, resulting again in repulsion. Carbon black removal can be achieved, if there

are adequate amounts of cationic surfactants and if their alkyl chains are somewhat longer than those of comparable anionic surfactants. However, since the subsequent rinse and dilution processes cause charge reversal in the direction of negative zeta-potentials, a large fraction of the previously removed soil is once more attracted to the fibers. Therefore there is a small amount of removal carbon black by using a cationic surfactant.

4.3.2 Effect of Surfactant Concentration and pH on Detergency Performance of Cotton Fiber

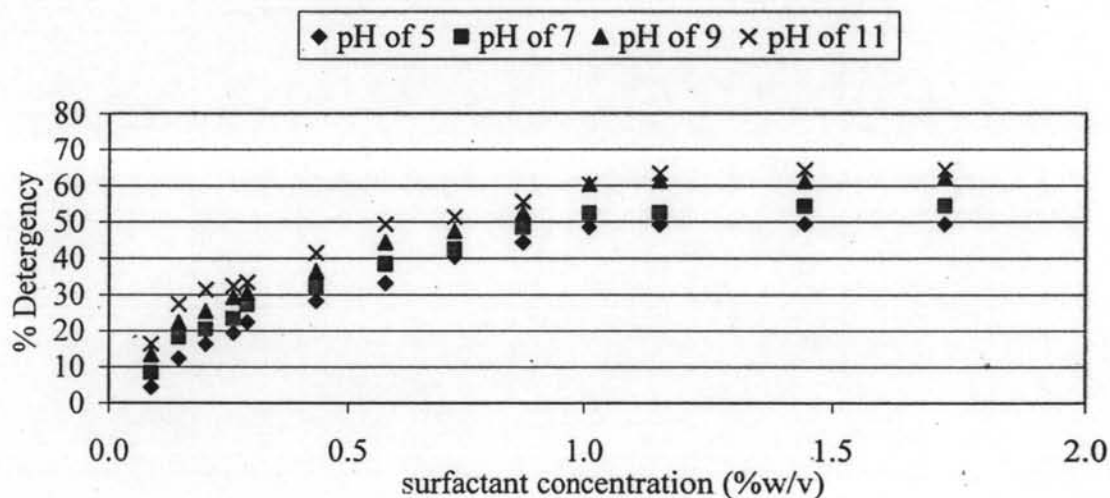


Figure 4.14 % Detergency as a function of active surfactant (SDS) concentration at various pH levels of cotton fabric.

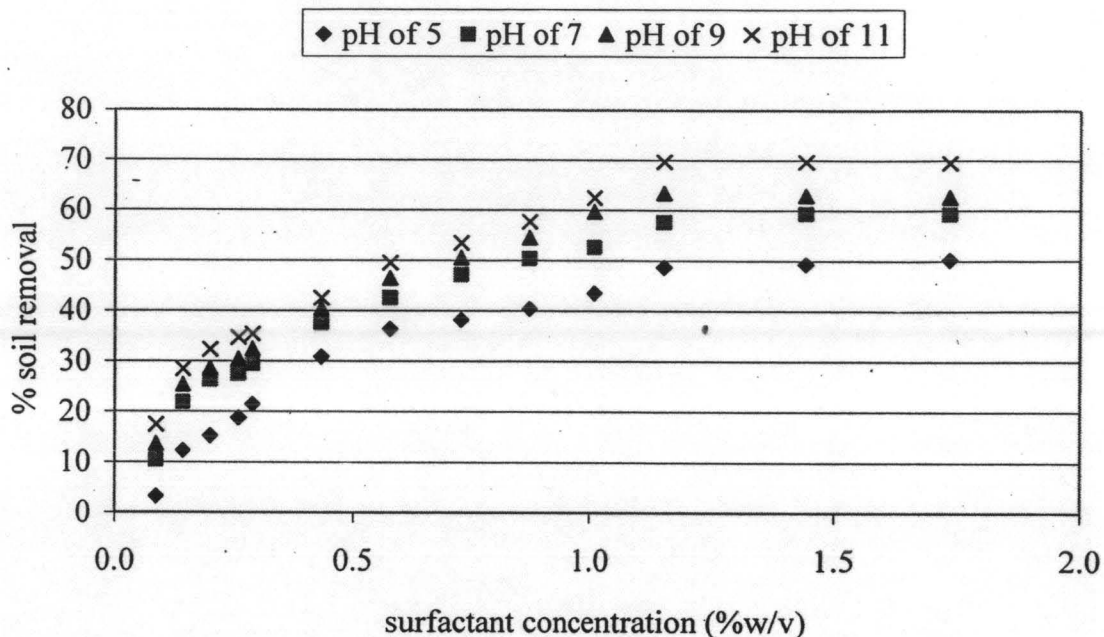


Figure 4.15 % Soil removal as a function of active surfactant (SDS) concentration at various pH levels of cotton fabric.

From this study it was found that the % detergency of cotton fabric is around 63% and % soil removal is around 69% at a pH of 11. We found that both of % detergency and % soil removal of cotton fabric is lower than in the case of polyester fiber. There are many reasons which support this phenomena: 1) because of The hydrophilic nature of cotton and the hydrophobic nature of polyester - fiber geometry play an important role in the degree of adhesion and particle size distribution of carbon black before and after laundering; 2) because of that the the chemical property of the fibers - cotton fiber has a lot of functional groups, so it can easily attract with carbon black, which is the opposite of polyester fibers which normally contain no reactive chemical groups, so they are not easily penetrated by dyes and carbon black or dispersed carbon black, as reported by M.Esinosa-Jimenez (2002).

