# CHAPTER IV

# RESULTS AND DISCUSSION

## 4.1 Sorption Kinetics

The preliminary tests of sorption kinetics showed that while acetaminophen did not sorb onto any adsorbent materials (silica, alumina or porapak), nalidixic acid sorbed onto all sorbent materials. And, 17-α-ethynylestradiol showed no sorption onto silica and alumina but did sorb onto Porapak P. For these reasons, kinetic sorption studies were conducted with nalidixic and all three sorbent materials, and were conducted with 17-α-ethynylestradiol and porapak.

Kinetic studies for nalidixic acid and all three pure sorbents are shown in Figure 4.1. Nalidixic acid sorbed well onto alumina and reached equilibrium within 3 hours. On silica, equilibrium sorption occurred for a time of 3 to 6 hours. On Porapak, the majority of nalidixic acid sorption occurred within the first three hours; a small amount of additional adsorption occurred over one and a half days. Figure 4.2 shows the sorption of 17-α-ethynylestradiol on Porapak as a function of time. As the sorption of 17-α-ethynylestradiol occurred onto the significant internal porosity of the Porapak, the internal diffusion made the sorption process quite slow, requiring 3 days to reach equilibrium.

From these kinetic studies, it was decided to conduct equilibrium isotherm for 3 hours for nalidixic acid and for 72 hours for 17-α-ethynylestradiol and porapak
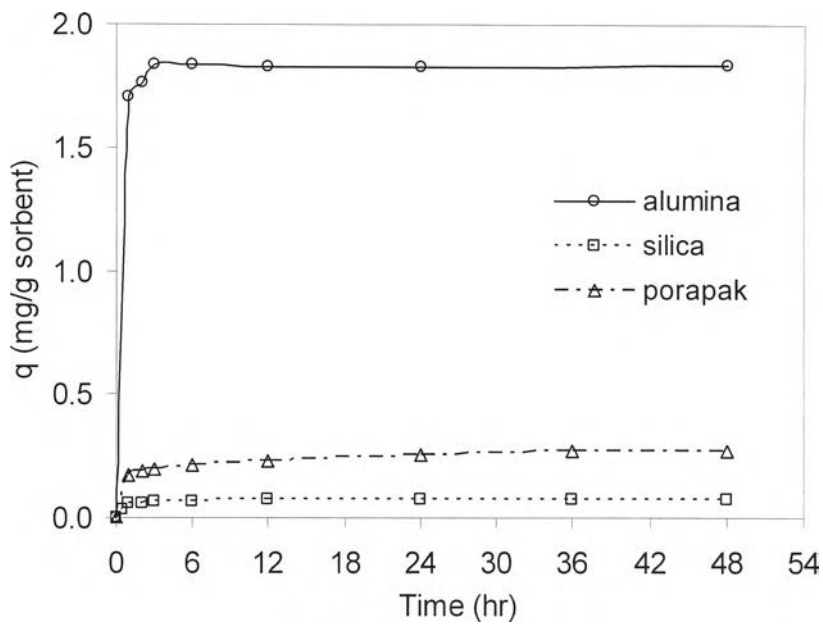
**FIGURE 4.1 The sorption kinetics of nalidixic acid onto alumina silica and porapak.**
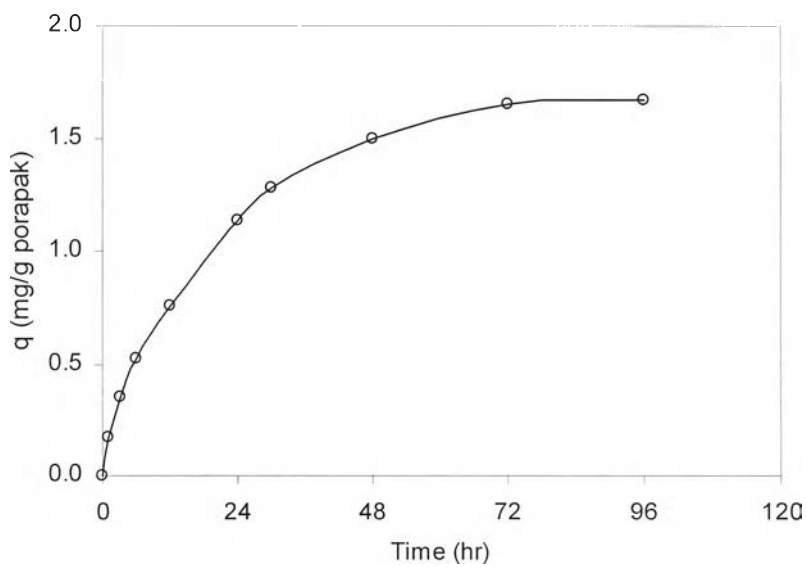


