CHAPTER V

RESULTS AND DISCUSSION

In this chapter, the experimental results are analyzed.

5.1 OPTIMUM COMPOSITION OF PVA SPONGE

5.1.1 FOAMING

For the polyvinyl alcohol-formaldehyde system, froth volume and stability depend on two parameters:

- Molecular weight of PVA resin
- Surfactant

Experimental results are presented in Tables 5.1 and 5.2.

5.1.1.1 Molecular Weight of Polyvinyl Alcohol

The molecular weight of the polyvinyl alcohol is a major factor in determining the ultimate density of the foam. Figure 5.1 shows that the froth volume depends on the molecular weight of the polyvinyl alcohol solution. As the molecular weight of the resin increases the froth is more stabilized and the lowest-density foams are produced as shown in Figure 5.2. From these data, the molecular weight of the polyvinyl alcohol of about 64,500 are the desire molecular weight since it has been found that improved uniformity of pore size can be obtained therewith.

Table 5.1 Effect of molecular weight of polyvinyl alcohol and sodium lauryl sulfate quantity on froth volume.

Formulation

polyvinyl alcohol [10% aqueous solution]	40 g
sulfuric acid [98% concentration]	$6.0\ cm^3$
formaldehyde[37% aqueous solution]	$5.0\ cm^3$
sodium lauryl sulfate	variable

froth volume, cm^3

sodium lauryl sulfate, g \ MW.of PVA	115,000	72,000	64,500	43,000
0.2	140	120	120	110
0.4	180	160	150	140
0.6	240	230	220	180
0.8	260	230	220	200
1.0	250	220	220	210

5.1.1.2 Surfactant

In the sponge synthesis process, the solution containing surfactant, acid, and formaldehyde, is whipped into a stable froth. The volume of froth is dependent on the surface tension and viscosity of aqueous solution. Figure 5.1 shows the effect of the concentration of surfactant on froth volume. The data show that there is a maximum froth volume at the concentration of the sodium lauryl sulfate of 0.6 gram or about 1.0 % by weight. If the amounts of sodium lauryl sulfate is in excess of 1.0 % by weight, it will result in stiffer foams prior to curing and formation of sponges having a relatively small pore size is promoted, When employing sodium lauryl sulfate less than 1.0 % by the resultant sponge exhibits a relatively large non-uniform pore size.

Table 5.2 Effect of molecular weight of polyvinyl alcohol and sodium lauryl sulfate

quantity on final foam density

formulation as given in Table 5.1

foam density, g/cm^3

MW.of PVA / sodium lauryl sulfate, g	115,000	72,000	64,500	43,000
0.2	0.071	0.075	0.086	-
0.4	0.060	0.066	0.069	-
0.6	0.052	0.062	0.067	0.140
0.8	0.046	0.058	0.062	0.153
1.0	0.045	0.056	0.058	0.155

5.1.2 DEGREE OF CROSS-LINKING

The following factors which effect the degree of cross-linking were observed in this study.