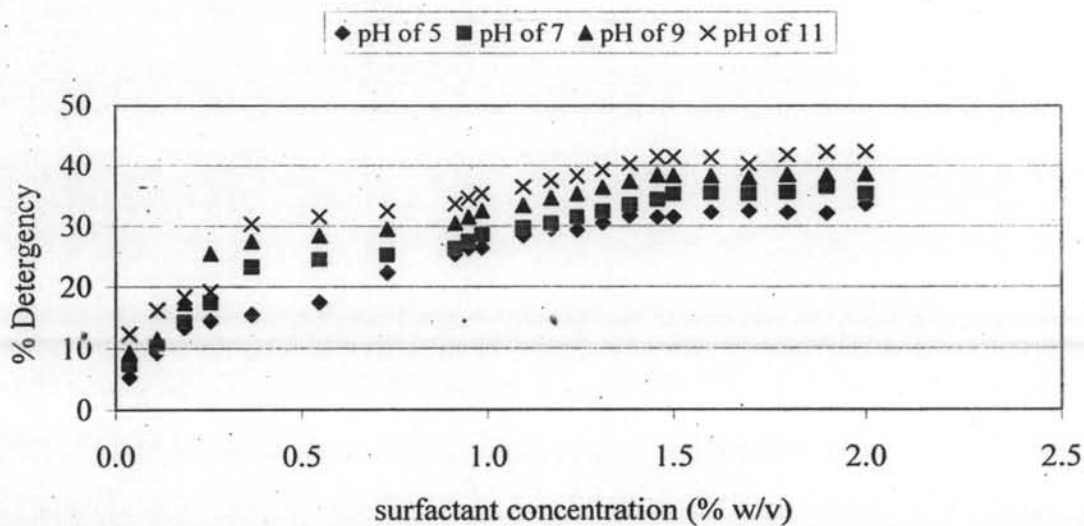


Figure 4.16 % Detergency as a function of active surfactant (CTAB) concentration at various pH levels of cotton fabric.

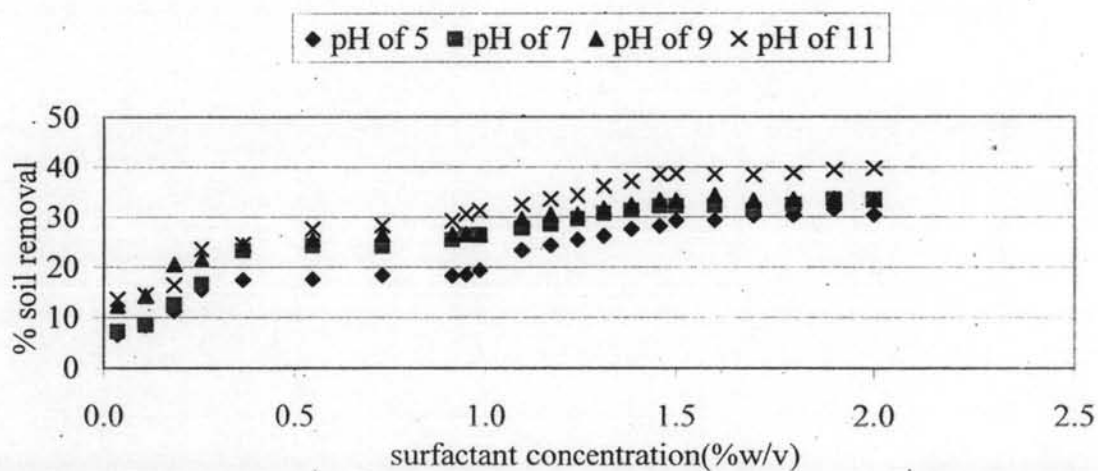


Figure 4.17 % Soil removal as a function of active surfactant (CTAB) concentration at various pH levels of cotton fiber.

From all figures, I found that % detergency of CTAB is lower than SDS in all cases. The main reason of this effect is in the point of electrical neutrality where redeposition of previously removed carbon black soil is observed in the case

of the cationic surfactant. This is why cationic surfactants have lower carbon black removal in my experiment than anionic surfactants.

