*Chapter Three*

# DISCOVERY OF NEW ETCHANTS

## 3.1 Introduction

CR-39 is the most popular member of the SSNTDs family and has been widely used in many fields of Science and Technology (Cartwright et al., 1978; Durrani and Bull, 1987; Fleischer et al., 1975; Matiullah et al., 1988a,b, 1990, 1991, 2001; Khan et al., 1991; Rashid et al., 1993; Benton and Richmond, 1986; Brandt, 1993; Qureshi et al., 1991; Bashir et al., 1993; Dwivedi, 1997). Besides working on improving the quality of CR-39 detector, continuing efforts have been made to discover new etchants for which CR-39 detector has relatively higher efficiency and shorter etching time. This is desirable because the chemical etching techniques that are presently used for CR-39 detectors are time consuming.

Aqueous solutions of the hydroxides of alkali metals (group-IA) viz. NaOH, LiOH and KOH have been extensively studied as etchants for CR-39 detector (Durrani and Bull, 1987). Amongst the chemical etchants, reported for CR-39 detector, 6 M NaOH at 70 °C is considered to be the best etchant. Tahiri et al. (2003) went one step forward and introduced $Ba(OH)_2.8H_2O$ as a new etchant. They reported that molten $Ba(OH)_2.8H_2O$ at 84 °C yields ~ 72% efficiency (for normal incidence of α–particle from $^{252}Cf$), which is greater than that of 6 M NaOH at 70 °C (i.e. 64%). In addition to the above, they have claimed that etching time is drastically reduced if molten $Ba(OH)_2.8H_2O$ is used as an etchant. However due to some practical problems associated with molten $Ba(OH)_2.8H_2O$, search for new etchants is still desirable.

In this regard, more systematic studies were carried out wherein a number of new etchants were studied with an aim to find etchants that would yield desirable results. As a result, four new etchants were discovered which are dealt with in this chapter. These included NaOH dissolved in Ethanol, NaOH dissolved in 1-Propanol, NaOH dissolved in methanol and NaOH dissolved in methanol + water (from now onward called SMW solution).

## 3.2 Experimental Procedures

Large sheets of CR-39, having thicknesses of 500 μm, were purchased from Page Mouldings, Ltd., UK. These sheets were cut into small detectors of sizes 3 cm x 2.5 cm and were irradiated with alpha particles and fission fragments from a thin $^{252}Cf$ source in 2 pi geometry. After irradiation the samples were etched in the solutions of the hydroxides of alkali metals (group-IA) viz. LiOH, NaOH and KOH. The etching conditions used were: 3–7 M LiOH at 60–88 °C, 4–12 M NaOH at 50–80 °C and 4–12 M KOH at 60–90 °C. After each two hours etching step, all the etched detectors were washed under running tap water and then with distilled water. After drying CR-39 detectors, diameters of the fission fragment and alpha particle tracks were measured under an optical microscope. $V_B$ and $V_T$ were determined using track diameter method (Henke et al., 1986; Matiullah et al., 2001).

After studying the group-IA metal-hydroxides, some more etchants were then tried. These included $Mg(OH)_2$, $Ca(OH)_2$, $Ba(OH)_2.8H_2O$ dissolved in distilled water and molten $Ba(OH)_2.8H_2O$. During this study, it was observed that $Mg(OH)_2$ and $Ca(OH)_2$ have considerably low solubility in aqueous solutions and do not provide sufficient $OH^-$ ions necessary to perform etching process. $Mg(OH)_2$ has solubility of 0.0009g/100g of $H_2O$ at 18°C and 0.004g/100g of $H_2O$ at 100°C. Similarly, $Ca(OH)_2$ has 0.077g /100g of $H_2O$ at 0°C and 0.185g /100g of $H_2O$ at 100°C (see Table 3.2). Therefore $Mg(OH)_2$ and $Ca(OH)_2$ were unable to work as etchants even for a longer etching time. Hence, $Mg(OH)_2$ and $Ca(OH)_2$ were rejected as etchants for CR-39 detector.

$Ba(OH)_2.8H_2O$ provides satisfactory solubility on heating the solution. Different concentrations of $Ba(OH)_2.8H_2O$ that ranged from 0.5 M to 2.75 M were prepared and studied at different temperatures. Precautionary measures were taken during the preparation of $Ba(OH)_2.8H_2O$ solution because it rapidly absorbs carbon dioxide from air and become insoluble in water. To avoid this problem, experimental conditions were kept free from $CO_2$. To do so, solutions were prepared in a close container and heated using hot plate. As $Ba(OH)_2.8H_2O$ has maximum solubility at 78 °C, therefore hot plate was used with control temperature and magnetic stirring. CR-39 detectors exposed to fission fragments and alpha particles from a thin $^{252}Cf$ source were etched in $Ba(OH)_2.8H_2O$ solutions of different concentrations at 78 °C up to 30 minutes. After etching, the detectors were immediately washed with hot distilled water to avoid solidification of the etchant on the detector surface. Track diameter measurements were carried in a similar manner as described above.

Finally, molten $Ba(OH)_2.8H_2O$ was tried. Pure 400 g of $Ba(OH)_2.8H_2O$ was placed in a 250 ml beaker which was clipped with a stand and kept on oil bath in order to get molten state of Barium hydroxide at 78 °C. After $Ba(OH)_2.8H_2O$ was melted, it was studied as an etchant at different temperatures. The irradiated CR-39 detectors were etched in molten Barium hydroxide in steps of 2 minutes each and then quickly washed with hot distilled water. After drying, track diameters were measured under an optical microscope.

After studying the already reported group-IA metal hydroxides and $Mg(OH)_2$, $Ca(OH)_2$, $Ba(OH)_2.8H_2O$ dissolved in distilled water and molten $Ba(OH)_2.8H_2O$, once again, CR-39 detectors were irradiated in 2 pi geometry with alpha particles and fission fragments from a thin source of $^{252}Cf$. These detectors were then etched in our newly introduced etchants, namely NaOH dissolved in Ethanol, NaOH dissolved in 1-Propanol and NaOH dissolved in methanol and SMW solution at different concentrations and etching temperatures. After each 4 minutes etching step, detectors were washed under running tap water and then with distilled water. Diameters of the fission fragment and alpha particle tracks were measured under an optical microscope. Optimum values of etching temperature and concentration were determined. $V_B$, $V_T$ and etching efficiency ($\eta$) were calculated using track diameter method. The values obtained for new etchants were found to be much better than those obtained for CR-39 detectors etched in conventional 6 M aqueous solution of NaOH at 70 °C.

## 3.3 Results and discussion

In the search for relatively better etchants for CR-39, a number of new etchants have been studied. To decide whether or not any newly introduced etchant would be better, one needs to study its chemical etching properties in details.

The formation of etchable tracks in a detector depends on certain critical etching parameters like bulk etching rate ($V_B$) and track etching rate ($V_T$) which must be experimentally determined. From the knowledge of $V_B$ and $V_T$, etching efficiency ($\eta$) for etchant used can be calculated. To determine $V_B$, $V_T$ and $\eta$, the following equations were used (Durrani and Bull, 1987):

$$V_B = \frac{D_{ff}}{2t} \quad (3.1)$$

$$V_T = \frac{V_B\left(1+X^2\right)}{\left(1-X^2\right)} \quad (3.2)$$

$$X = \frac{D_\alpha}{D_{ff}} \quad (3.3)$$

$$\eta = 1 - \frac{V_B}{V_T} \quad (3.4)$$

Where $D_{ff}$ and $D_\alpha$ are the average fission fragment and alpha track diameters; and $t$ is the etching time.

### 3.3.1 NaOH, KOH and LiOH Etchants (Group-IA)

NaOH is the most popular etchant and has been extensively studied. Etching time and etching efficiency ($\eta$) are the most important parameters in deciding the choice of an etchant for any detector (Durrani and Bull, 1987). Hence, to judge the ability of a newly introduced etchant, one must compare these parameters of the new etchant with those of the conventionally used 6 M NaOH at 70 °C. Although NaOH has been extensively studied as an etchant for CR-39 detector, yet in the present work the etching conditions have independently been optimized in order to compare it with the newly introduced etchants for the same batch of CR-39 detectors under similar experimental conditions used in this study.

Table 3.1 shows observed average track diameters, $V_B$, $V_T$ and $\eta$ values for CR-39 detectors that were etched in the listed concentrations of NaOH solution at 70 °C. As expected, both $D_{ff}$ and $D_\alpha$ are seen to increase with etchant concentration. About 6 M concentration yields the highest value of the efficiency (64%) which is in agreement within experimental error with the published data (Durrani and Bull, 1987).

To study the temperature effect on $\eta$, Fig. 3.1 shows variation of $\eta$ as a function of temperature for 6 M NaOH. It may be seen in Fig. 3.1 that 70 °C seems to be the optimum temperature at which 6 M NaOH has maximum value of the efficiency. These results are in good agreement with the published work (Durrani and Bull, 1987; Randhawa, 1997).

