CHAPTER VII

Effect of Pretilt on the Threshold Voltage and Relaxatiom Time of Different Multi-component Mixtures

7.1. Introduction:

Pretilt angle effect [1-17] is found to make an important contribution to the liquid crystal dynamics [1-4]. The use of pretilted cells has important consequences on the threshold voltage (V_{th}) and relaxation time (τ_0) of the liquid crystalline material. In this type of cells, the director is tilted with respect to the cell walls which are advantageous since the tilted alignment aids in the switching of the cell operation. From technological viewpoint, a precise and reliable control of the easy axis is indispensable. The selective pretilting remarkably reduces the apparent tilt angle, i.e., the angle between the projections onto the substrate plate of the nematic layer normal and the director in the uniform states, which has a better effect on relaxation time, threshold voltage and the display contrast [5, 6]. Small pretilt angles are typically used with positive anisotropic liquid crystals and high pretilt angles (close to 90°) are used with negative liquid crystals i.e. in Vertically Aligned mode Liquid Crystal Displays (VA-LCD's) [1]. In a Vertically Aligned (VA) cell, the pretilt angle (α) affects the device contrast ratio and response time. In this case, the pretilt angle is defined as the angle of the Liquid Crystal (LC) directors deviated from cell normal. For α = 0, it implies that the LC directors are aligned perpendicular to the substrate surfaces. As the pretilt angle deviates from the cell normal, the Freedericksz threshold voltage is gradually decreased and hence the operating voltage is reduced. In fact, in a real LC device a small pretilt angle is required for LC directors to relax back without creating domains [3]. In Vertically Aligned Nematics (VAN), the pretilt angle determines the maximum contrast that can be realized; pretilt angle different from 90° is necessary to "orient" the molecules in a preferred direction to switch and to speed up the start of the switching process. When the pretilt moves away from the perpendicular, switching process runs faster, however, the contrast ratio decreases [1]. In nematic Liquid Crystal Displays, a slightly pretilted alignment plays an important role to eliminate orientational defects which further helps us to improve the device quality [3].

Further work in this dissertation involves study of two important material properties (V_{th} and τ_0) of the mixtures using different pretilted cells (2° and 5° pretilt). The results obtained from this study are compared with the mixtures filled in 0° pretilted cells. It is found that as the pretilted angle is increased from 2° to 5°, improvement is observed in the values of threshold voltage and relaxation time. However, the response time is not only dependent on the pretilt angle, but the switching and relaxing processes also depend on the liquid crystalline material, cell gap and anchoring strength to the aligning surfaces. For a particular material, selection of pretilt angle is always a compromise between contrast and speed, taking into account that both depend simultaneously on the cell gap [5-10].

The study of pretilt angle effect on display device thereby is expanding very rapidly in a quest to improve performance and reliability of display device. However the pretilt has also a drawback - the relaxed state becomes birefringent, and the contrast decays dramatically as pretilt increases (as the increasing value of pretilt angle causes birefringence in the dark state and the pretilt of the LC molecules causes a light leakage). Therefore, choosing a precise pretilt is an important tradeoff when designing real VAN displays [4].

The pre-tilt angle of high resolution VAN display devices should be controlled within 5^{o} in order to prevent disclination [4].

The basic concept in the pretilt control scheme is to use two competing alignment forces, one of which gives the homogeneous alignment and the other the homeotropic alignment. For relatively large sizes of the two types of patterns, there exist two different domains producing separately the homogeneous and homeotropic alignment. However, as the pattern sizes decrease, two alignment forces tend to compete with each other and result in an intermediate state having a certain pretilt angle in the bulk whereas they produce an inhomogeneous director field on the surface. This is because the resultant surface-induced inhomogeneity decays to become uniform within a distance of about $k=2p$ from the surface where, k is the period of the surface pattern and p is the cell thickness. In this study, the cell thickness is about 8-9 μm and as a result the period k will be varying from 15-20 μm [11-15].

The magnitude of the pretilt angle can be varied by varying the relative dimension between two patterns [6-7]. For example, when the homeotropic pattern is larger than the homogeneous pattern, a higher pretilt can be obtained. The other case is also valid since the relative anchoring energy governs primarily the magnitude of the pretilt. The alignment materials chosen for the display devices ensure that the director is aligned quasi perpendicularly to the display normal. A non-zero very small angle (known as tilt angle, β, where $\beta=90^{o}-$pretilt angle) between the display normal and the director must be introduced in order to establish plane of communication and to increase the torque resulting from the coupling between the dielectric tensor of the molecules and an applied electric field [8-10]. If $\beta\rightarrow 0$ the display will switch after a long delay time (10s) to generate a conic texture [16-17]. On the other hand increasing β means sacrificing the quality of the clarity state and thus in case of manufacturing a VAN display a delicate balance between delay time and contrast has to be sought. In this chapter study in 0°, 2° and 5° pretilted cell has been undertaken.

7.2 Effect of pretilt on different multicomponent mixtures:

The effects of 2° and 5° pretilt with respect to normal cell (cell with 0° pretilt) have been thoroughly investigated for mixtures **A-G**. The details of the experimental results are given in the following sections.

