



CHAPTER IV

RESULT

Flammability Measurement

1. Limiting Oxygen Index (LOI) measurements

Table 4-1 Effect of ZHS, ZS, Sb_2O_3 and AS as fire retardant in hard film (LOI)

Fire retardant	LOI			
	ZHS	ZS	Sb_2O_3	AS
No additive	24.20	24.20	24.20	24.20
1% additive	26.90	27.00	26.90	24.70
2% additive	28.00	29.00	29.00	25.00
3% additive	29.50	30.20	30.00	25.40
4% additive	30.60	31.00	30.30	26.00
5% additive	31.50	31.80	30.70	26.40
10% additive	36.50	36.50	30.70	26.80

Table 4-2 Effect of ZHS, ZS, Sb_2O_3 and AS as fire retardant in soft film (LOI)

Fire retardant	LOI			
	ZHS	ZS	Sb_2O_3	AS
No additive	22.00	22.00	22.00	22.00
1% additive	24.50	24.00	25.00	22.80
2% additive	25.50	25.00	26.00	23.20
3% additive	27.00	26.50	27.50	23.40
4% additive	28.00	27.50	28.20	23.80
5% additive	29.00	28.70	29.00	24.20
10% additive	30.50	30.50	29.20	24.40

Table 4-3 Effect of ZHS, ZS, Sb_2O_3 and AS as fire retardant in highly soft film (LOI)

Fire retardant	LOI			
	ZHS	ZS	Sb_2O_3	AS
No additive	21.00	21.00	21.00	21.00
1% additive	22.20	21.50	22.50	21.50
2% additive	22.70	22.00	23.70	22.00
3% additive	23.00	22.70	24.40	22.40
4% additive	23.20	23.00	25.20	22.60
5% additive	23.60	23.30	25.70	22.80
10% additive	25.00	24.50	26.50	23.00

4.1.2 Flammability Measurement

Table 4-4 Effect of ZHS, ZS, Sb_2O_3 and AS as fire retardant in hard film (Burning Rate)

Fire retardant	Burning Rate (mm/min.)			
	ZHS	ZS	Sb_2O_3	AS
No additive	133	133	133	133
1% additive	selx	selx	selx	300
2% additive	selx	selx	selx	255
3% additive	selx	selx	selx	240
4% additive	selx	selx	selx	252
5% additive	selx	selx	selx	300
10% additive	selx	selx	selx	285

selx = self-extinguished

Table 4-5 Effect of ZHS, ZS, Sb_2O_3 and AS as fire retardant in soft film (Burning Rate)

Fire retardant	Burning Rate (mm/min.)			
	ZHS	ZS	Sb_2O_3	AS
No additive	210	210	210	210
1% additive	selx	selx	selx	290
2% additive	selx	selx	selx	360
3% additive	selx	selx	selx	400
4% additive	selx	selx	selx	300
5% additive	selx	selx	selx	345
10% additive	selx	selx	selx	375

selx = self-extinguished

Table 4-6 Effect of ZHS, ZS, Sb₂O₃ and AS as fire retardant in highly soft film (Burning Rate)

Fire retardant	Burning Rate (mm/min.)			
	ZHS	ZS	Sb ₂ O ₃	AS
No additive	257	257	257	257
1% additive	283	274	385	366
2% additive	125	38	394	356
3% additive	selx	selx	selx	360
4% additive	selx	selx	selx	424
5% additive	selx	selx	selx	402
10% additive	selx	selx	selx	433

selx = self-extinguished

4.2 Evolved Gas Analysis

4.2.1 Pyrolysis GC

Table 4-7 Effect of ZHS, ZS, Sb₂O₃ and AS on Hydrocarbon evolution in Pyrolysis of hard film

Fire retardant	Hydrocarbon Evolution (%Area)			
	ZHS	ZS	Sb ₂ O ₃	AS
No additive	19.96	19.96	19.96	19.96
1% additive	34.50	33.21	9.90	27.44
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	21.37	32.72	25.50	37.76
5% additive	-	-	-	-
10% additive	22.11	28.09	26.56	18.42

Table 4-8 Effect of ZHS, ZS, Sb_2O_3 and AS on Benzene evolution in Pyrolysis of hard film

Fire retardant	Benzene Evolution (%Area)			
	ZHS	ZS	Sb_2O_3	AS
No additive	21.64	21.64	21.64	21.64
1% additive	6.24	5.01	24.67	17.64
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	2.10	4.70	26.41	1.68
5% additive	-	-	-	-
10% additive	5.41	4.57	29.19	10.68

**Table 4-9 Effect of ZHS, ZS, Sb₂O₃ and AS on Toluene evolution
in Pyrolysis of hard film**

Fire retardant	Toluene Evolution (%Area)			
	ZHS	ZS	Sb ₂ O ₃	AS
No additive	17.64	17.64	17.64	17.64
1% additive	16.28	14.53	11.55	2.81
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	14.02	16.08	8.24	1.68
5% additive	-	-	-	-
10% additive	24.20	18.78	10.83	10.68

Table 4-10 Effect of ZHS, ZS, Sb₂O₃ and AS on Hydrocarbon evolution in Pyrolysis of soft film

Fire retardant	Hydrocarbon Evolution (%Area)			
	ZHS	ZS	Sb ₂ O ₃	AS
No additive	31.30	31.30	31.30	31.30
1% additive	27.23	27.46	32.91	19.10
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	23.96	21.72	31.13	16.42
5% additive	-	-	-	-
10% additive	17.22	17.77	24.48	8.67

Table 4-11 Effect of ZHS, ZS, Sb_2O_3 and AS on Benzene evolution in Pyrolysis of soft film

Fire retardant	Benzene Evolution (%Area)			
	ZHS	ZS	Sb_2O_3	AS
No additive	40.50	40.50	40.50	40.50
1% additive	4.27	4.27	22.53	40.05
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	2.37	2.48	20.36	26.96
5% additive	-	-	-	-
10% additive	2.80	3.20	28.50	37.13

Table 4-12 Effect of ZHS, ZS, Sb₂O₃ and AS on Toluene evolution in Pyrolysis of soft film

Fire retardant	Toluene Evolution (%Area)			
	ZHS	ZS	Sb ₂ O ₃	AS
No additive	10.50	10.50	10.50	10.50
1% additive	16.11	15.46	7.96	6.51
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	16.76	20.12	9.80	13.79
5% additive	-	-	-	-
10% additive	19.66	18.15	11.21	7.94

Table 4-13 Effect of ZHS, ZS, Sb_2O_3 and AS on Hydrocarbon evolution in Pyrolysis of highly soft film

Fire retardant	Hydrocarbon Evolution (%Area)			
	ZHS	ZS	Sb_2O_3	AS
No additive	47.01	47.01	47.01	47.01
1% additive	14.12	14.96	37.83	5.42
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	11.83	12.24	33.43	14.78
5% additive	-	-	-	-
10% additive	10.81	13.72	29.24	14.99

Table 4-14 Effect of ZHS, ZS, Sb_2O_3 and AS on Benzene evolution in Pyrolysis of highly soft film

Fire retardant	Benzene Evolution (%Area)			
	ZHS	ZS	Sb_2O_3	AS
No additive	31.76	31.76	31.76	31.76
1% additive	2.71	2.76	31.90	39.32
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	2.23	2.47	30.06	52.08
5% additive	-	-	-	-
10% additive	1.45	2.17	25.05	31.85

**Table 4-15 Effect of ZHS, ZS, Sb₂O₃ and AS on Toluene evolution
in Pyrolysis of highly soft film**

Fire retardant	Toluene Evolution (%Area)			
	ZHS	ZS	Sb ₂ O ₃	AS
No additive	7.04	7.04	7.04	7.04
1% additive	22.21	21.20	10.02	3.05
2% additive	-	-	-	-
3% additive	-	-	-	-
4% additive	23.88	26.66	12.79	10.37
5% additive	-	-	-	-
10% additive	22.66	29.40	10.43	19.03

4.3 Mechanical Properties Measurements

Table 4-16 Mechanical properties of hard film containing ZHS and ZS

Fire retardant	Tensile Strength (Kg/cm ²)		Elongation (%)		Tear Strength (Kg/cm)	
	MD	TD	MD	TD	MD	TD
No additives	270	260	537.5	500.0	2.5	2.3
1% ZHS	265	240	525.0	500.0	2.4	2.2
2% ZHS	255	255	500.0	512.5	2.4	2.2
3% ZHS	295	255	500.0	525.0	2.6	2.4
4% ZHS	285	255	512.5	500.0	2.5	2.5
5% ZHS	265	240	512.5	475.0	2.4	2.3
10% ZHS	235	225	475.0	500.0	2.3	2.2
1% ZS	245	250	512.5	525.0	2.2	2.1
2% ZS	245	235	512.5	500.0	2.2	2.1
3% ZS	255	220	550.0	487.5	2.2	2.0
4% ZS	260	245	525.0	512.5	2.3	2.1
5% ZS	285	235	550.0	500.0	2.5	2.1
10% ZS	255	245	525.0	500.0	2.5	2.2

Table 4-17 Mechanical properties of hard film containing Sb_2O_3 and AS.

Fire retardant	Tensile Strength (Kg/cm ²)		Elongation (%)		Tear Strength (Kg/cm)	
	MD	TD	MD	TD	MD	TD
No additives	270	260	537.5	500.0	2.5	2.3
1% Sb_2O_3	265	260	550.0	512.5	2.3	2.2
2% Sb_2O_3	285	245	525.0	500.0	2.3	2.2
3% Sb_2O_3	270	260	550.0	537.5	2.1	2.3
4% Sb_2O_3	275	285	512.5	537.5	2.3	2.4
5% Sb_2O_3	250	255	500.0	500.0	2.3	2.2
% Sb_2O_3	240	255	512.5	500.0	2.2	2.3
1% AS	160	155	362.5	375.0	1.9	1.8
2% AS	160	160	337.5	337.5	1.9	1.8
3% AS	170	150	300.0	337.5	1.7	1.9
4% AS	150	140	250.0	250.0	1.9	1.9
5% AS	150	145	250.0	275.0	1.8	1.8
10% AS	140	135	200.0	225.0	1.6	1.7

Table 4-18 Mechanical properties of soft film containing ZHS and ZS

Fire retardant	Tensile Strength (Kg/cm ²)		Elongation (%)		Tear Strength (Kg/cm)	
	MD	TD	MD	TD	MD	TD
No additives	220	205	650.0	637.5	1.5	1.4
1% ZHS	210	205	550.0	575.0	1.5	1.6
2% ZHS	205	195	550.0	562.5	1.5	1.4
3% ZHS	195	195	625.0	600.0	1.6	1.3
4% ZHS	210	215	550.0	625.0	1.7	1.5
5% ZHS	205	210	600.0	625.0	1.4	1.5
10% ZHS	205	195	600.0	637.5	1.6	1.5
1% ZS	235	195	637.5	637.5	1.5	1.4
2% ZS	220	195	650.0	600.0	1.5	1.4
3% ZS	210	180	612.5	600.0	1.5	1.4
4% ZS	210	180	650.0	587.5	1.5	1.3
5% ZS	220	195	637.5	612.5	1.5	1.4
10% ZS	215	195	575.0	575.0	1.7	1.6

Table 4-19 Mechanical properties of soft film containing Sb_2O_3 and AS.

Fire retardant	Tensile Strength (Kg/cm ²)		Elongation (%)		Tear Strength (Kg/cm)	
	MD	TD	MD	TD	MD	TD
No additives	220	205	650.0	637.5	1.5	1.4
1% Sb_2O_3	220	215	650.0	625.0	1.4	1.5
2% Sb_2O_3	200	235	587.5	662.5	1.5	1.7
3% Sb_2O_3	220	200	675.0	625.0	1.5	1.5
4% Sb_2O_3	225	230	675.0	662.5	1.5	1.7
5% Sb_2O_3	230	195	650.0	562.5	1.5	1.6
10% Sb_2O_3	205	130	512.5	500.0	1.5	1.4
1% AS	145	135	437.5	412.5	1.2	1.0
2% AS	130	125	400.0	337.5	1.1	1.0
3% AS	150	155	375.0	362.5	1.3	1.3
4% AS	135	115	312.5	312.5	1.2	1.0
5% AS	130	120	350.0	300.0	1.2	1.0
10% AS	120	95	275.0	275.0	1.3	1.0

Table 4-20 Mechanical properties of highly soft film containing ZHS and ZS

Fire retardant	Tensile Strength (Kg/cm ²)		Elongation (%)		Tear Strength (Kg/cm)	
	MD	TD	MD	TD	MD	TD
No additives	160	155	875.0	875.0	0.7	0.7
1% ZHS	165	150	900.0	850.0	0.7	0.7
2% ZHS	170	125	925.0	825.0	0.8	0.8
3% ZHS	170	145	875.0	850.0	0.8	0.7
4% ZHS	155	165	850.0	875.0	0.7	0.8
5% ZHS	170	150	850.0	850.0	0.8	0.7
10% ZHS	170	120	837.5	700.0	0.8	0.7
1% ZS	150	160	800.0	912.5	0.8	0.6
2% ZS	155	135	800.0	875.0	0.8	0.6
3% ZS	150	155	825.0	850.0	0.7	0.8
4% ZS	160	155	837.5	912.5	0.7	0.7
5% ZS	160	130	875.0	812.5	0.8	0.7
10% ZS	135	125	675.0	775.0	0.7	0.7



Table 4-21 Mechanical properties of highly soft film containing Sb_2O_3 and AS.