**Table 3.1:** $D_\alpha$, $D_{ff}$, $V_B$, $V_T$ and $\eta$ values of CR-39 detectors for the listed concentration of NaOH solution at 70 °C

| Etchant Conc. | $D_\alpha$ (μm) | $D_{ff}$ (μm) | $V_B$ (μm.h$^{-1}$) | $V_T$ (μm.h$^{-1}$) | $\eta$ (%) |
|---|---|---|---|---|---|
| 4 M | 8.12 | 13.82 | 0.86 | 1.77 | 51.33 |
| 6 M | 9.67 | 14.09 | 0.88 | 2.45 | 64.04 |
| 8 M | 10.66 | 16.32 | 1.02 | 2.54 | 59.81 |
| 10 M | 11.34 | 17.73 | 1.11 | 2.64 | 58.06 |
| 12 M | 12.32 | 19.85 | 1.24 | 2.79 | 55.62 |

After NaOH, the 2nd most popular etchant for CR-39 detector is KOH. Like NaOH, it was found (see, Figs. 3.2 a & b) that 6 M KOH at 70 °C yields maximum value of the etching efficiency. These results are also in good agreement with the already published work (Durrani and Bull, 1987). The next rarely used etchant of the Group-IA is LiOH. As may be seen in Figs. 3.3 a & b, this etchant behaves in a similar manner like NaOH and KOH. It has lower etching efficiency and longer etching time than that of both NaOH and KOH. Therefore, it is not used as a routine etchant for CR-39 detector.

### 3.3.2 $Mg(OH)_2$, $Ca(OH)_2$, $Ba(OH)_2.8H_2O$ Solutions and Molten $Ba(OH)_2.8H_2O$

$Mg(OH)_2$ and $Ca(OH)_2$ are weak bases. They have lower dissociation constants, $K_b = 2.51 \times 10^{-3}$ and $3.98 \times 10^{-2}$, respectively. Due to their low dissociation constants they have poor solubility in water even at very high temperature (see, Table 3.2). Because they do not have sufficient solubility, therefore they are not used as etchants.

$Ba(OH)_2.8H_2O$ is also a weak base but has dissociation constant, $K_b = 0.253$ which is higher than that of $Mg(OH)_2$ and $Ca(OH)_2$. It has reasonable solubility in water at 78 °C (see, Table 3.2). This property of $Ba(OH)_2.8H_2O$ inspired Tahiri et al. to study it as an etchant for CR-39 detector. The maximum solubility of $Ba(OH)_2.8H_2O$ was found to be about 2.75 M at 78 °C, which is near to the published value (see, Table 3.2). The main disadvantage of the $Ba(OH)_2.8H_2O$ is its lower limit of temperature (i.e. 78 °C) below which solubility decreases. Therefore, one has always to use $Ba(OH)_2.8H_2O$ at a temperature ≥ 78 °C. Like the other etchants discussed above, $V_B$ and $V_T$ are strongly affected by the concentration of $Ba(OH)_2.8H_2O$.

Fig.3.4 shows the etching efficiency as a function of the concentration of Barium hydroxide solution. As may be seen in Fig. 3.4, the etching efficiency is approximately inversely proportional to the concentration of the Barium hydroxide. An etching solution of 0.5 M yields the highest efficiency (~ 66%) at 78 °C which is slightly greater than that of the 6 M NaOH (i.e. ~ 64 %) at 70 °C. The etching time for Barium hydroxide etching solution is reduced by a factor of ~ 2.

Having studied $Ba(OH)_2.8H_2O$ solution as an etchant, we next study it in molten state. Its lower melting point of 78 °C makes it possible to use it as an etchant in molten form. Fig. 3.5 shows $\eta$ as a function of etching temperature. It is clear from Fig. 3.5 that $\eta$ has maximum value of 72% at 84 °C.

**Table 3.2:** Melting points and solubility values of metallic hydroxides of group-IA and group-IIA (David, 1999)

| Etchant | Mol. Wt | Density ($g.ml^{-1}$) | Melting Point (°C) | Solubility (g/100g of $H_2O$) |
|---|---|---|---|---|
| LiOH | 23.95 | 1.45 | 471.2 | $12.8^{20}$ / $17.5^{100\,a}$ |
| NaOH | 40.00 | 2.13 | 318.4 | $42^{0}$ / $347^{100}$ |
| KOH | 56.11 | 2.04 | 360.4 | $107^{15}$ / $178^{100}$ |
| $Mg(OH)_2$ | 58.32 | 2.37 | 350 | $0.0009^{18}$ / $0.004^{100}$ |
| $Ca(OH)_2$ | 74.09 | 2.20 | 580 | $0.077^{0}$ / $0.185^{100}$ |
| $Ba(OH)_2.8H_2O$ | 315.46 | 2.18 | 78 | $5.6^{15}$ / $94.7^{78}$ |

[a] Temperature at which solubility has been achieved.