- formaldehyde concentration

- concentration of acid

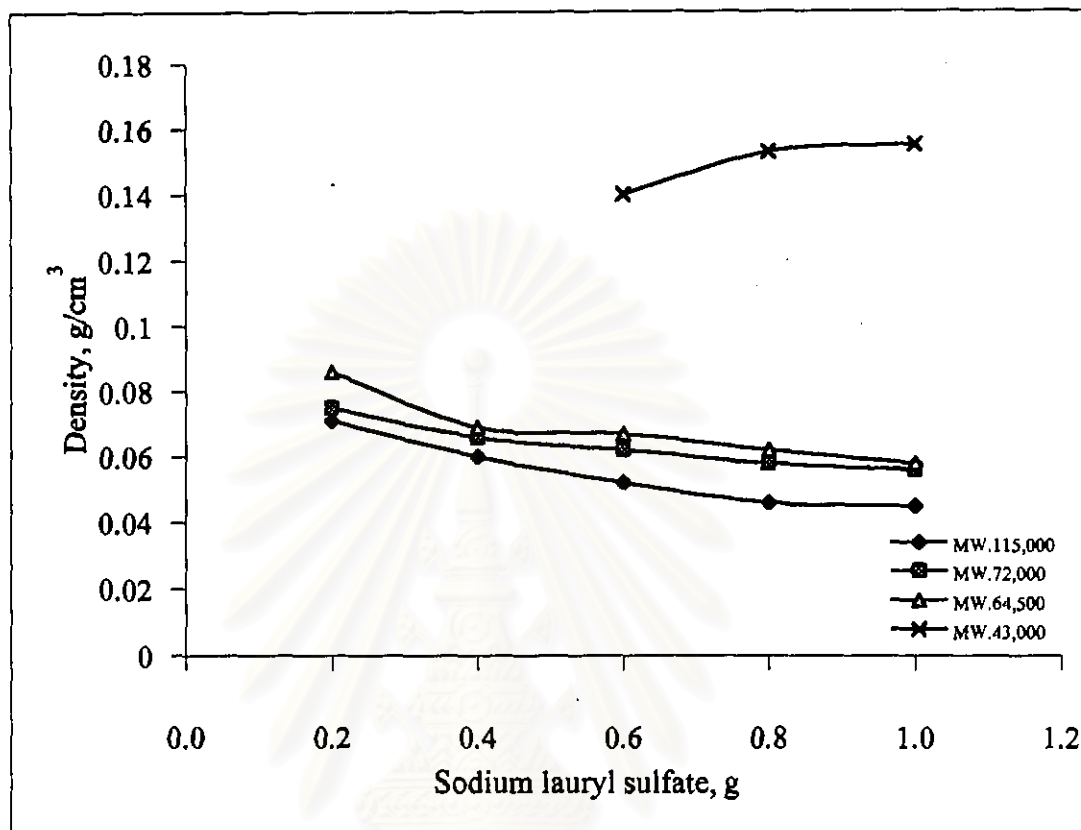- curing time

- agitation rate

The experimental results are presented in Table 5.3 through 5.6. In these experiments, quantity of sodium lauryl sulfate that yield maximum froth volume was used, i.e., 0.6 g.
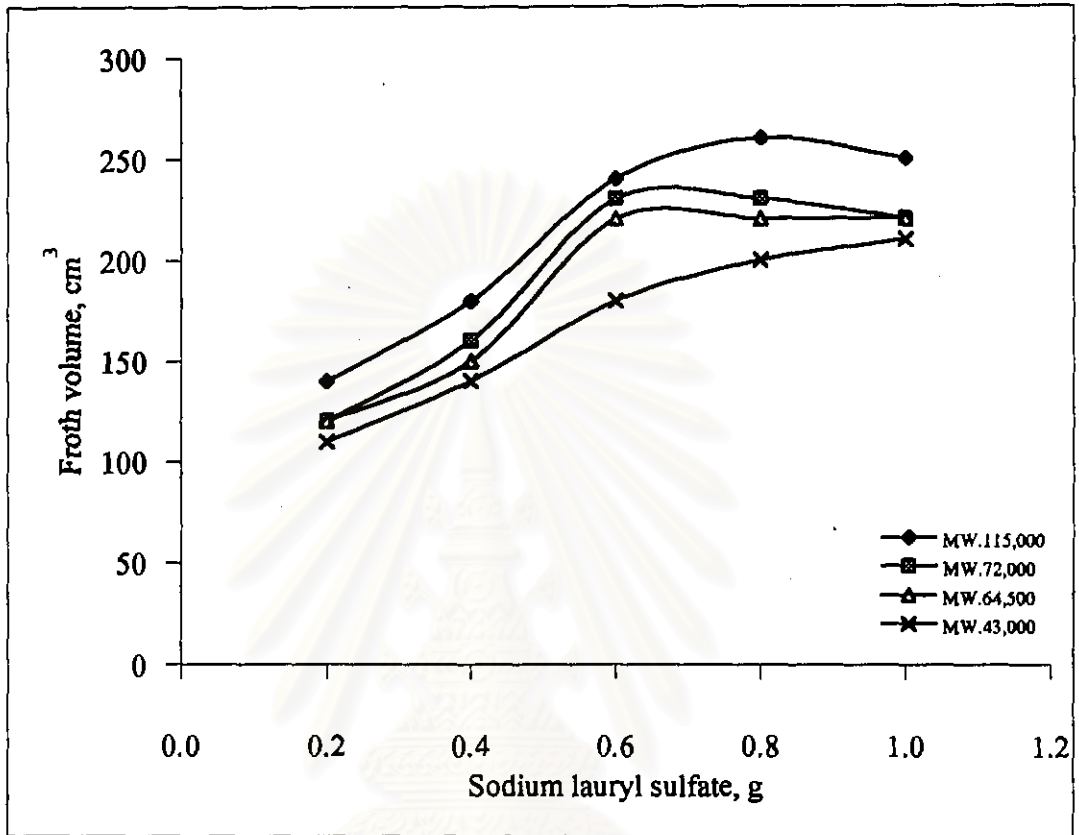
(based on data in Table 5.1)