Fire retardant	Tensile Strength (Kg/cm ²)		Elongation (%)		Tear Strength (Kg/cm)	
	MD	TD	MD	TD	MD	TD
No additives	160	155	875.0	875.0	0.7	0.7
1% Sb_2O_3	165	155	825.0	900.0	0.7	0.7
2% Sb_2O_3	150	140	875.0	800.0	0.7	0.6
3% Sb_2O_3	155	145	900.0	837.5	0.7	0.6
4% Sb_2O_3	160	115	862.5	750.0	0.7	0.7
5% Sb_2O_3	170	135	887.5	850.0	0.7	0.6
10% Sb_2O_3	155	125	750.0	762.5	0.7	0.7
1% AS	120	110	675.0	662.5	0.7	0.6
2% AS	120	105	575.0	625.0	0.9	0.8
3% AS	115	95	650.0	537.5	0.8	0.7
4% AS	100	95	525.0	550.0	0.8	0.7
5% AS	85	95	525.0	550.0	0.7	0.6
10% AS	70	65	475.0	500.0	0.7	0.5

Figure 4-1 Effect of ZHS, ZS, Sb_2O_3 and AS as fire retardant in hard film (LOI)

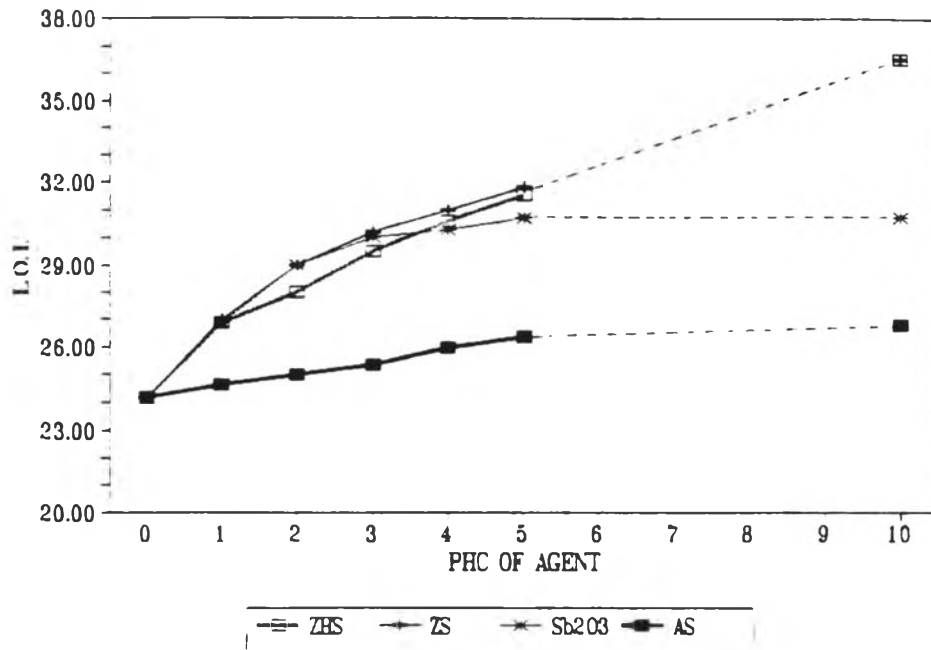


Figure 4-2 Effect of ZHS, ZS, Sb_2O_3 and AS as fire retardant in soft film (LOI)

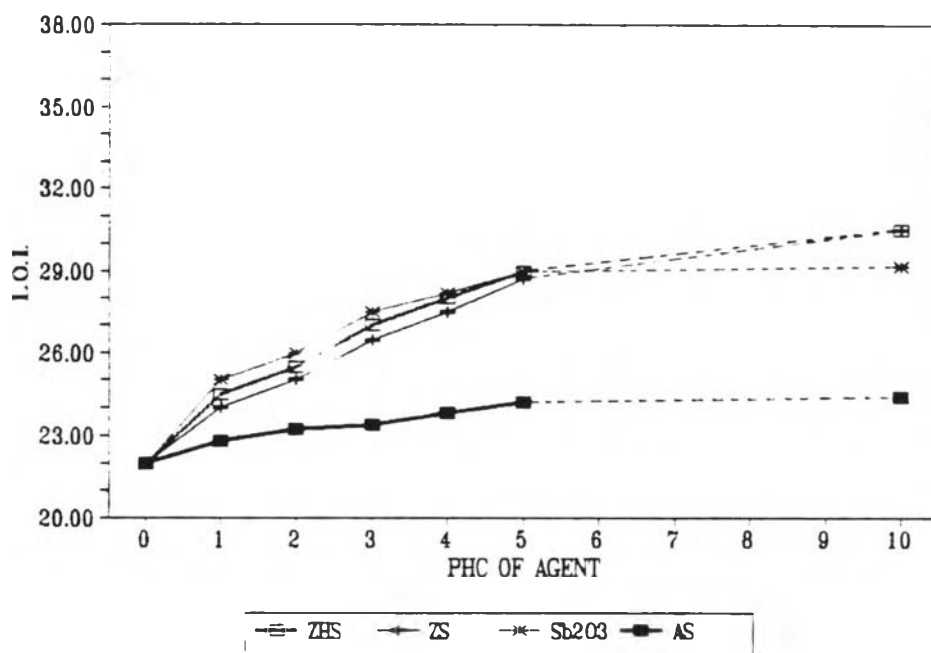


Figure 4-8 Effect of ZHS, ZS, Sb_2O_3 and AS as fire retardant in highly soft film (LOI)