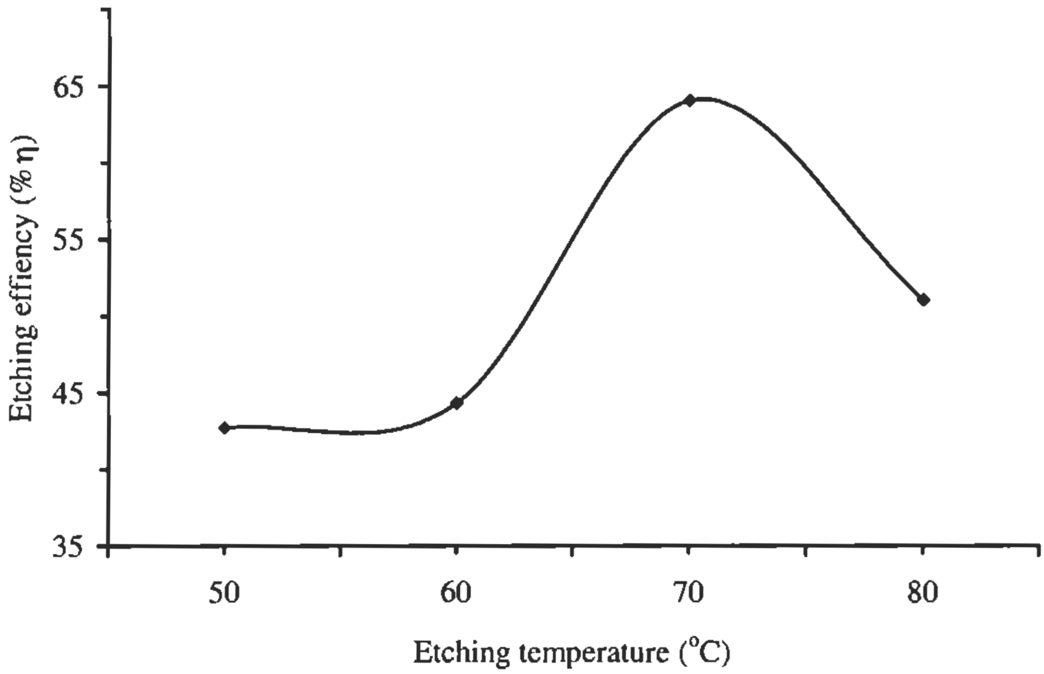


**Figure 3.1:** *Etching efficiency of CR-39 detector as a function of temperature of 6 M NaOH solution.*

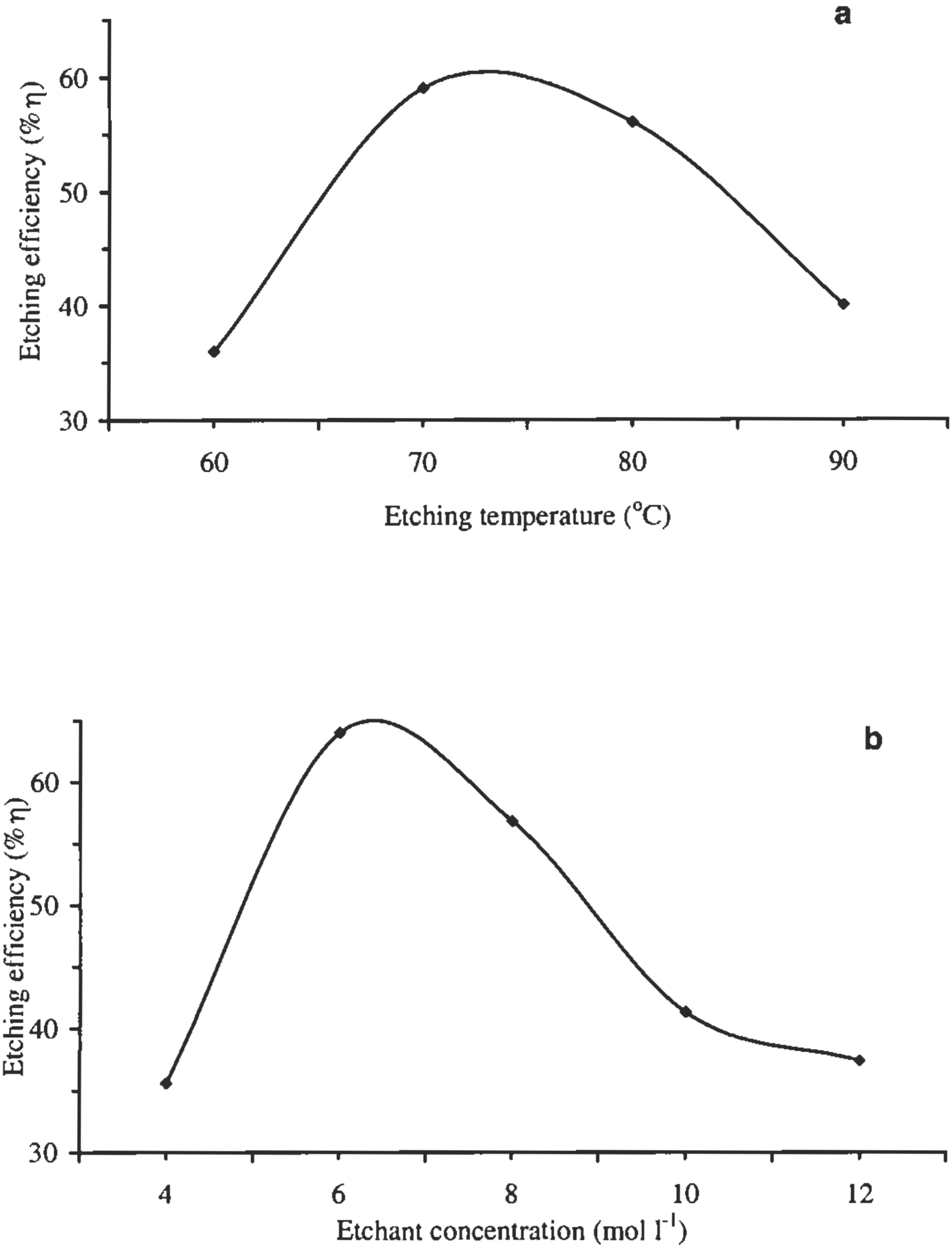


**Figure 3.2:** *(a) Etching efficiency as a function of temperature for 6 M KOH (b) Etching efficiency as a function of concentration for KOH at 70 °C.*

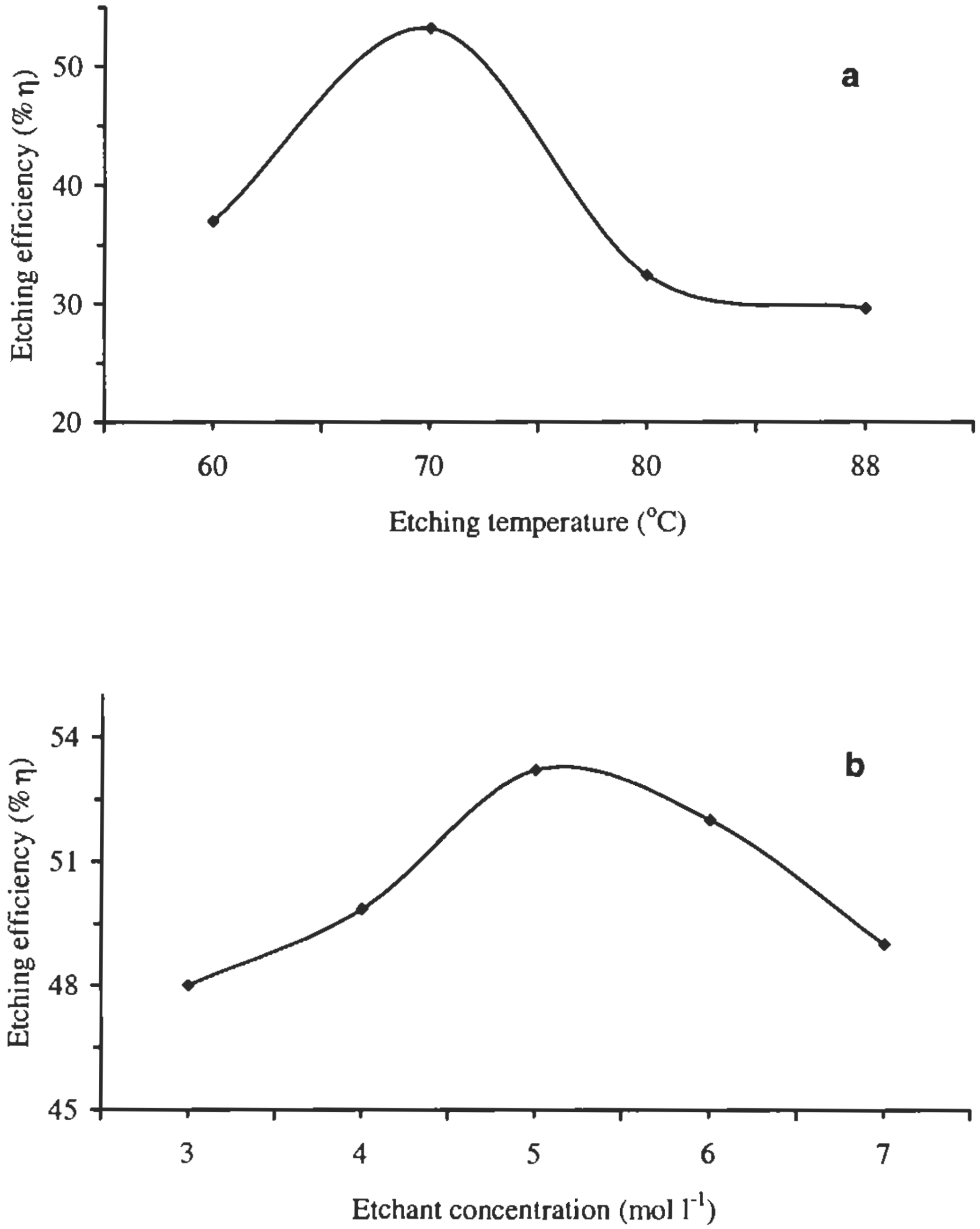


**Figure 3.3:** *(a) Etching efficiency as a function of temperature for 5 M LiOH (b) Etching efficiency as a function of concentration for LiOH at 70 °C.*

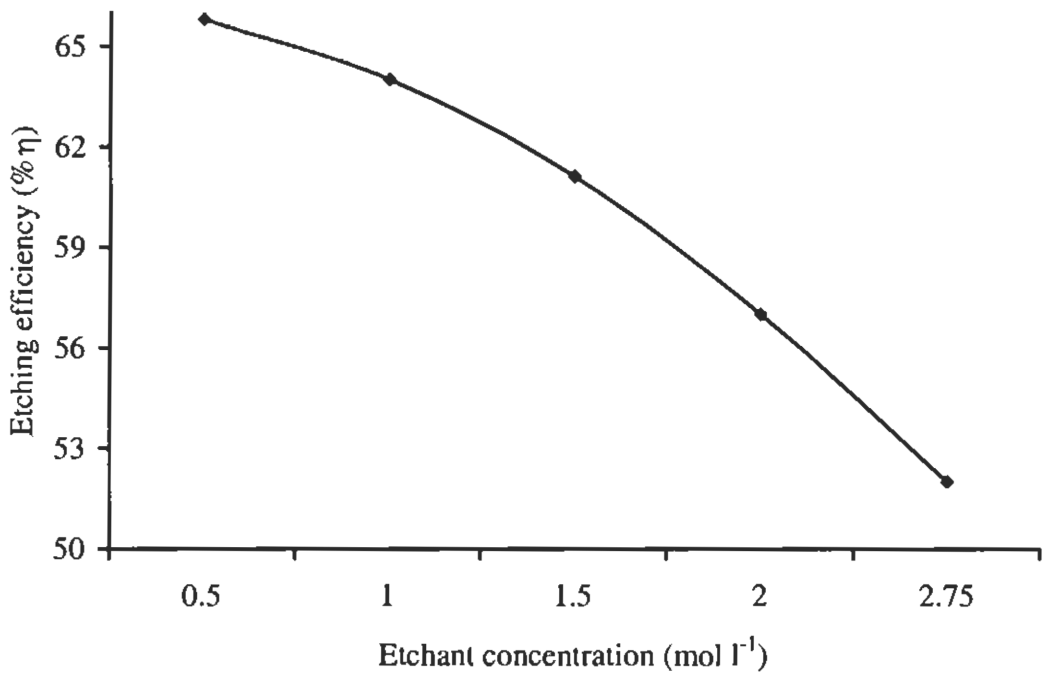


**Figure 3.4:** *Etching efficiency of CR-39 as a function of concentration of the* $Ba(OH)_2.8H_2O$ *solution at 78 °C.*