7.2.1. Three component mixture (mixture A and mixture B):

Figures 7.1 and 7.2 illustrate the variation of threshold voltage with relative temperature (T_{NI}-T) for different pretilted cells for mixtures **A** and **B** respectively. In Figures 7.3 and 7.4, the relaxation time as a function of relative temperature at $\alpha = 0^{\circ}$, 2° and 5° pretilt angles for mixtures **A** and **B** respectively have been plotted. In general, at a given temperature a smaller pretilt angle would lead to a slower response time. As the pretilt angle increases the response time gradually decreases. In fact at T = 20°C the response time decreases to 25% and 35% for mixture **A** for 2° and 5° cells respectively compared to 0° pretilt. On the other hand, at the same temperature for mixture **B**, reduction in these values are 16% and 35% respectively [18]. It may be mentioned that, increasing α means sacrificing the quality of the state, since the dark state becomes more birefringent.

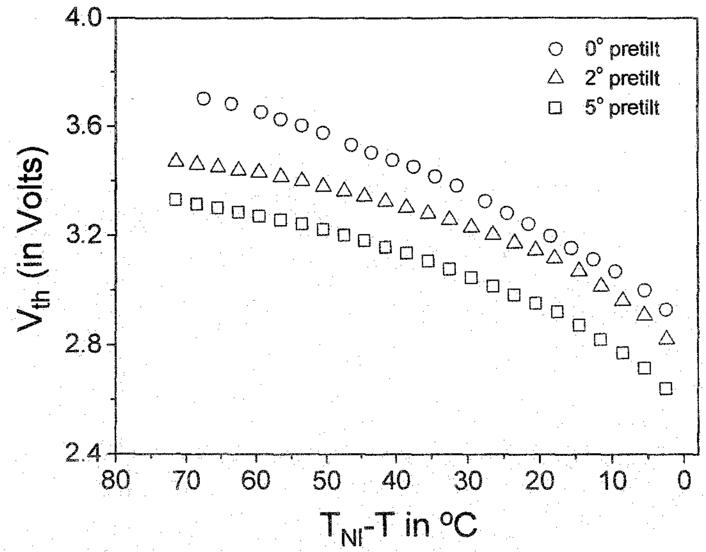

Figure 7.1. Variation of threshold voltage (V_{th}) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **A.** Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and □ = 5° pretilt.

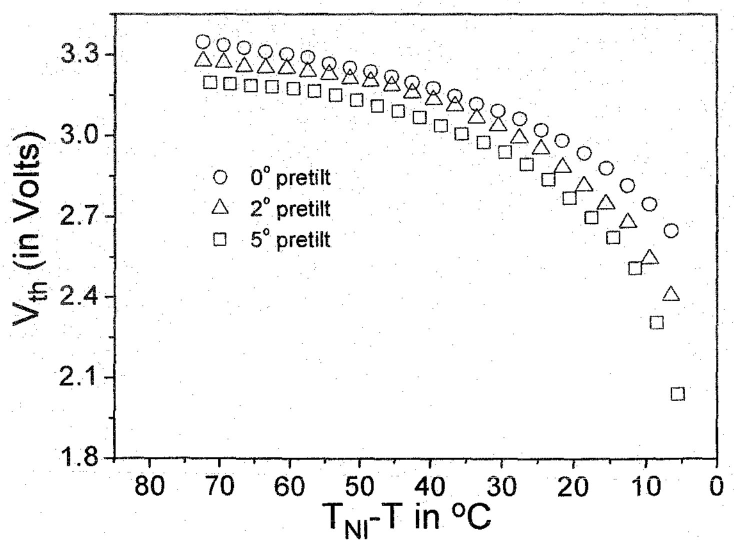

Figure 7.2. Variation of threshold voltage (V_{th}) as functions of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **B.** Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and □ = 5° pretilt.

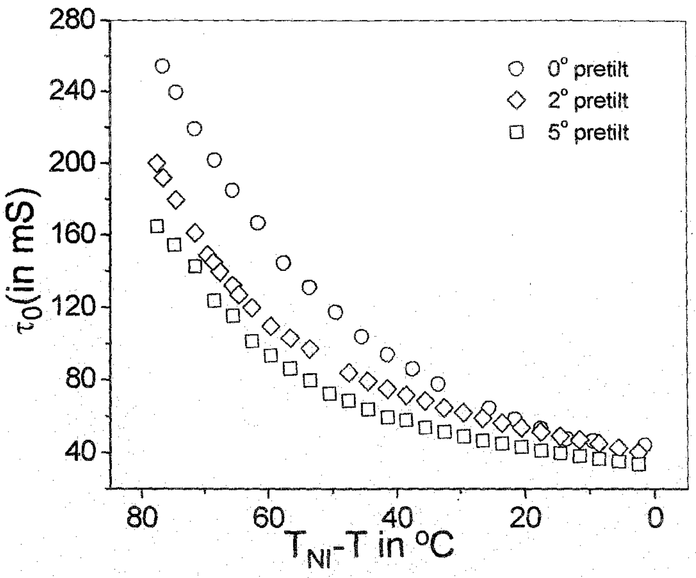

Figure 7.3. Variation of relaxation time (τ_o) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **A**. Key to symbols: ○ = 0° pretilt; ◊ = 2° pretilt and □ = 5° pretilt.