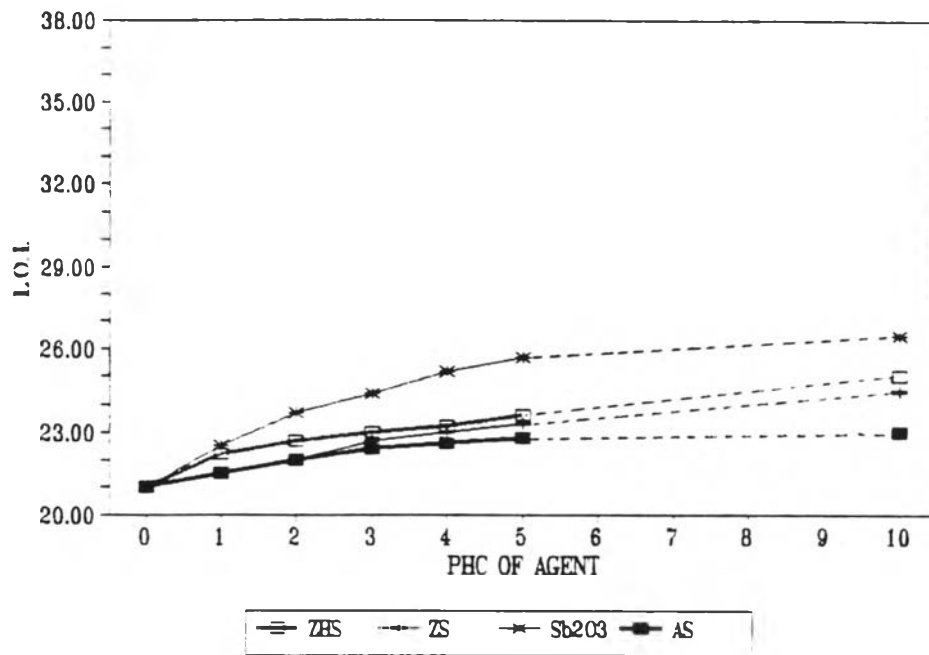


Figure 4-4 Pyrogram of hard film containing no fire retardant

Sample # : 5 Channel : Channel #1
Sample ID : 1.1F1 0 PHC Chromatogram : TA9

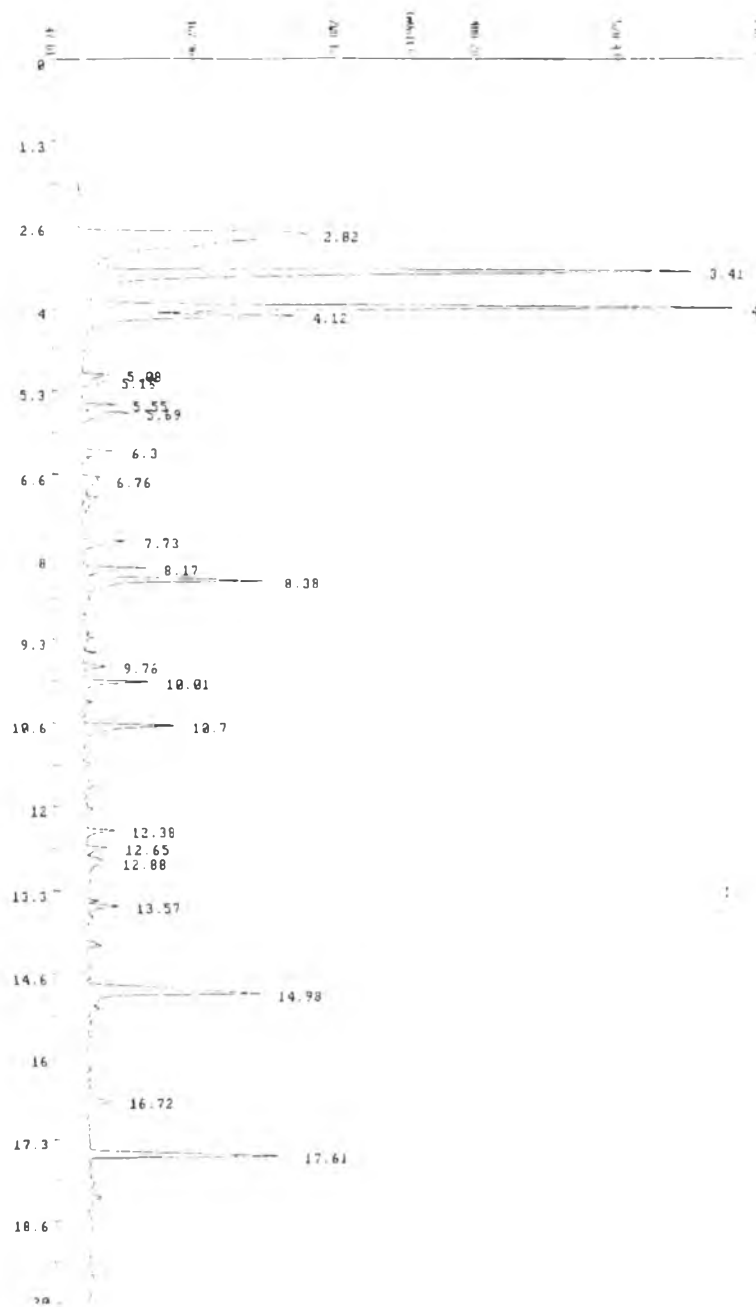


Figure 4-5 Pyrogram of soft film containing no fire retardant

Sample # : 1 Channel : Channel #1
Sample ID : 2.1F1 0 PHC Chromatogram : TB1

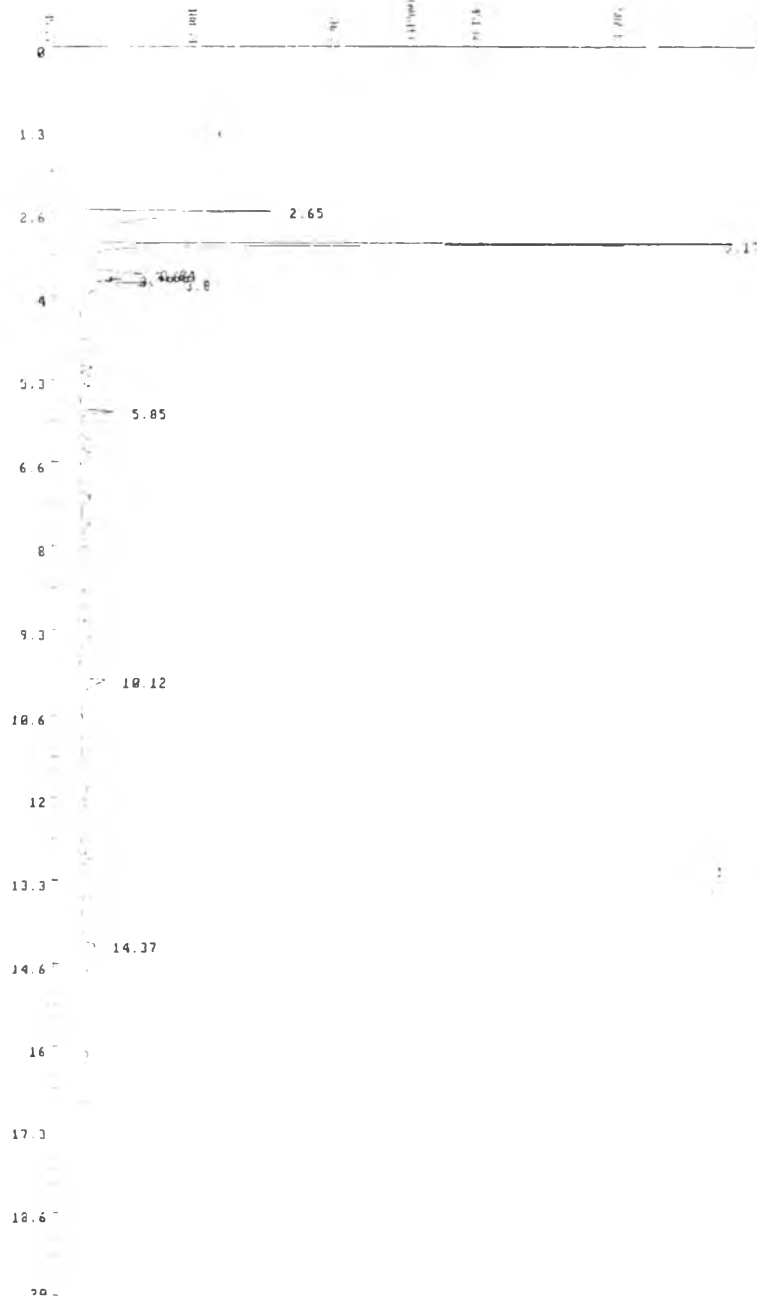
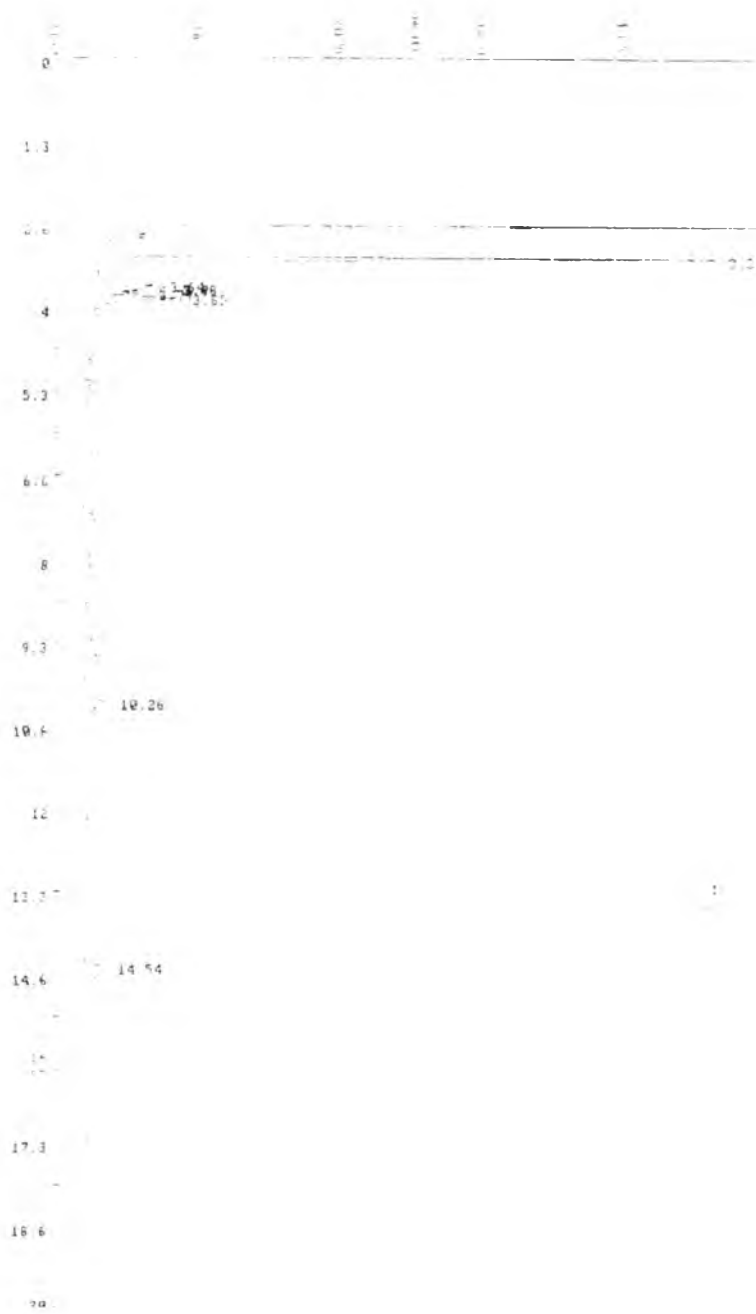


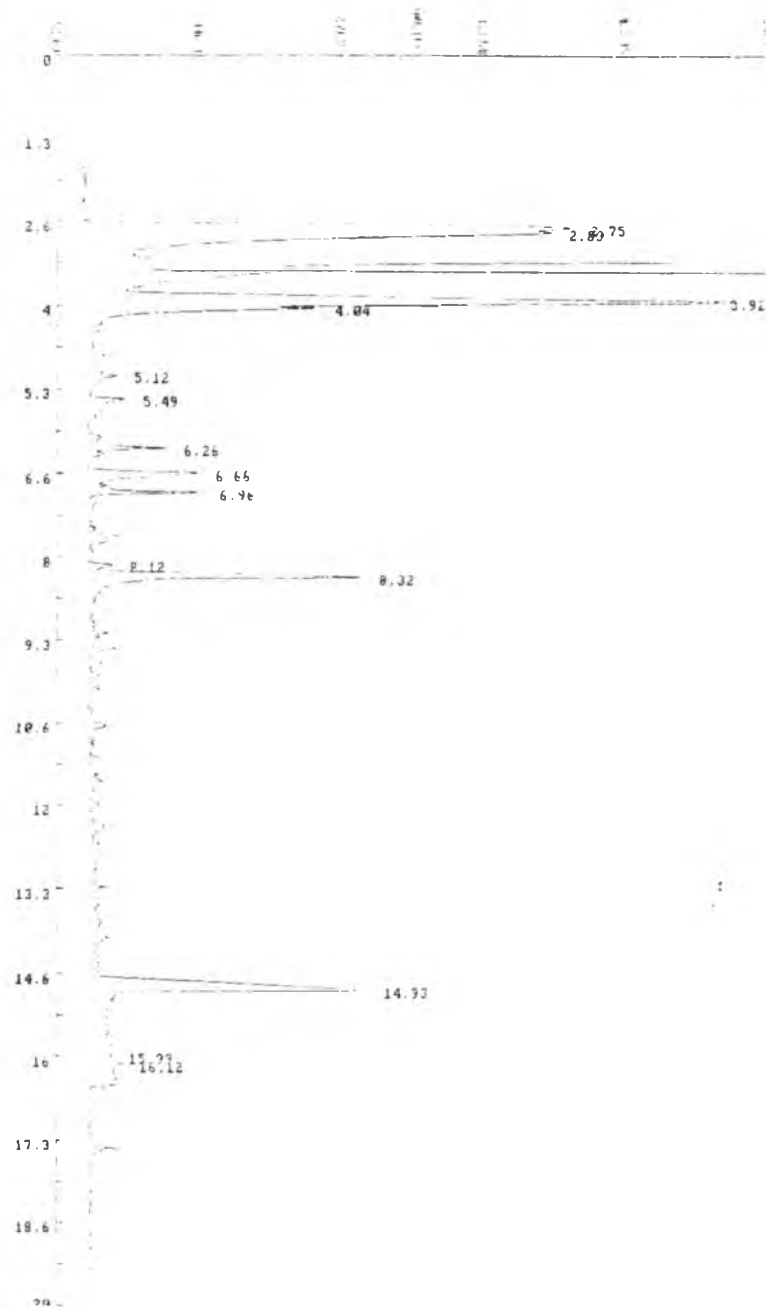
Figure 4-6 Pyrogram of highly soft film containing no fire retardant

Sample # : 2 Channel : Channel #1
Sample ID : 3.1F1 0 PHC Chromatogram : TCC



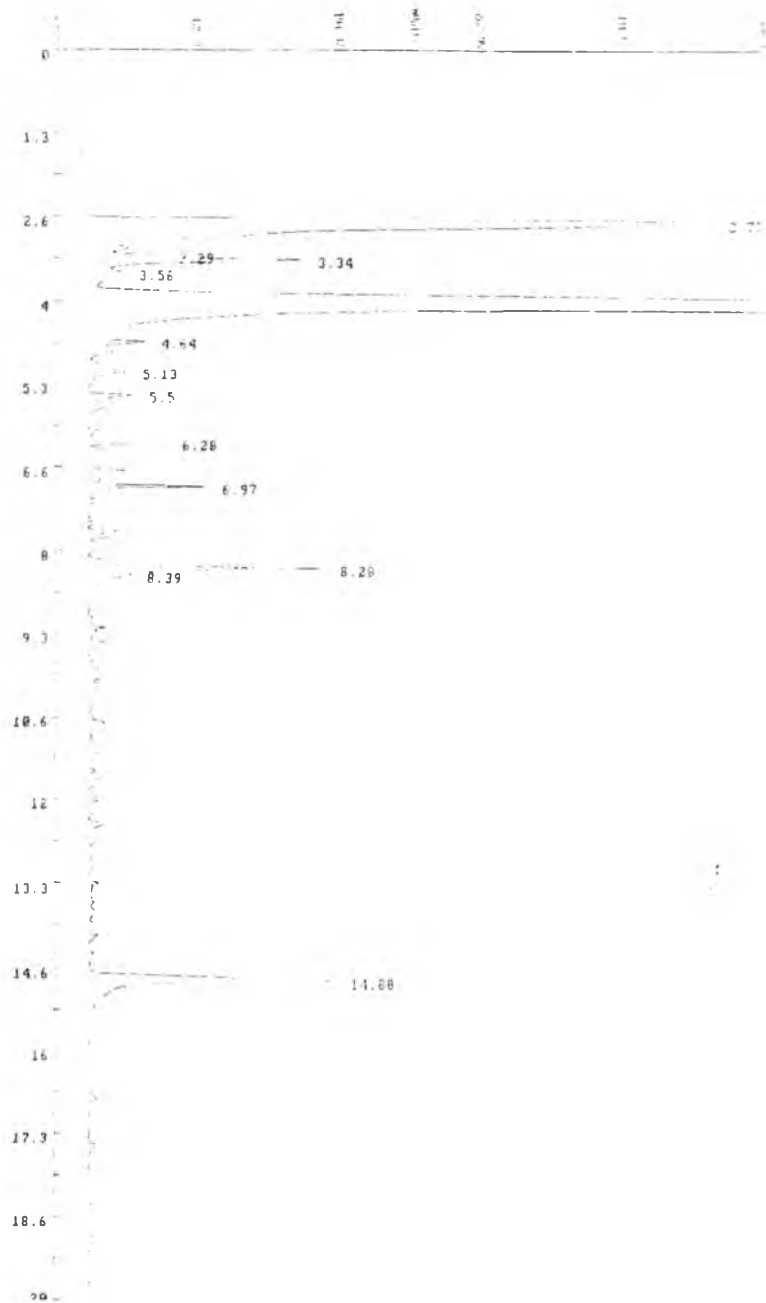
**Figure 4-7 Pyrogram of hard film containing 1% of ZHS
fire-retardant and Benzene**

Sample # : 2 Channel : Channel #1
Sample ID : ZHS 1 PHC+BENZEN Chromatogram : TA2



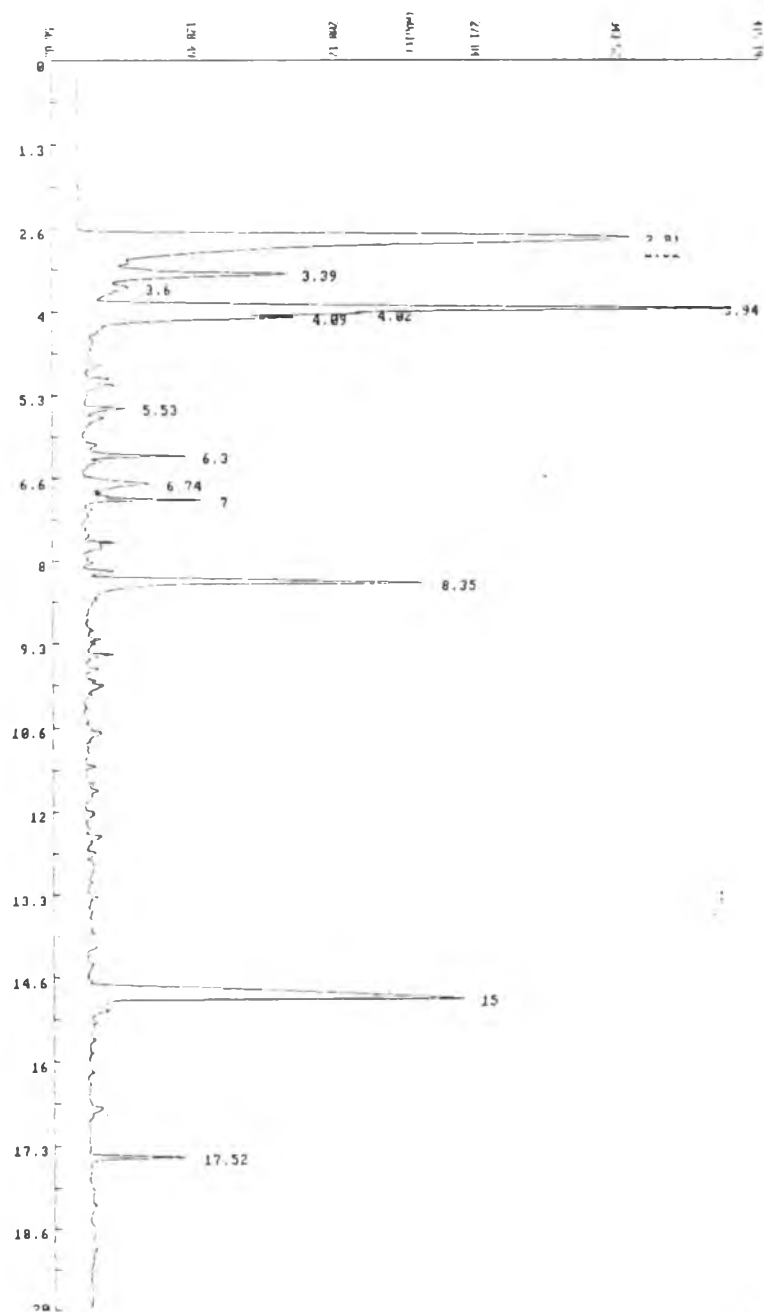
**Figure 4-8 Pyrogram of hard film containing 1% of ZHS
fire-retardant and Toluene**