4.3.3 Fiber Surface Morphology of the Polyester Fiber and Cotton Fiber

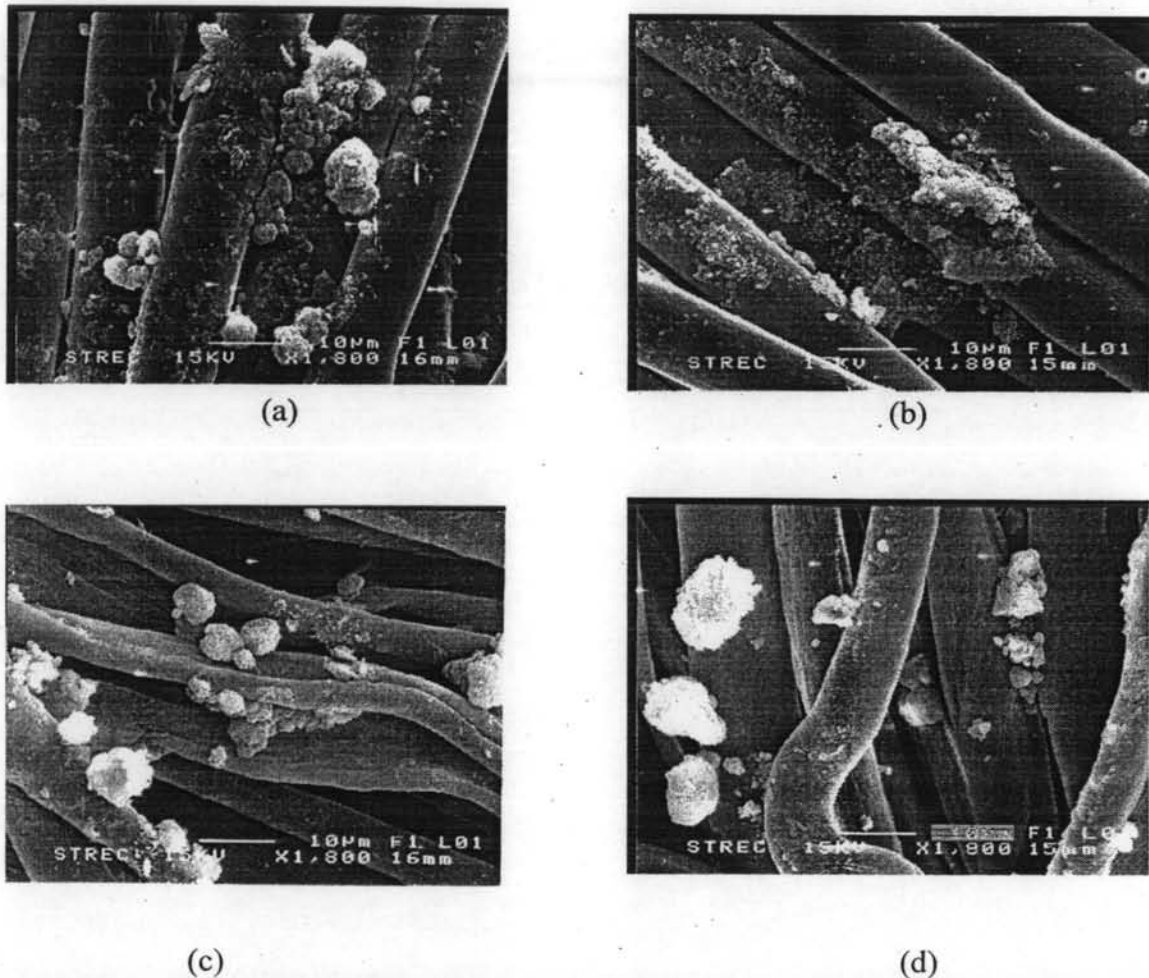


Figure 4.18 SEM micrograph of Fiber (x 1,800)

- a) Polyester fiber before washing b) Polyester fiber after washing
 c) Cotton fiber before washing d) Cotton fiber after washing

In this experiment the best condition of 1.1(%w/v) SDS concentration at a pH of 11 was used, and from the pictures, the cotton after washing contained a lot of impurities on the surface (picture d) compared with the polyester fabric (picture b), where fewer impurities were left on the fiber surface. The fact that

carbon black is removed from polyester easier than from cotton fiber is because carbon black adheres differently to cotton than to the polyester. In the SEM micrograph because of the physical property of fiber- Cotton has a lot of hair on the surface so it easily attaches to carbon black. But in the case of the polyester, it has a smooth surface and has no hair on the surface fiber so carbon black does not easily attach to the surface and other possibly because of cotton fiber has a small diameter so the carbon black easily attaches to the space between the yarn, and polyester has a larger diameter so it does not have much space, so the carbon black does not easily attach to it.

Normally, the carbon black used in this experiment is $0.24\ \mu\text{m}$. But it will aggregate to $1\text{-}20\ \mu\text{m}$.

In one such experiment, the particle size distribution of the solid particle adhering to polyester were determined to be $10\text{-}20\ \mu\text{m}$, in contrast to that of cotton, which was from 1 to $20\ \mu\text{m}$. Since the same carbon black was used to soil both fabrics, it can be concluded that the larger particles of the solid particle tended to adhere to polyester but not the smaller solid particle. After both cotton and polyester fabrics were washed in water, the average solid particle distribution was $10\ \mu\text{m}$. When the identical soiled cotton and polyester fabrics were washed in a conventional detergent, all the solid particles ($10\text{-}20\ \mu\text{m}$) adhering to the polyester was removed. In contrast, most of the carbon black particle less than $5\ \mu\text{m}$ were left on the cotton fabric, demonstrating that small particles can adhere to cotton fibers and that the adhesion of the small carbon black particles ($1\ \mu\text{m}$) is stronger than both the builder and surfactant detergency effects.

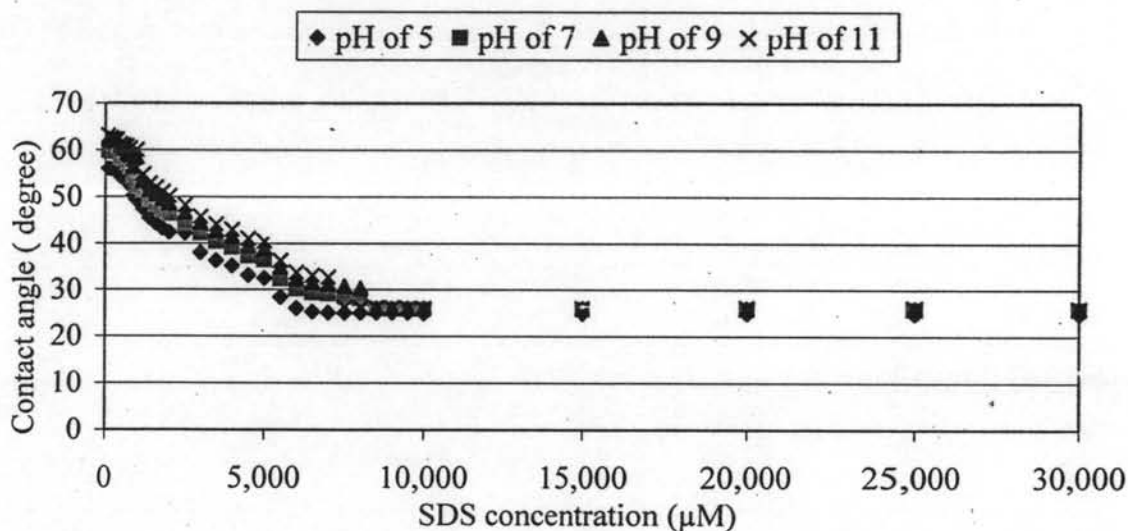
4.4 The Contact Angle

From the support of zeta potential at pH 11 was highest, the contact angle was used for ensure that pH 11 was the best for detergency performance. In this experiment PET replace for Polyester fabric. Because fabric can not measure contact angle. The Contact Angle of water on PET and carbon black and the specific surface area of the PET and carbon black used in this study are shown in table 4.1.