Figure 5.1 Effect of molecular weight of polyvinyl alcohol and sodium lauryl

sulfate quantity on froth volume

(based on data in Table 5.2)

Figure 5.2 Effect of molecular weight of polyvinyl alcohol and sodium lauryl

sulfate quantity on final foam density

5.1.2.1 Formaldehyde Concentration

Previous data revealed that the froth volume was dependent on the molecular weight of polyvinyl alcohol and concentration of surfactant. Comparing Figure 5.1 with Figure 5.3, shows that the molecular weight of the starting resins and the formaldehyde concentration (cross-linking agent) result in minor effects on the froth volume as compared to the surfactant effects. From these data polyvinyl alcohol resins of lower molecular weight requires more formaldehyde to react to produce insoluble gel than the higher-molecular weight resins. Experimental results show that the properties of sponge depend on the molecular weight of polyvinyl alcohol as well as formaldehyde concentration. For example, for polyvinyl alcohol of molecular weight 64,500, the optimum concentration of formaldehyde is about 8.0 cm^3 or about 13.44 % by weight. When formaldehyde of less than 13.44 % is used, the resultant sponge exhibits undesired weak mechanical properties and, therefore, it is not useful. When more than 13.44 % by weight formaldehyde is reacted, the resultant product is stronger but more abrasive to such a degree as render it not reasonably useful as a filter.

5.1.2.2 Concentration of Acid

In Table 5.5, the results of this study are shown using various concentration of acid. Increasing the amount of sulfuric acid increases froth volume. If the froth volume is increased too greatly, the froth either gives a weak product or partially collapses before being cure. Figure 5.5 shows the effect of acid concentration on final foam density. The lowest-density product was obtained when the concentration of acid was about 8.0 cm^3 or about 23.03 % by weight, for the polyvinyl alcohol aqueous solution having an average molecular weight of about 64,500, if more than 23.03 % of acid was used, partial foam collapse resulted and a higher-density foam was yielded.

Table 5.3 Effect of formaldehyde concentration on froth volume

Formulation

polyvinyl alcohol [10% aqueous solution]	40 g
sulfuric acid [98% concentration]	6.0 cm^3
formaldehyde[37% aqueous solution]	variable
sodium lauryl sulfate	0.6 g

froth volume, cm^3

MW.of PVA / formaldehyde, cm^3	115,000	72,000	64,500	43,000
4.0	220	210	210	160
6.0	240	230	230	180
8.0	250	240	230	180
10.0	250	240	240	200
12.0	250	240	240	210