Sample #: 4 Channel: Channel #1
Sample ID: ZHS 1 PHC+TOLLEN Chromatogram: T41



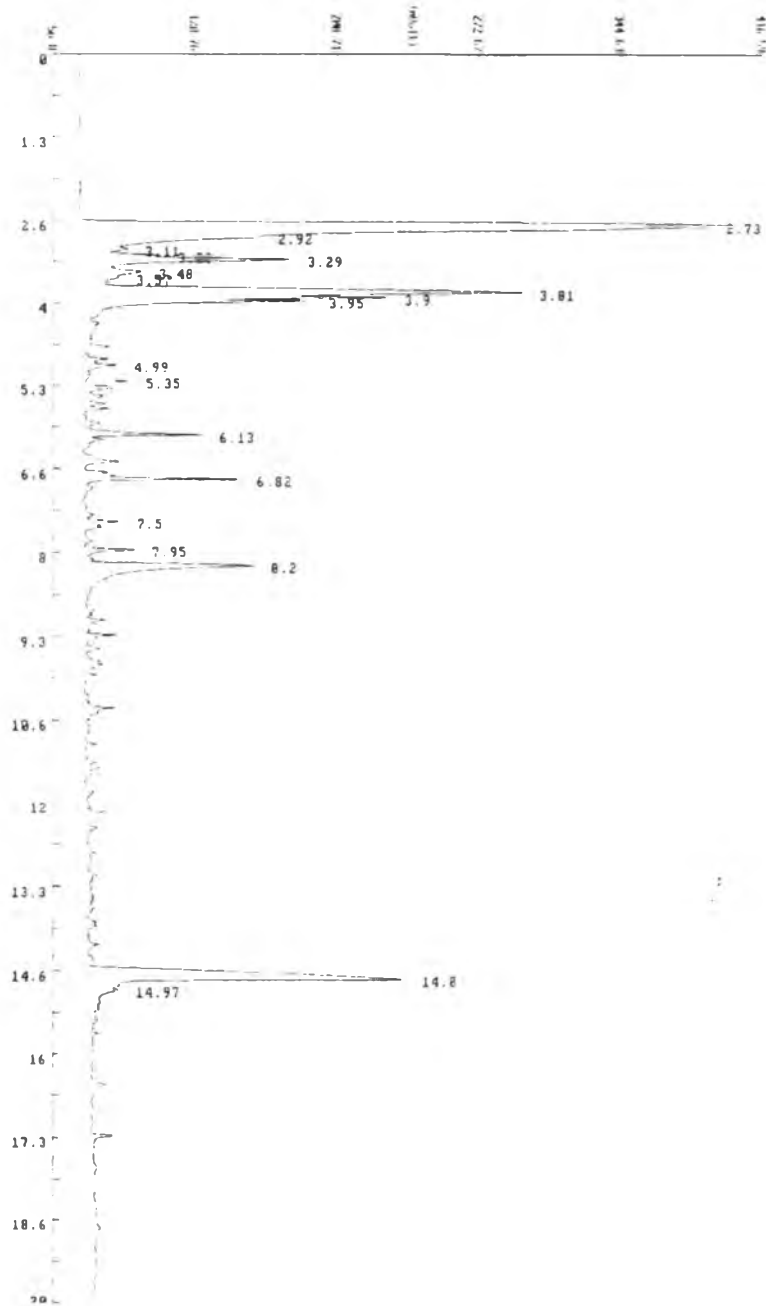
**Figure 4-9 Pyrogram of hard film containing 1% of ZHS
fire-retardant**

Sample # : 10 Channel : Channel #1
Sample ID : 1.1F2 ZHS 1 PHC Chromatogram : TA10



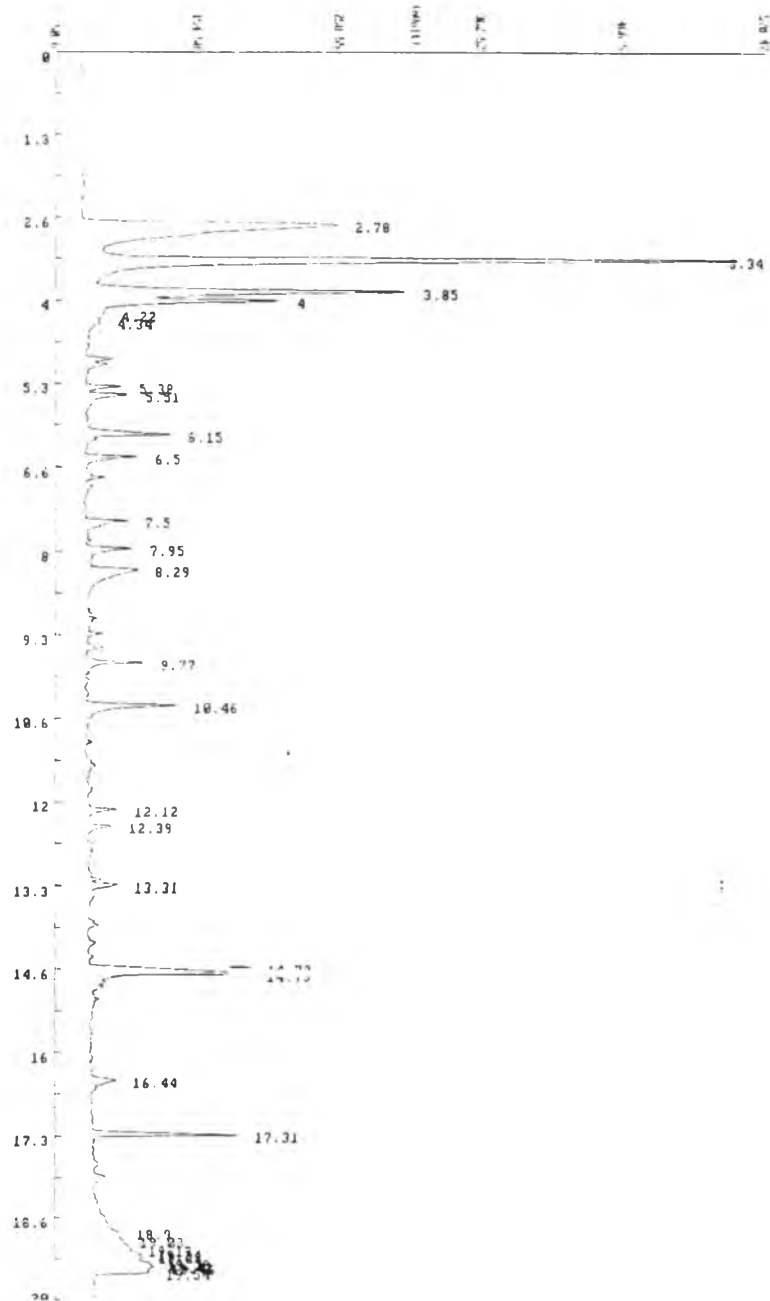
**Figure 4-10 Pyrogram of hard film containing 1% of ZS
fire-retardant**

Sample # : 24 Channel : Channel #1
Sample ID : 1.2F8 ZS 1 PHC Chromatogram : TA24



**Figure 4-11 Pyrogram of hard film containing 1% of Sb_2O_3
fire-retardant**

Sample # : 30 Channel : Channel #1
Sample ID : 1.3F14 Sb2O3 1 % Chromatogram : TA30



**Figure 4-12 Pyrogram of hard film containing 1% of AS
fire-retardant**

Sample # : 41 Channel : Channel #1
Sample ID : 1.4F20 AS 1 PHC Chromatogram : T41

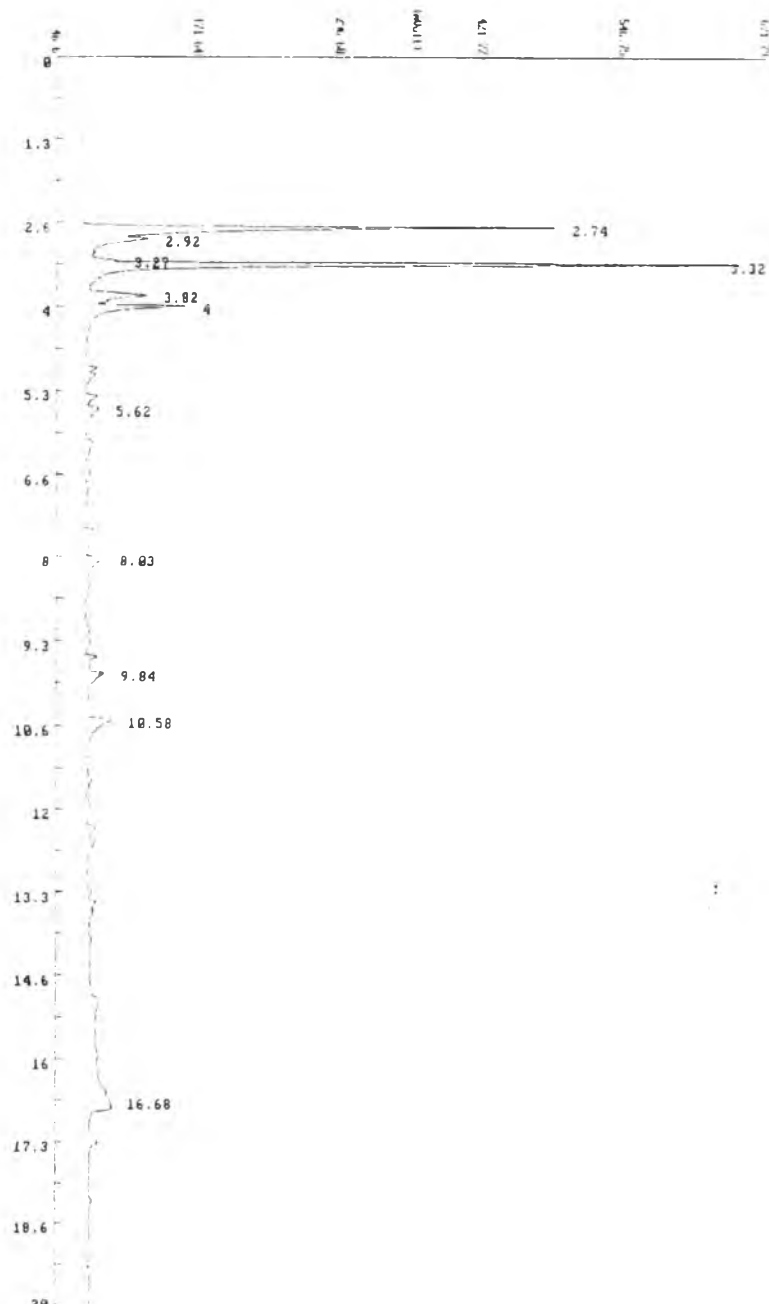


Figure 4-13 Effect of ZHS, ZS, Sb_2O_3 and AS on Hydrocarbon Evolution in Pyrolysis of hard film

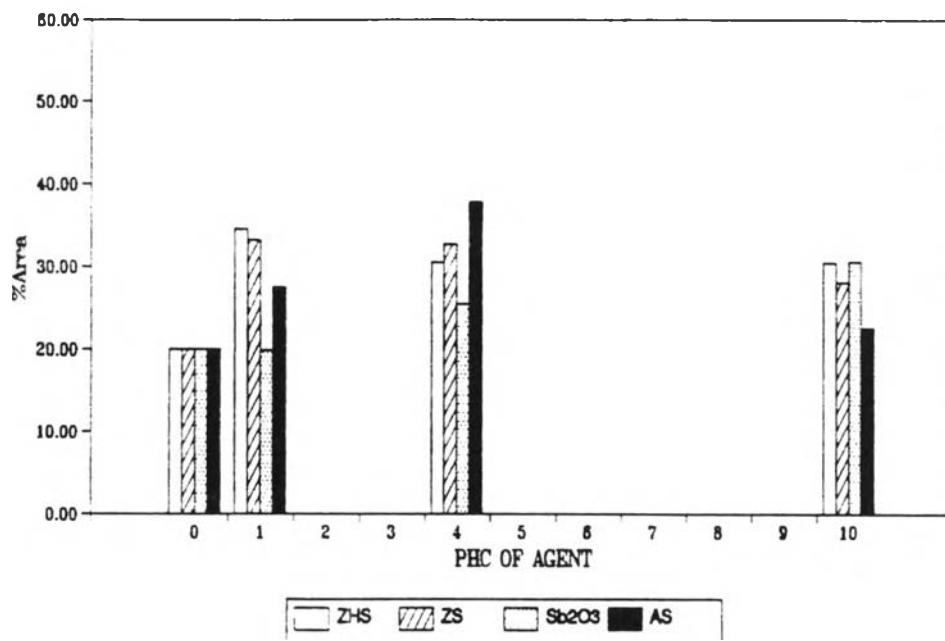


Figure 4-14 Effect of ZHS, ZS, Sb_2O_3 and AS on Hydrocarbon Evolution in Pyrolysis of soft film