Table 4.2 Properties of PET and carbon black

Sample	Contact angle of water (degree)	Specific surface area (m ² /g)
PET	74	3.2000
Carbon black	62	96.0000

4.4.1 The Contact Angle of SDS on Carbon Black

**Figure 4.19** Contact angle of SDS solution on carbon black with various pH levels.

It was found that the contact angles decreased significantly with increasing SDS concentration until reaching a plateau above the CMC of SDS concentration at around 8500 μM . At pH 11 SDS has a slightly higher of contact angle than other pH levels, and relates with the adsorption isotherm that at other pH levels, there is a little bit more adsorb than at pH 11. But after the CMC point, the contact angle is not different. Ionic solid surfaces in contact with aqueous solutions containing surfactant ions of a charge similar to the carbon black surface generally show only small adsorption of SDS onto the similar charge of the carbon black surface. As a result, γ_{SL} can be expected to show little change with a change in the

bulk concentration of surfactant, and any improvement in wetting with an increase in the latter is due mainly to the decrease in the value of γ_{LA} . The contact angle of SDS decrease with decreasing pH and increasing concentration reported by Crudden, B.J. Lambert and R.W.kohl 1994..

4.4.2 The Contact Angle of CTAB on Carbon Black

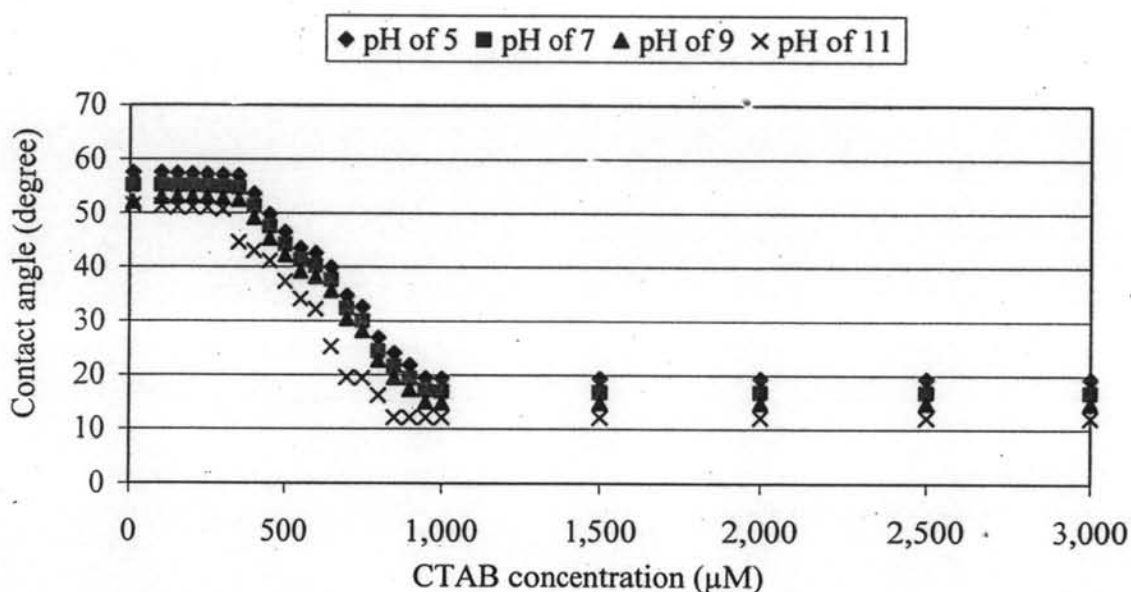


Figure 4.20 Contact angle of CTAB solution on carbon black with various pH levels.

In this case CTAB (cationic) has the lowest of contact angle at pH 11, surfactant will generally be adsorbed on the carbon black surface with their ionic hydrophilic heads oriented toward the carbon black and their hydrophobic groups oriented toward the aqueous phase. An increase in the concentration of surfactant in the aqueous phase will then result in decreasing γ_{SL} , thus decreasing wetting of carbon black, in spite of decreasing values for γ_{LA} , until the charge on the carbon black surface has been neutralized by the adsorption of oppositely charged surfactant ions. Once the surface charge has been neutralized, further adsorption of surfactant ions will generally occur, with their hydrophobic group oriented toward the surface

and their hydrophilic heads toward the aqueous phase. This will result in γ_{SL} being reduced, and wetting will improve as the bulk concentration of the surfactant increases. At a given concentration, the contact angle of CTAB solution was the lowest while the pH was highest. From the results obtained, it can be concluded that the wettability of CTAB solution on carbon black surface increase with an increase in pH levels.

From the result of contact angle measurement, the wettability of SDS onto carbon black is lower than that of CTAB that relate with the adsorption isotherm. CTAB has a higher adsorption onto carbon black than SDS.

4.4.3 The Contact Angle of SDS on PET

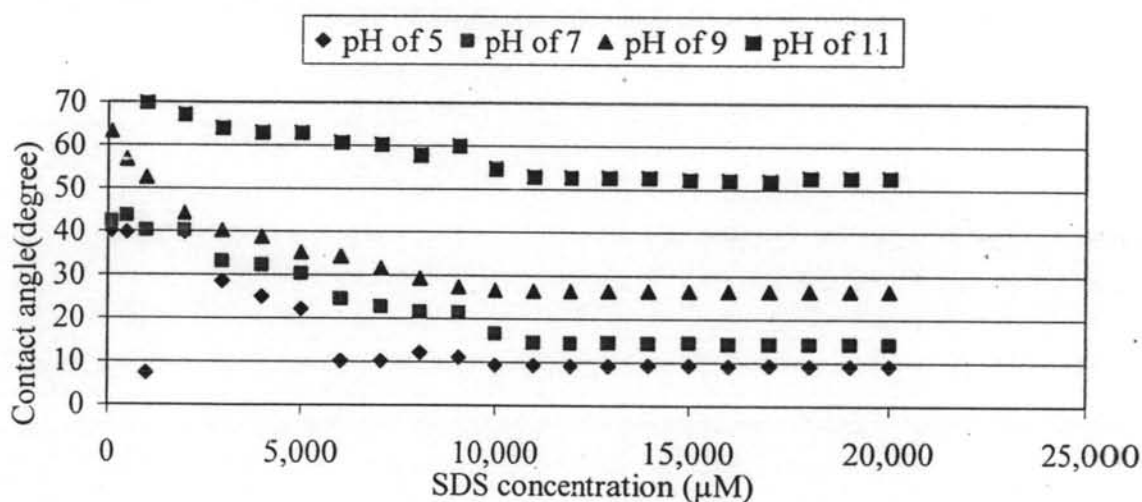


Figure 4.21 Contact angle of SDS solution on PET with various pH levels.