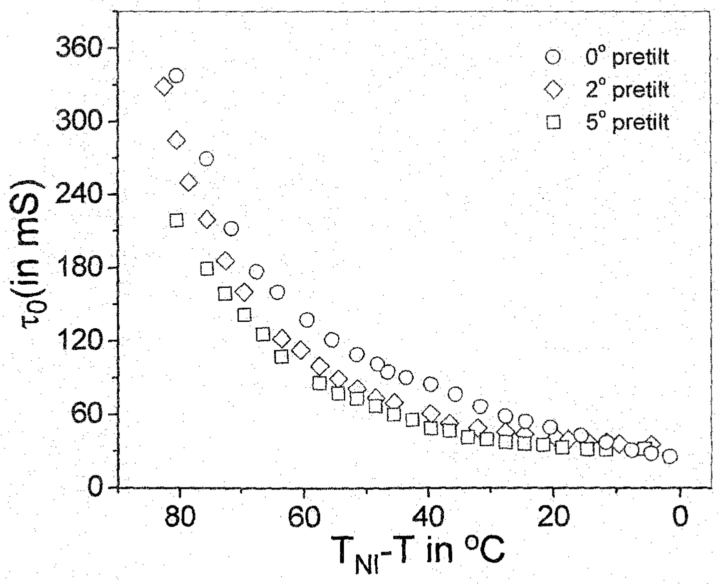

Figure 7.4. Variation of relaxation time (τ_o) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **B**. Key to symbols: ○ = 0° pretilt; ◊ = 2° pretilt and □ = 5° pretilt.

7.2.2. Five component mixture (mixture C):

Further work involves study of the threshold voltage, V_{th}, and relaxation time τ_0 of the five component mixture (mixture **C**) using different pretilted cells (pretilt angle $\alpha=2^o$ and 5^o). The results obtained from this study are then compared with the mixture in 0^o pretilted cells. In Figures 7.5 and 7.6 the threshold voltage and the relaxation time as a function of relative temperature at pretilt angle $\alpha = 0^o$, 2^o and 5^o have been plotted for the mixture **C**. It is found that as the pretilt angle is increased from 2^o to 5^o, improvement is observed in the values of the threshold voltage and relaxation time.

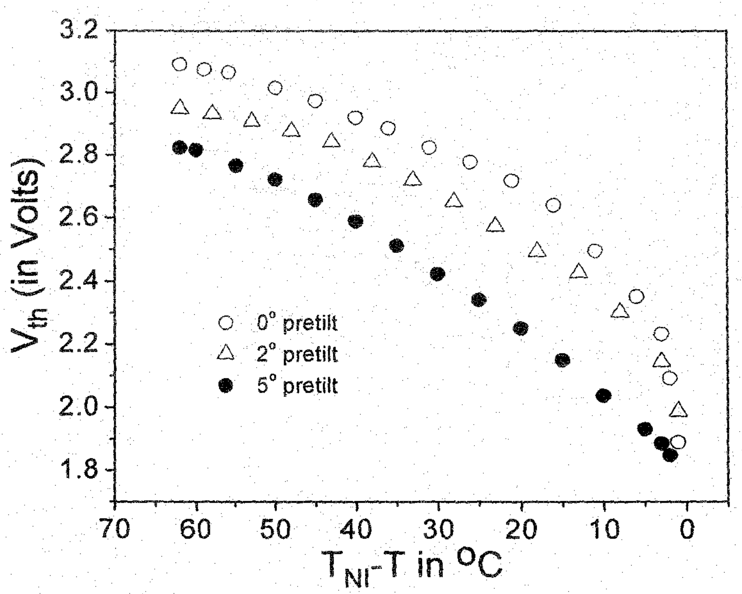

Figure 7.5. Variation of threshold voltage (V_{th}) as a function of relative temperature T_{NI}-T for (cell gap = 8.9μm) mixture **C**. Key to symbols: ○ = 0^o pretilt; Δ = 2^o pretilt and • = 5^o pretilt.

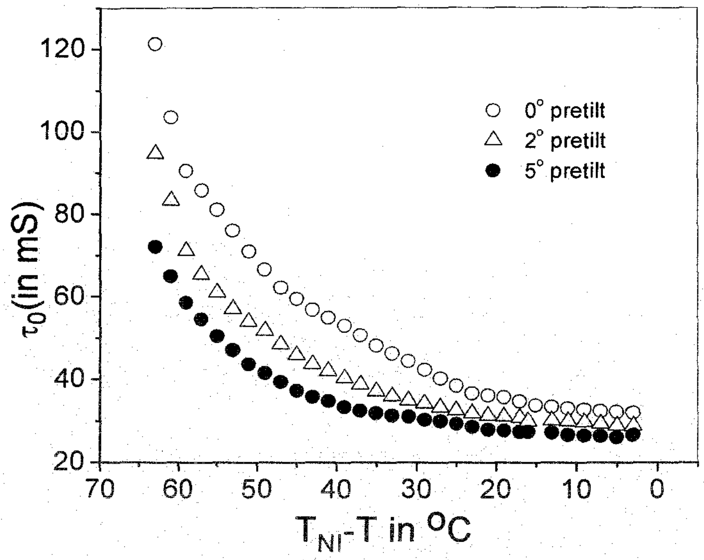

Figure 7.6. Variation of relaxation time (τ_o) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for Mixture **C**. Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and ● = 5° pretilt.