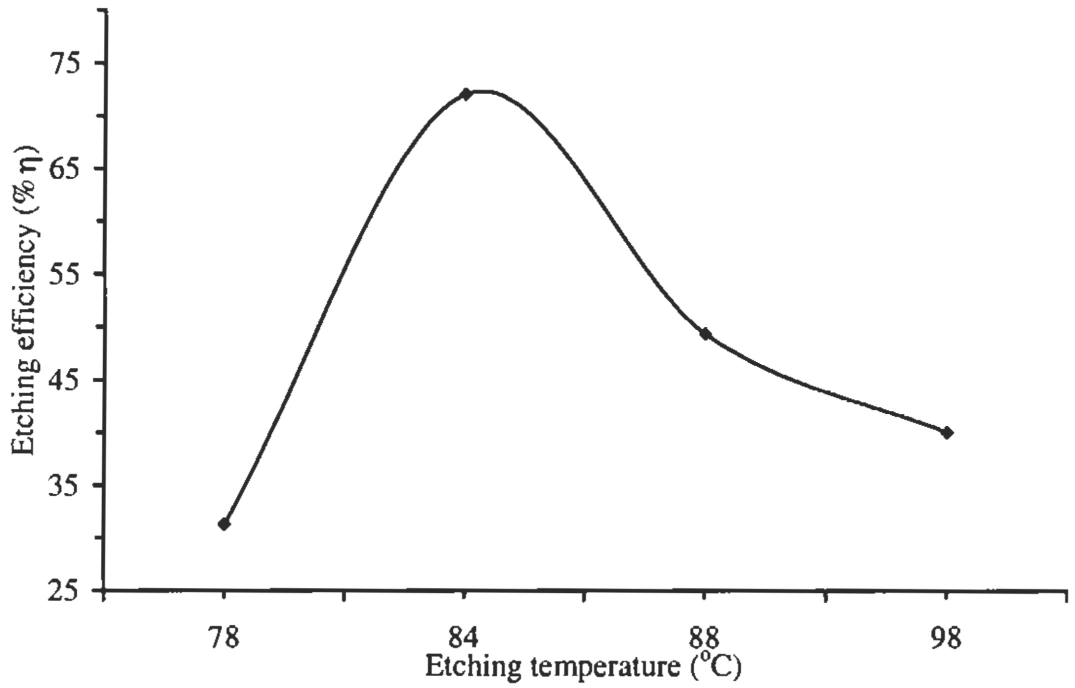


**Figure 3.5:** *Etching efficiency of CR-39 as a function of temperature of the molten $Ba(OH)_2.8H_2O$ solution.*

### 3.3.3 NaOH/1-Propanol Etchant

After verifying already published etching parameters data for Group-IA and Group-IIA, data for newly unveiled etchant NaOH/1-Propanol is presented here. Figs. 3.6 & 3.7 show average track diameter of fission fragments and alpha particles as a function of etching time for 1 M NaOH/1-Propanol etching solution at the listed temperatures respectively. As can be seen in the above figures, average track diameter sharply increases with an increase in the etching temperature. From track diameter data plotted in Figs. 3.6 & 3.7, $\eta$ values were calculated and are shown in Fig. 3.8. It can be seen in Fig. 3.8 that 1 M NaOH/1-Propanol yields maximum value of $\eta$ (~70%) at 49 °C.

Having determined optimum temperature, we then studied the effect of concentration on track diameter and consequently on $V_B$, $V_T$ and $\eta$ of CR-39. The data obtained for track diameters is plotted in Figs. 3.9 and 3.10 which show $D_\alpha$ and $D_{ff}$ as a function of etching time for the listed concentrations of NaOH/1-Propanol solution respectively. It may please be noted here that NaOH is relatively less soluble in 1-Propanol. Therefore, it was very difficult to achieve higher concentrations of NaOH in 1-Propanol. Track diameter is seen to increase with etchant concentration. At 1.34 M etchant concentration and beyond eight minutes of etching time, the track diameter increases drastically. This increase in the track diameter will be reflected in terms of an increase in bulk and track etching rates of CR-39. It may however be borne in mind that an increase in $V_B$ and $V_T$ does not necessarily mean an increase in $\eta$. Table 3.3 shows $V_B$, $V_T$, and $\eta$ values of CR-39 detector for the listed concentrations of NaOH/1-Propanol Solution at 49 °C. It may be seen in Table 3.3 that $\eta$ has maximum value at 1 M concentration of NaOH/1-Propanol Solution at 49 °C.

Fig. 3.11 shows the etching efficiency as a function of concentration for NaOH/1-Propanol solution at 49 °C. It can be seen from Fig. 3.11 that NaOH/1-Propanol solution at 49 °C yields the highest efficiency (~70%) at 1 M concentration which is higher than that of 6 M NaOH (64%) at 70 °C. Hence 1 M NaOH/1-Propanol at 49 °C are the optimum parameters/etching conditions.

**Table 3.3:** $D_\alpha$, $D_{ff}$, $V_B$, $V_T$ and $\eta$ values of CR-39 detectors for the listed concentrations of NaOH/1-Propanol solution at 49 °C

| Conc. (mol.l$^{-1}$) | $D_\alpha$ (μm) | $D_{ff}$ (μm) | $V_B$ (μm.m$^{-1}$) | $V_T$ (μm.m$^{-1}$) | Efficiency (% $\eta$) |
|---|---|---|---|---|---|
| 0.75 | 2.5 | 4.5 | 0.14 | 0.27 | 47.17 |
| 0.86 | 2.89 | 5.12 | 0.16 | 0.31 | 47.97 |
| 1.00 | 4.12 | 5.63 | 0.18 | 0.58 | 69.76 |
| 1.20 | 5.39 | 8.98 | 0.28 | 0.59 | 52.94 |
| 1.34 | 5.84 | 11.67 | 0.36 | 0.6 | 40.00 |

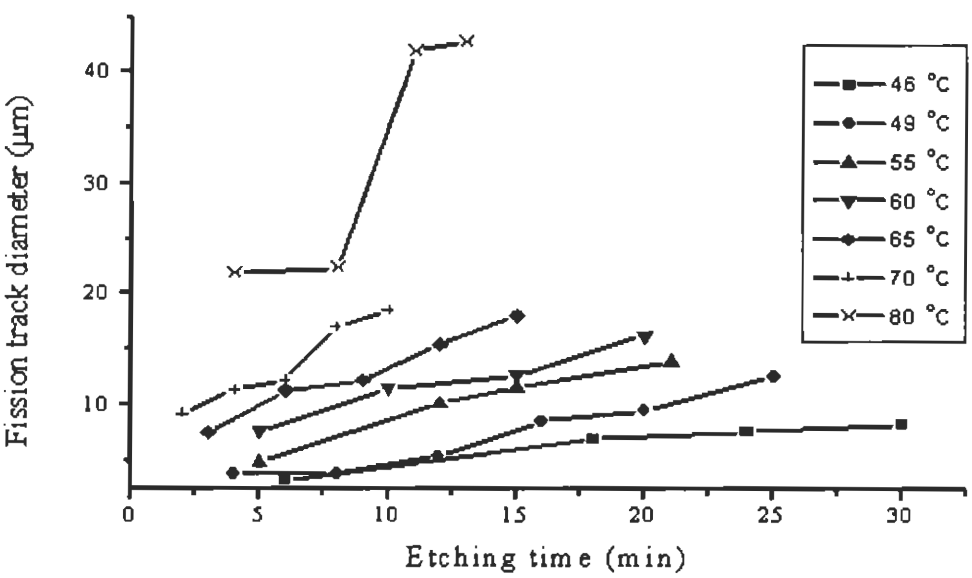


**Figure 3.6:** *Average track diameter of fission fragments as a function of etching time. Here CR-39 detectors were etched in 1M NaOH/1-Propanol at the listed temperatures.*

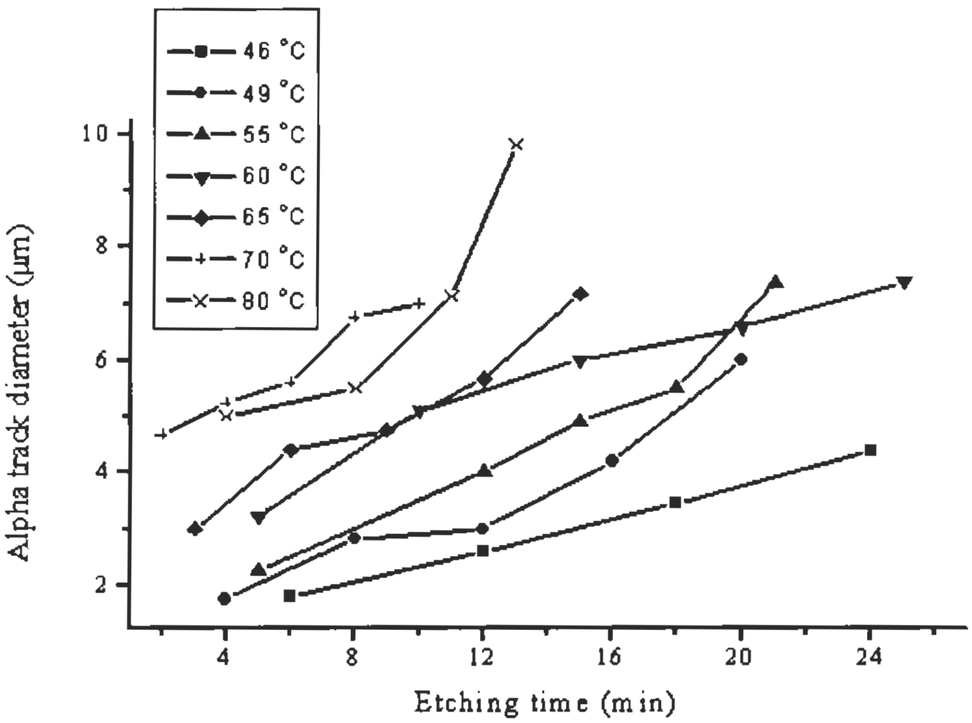


**Figure 3.7:** *Average track diameter of alpha particles as a function of etching time. Here CR-39 detectors were etched in 1M NaOH/1-Propanol at the listed temperatures.*