In case of PET, it is also found that the increase surfactant it reduced the contact angle. In this case pH of 11 has highest contact angle and the lowest at pH with has the same trend with SDS on CTAB. The adsorption of SDS surfactant will be the tail-down orientation and at pH 5, surface of PET is lowest negative charge so it easy to adsorb at this pH.

4.4.4 The Contact Angle of CTAB on PET at Various pH Levels

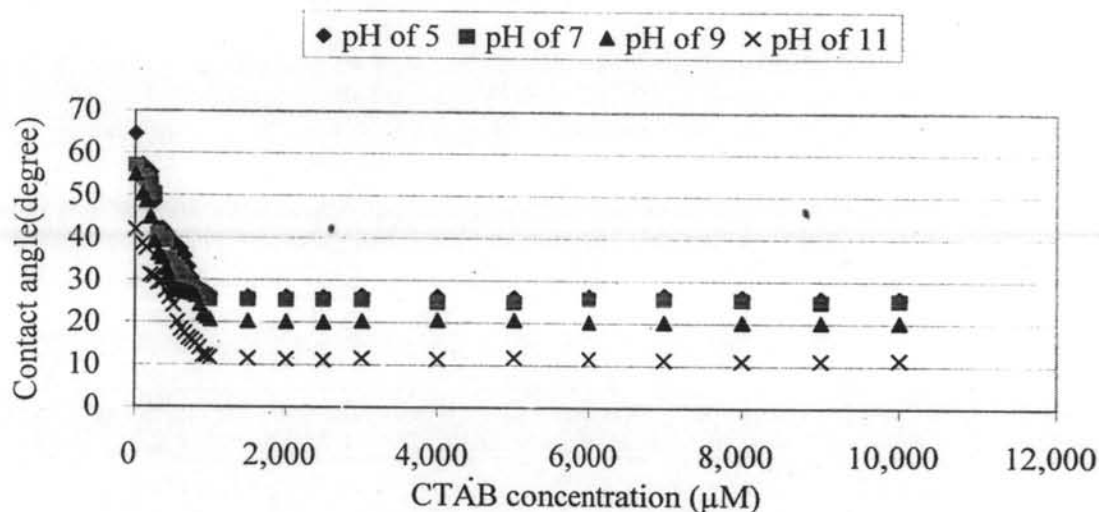


Figure 4.22 Contact angle of CTAB solution on PET with various pH levels.

Since surface of PET is hydrophobic, adsorption of CTAB molecules on the surfaces is a monolayer coverage with tail-in and head-out arrangement. But in pH 11 the hydrophobic surface of PET change to hydrophilic (-) charge so, a bilayer probably form head down in the first layer and second layer head group out toward the solution.

4.5 Surface Tension

This experiment measured the surface tension from the Bubble Pressure Tensiometer. Wetting is the first step for removing carbon black, which relate from adsorption of surfactant molecules on to the surfaces of both fiber and carbon black. In this experiment, we measure surface tension of SDS and CTAB at pH of 5,7,9 and 11. In case of SDS the liquid/vapor surface tension (γ_{LV}) of SDS decrease with increasing SDS until reaching CMC at about 9,000 μmole . We can observe the plateau surface tension of SDS are about 32 mN/m. The values show that surface tension varies very slightly when pH in the medium is modified. The lowest values for surface tension are generally found in clearly acid mediums, although there is no

great difference when compare with neutral or alkaline medium this finding agrees with the values reported by Hernainz and Caro. From the graph we found that at pH5 has slightly lower of surface tension than at pH 7,9 and 11 but when reach the CMC point the pH does not have effect with surface tension.

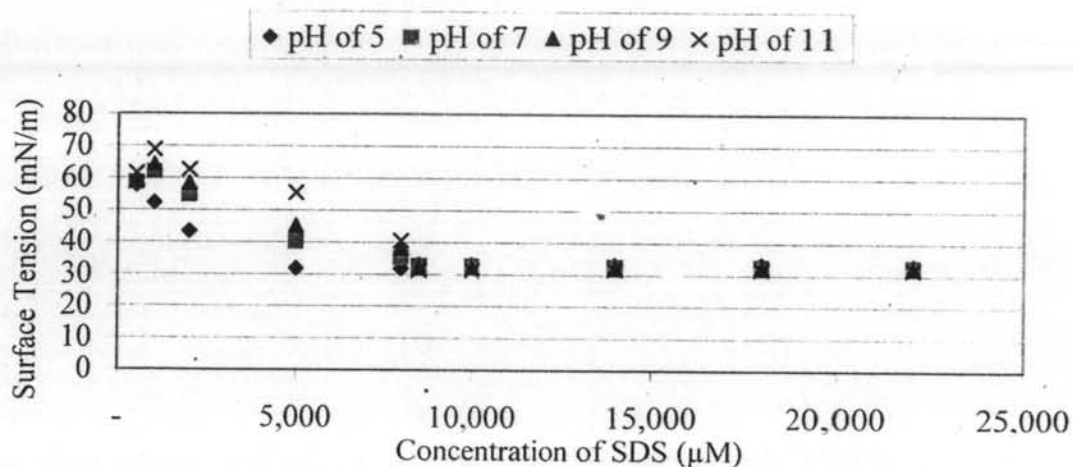


Figure 4.23 Surface Tension of SDS versus SDS concentration (μM).