**FIGURE 4.2 The sorption kinetics of 17-α-ethynylestradiol onto porapak.**

## 4.2 Equilibrium Isotherms

Equilibrium sorption studies were conducted with three pharmaceutical compounds (acetaminophane nalidixic acid and 17-α-ethynylestradiol) and three adsorbents (silica alumina and porapak) in order to investigate the sorption behavior between pharmaceuticals and adsorbents with varying charge/hydrophobicity. Sorption of these pharmaceuticals was tested using batch studies with a concentration of each pharmaceutical at the mg/L level. The sorption data was fit by a linear isotherm. Figure 4.3, 4.4 and 4.5 show the sorption isotherms of three pharmaceuticals on the adsorbent materials which were alumina, silica and porapak, respectively. Summary results of this experiment including with the values of sorption coefficients ($K_d$) and correlation coefficients ($R^2$) are given in Table 4.1.

Since the isotherms were conducted at a pH between 6.5 and 7, which is slightly higher than the reported nalidixic acid $pK_a$ value of 6.3, nalidixic acid existed in both their ionic and neutral form (the carboxylic group was partially ionized), while acetaminophen ($pK_a = 9.4$) and 17-α-ethynylestradiol ($pK_a = 10.4$) existed predominantly in their neutral form. At pH 7, the alumina, with a PZC of ~9, has a net positive charge, the silica, with a PZC of ~3, has a net negative charge and the porapak, a neutral organic compound, has a zero charge.

On alumina, nalidixic acid showed the highest sorption, while acetaminophen and 17-α-ethynylestradiol showed no significant adsorption (see Figure 4.3). Nalidixic acid has one ionized carboxylic group. Since, at the experimental condition, nalidixic acid was ionized to its negatively charge form and alumina has positively charged surface, it was expected to have a high adsorption. The results for acetaminophen and 17-α-ethynylestradiol indicates that they were not in the anionic form, which was consistent with the functionality and $pK_a$ values as discussed above.

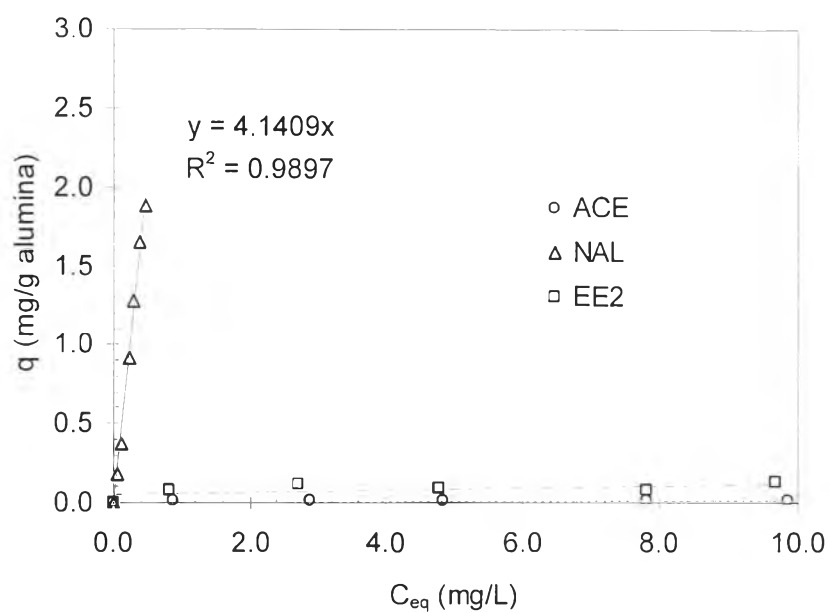Thus, the nalidixic acid showed strongest sorption onto the positively charged alumina surface.