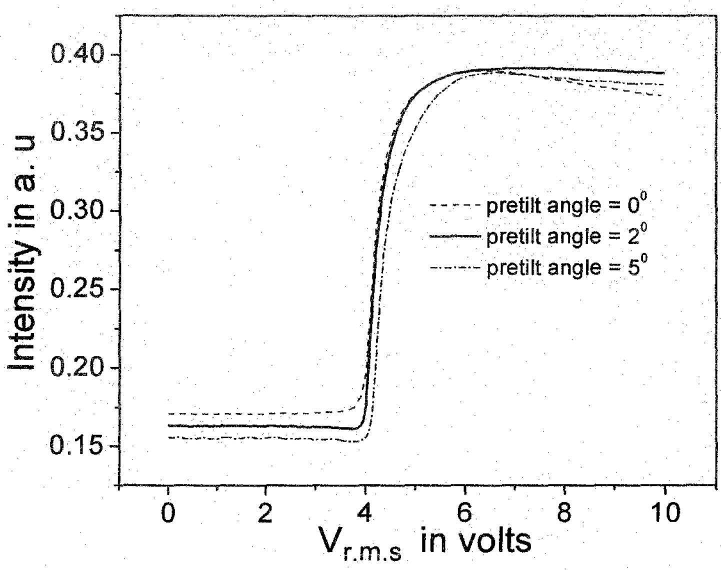

Figure 7.7. Voltage dependent intensity (at a fixed temperature T=30°C) of mixture **C** filled in VA cell with three pretilt angles α = 0° (dashed line), α = 2° (solid line) and α = 5° (dashed dot line).

As observed in Figure 7.6, at T_{NI}-T= 63°C (i.e. T = 20°C), the response time for the mixture decreases to 22% and 41% for 2° and 5° pretilted cell respectively, compared to zero pretilt. On the other hand, at the same temperature the V_{th} values are decreased by 5% and 9% respectively (Figure 7.5) [19]. The voltage dependent transmittance curves of the mixture for different pretilted cells are shown in Figure 7.7. There is a drop in the threshold voltages with increasing pretilt angle as observed in Figure 7.7.

7.2.3. Nine and Ten component mixtures (mixture D, E and F):

As observed in Figures 7.8-7.10, at T_{NI}-T = 63°C (i.e. T = 20°C), the V_{th} value for mixtures **D**, **E** and **F** decreases for 2° and 5° pretilt, compared to 0° pretilt. On the other hand, at the same temperature, the relaxation time is also decreased (Figures 7.11-7.13). The voltage dependent transmittance curves of these mixtures for different pretilted cells are shown in Figure 7.14-7.16. There is a drop in the threshold voltages with increasing pretilt angle as observed in these Figures. It is observed in Figures 7.11-7.13 that when 2° pretilted cells are used, the relaxation time (τ_0) for mixtures **D, E** and **F** are decreased by 6%, 14% and 11% respectively and for 5° pretilted cell the same values are reduced by 14%, 18% and 47% respectively for mixtures **D, E** and **F**. Similar behaviour was also found for V_{th} value of these mixtures. It is observed from Figures 7.8-7.10 that the V_{th} value for mixtures **D, E** and **F** is reduced by 5%, 18% and 12% for 2° pretilted cell and for 5° pretilted cell the same are reduced by 10%, 16% and 13% respectively. The voltage dependent transmittance curve for the mixtures **D, E** and **F** for different pretilted cells are shown in Figures 7.14-7.16.

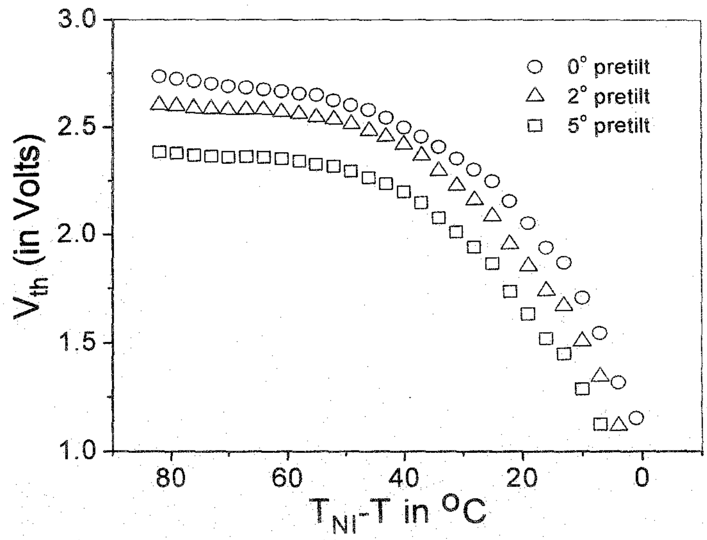

Figure 7.8. Variation of threshold voltage (V_{th}) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **D.** Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and □ = 5° pretilt.