Table 5.4 Effect of formaldehyde concentration on final foam density

formulation as given in Table 5.3

foam density, g/cm^3

MW.of PVA / formaldehyde, cm^3	115,000	72,000	64,500	43,000
4.0	0.082	0.070	0.072	-
6.0	0.054	0.045	0.046	-
8.0	0.037	0.040	0.041	0.061
10.0	0.040	0.043	0.038	0.056
12.0	0.042	0.042	0.040	0.044
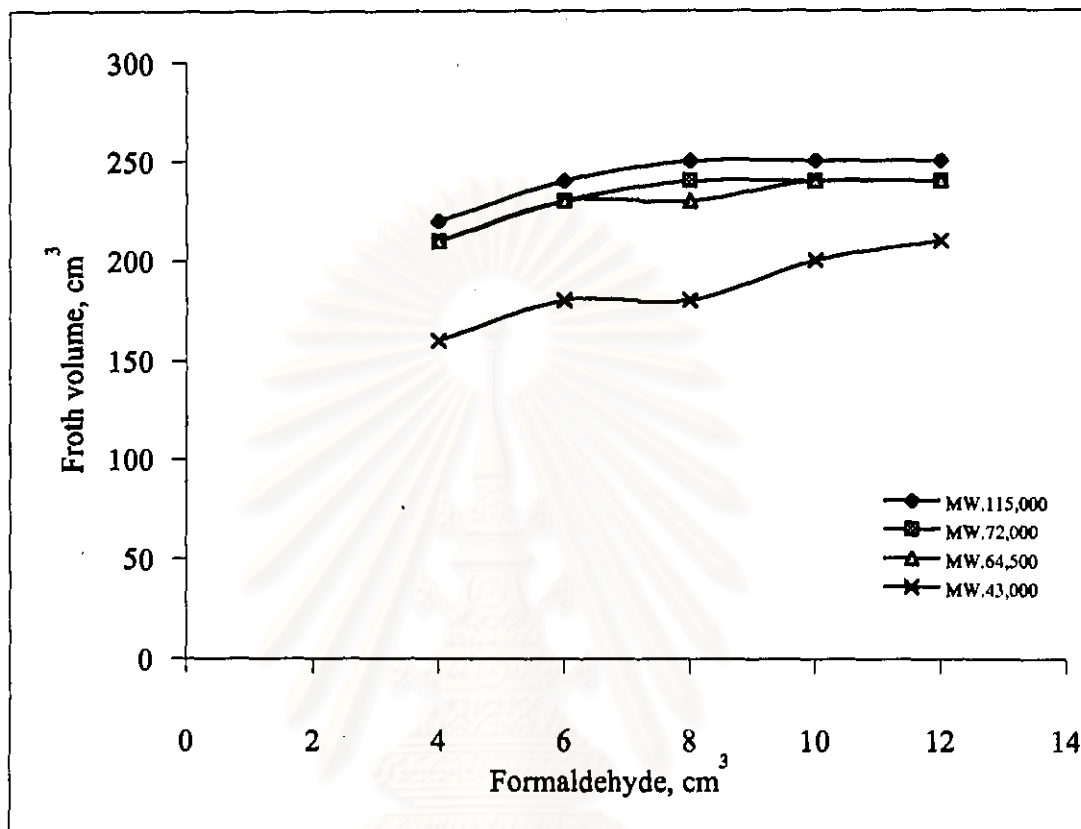
(based on data in Table 5.3)

Figure 5.3 Effect of formaldehyde concentration on froth volume
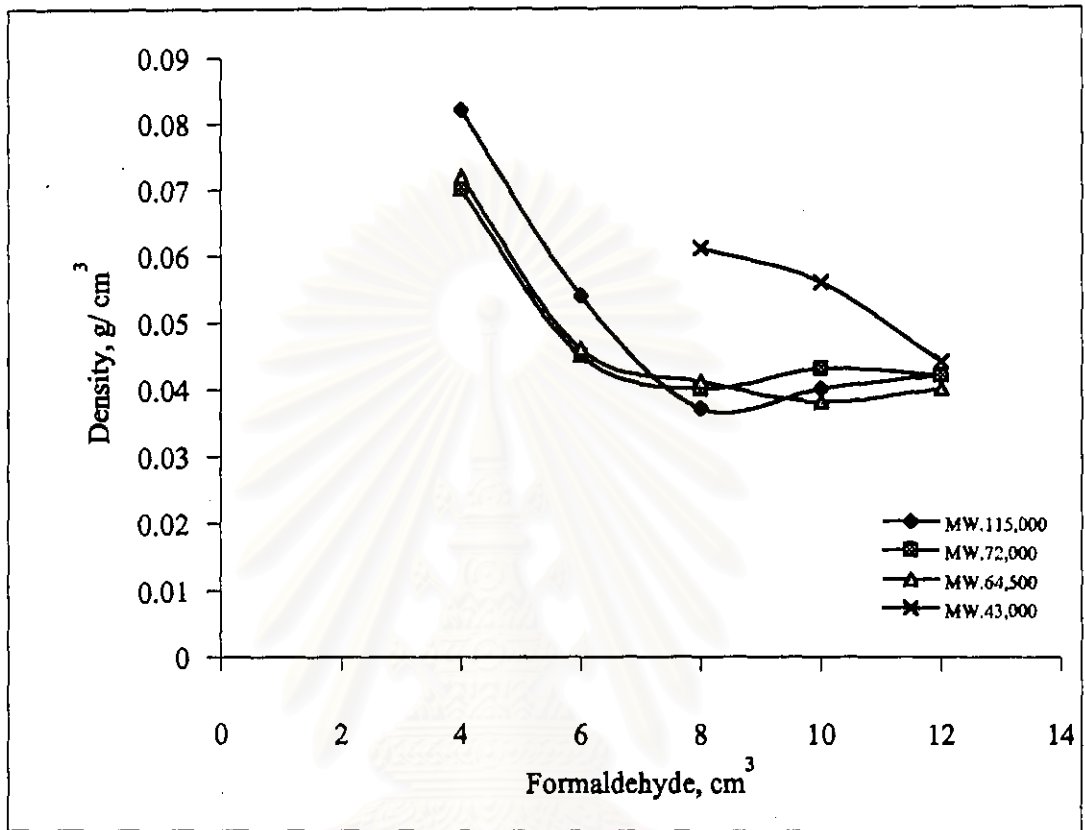
(based on data in Table 5.4)