FIGURE 4.3 The sorption isotherms of acetaminophen, nalidixic acid, and 17-α-ethynylestradiol onto the alumina surface.
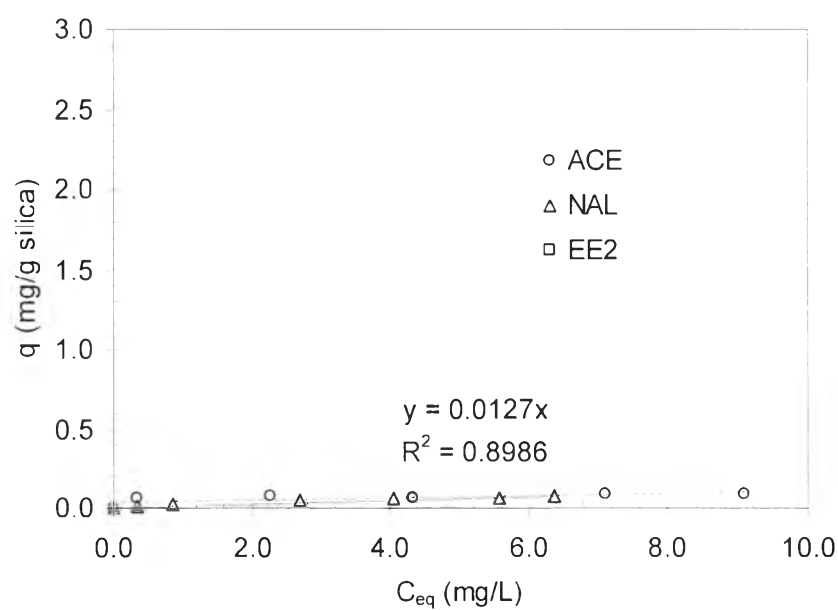


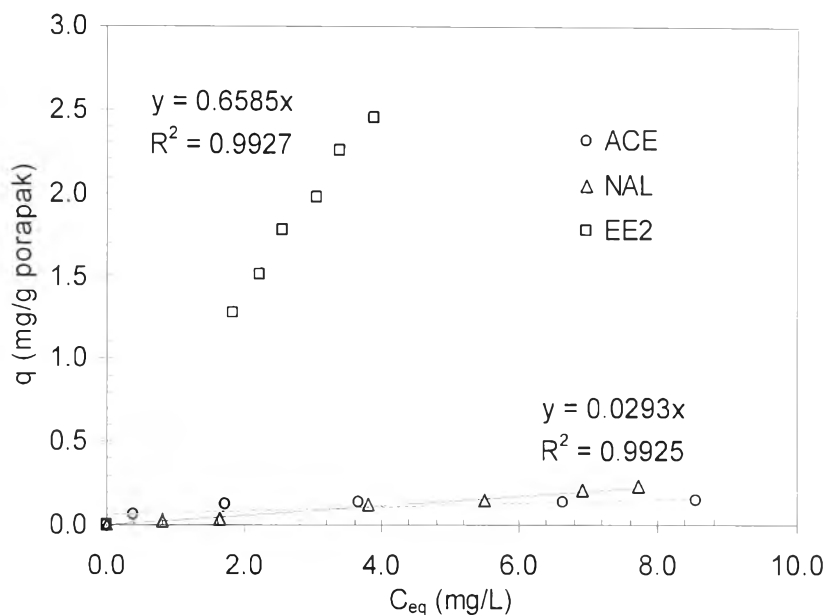FIGURE 4.4 The sorption isotherms of acetaminophen, nalidixic acid, and 17-α-ethynylestradiol onto the silica surface.

**FIGURE 4.5 The sorption isotherms of acetaminophen, nalidixic acid, and 17-α-ethynylestradiol onto porapak surface.**

On silica, all pharmaceutical compounds exhibited negligible sorption (see Figure 4.4). These pharmaceuticals have no positively charged functioned groups in their molecule to interact with the negatively charged silica surface. Thus, no adsorption was anticipated.