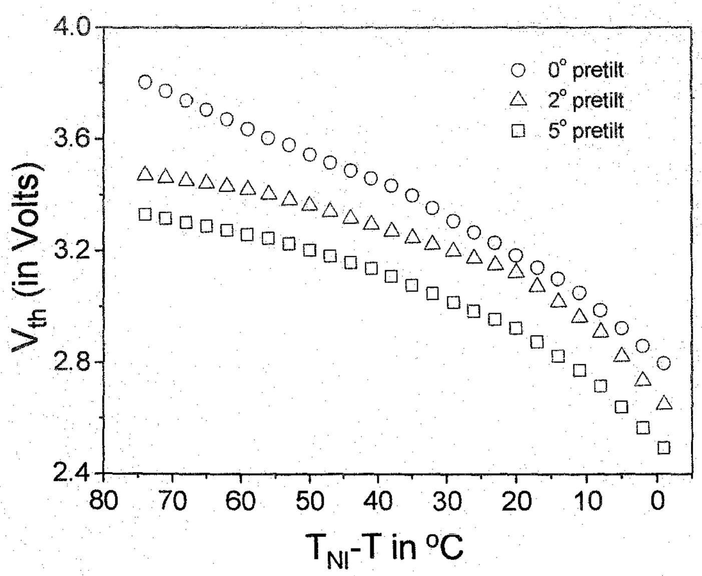

Figure 7.9. Variation of threshold voltage (V_{th}) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **E.** Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and □ = 5° pretilt.

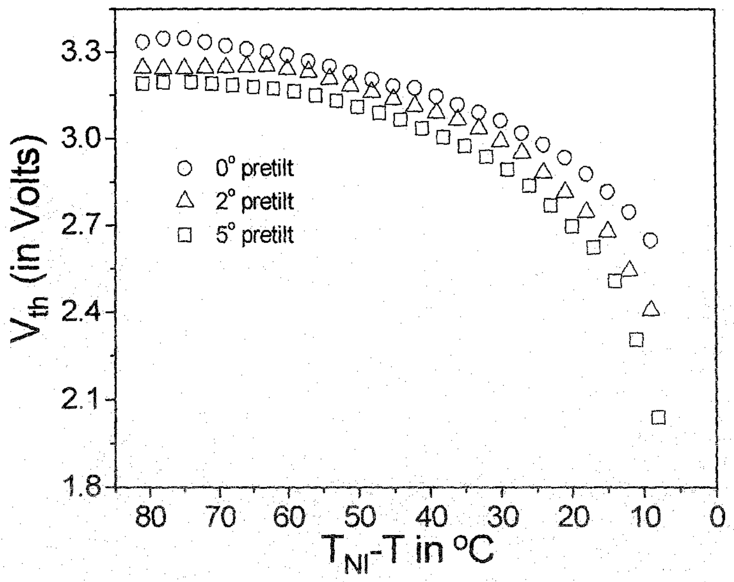

Figure 7.10. Variation of threshold voltage (V_{th}) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **F.** Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and □ = 5° pretilt.

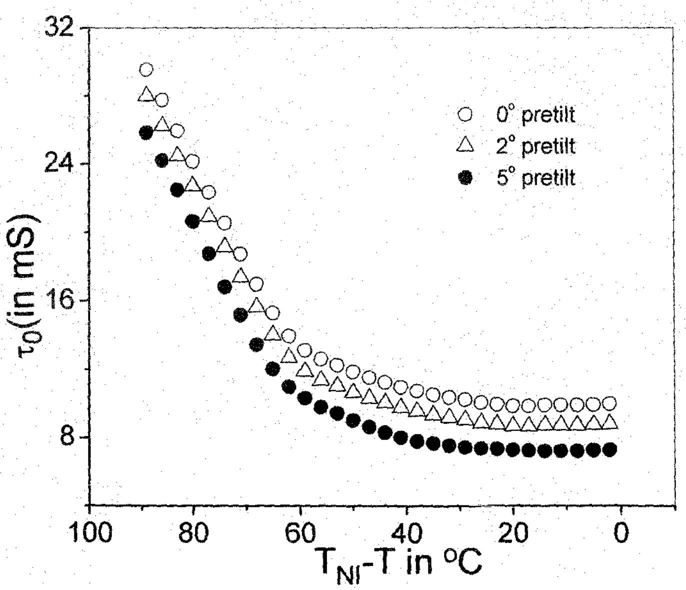

Figure 7.11. Variation of relaxation time (τ_o) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **D.** Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and ● = 5° pretilt.

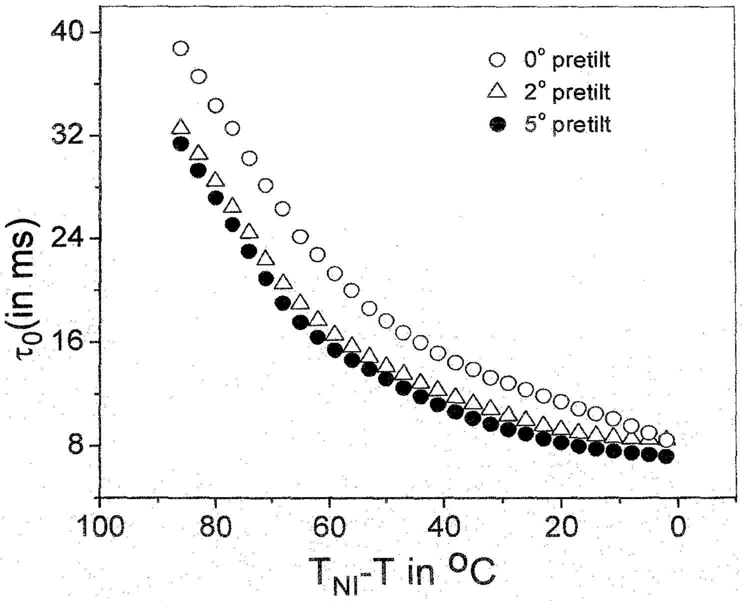

Figure 7.12. Variation of relaxation time (τ_o) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **E.** Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and ● = 5° pretilt.