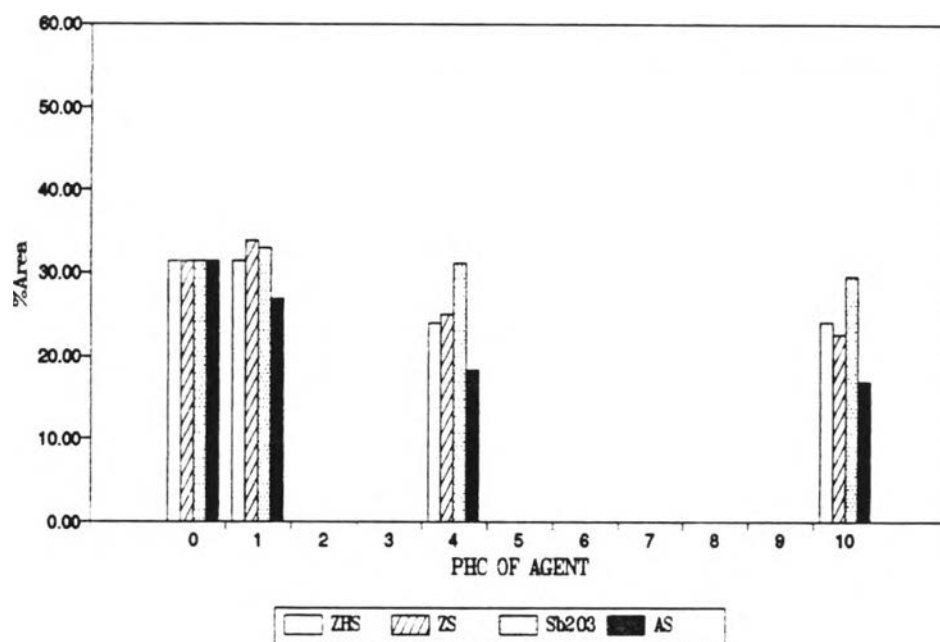


Figure 4-15 Effect of ZHS, ZS, Sb_2O_3 and AS on Hydrocarbon Evolution in Pyrolysis of highly soft film

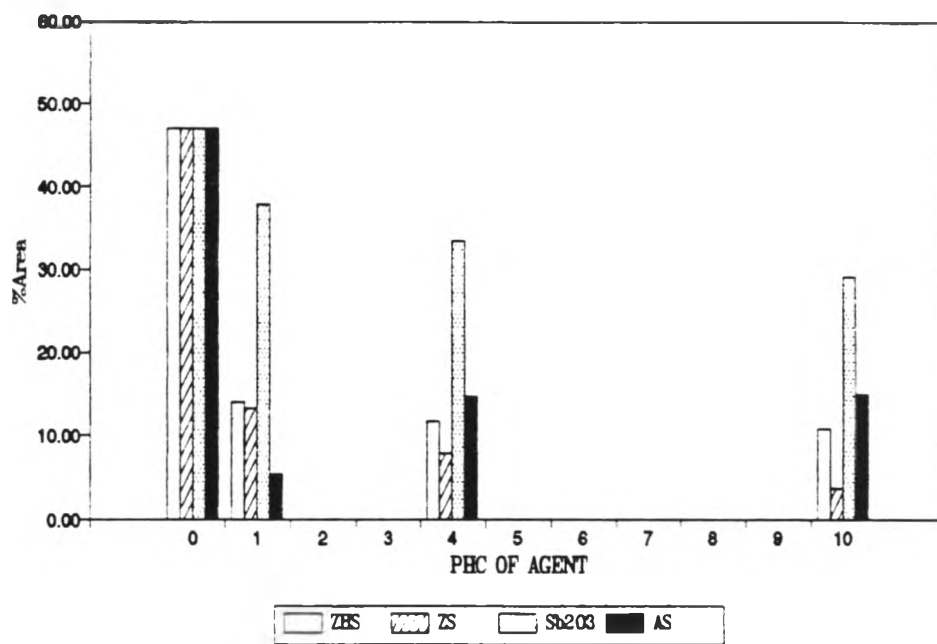


Figure 4-16 Effect of ZHS, ZS, Sb_2O_3 and AS on Benzene Evolution in Pyrolysis of hard film

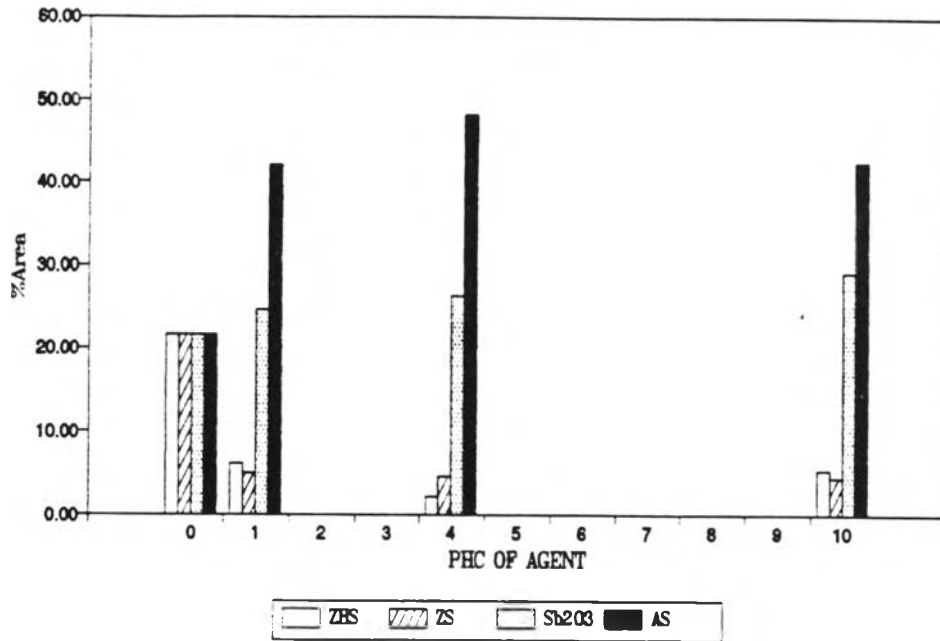


Figure 4-17 Effect of ZHS, ZS, Sb_2O_3 and AS on Benzene Evolution in Pyrolysis of soft film

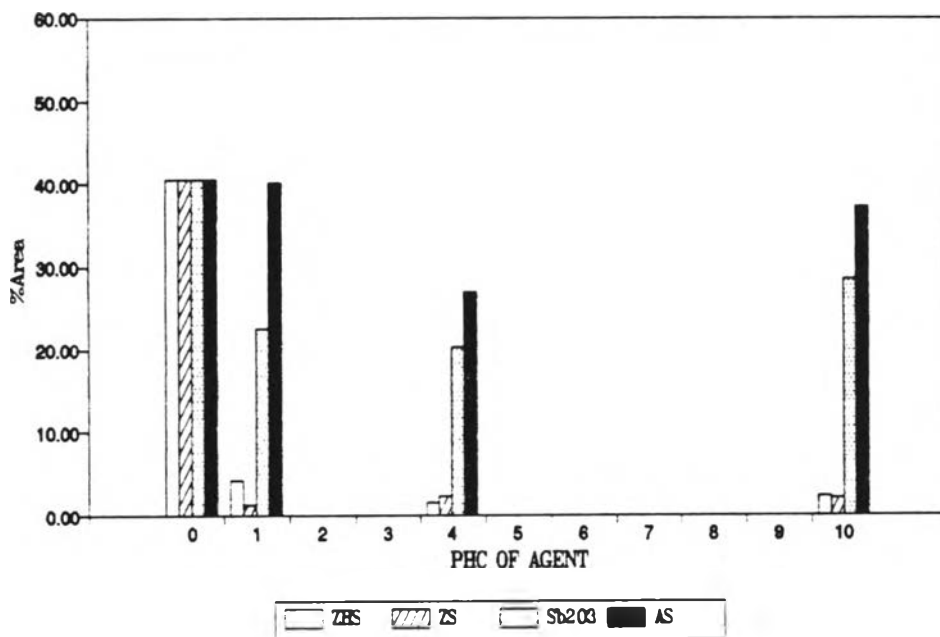


Figure 4-18 Effect of ZHS, ZS, Sb₂O₃ and AS on Benzene Evolution in Pyrolysis of highly soft film

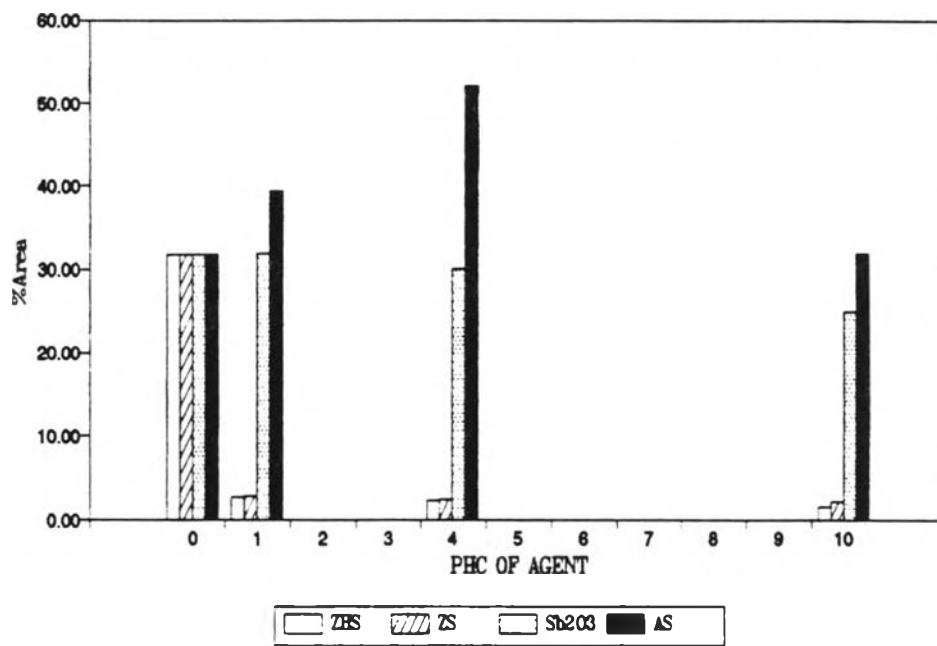


Figure 4-19 Effect of ZHS, ZS, Sb_2O_3 and AS on Toluene Evolution in Pyrolysis of hard film

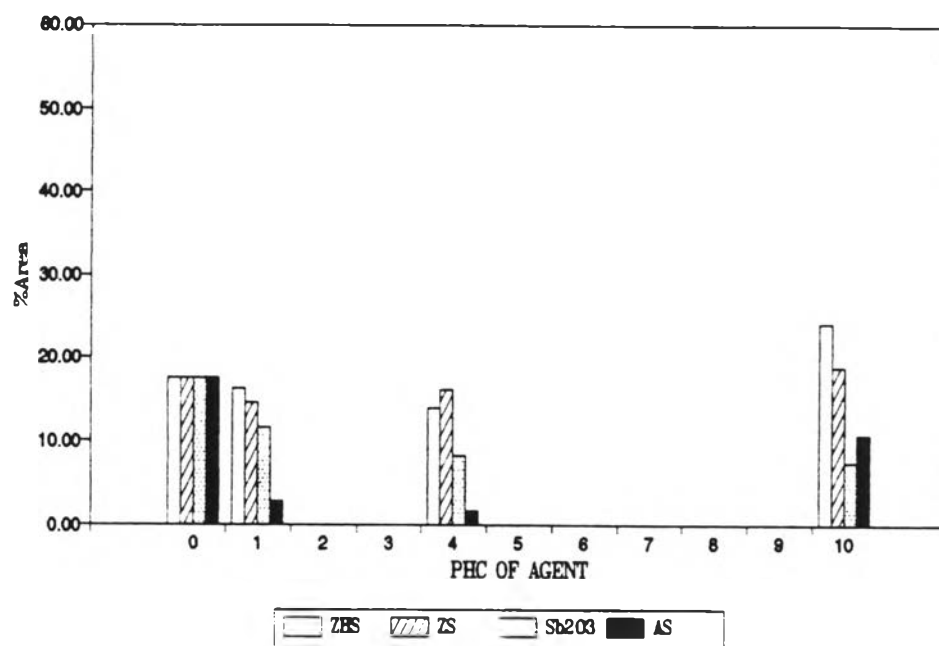


Figure 4-20 Effect of ZHS, ZS, Sb_2O_3 and AS on Toluene Evolution in Pyrolysis of soft film