The liquid/vapor surface tension (γ_{LV}) of CTAB solutions is as a function of its concentration as shown in Figure 4.24.

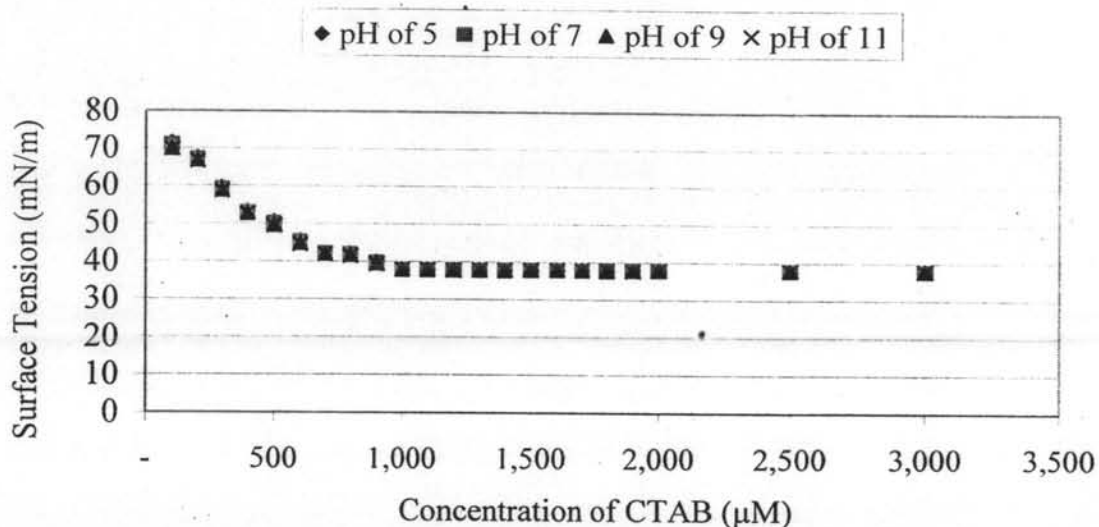


Figure 4.24 Surface Tension of CTAB versus CTAB concentration (μM).

Figure 4.24 shows the variation in surface tension of aqueous CTAB solutions at various pH and difference agent concentrations. The liquid/vapor surface tension (γ_{LV}) decrease with CTAB concentration until reaching CMC at about 930 μM . The plateau surface tension (at concentrations above the CMC) of CTAB are about 38 mN/m. It found that CTAB vary pH 5,7,9 and 11 have small effect with surface tension.

4.6 Effect of Amount of Rinsing Water and Number of Rinsing Step on % Detergency

From this experiment, the washing experiment was done with the best condition for remove carbon black, that is SDS concentration 1.1 (%w/v) at pH 11 from figure 4.25 show the comparison of % detergency of each step in detergency process and vary with rinse number. From the graph comparing the % detergency in each rinse, the % detergency of the wash step was highest. For the first rinse and second rinse % detergency were decrease respectively. This experiment show the significantly that the amount of rinsing water has effect with detergency performance in the first and the second rinse steps.

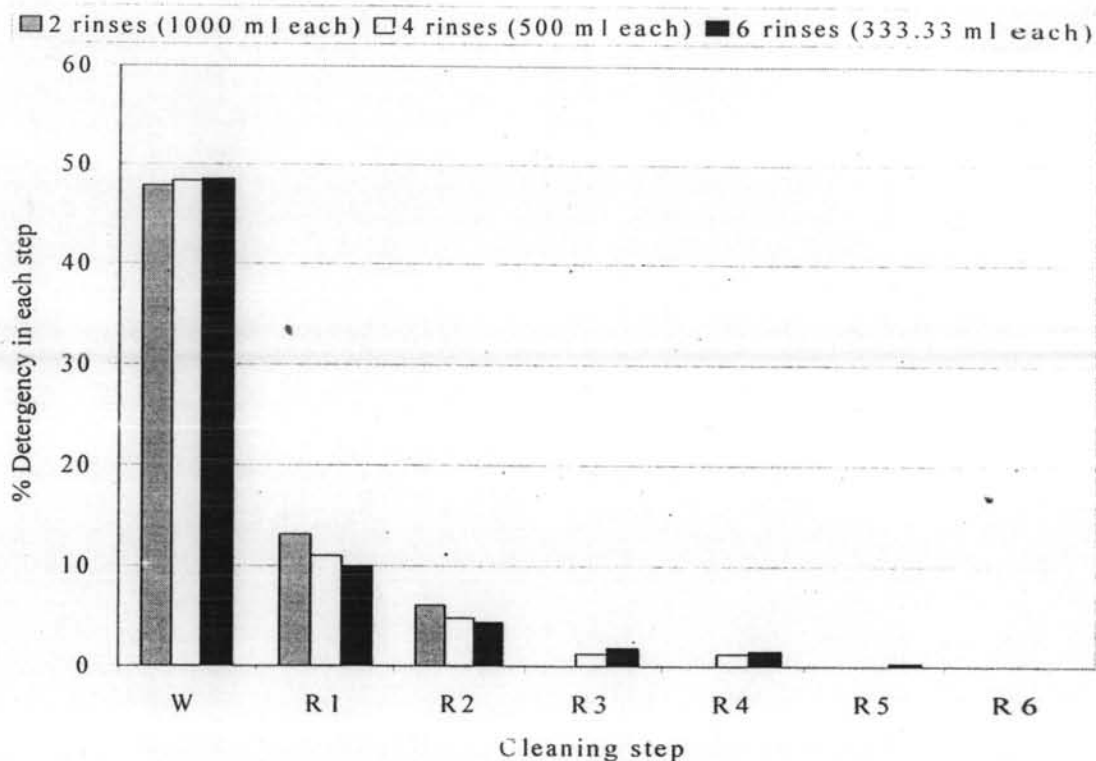


Figure 4.25 The %detergency of wash step and each rinse step using the concentration of surfactant 1.1 (%w/v) at pH of 11.