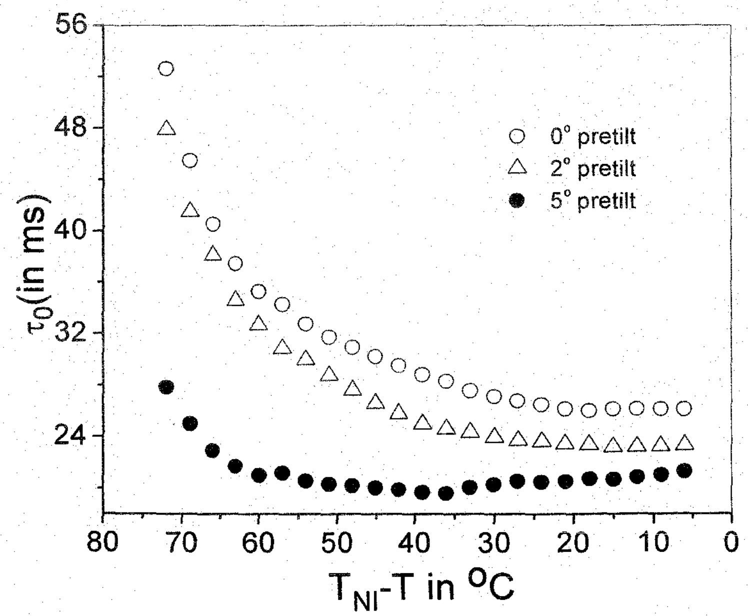

Figure 7.13. Variation of relaxation time (τ_o) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **F.** Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and ● = 5° pretilt.

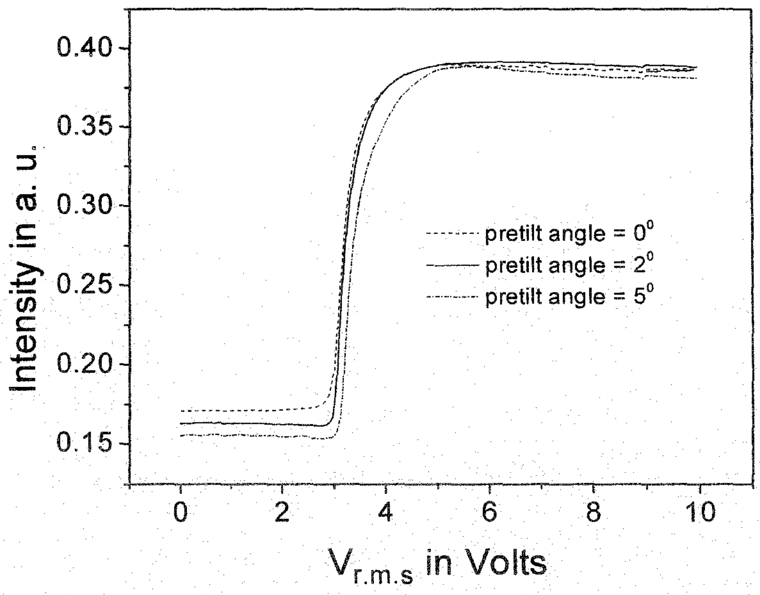

Figure 7.14. Voltage dependent intensity (at a fixed temperature T=65°C) of mixture **D** filled in VA cell with three pretilt angles α = 0° (dashed line), α = 2° (solid line) and α = 5° (dashed dot line).

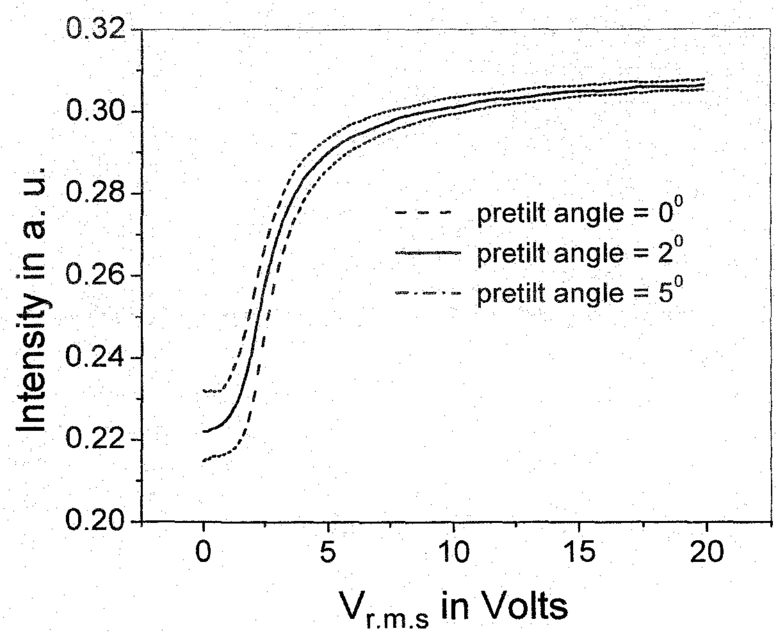

Figure 7.15. Voltage dependent intensity (at a fixed temperature T=80°C) of mixture **E** filled in VA cell with three pretilt angles α = 0° (dashed line), α = 2° (solid line) and α = 5° (dashed dot line).