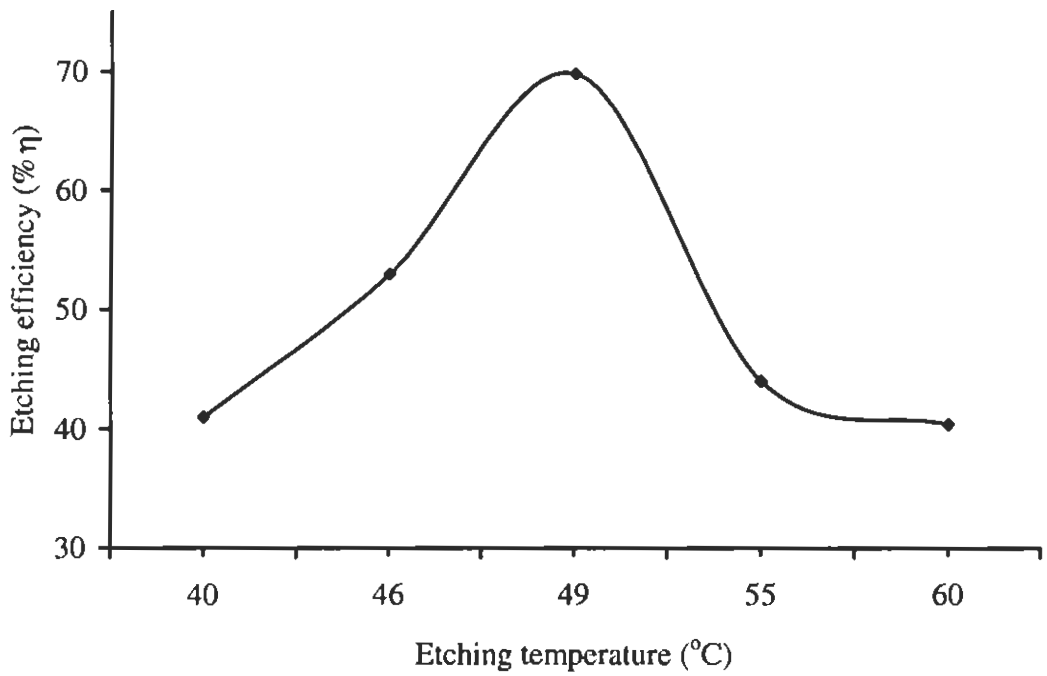


**Figure 3.8:** *Etching efficiency of CR-39 detector as a function of temperature for 1M NaOH/1-Propanol etchant.*

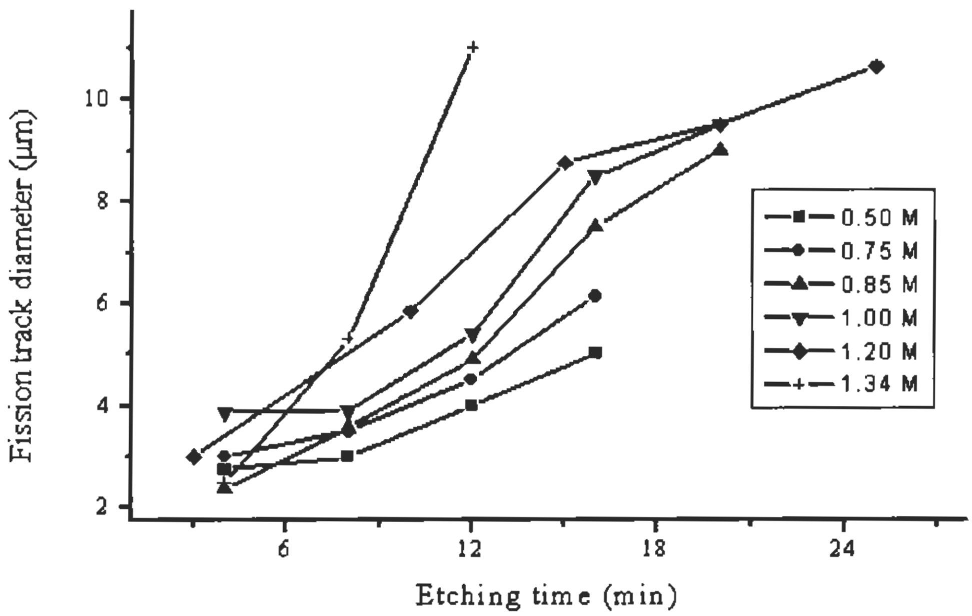


**Figure 3.9:** *Average track diameter of fission fragments as a function of etching time. Here CR-39 detectors were etched at 49 °C in NaOH/1-Propanol at the listed etchant concentrations.*

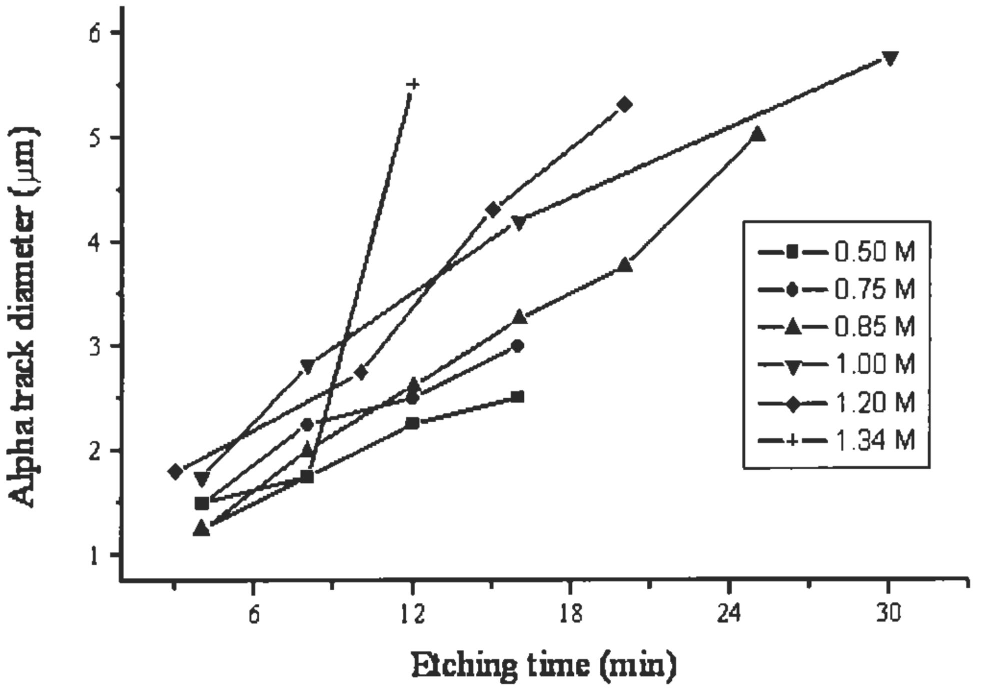


**Figure 3.10:** *Average track diameter of alpha particles as a function of etching time. Here CR-39 detectors were etched at 49 °C in NaOH/1-Propanol at the listed etchant concentrations.*

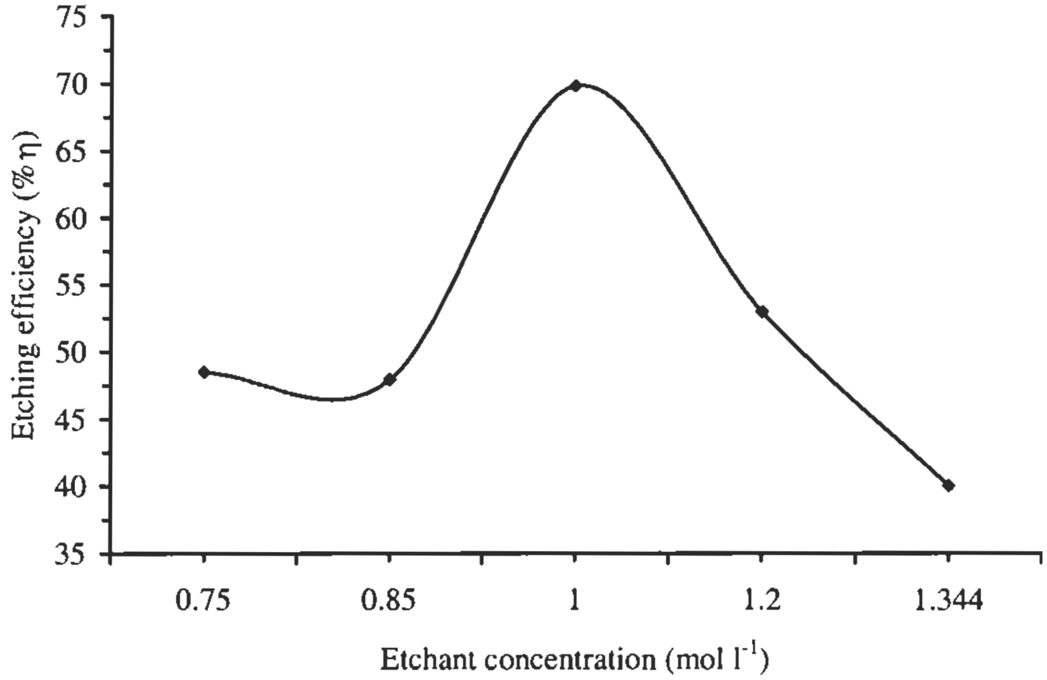


**Figure 3.11:** *Etching efficiency of CR-39 detector as a function of concentration of NaOH/1-Propanol etchant at 49 °C.*

### 3.3.4 NaOH/Ethanol Etchant

Experimental data concerning the etching properties of 2nd newly introduced etchant i.e. NaOH/Ethanol is presented here. Like NaOH/1-Propanol etchant, CR-39 detectors were etched in different concentrations of NaOH/Ethanol solution ranging from 0.5 to 2.52 M at different temperatures. The effect of temperature on efficiency of CR-39 is shown in Fig. 3.12a for 1.5 M NaOH/Ethanol. It is clear from Fig. 3.12a that $\eta$ has maximum value of ~ 77% at 55 °C.