From all of three rinse methods used the results show that after the second rinse, rinse step did not have the effect with % detergency. So twice rinses are sufficient for remove carbon black. From this experiment can be explain that the amount of surfactant in after the second rinse is very low. Therefore, it does not have sufficient repulsion force between the charge of surfactant on the substrate and on the particulate soil. So the amount of energy is not sufficient enough to separate a particle from the substrate. Then % detergency was almost none after the second rinse. This experiment can be explain in lower amount of surfactant available after the second rinse step.

The total % detergency of the washing and the rinsing steps with 2 rinses, 4 rinses, 6 rinses are shown in figure 4.26 From the graph, % detergency of the wash step (W) was very high about 47-48 %.

For the first rinse (R1) and second rinses (R2) with different amount of rinsing water, the graph show the different in the % detergency, the total %

detergency with 2 rinses 1000 ml rinsing water was higher than that with 4 rinses 500 ml and 300 ml rinsing water a little bit.

From the experiment, show that for single and second rinse, require a sufficient of rinsing water to get a desirable detergency performance.

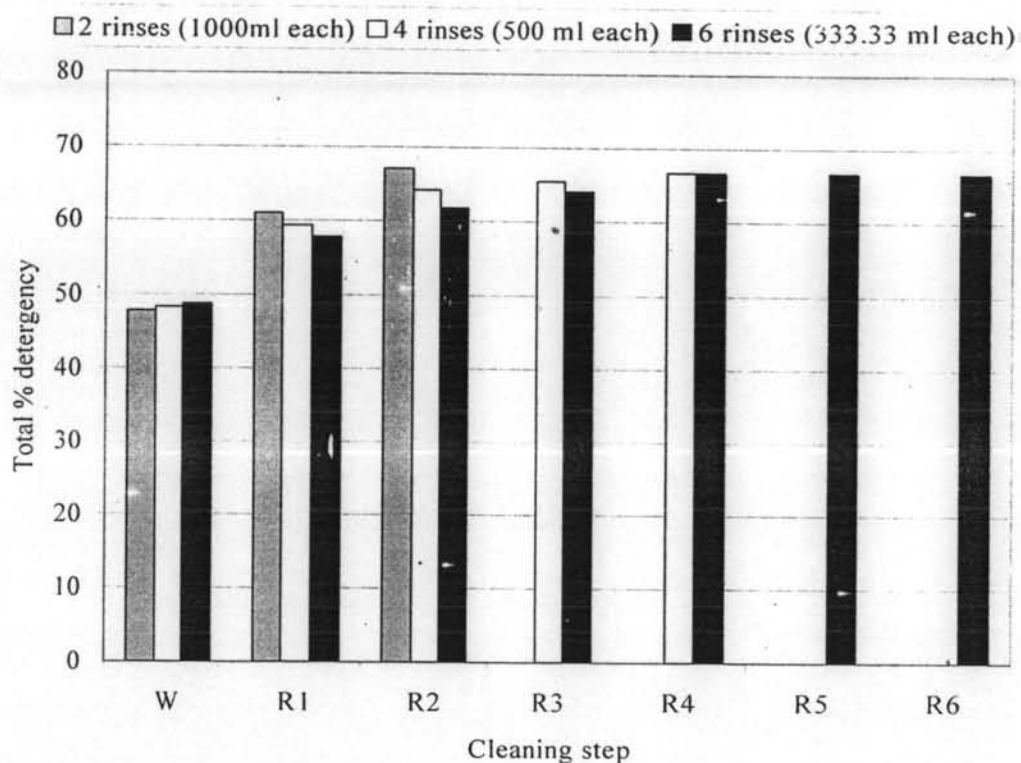


Figure 4.26 The total % detergency of each step with different rinse methods using the concentration of surfactant 1.1 (%/v) at pH of 11.

According from the washing process, it was found that the higher amount of rinsing water was the best. Interestingly, it was found that when use low amount of rinsing step the % detergency is a little bit decrease. It found that after two rinses in operation the % detergency does not have effect so much on the total of % detergency. From this result, the amount of rinsing water had effect with % detergency in each step but it does not have the affect of overall % detergency, so lower rinsing water can be use in the real situation.

4.6.1 Surface Tension During Washing Step and Rinse Step

The best conditions for the removal of carbon black, that is SDS concentration 1.1 (%w/v) at pH 11 and 2 rinses (1000 ml each), were used. The surface tension and carbon black removal experimental results are shown in Figure 4.27. From the graph, the surfactant in the washing step had the lowest surface tension of about 32 mN/m and shows that the washing step can remove the carbon black particulate soil the highest because of the lowest surface tension value. The reduction of surface tension shows that the carbon black removal is by the increase in electrical potentials. This adsorption of surfactant changes the electrical potentials of the substrate and soil. As might be expected, anionic surfactants in the bath are particularly effective for increasing the negative potential on both substrate and particulate soil. This increase in the negative potentials of both substrate and soil increases their mutual repulsion. For comparison of the rinsing steps, the first one has a surface tension of about 69 mN/m. It shows that the first rinse % detergency about (10-12%) because the adsorption of surfactants is very low, so it only changes a small amount of the electrical potential of the substrate.