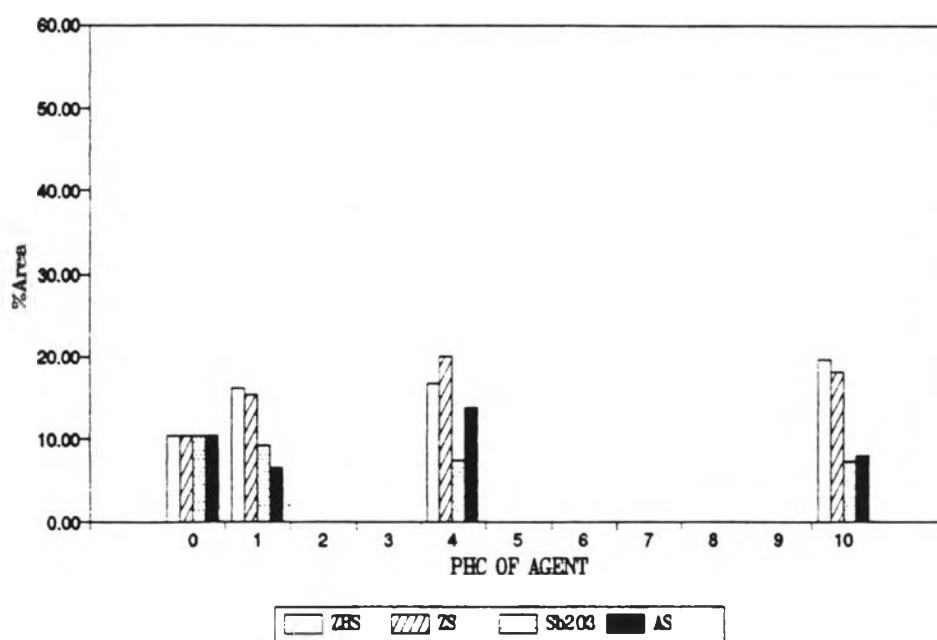


Figure 4-21 Effect of ZHS, ZS, Sb_2O_3 , and AS on Toluene Evolution in Pyrolysis of highly soft film

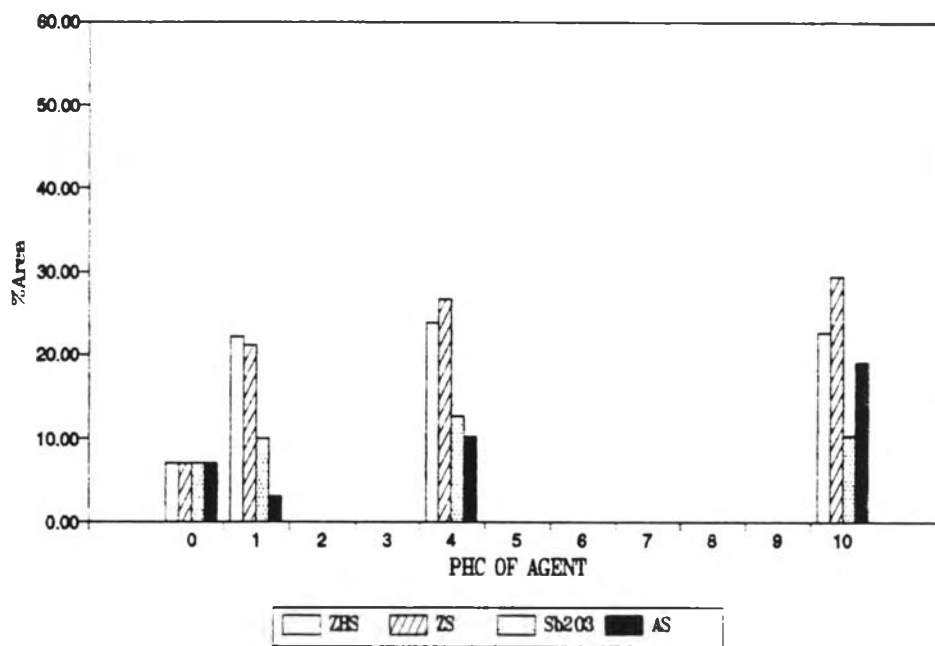


Figure 4-22 Effect of ZHS, ZS, Sb₂O₃ and AS on Tensile Strength of hard film in mechanical direction

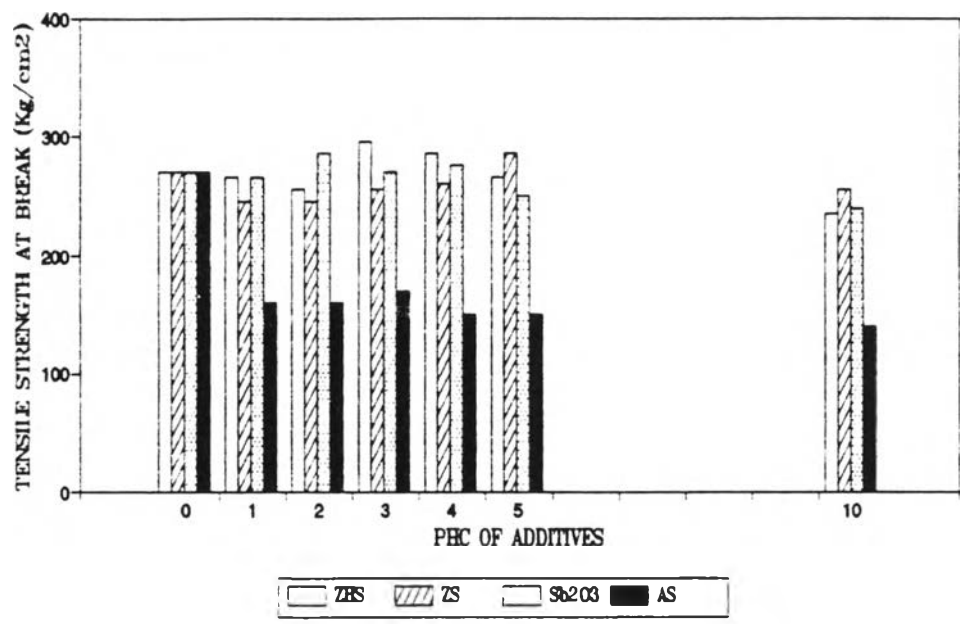


Figure 4-23 Effect of ZHS, ZS, Sb₂O₃ and AS on Tensile Strength of hard film in transverse direction

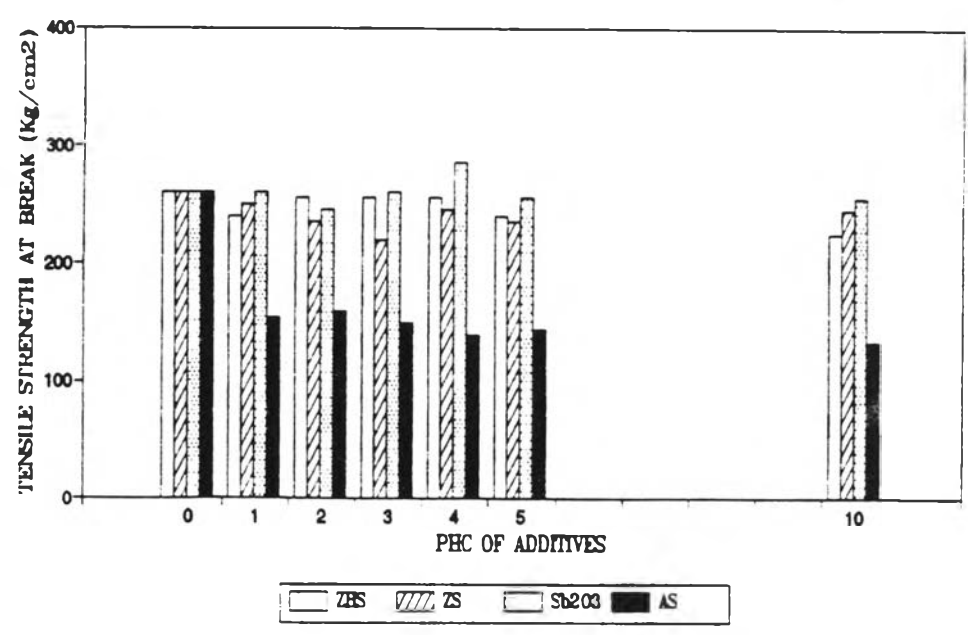


Figure 4-24 Effect of ZHS, ZS, Sb_2O_3 and AS on Elongation of hard film in mechanical direction

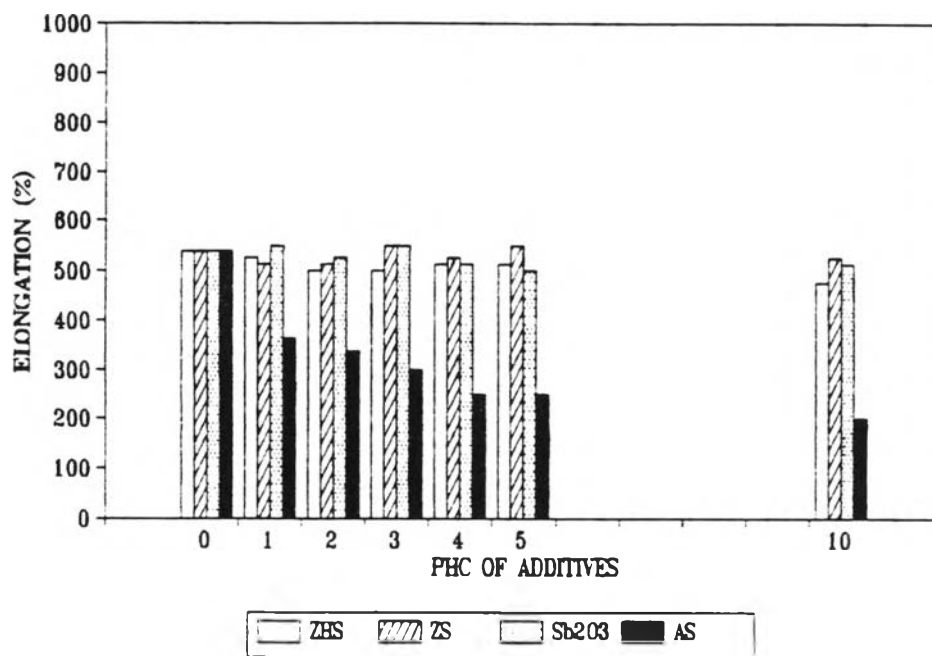


Figure 4-25 Effect of ZHS, ZS, Sb_2O_3 and AS on Elongation of hard film in transverse direction

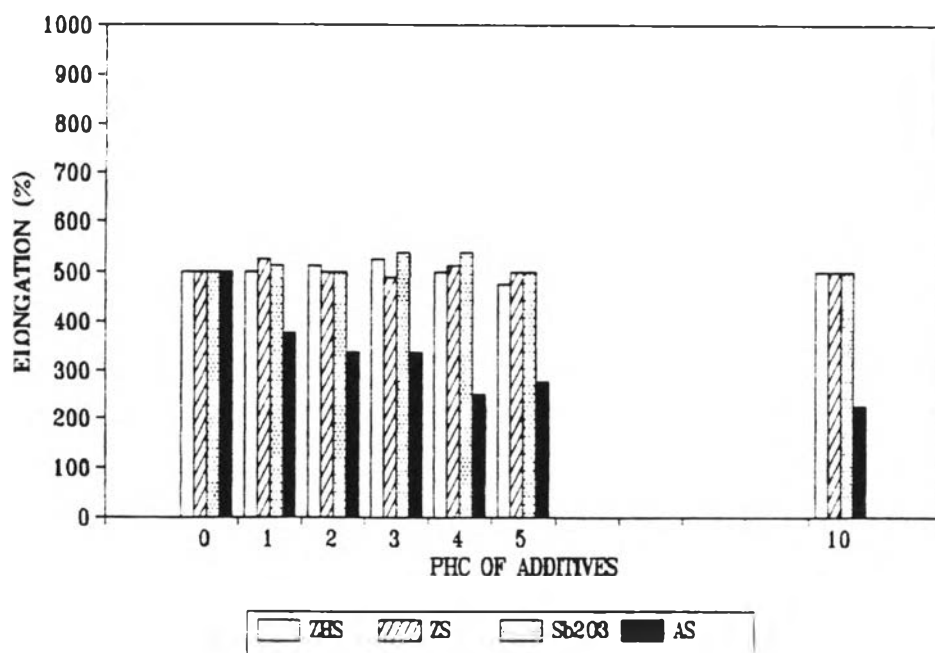


Figure 4-26 Effect of ZHS, ZS, Sb₂O₃ and AS on Tear Strength of hard film in mechanical direction