Having determined optimum temperature, the effect of concentration on $\eta$ of CR-39 was then studied. Table 3.4 shows $V_B$, $V_T$, and $\eta$ of CR-39 detectors for the listed concentrations of NaOH/Ethanol Solution at 55 °C. It may be seen in Table 3.4 that $\eta$ has maximum value for 1.5 M concentration of NaOH/Ethanol Solution at 55 °C.

Fig. 3.12b shows etching efficiency as a function of concentration for NaOH/Ethanol solution at 55 °C. The 1.5 M solution yields highest efficiency (~ 77%) at 55 °C which is higher than both 6 M NaOH (i.e. 64%) at 70 °C and 1 M NaOH/1-Propanol (i.e. ~ 70%) at 49 °C. Although NaOH/Ethanol produces a larger track diameter than that of NaOH/1-Propanol solution, the efficiency curves for both of the etchants have similar trend. To avoid evaporation of Ethanol due to its lower boiling point, etching was carried out at relatively lower temperatures.

**Table 3.4:** $D_\alpha$, $D_{ff}$, $V_B$, $V_T$ and $\eta$ values of CR-39 detectors for the listed concentrations of NaOH/Ethanol solution at 55 °C

| Conc. (mol.l$^{-1}$) | $D_\alpha$ (μm) | $D_{ff}$ (μm) | $V_B$ (μm.h$^{-1}$) | $V_T$ (μm.h$^{-1}$) | % $\eta$ |
|---|---|---|---|---|---|
| 0.50 | 5.7 | 9.5 | 15.83 | 33.65 | 52.94 |
| 1.00 | 12 | 18.95 | 31.58 | 73.87 | 57.25 |
| 1.50 | 17.14 | 21.65 | 36.08 | 157.27 | 77.05 |
| 2.00 | 26.72 | 41.53 | 69.22 | 166.99 | 58.55 |
| 2.15 | 34.58 | 54.03 | 90.05 | 215.01 | 58.12 |
| 2.52 | 46.23 | 74.73 | 124.55 | 278.98 | 55.35 |

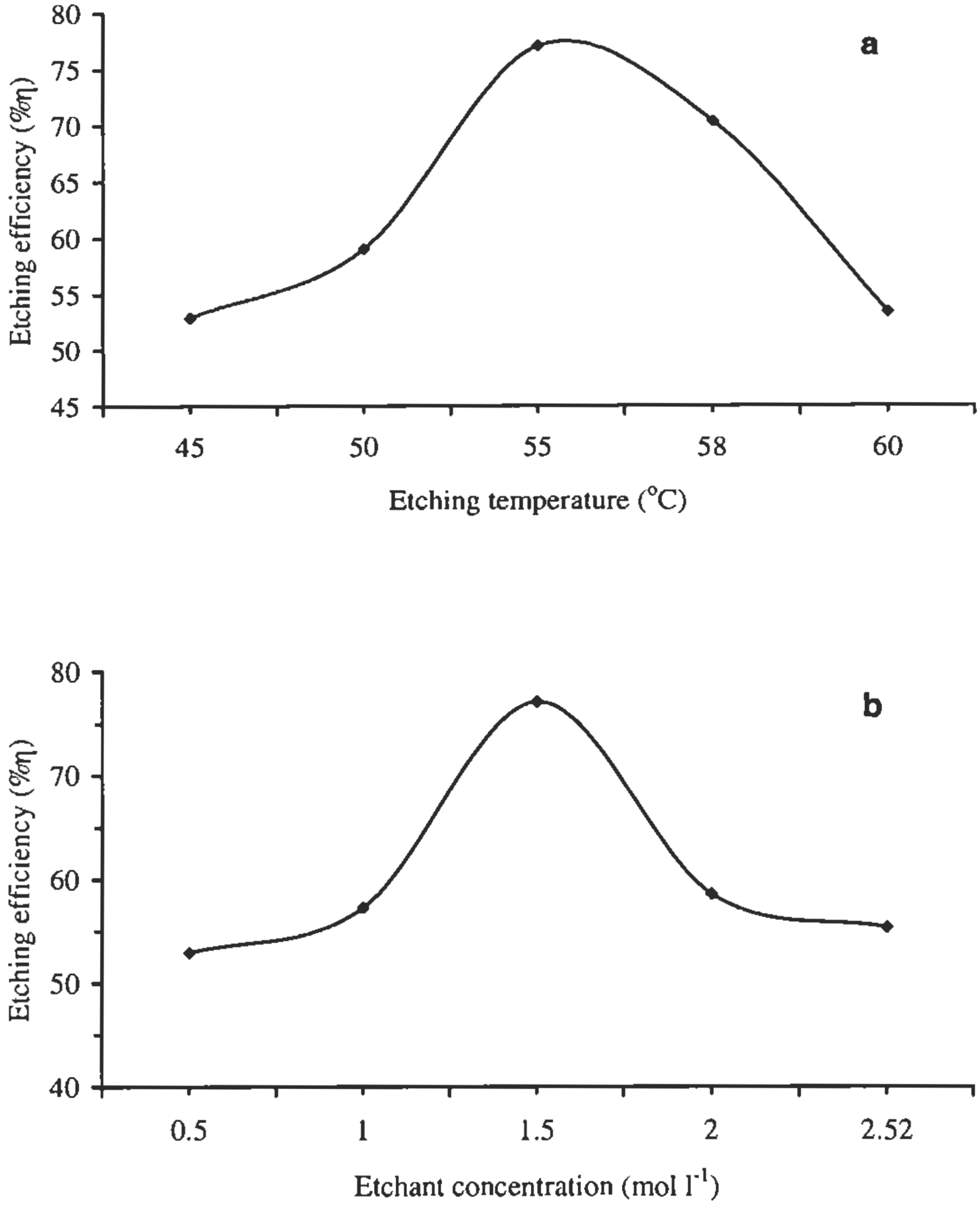


**Figure 3.12:** *(a) Etching efficiency of CR-39 as a function of temperature for 1.5 M NaOH/Ethanol; (b) Etching efficiency as a function of concentration for NaOH/Ethanol at 55 °C.*

### 3.3.5 NaOH/Methanol Etchant

Experimental data concerning determination of the optimum values of etchant concentration and temperature for NaOH dissolved in methanol is presented here. First, the effect of temperature was studied. To do so, CR-39 detectors, irradiated with fission fragments and alpha particles, were etched in 1.5 M NaOH/Methanol solution at different temperatures. There was not any special reason behind choosing the value 1.5 M of NaOH/Methanol solution. In fact any other value would have also yielded similar results. Figs. 3.13 & 3.14 show average track diameter of fission fragments and alpha particles as function of etching time for 1.5 M NaOH/ Methanol solution at the listed temperatures.

As was expected, average track diameter is seen to increase with an increase in the temperature of the etching solution. Initially, at lower values of the temperature (i.e. from 40 °C to 45 °C), increase in the track diameter is negligibly small. Beyond 12 minutes etching time, increase in the track diameter becomes significant. It is clear from the above figures that at any etching time, higher values of the etching temperatures yield greater values of tracks diameter and hence higher $V_B$ and $V_T$ values. At 55 °C, the track diameter increases steeply with an increase in the etching time. From these figures it may be clearly seen that only several minutes of etching time are required to have reasonable size of track diameters. This is a great advantage over 6 M NaOH aqueous solution where several hours of etching would have been required to get similar track diameters.

From the measured track diameter data, $V_B$, $V_T$ and $\eta$ were calculated. The results obtained are shown in Table 3.5. For clarity, the data shown in this table is plotted in Fig. 3.15a. It may be seen in Fig. 3.15a that 1.5 M NaOH/Methanol yields maximum value of $\eta$ (~ 78 %) at 55 °C.

Having determined optimum etching temperature, then the effect of concentration on $\eta$ of CR-39 detector was studied. Fig. 3.15b shows etching efficiency as a function of the etchant concentration. It is obvious from this figure that 1.5 M NaOH/Methanol solution at 55 °C yields maximum value of the efficiency.