On Porapak P, 17-α-ethynylestradiol exhibited the highest sorption, while acetaminophane and nalidixic showed lower sorption (see Figure 4.5). Since 17-α-ethynylestradiol has a core structure of polycyclic aromatic benzene ring; it is the most hydrophobic molecule (see table 3.2) with a log $K_{ow}$ of 3.67 (versus between 0 and 1 for the other two pharmaceuticals). Thus, 17-α-ethynylestradiol showed the highest sorption onto hydrophobic Porapak which is consistent with the hydrophobicity (log $K_{ow}$) of this pharmaceutical.
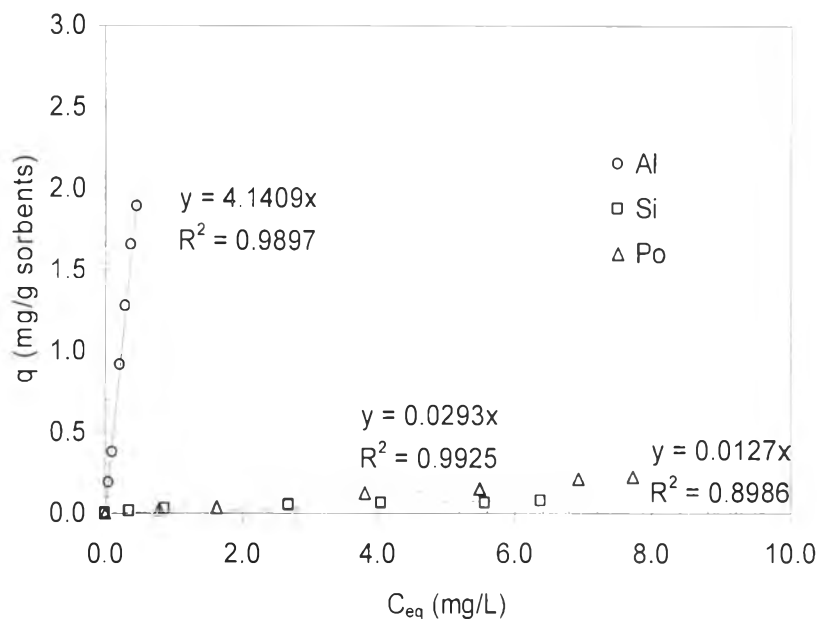
**FIGURE 4.6 The sorption isotherms of nalidixic acid onto alumina silica and porapak surfaces.**

The sorption isotherms of nalidixic acid with all sorbents are presented in the Figure 4.6 above. The sorption isotherm of nalidixic acid with alumina showed a very steep line, indicating the significant adsorption of nalidixic acid on the alumina surface. Since the positively charged alumina surface was present at the experimental condition, nalidixic acid, which has oppositely charged, showed strong sorption onto alumina surface. A negatively charged of silica surface, which was the same charge as ionized nalidixic acid; the lowest adsorption isotherm was presented. On porapak, sorption is higher than on silica. Some of nalidixic acid existed in neutral form because the experimental condition close to its $pK_a$. A neutral molecule of nalidixic acid absorbs/partitions into the porapak.

**TABLE 4.1 Pharmaceutical Sorption Batch Test Results- Alumina Silica Porapak. The sorption coefficient ($K_d$) of pharmaceuticals onto sorbent materials, and the sorption coefficients which were normalized by specific surface area.**

| Pharmaceuticals | Alumina | | | Silica | | | Porapak | | |
|---|---|---|---|---|---|---|---|---|---|
| | $K_d$ (L/g) | $R^2$ | $K_d$/SSA (L/m$^2$) | $K_d$ (L/g) | $R^2$ | $K_d$/SSA (L/m$^2$) | $K_d$ (L/g) | $R^2$ | $K_d$/SSA (L/m$^2$) |
| Acetaminophen | N/S | N/S | N/S | N/S | N/S | N/S | N/S | N/S | N/S |
| Nalidixic acid | 4.15 | 0.98 | 0.0263 | 0.013 | 0.89 | 4.3E-5 | 0.03 | 0.99 | 1.5E-4 to 3E-4 |
| 17-α-ethynylestradiol | N/S | N/S | N/S | N/S | N/S | N/S | 0.65 | 0.99 | 3.2E-3 to 6.4E-3 |