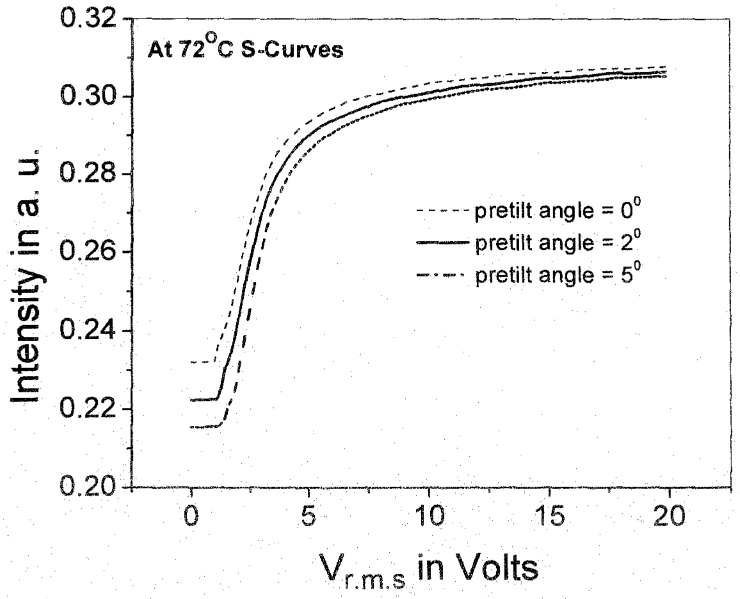

Figure 7.16. Voltage dependent intensity (at a fixed temperature T=72°C) of mixture **F** filled in VA cell with three pretilt angles $\alpha = 0^\circ$ (dashed line), $\alpha = 2^\circ$ (solid line) and $\alpha = 5^\circ$ (dashed dot line).

7.2.4. Fifteen component mixture (mixture G):

Similar effects are also found for the fifteen component mixture (mixture **G**). It is observed that the V_{th} and τ_0 values are comparatively less for 5° pretilted cell relative to those for 0° and 2° pretilted cell. As observed in Figure 7.18, at T_{NI}-T = 63°C (i.e. T = 20°C), the response time for the mixture is decreased by 14% and 44% for 2° and 5° pretilted cell respectively, On the other hand, from Figure 7.17 it is observed that at the same temperature the V_{th} values are decreased by 6% and 11% respectively for 2° and 5° pretilted cell. Figure 7.19 illustrates the voltage dependent transmittance curve for mixture **G**.

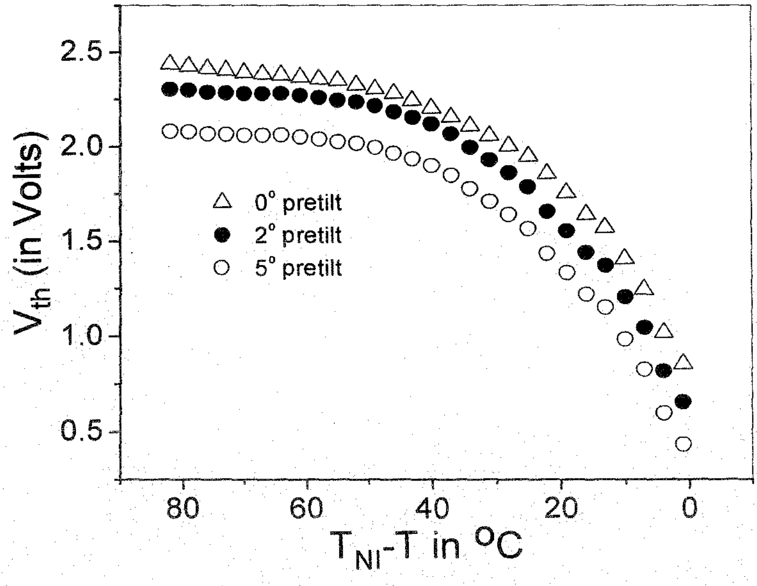

Figure 7.17. Variation of threshold voltage (V_{th}) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **G**. Key to symbols: Δ = 0° pretilt; ● = 2° pretilt and ○ = 5° pretilt.