**Table 3.5:** $V_B$, $V_T$ and etching efficiency of CR-39 detector for 1.5 M NaOH/Methanol at the listed temperatures

| Etchant Temperature (°C) | $V_B$ (μm.h$^{-1}$) | $V_T$ (μm.h$^{-1}$) | Sensitivity ($\nu = V_T / V_B$) | % $\eta$ |
|---|---|---|---|---|
| 40 | 30.01 | 107.17 | 3.57 | 72 |
| 45 | 39.65 | 112.36 | 2.83 | 64.68 |
| 50 | 42.92 | 185.89 | 4.33 | 76.91 |
| 55 | 50.32 | 229.19 | 4.55 | 78.04 |
| 60 | 64.78 | 244.26 | 3.77 | 73.5 |

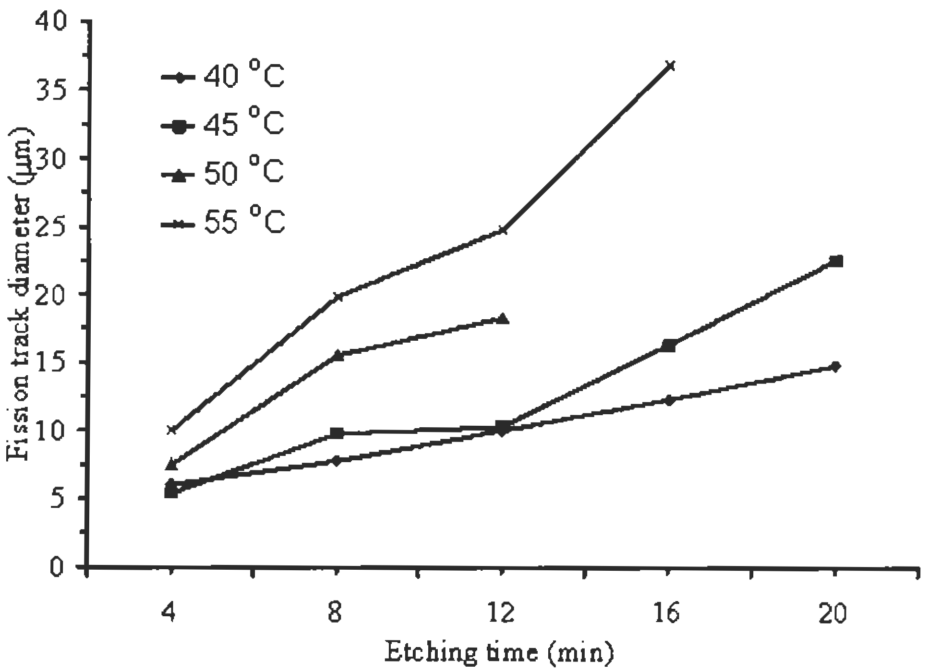


**Figure 3.13:** *Average fission fragment track diameter as a function of etching time. Here CR-39 detectors were etched in 1.5 M NaOH/Methanol at the listed temperatures.*

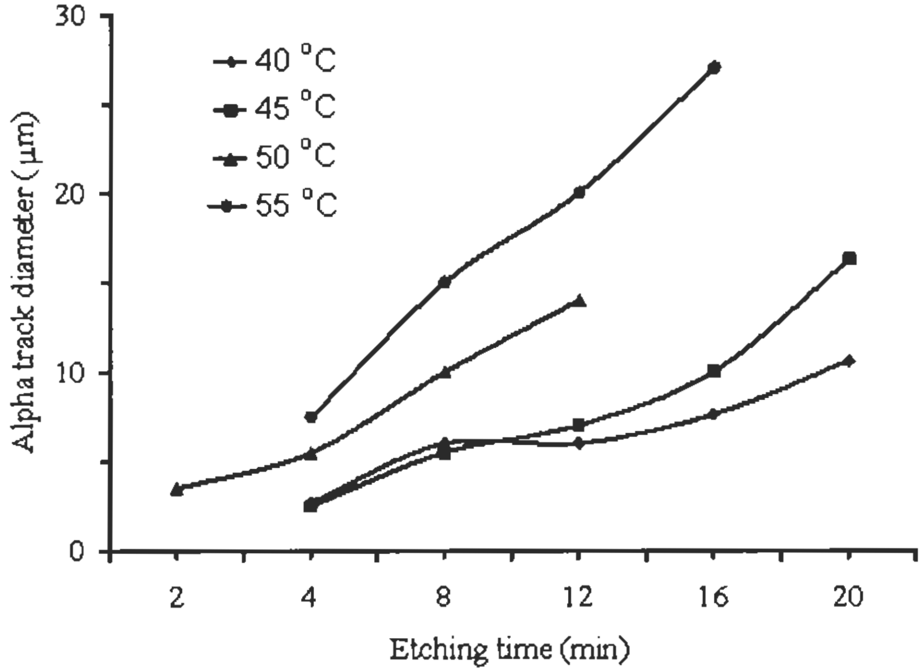


**Figure 3.14:** *Average alpha particle track diameter as a function of etching time. Here CR-39 detectors were etched in 1.5 M NaOH/Methanol at the listed temperatures.*

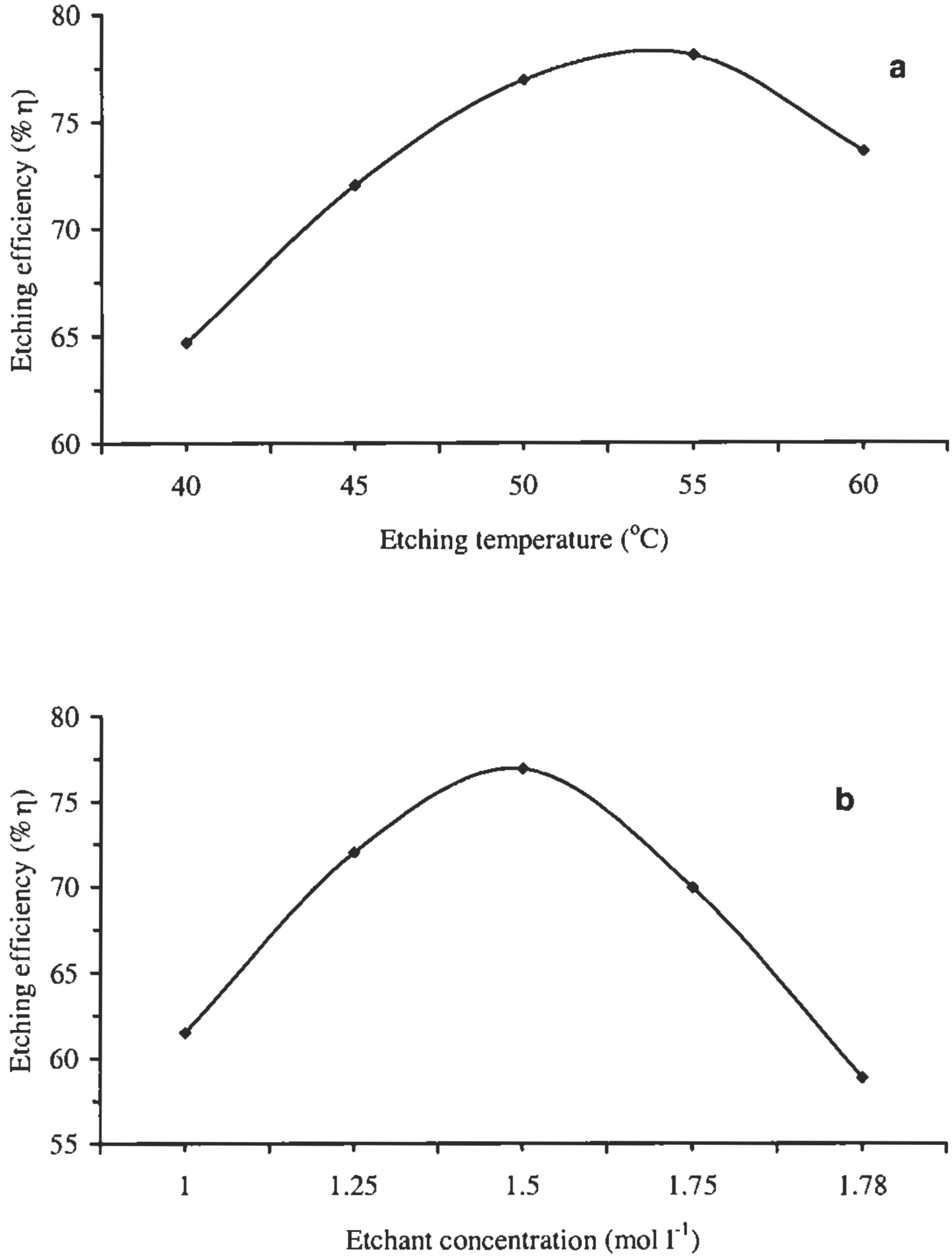


**Figure 3.15:** *(a) Etching efficiency of CR-39 as a function of temperature for 1.5 M NaOH/Methanol; (**b**) Etching efficiency of CR-39 as a function of concentrations of NaOH/Methanol at 55 °C.*

### 3.3.6 SMW (NaOH + Methanol + Water) Etchant

The last etchant studied was SMW solution. SMW is the solution that contain 10% NaOH dissolved in X% methanol and (90-X) % water. Since NaOH/Methanol solution has maximum efficiency at 55 °C (see Fig. 3.15a), the same value of temperature for SMW etchant was used and then the effect of varying %age of methanol in SMW solution on track diameters of alpha particles and fission fragments was studied. Results obtained are plotted in Figs. 3.16 and 3.17 for the listed %age values of methanol in SMW solution. Track diameter is seen to increase linearly with an increase in X% value.