N/S : not significant

### 4.3 Influence of pH on Nalidixic acid Sorption

Sorption studies of nalidixic acid onto alumina were also conducted at a varying pH of 4 to 11 to evaluate pH impacts on nalidixic acid sorption.
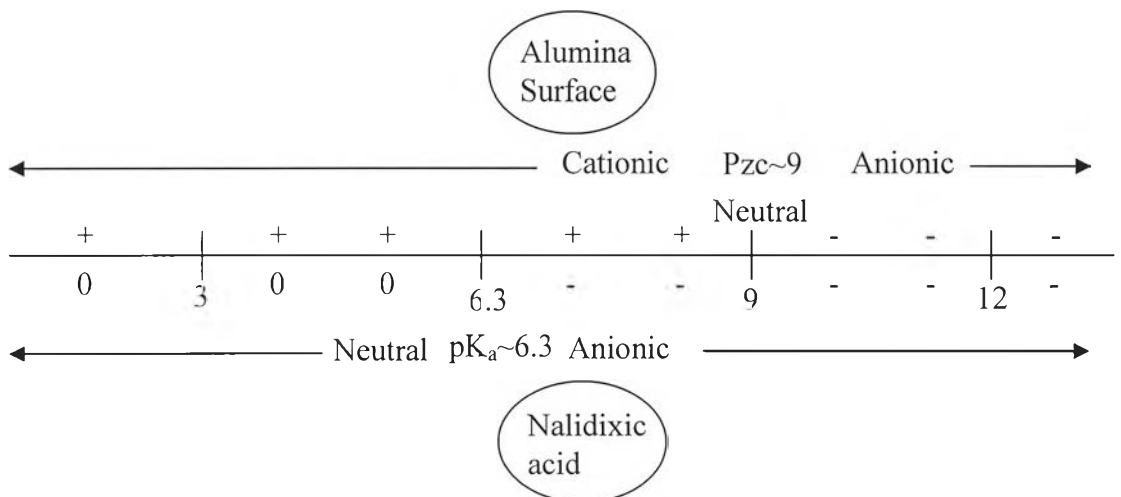


**FIGURE 4.7 Electrical charged of nalidixic acid and alumina surface as a function of pH.**

At pH about 6, from Figure 4.7, the highest sorption of Nalidixic acid onto alumina. Since the $pK_a$ of nalidixic acid is about pH 6.3, the carboxylic group was ionized to form negatively charged of nalidixic acid molecules. At this pH, the amount of nalidixic acid in negatively charged form and the amount of surface charge is the highest relative to other pH values; the sorption of nalidixic acid onto alumina is thus its highest. Below pH 6.3, there are only a few nalidixic acid molecules ionized, and the sorption decreases. Above pH 6.3, the amount of positively charged surface decreases as we approach the pzc of the alumina, and the sorption decreases. At pH about 9, the sorption of nalidixic acid on alumina decreases as the alumina becomes neutral. This result thus implies that the sorption of nalidixic acid onto alumina was a function of pH and charge of sorbent surface.
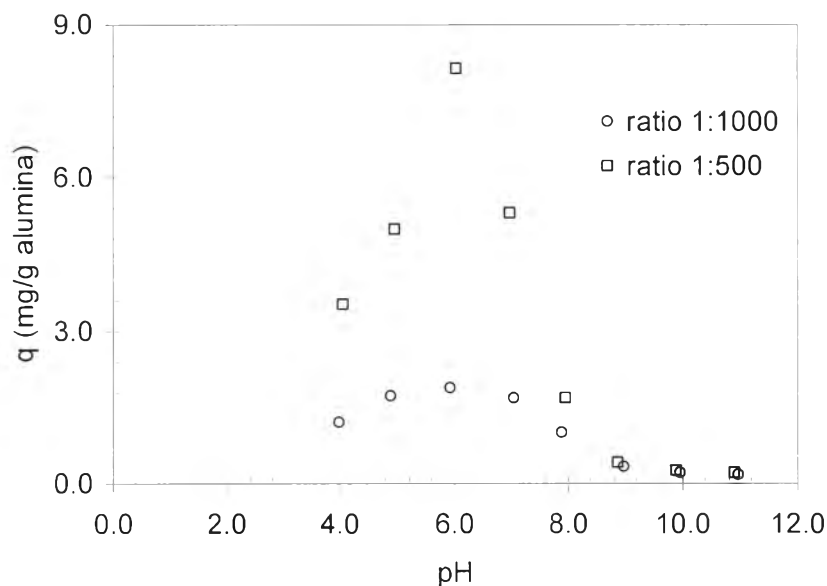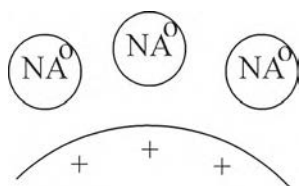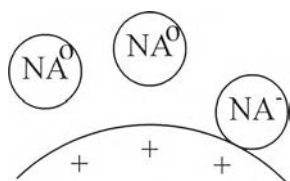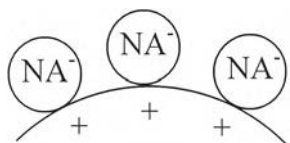