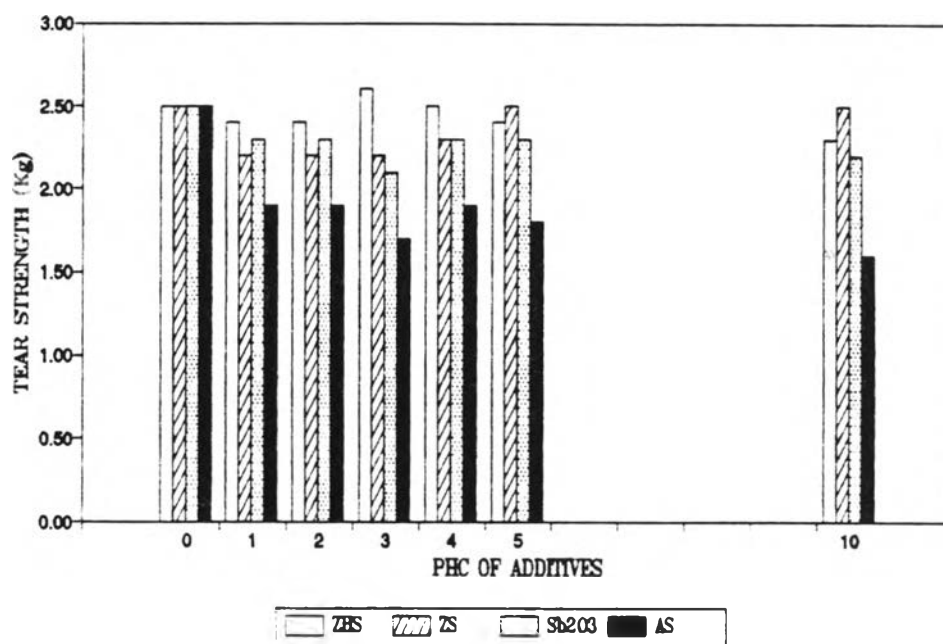


Figure 4-27 Effect of ZHS, ZS, Sb₂O₃ and AS on Tear Strength of hard film in transverse direction

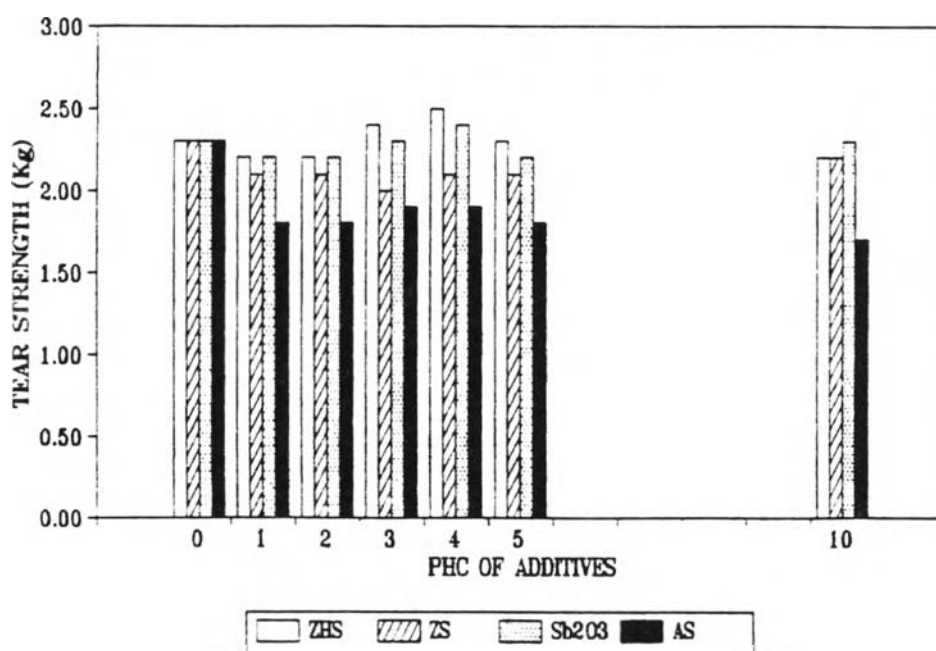


Figure 4-28 Effect of ZHS, ZS, Sb_2O_3 and AS on Tensile Strength of soft film in mechanical direction

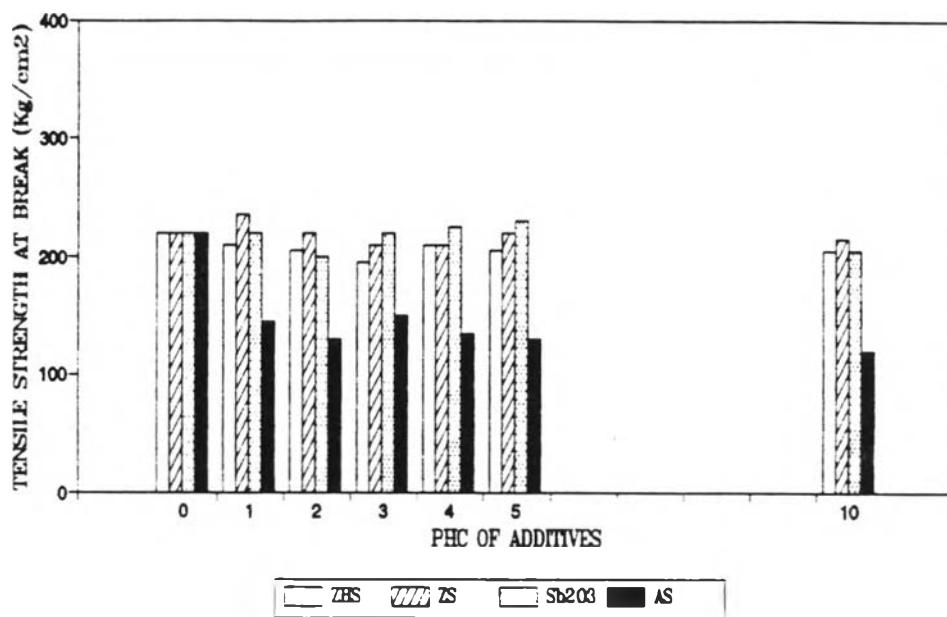


Figure 4-29 Effect of ZHS, ZS, Sb_2O_3 and AS on Tensile Strength of soft film in transverse direction

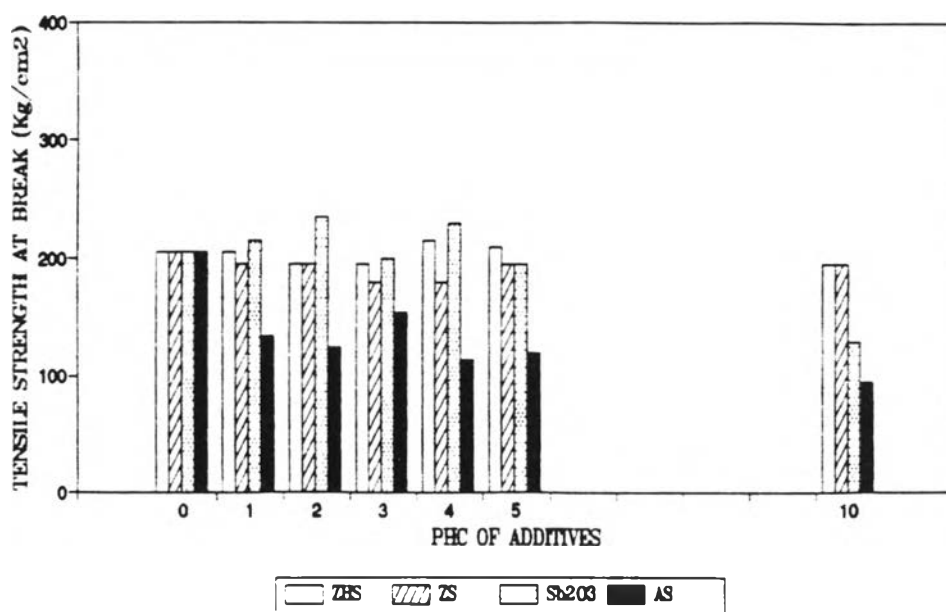


Figure 4-30 Effect of ZHS, ZS, Sb_2O_3 and AS on Elongation of soft film in mechanical direction

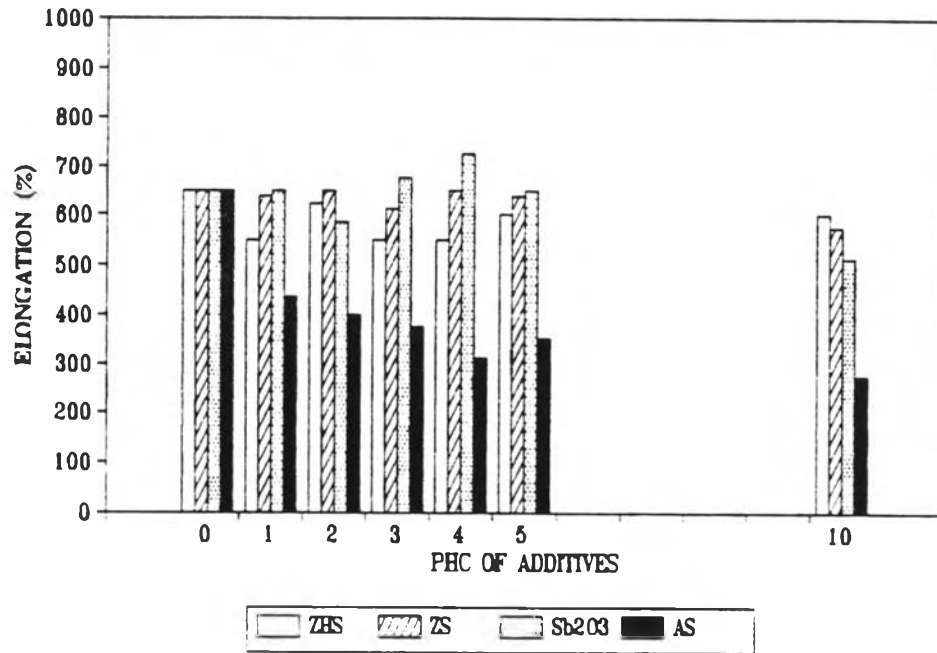


Figure 4-31 Effect of ZHS, ZS, Sb_2O_3 and AS on Elongation of soft film in transverse direction

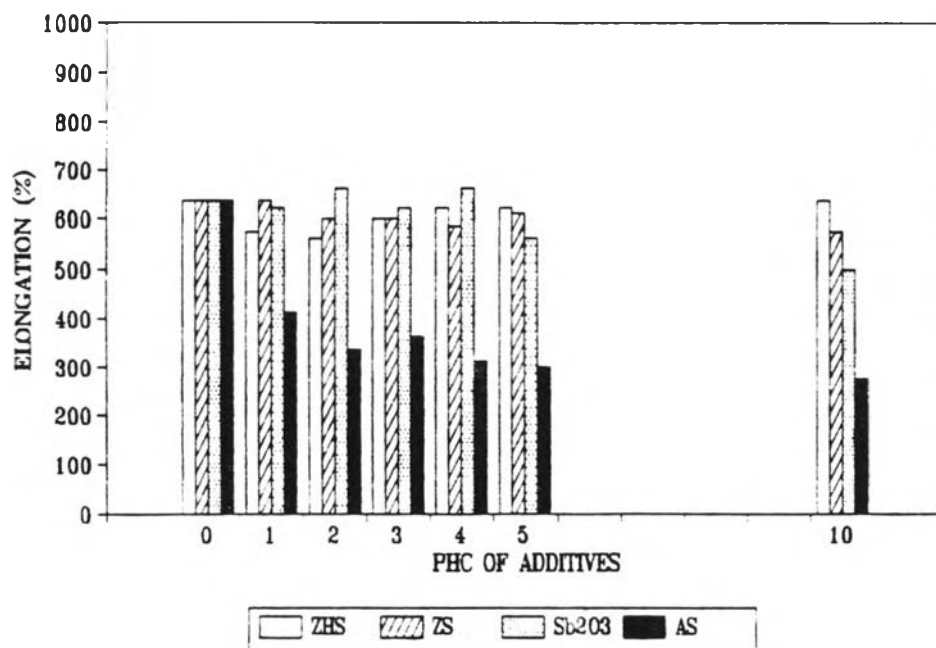


Figure 4-32 Effect of ZHS, ZS, Sb_2O_3 and AS on Tear Strength of soft film in mechanical direction

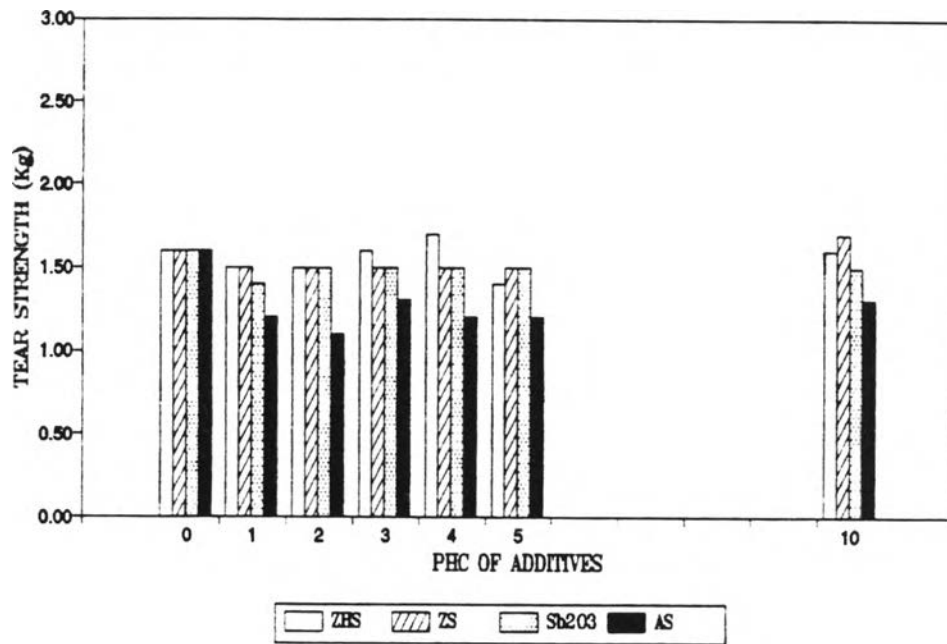


Figure 4-33 Effect of ZHS, ZS, Sb_2O_3 and AS on Tear Strength of soft film in transverse direction