**Table 3.6:** $V_B$, $V_T$ and etching efficiency of CR-39 detector for the listed concentrations of Methanol (X %) in SMW solution at 55 °C

| Methanol (X%) | $V_B$ (µm.m$^{-1}$) | $V_T$ (µm.m$^{-1}$) | Sensitivity (v) | % $\eta$ |
|---|---|---|---|---|
| 40 | 0.19 | 0.49 | 2.60 | 61.50 |
| 50 | 0.59 | 1.64 | 2.76 | 63.76 |
| 60 | 0.71 | 3.70 | 5.21 | 80.81 |
| 70 | 1.29 | 6.09 | 4.72 | 78.79 |
| 80 | 2.68 | 8.26 | 3.08 | 67.54 |

From measured track diameter data, shown in Figs. 3.16 and 3.17, $V_B$, $V_T$ and $\eta$ were calculated which are shown in Table 3.6. For more clarity, in Fig. 3.18, etching efficiency ($\eta$) shown in Table 3.6 is plotted as a function of Methanol concentration (X %) in the SMW solution. As can be seen in this figure, maximum efficiency (~ 81 %) is achieved at 60% methanol concentration in SMW solution i.e. optimum %age ratio of Methanol/water lies around 60/30 with 10% NaOH.

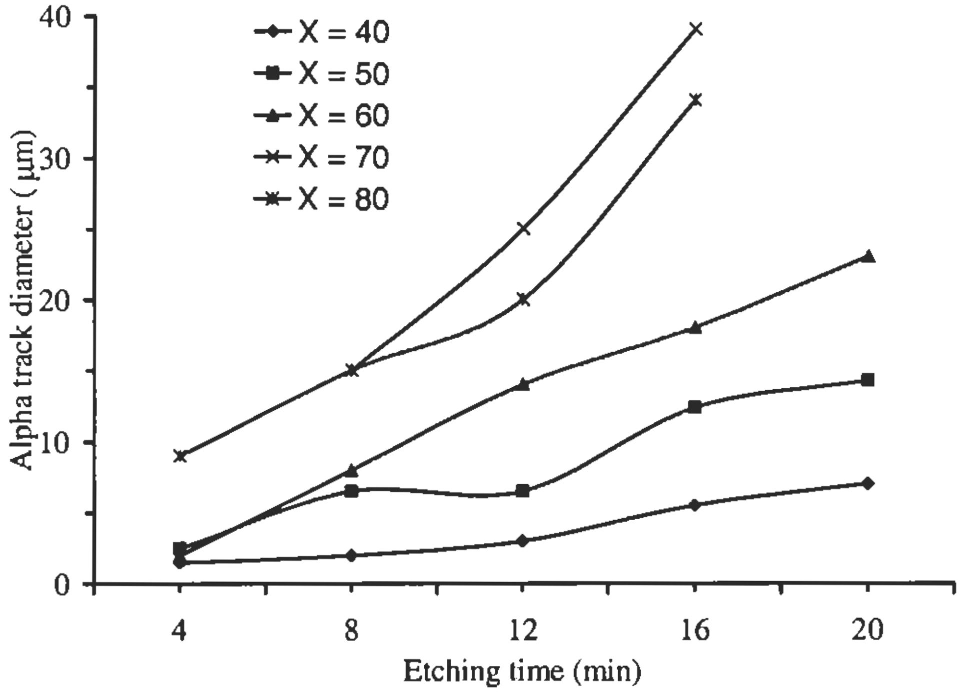


**Figure 3.16:** *Average alpha particle track diameter as a function of Methanol concentrations (X %) in SMW solution at 55 °C.*

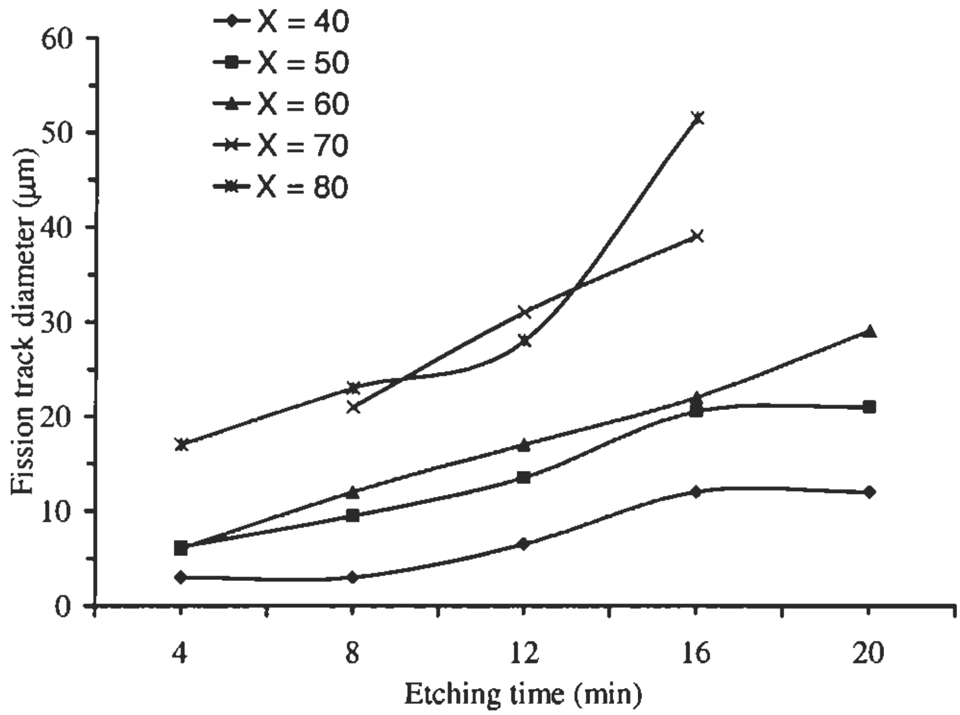


**Figure 3.17:** *Average fission fragment track diameter as a function of Methanol concentrations (X %) in SMW solution at 55 °C.*

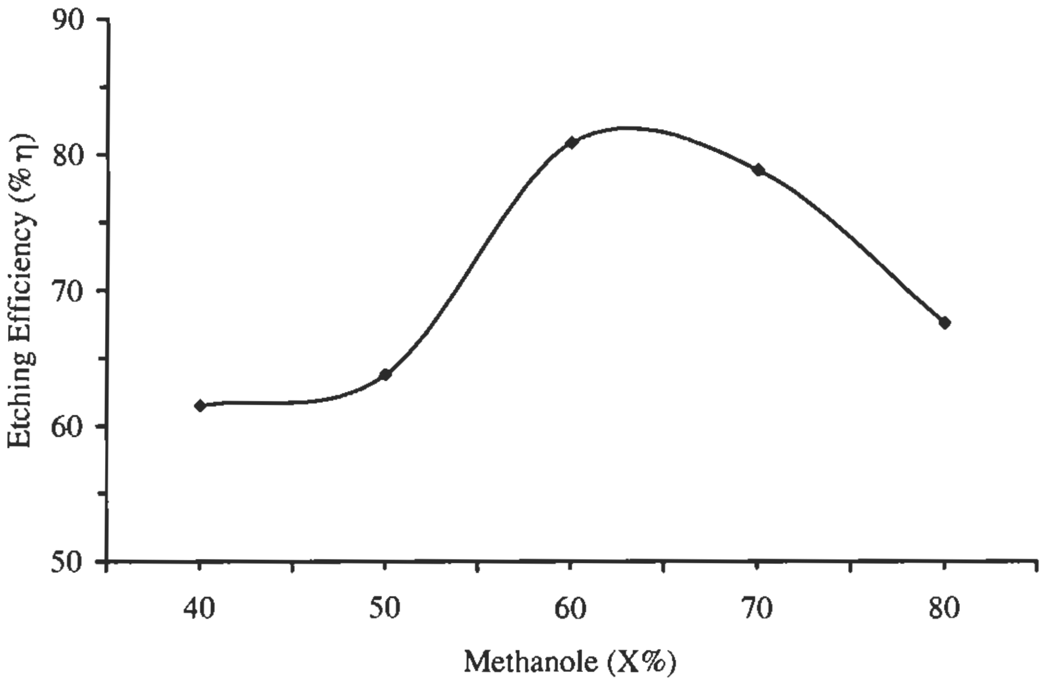


**Figure 3.18:** *Etching efficiency of CR-39 detector as a function of Methanol Concentration (X%) in SMW solution.*

## 3.4 Conclusion

In the foregoing, I have presented experimental data concerning newly discovered etchants namely, NaOH/Ethanol, NaOH/1-Propanol, NaOH/Methanol and SMW solution have been introduced and systematically studied. It was found that 1 M NaOH/1-Propanol Solution at 49 °C yields a maximum value of the etching efficiency (~ 70%), 1.5 M NaOH/Ethanol solution at 55 °C yields a maximum value of the etching efficiency (~ 77%), 1.5 M NaOH/ Methanol Solution at 55 °C yield maximum value of the etching efficiency (~ 78%). Maximum efficiency was found to be ~ 81% for SMW solution that consisted 60% Methannol, 10% NaOH and 30% water at 55 °C. All the above mentioned four etchants are more efficient than conventionally used 6 M aqueous NaOH (i.e. 64%) at 70 °C. Besides having higher etching efficiencies than 6 M NaOH (64%) at 70 °C, these etchants have the advantage that they require much less processing time when used as etchants. This is a great discovery. The introduction of these etchants in routine dosimetry will reduce the lower detection limit and processing time of the CR-39 detector.

## 3.5 References


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