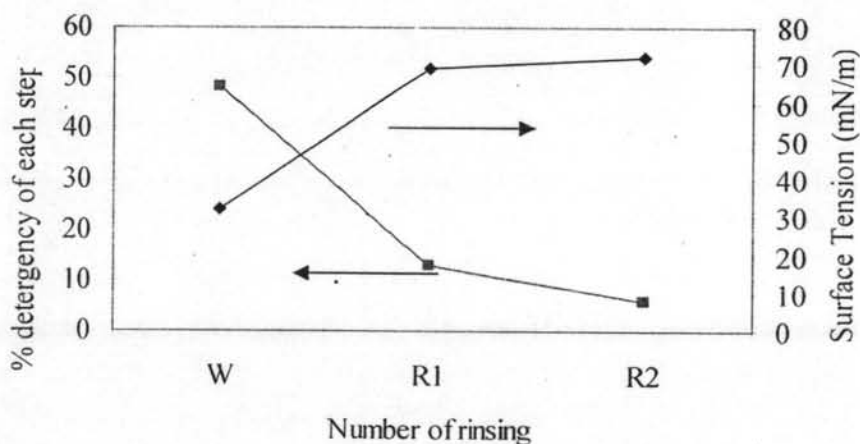


Figure 4.27 Correlation between equilibrium surface tension and %detergency of 2 rinse steps with SDS of 1.1 surfactant concentration at pH 11.

This result reveals that the % detergency efficiency for carbon black removal increase with decreasing surface tension of the system. To maximize the %detergency, obtaining lower surface tension should be considered.

4.6.2 Comparison of the First, Second and Third Washings

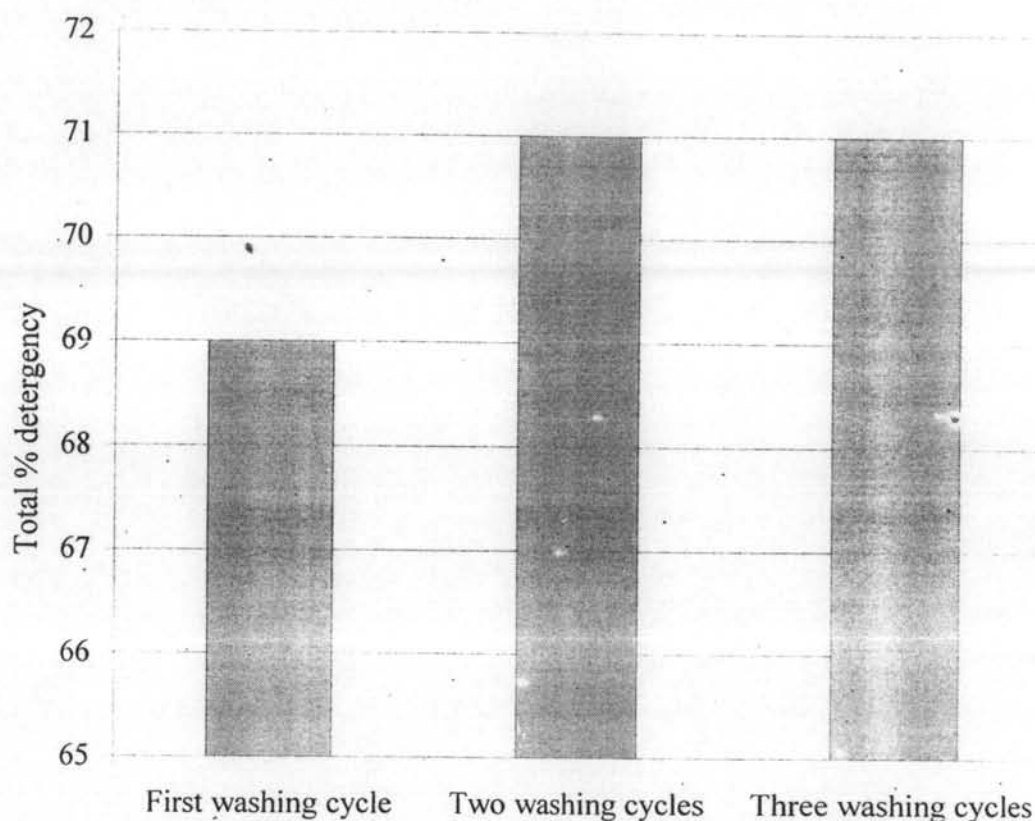


Figure 4.28 Comparison between first, second and third washings using the SDS concentration of surfactant 1.1 (%/v) at pH of 11.

From figure 4.28 it can be seen that the total %detergency increases slightly with the second washing. Although not significant, one possible reason for this effect is that the presence of surfactant and the repulsion force of both substrate and soil and the energy barrier for removal of the carbon black from the substrate is decreased and, at the same time, the energy barrier for soil redeposition is increased (Kling and Lange, 1960) The other reason is that in the first washing, the amount of carbon black removal is high so that redeposition can occur. But in the second washing, the amount of carbon black is less, so the soil redeposition is less. Then, the total % detergency of the second washing was higher than the first washing. Finally in the third washing the total % detergency is same with the second washing because the small size of carbon black particle attach in the fiber and cannot remove. In

addition this experiment, temperature of both washing solution and rinse water was varied from 20, 30 and 40 °C. It was found that the %Detergency was not different.

4.7 Proposed Mechanism for Carbon Black Removal

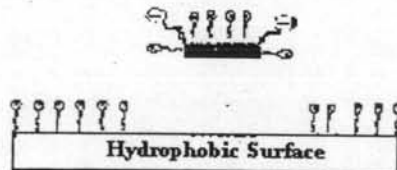
From the results of this work, the proposed mechanism for the removal of carbon black from the fiber surface , consists of three main steps. (In case of SDS).

Step 1) Surfactant adsorption on both fiber and carbon black.



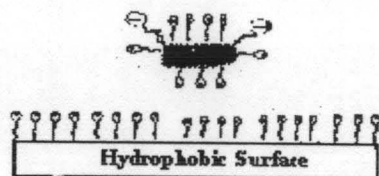
In this case, the interaction at the adsorption site is a hydrophobic chain/surface interaction.

Step 2) Detachment of carbon black from the fiber surface.



The corresponding increase in mutual repulsion so that the carbon black can be removed.

Step 3) Stabilization of dispersion of carbon black.



The dispersion power for carbon black also increased so it cannot come back.

Figure 4.29 Proposed mechanism for carbon black removal.