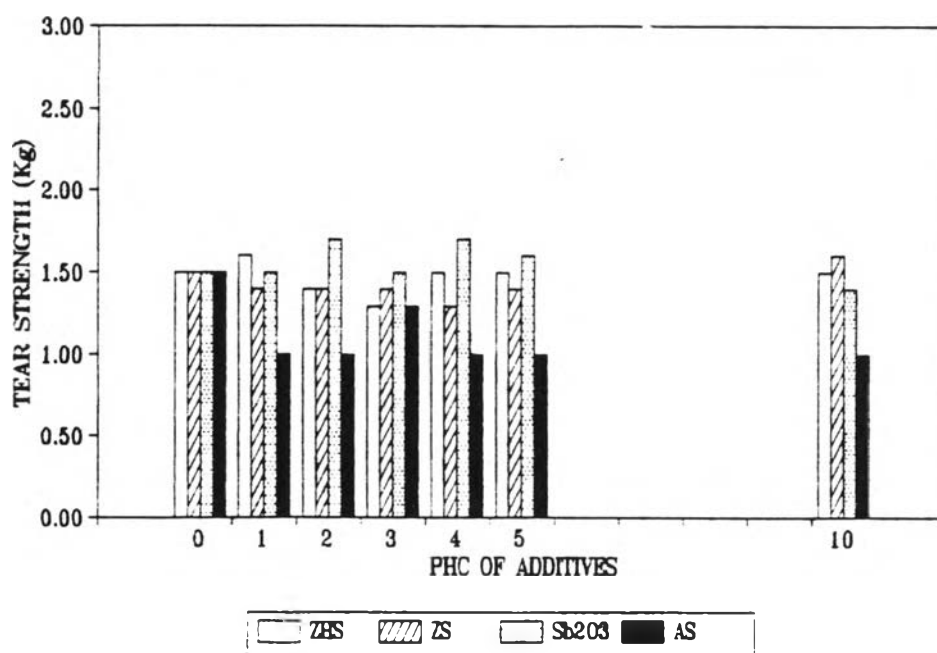


Figure 4-34 Effect of ZHS, ZS, Sb₂O₃ and AS on Tensile Strength of highly soft film in mechanical direction

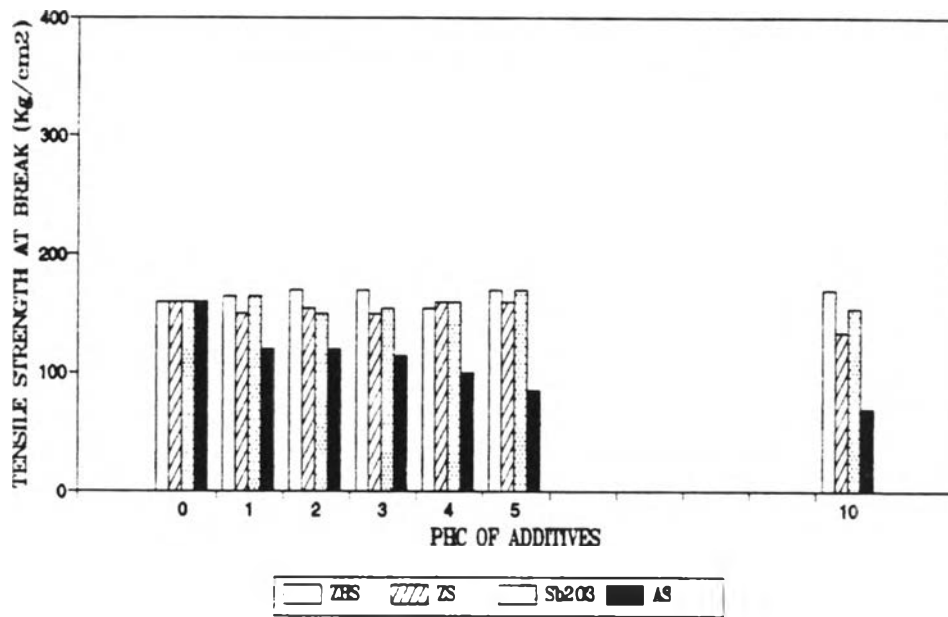


Figure 4-35 Effect of ZHS, ZS, Sb₂O₃ and AS on Tensile Strength of highly soft film in transverse direction

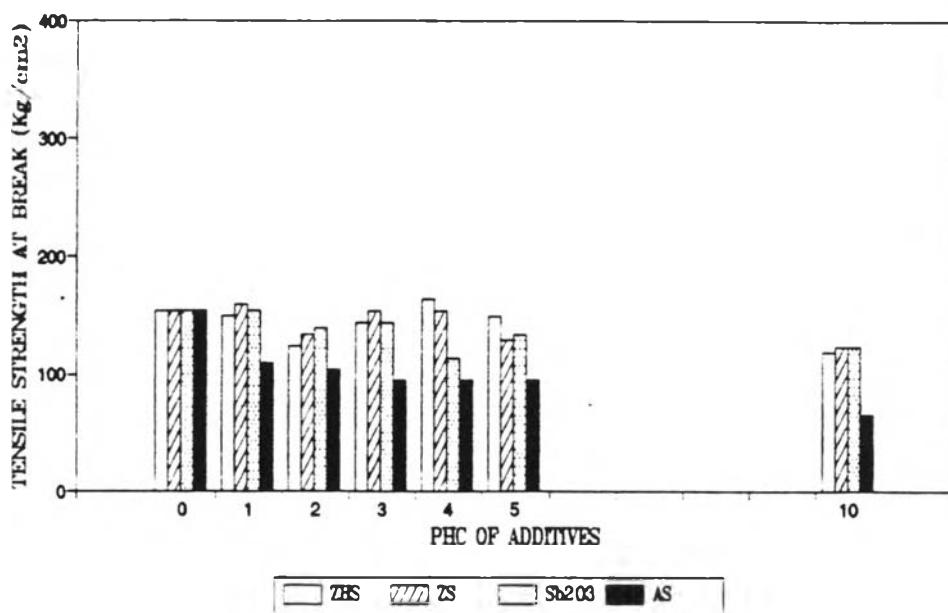


Figure 4-36 Effect of ZHS, ZS, Sb_2O_3 and AS on Elongation of highly soft film in mechanical direction

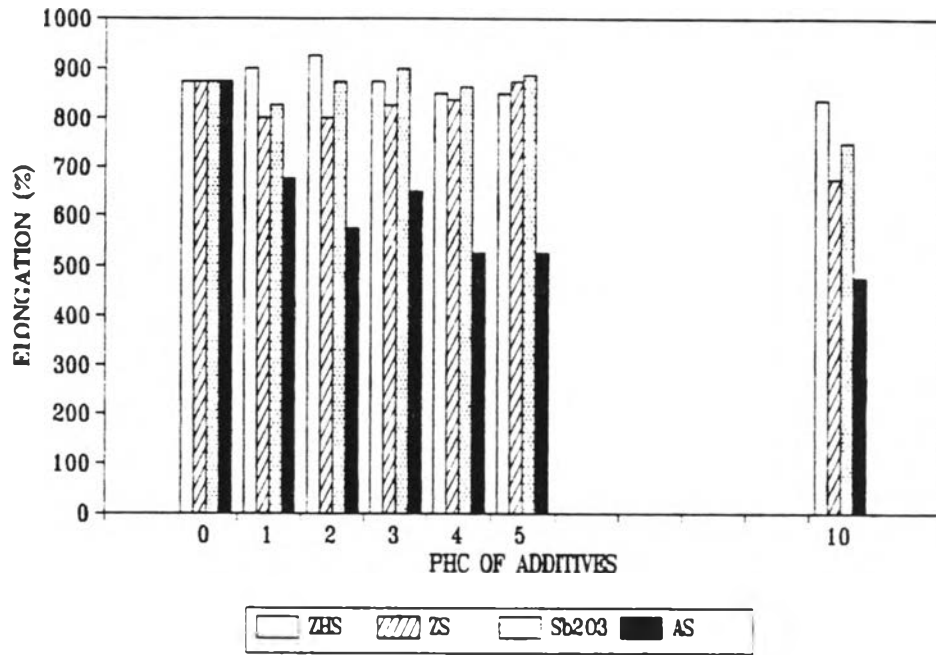


Figure 4-37 Effect of ZHS, ZS, Sb_2O_3 and AS on Elongation of highly soft film in transverse direction

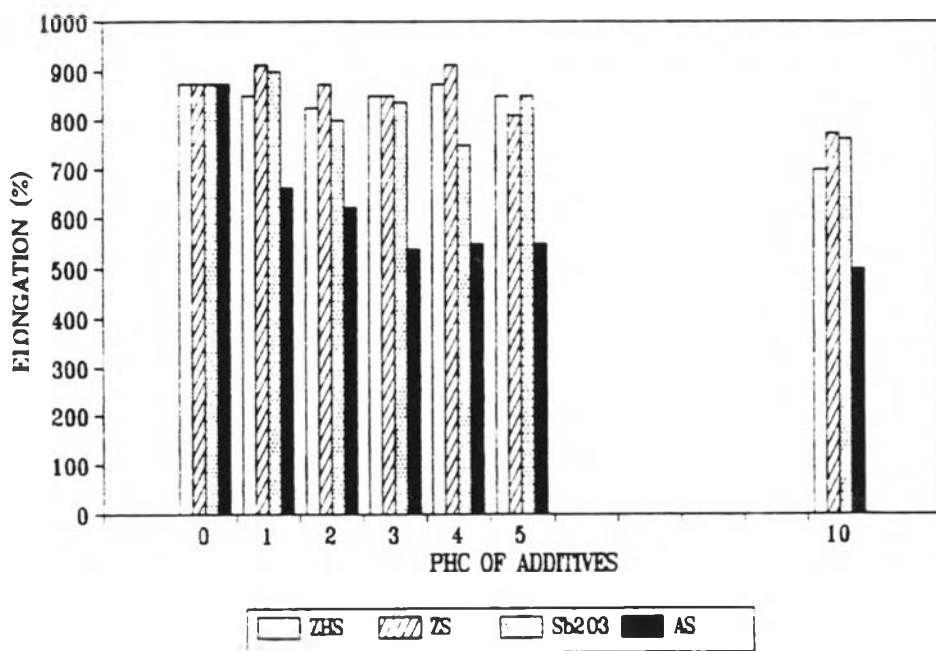


Figure 4-38 Effect of ZHS, ZS, Sb_2O_3 and AS on Tear Strength of highly soft film in mechanical direction

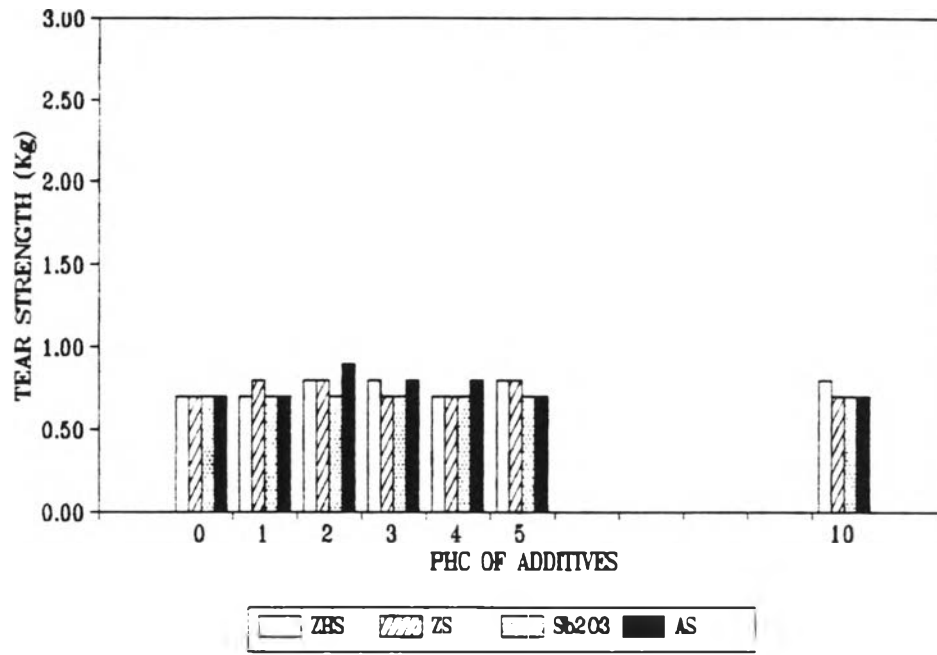


Figure 4-39 Effect of ZHS, ZS, Sb_2O_3 and AS on Tear Strength of highly soft film in transverse direction