**FIGURE 4.8 The sorption of nalidixic acid onto alumina with varying pH range between 4 and 11.**

pH << **6.3**; nalidixic acid is in neutral form, positively charges of alumina are presented, no adsorption.

pH = **6.3**; nalidixic acid is in both neutral and ionized form (negatively charge), positively charges of alumina are presented, significant adsorption is occurred.

**6.3 < pH < 9**; more nalidixic acid are ionized, high adsorption is occurred but decreased when pH increased, positively charge of alumina surface decrease and change to neutral when pH close to Pzc.
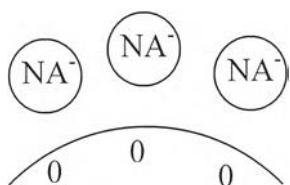
**pH = 9** ; alumina surface is changed to neutral while nalidixic acid present in their ionized form, adsorption was ceased.
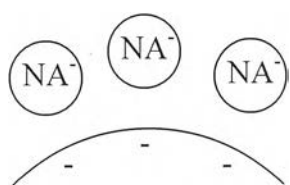
**pH >> 9** ; both nalidixic acid and alumina surface are in their negatively charge form, no adsorption.

**FIGURE 4.9 Scheme of nalidixic acid adsorption onto alumina surface.**

## 4.4 Octanol-Water partition of Nalidixic acid

We have now evaluated the potential for electrostatic interactions between the nalidixic acid and charged media species (e.g. ion exchange) and will now move onto considering the nalidixic acid interactions with neutral organic phases present in the media. The octanol-water partition coefficients ($K_{ow}$) were measured for the nalidixic acid to assess their potential for sorption by hydrophobic forces (i.e. expulsion of neutral organic molecules from the polar water phase). $K_{ow}$ values were evaluated as a function of pH to determine Nalidixic acid hydrophobicity above and below its $pK_a$ value.

Figure 4.10(a) plots the $K_{ow}$ versus pH values and Figure 4.10(b) plots the log $K_{ow}$ versus pH values for the nalidixic acid. As the pH level decreases, the increasing $H^+$ concentration neutralizes the anionic nalidixic functional groups, thereby rendering the nalidixic acid less water soluble and more susceptible to hydrophobic partitioning (e.g. results in higher $K_{ow}$ values). As the pH level increases, the decreasing $H^+$ concentration causes the nalidixic acid carboxyl group to dissociate in water, thus rendering the nalidixic acid less hydrophobic and more soluble in the water phase (e.g. resulting in a lower $K_{ow}$ values).