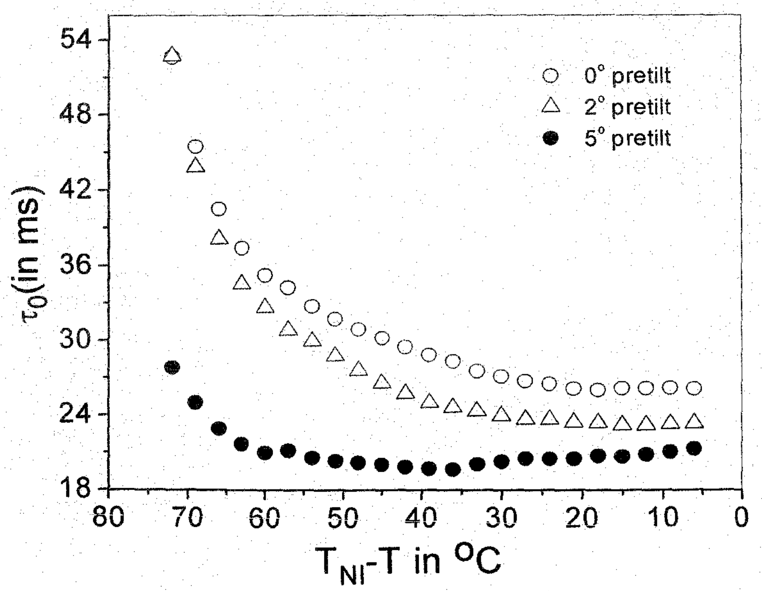

Figure 7.18. Variation of relaxation time (τ_o) as a function of relative temperature T_{NI}-T (cell gap = 8.9μm) for mixture **G**. Key to symbols: ○ = 0° pretilt; Δ = 2° pretilt and ● = 5° pretilt.

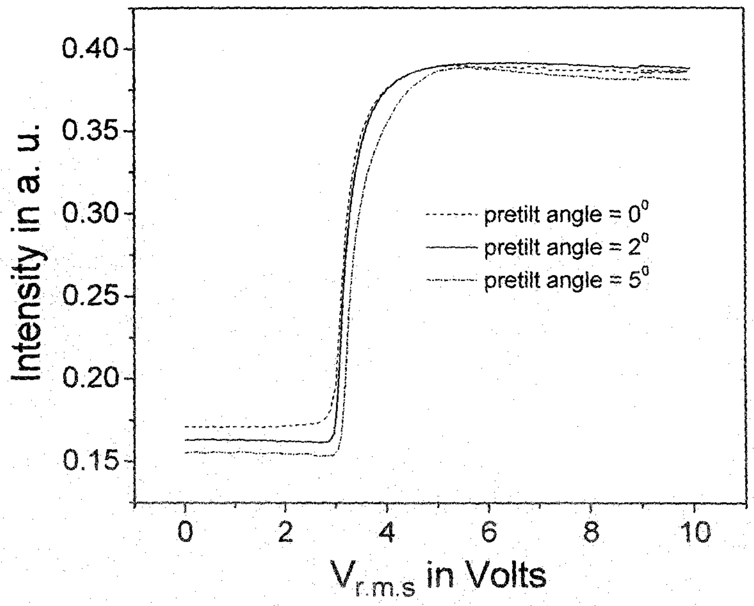

Figure 7.19. Voltage dependent intensity (at a fixed temperature T=52°C) of mixture **G** filled in VA cell with three pretilt angles $\alpha = 0^{o}$ (dashed line), $\alpha = 2^{o}$ (solid line) and $\alpha = 5^{o}$ (dashed dot line).

7.3. Summary and Conclusions:

A comparative study of the effect of pretilt angle on the threshold voltage (V_{th}) and relaxation time τ_0 for the multicomponent nematic mixtures (mixtures **A-G**) are studied and the results are listed in Tables 7.1 and 7.2 respectively. It is observed that both the threshold voltage as well as the relaxation times shows improvement for all the mixtures using pretilted cells. As the pretilt angle deviates from the cell normal, the threshold behaviour is gradually smeared and the turn-on voltage is decreased. A display device manufacturer should keep in mind that the threshold behavior exists only when the pretilt angle is zero. The free relaxation time τ_0 is derived based on the assumptions that $\alpha = 0$ and the applied voltage is not too far from the threshold voltage. However, in many LC devices a non-zero pretilt angle is required in order to avoid domain formation during molecular reorientation.

Table 7.1. Comparative study of threshold voltage V_{th} (in volts) of multicomponent mixtures **A-G** (~ 20°C) using different pretilted cells.

	A	**B**	**C**	**D**	**E**	**F**	**G**
0° pretilt	3.72	3.35	3.09	2.73	3.81	3.34	2.41
2° pretilt	3.47	3.28	2.95	2.60	3.47	3.24	2.29
5° pretilt	3.33	3.20	2.82	2.38	3.33	3.19	2.07

Table 7.2. Comparative study of relaxation time τ_0 (in milisec) of multicomponent mixtures **A-G** (~ 20°C) using different pretilted cells.

	A	**B**	**C**	**D**	**E**	**F**	**G**
0° pretilt	254	337	121	29	38	53	57
2° pretilt	199	328	94	27	32	47	55
5° pretilt	164	218	72	25	31	28	32

It may be mentioned that there are limitations on the choice of the values of the pretilt angle, since the birefringence due to the pretilt of the liquid crystalline molecules causes a light leakage in the dark state and reduces the contrast ratio. The pre-tilt angle of high resolution VA nematic displays is thus restricted to within 5° in order to prevent disclination. Display applications probably would prefer higher pretilt angles to minimize the response time. The slightly lower phase delay ranges achieved in these cells are relevant for the device performance in most cases [1, 4].

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