From Figure 4.8 the $pK_a$ of nalidixic acid appears to be around 6.5, as at the $pK_a$ the nalidixic acid will be half neutral and half ionic, and the $K_{ow}$ will thus be intermediate in value. This value is slightly higher than but quite similar to the value of 6.3 reported in the literature (Hyoung-Ryun Park et al., 2000).
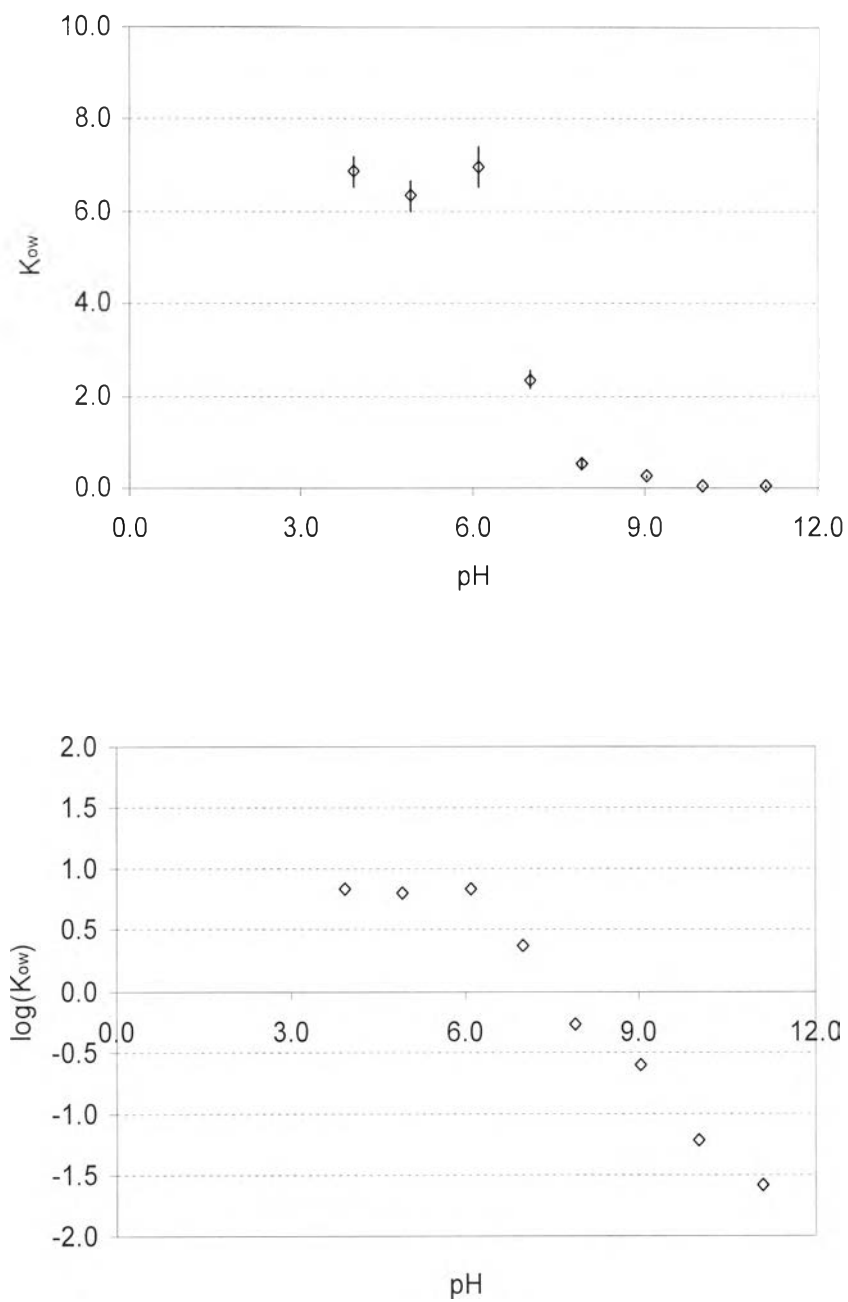
**FIGURE 4.10 The octanol water partitioning of nalidixic acid with varying pH, (a) plots $K_{ow}$ versus pH, (b) plots log ($K_{ow}$) versus pH.**