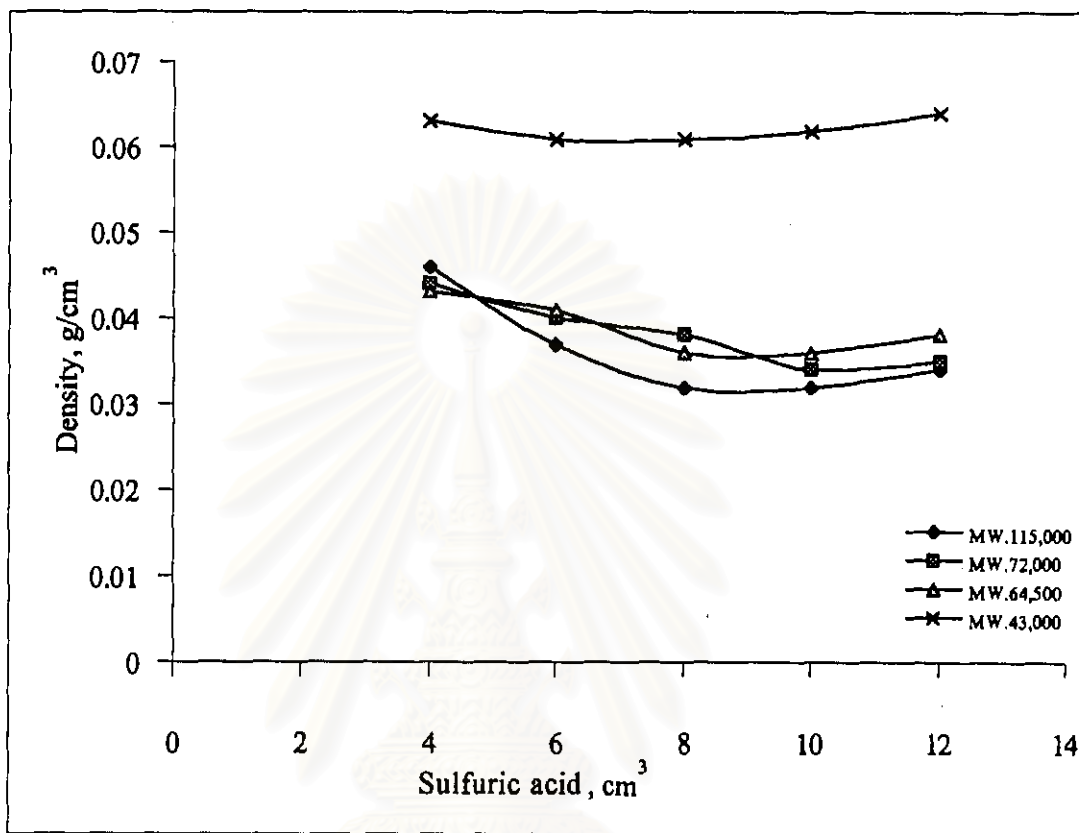Figure 5.4 Effect of formaldehyde concentration on final foam density

Table 5.5 Effect of acid concentration on final foam density

Formulation

polyvinyl alcohol [10% aqueous solution]	40 g
sulfuric acid [98% concentration]	variable
formaldehyde[37% aqueous solution]	8.0 cm^3
sodium lauryl sulfate	0.6 g

foam density, g/cm^3

MW. of PVA \ Sulfuric acid, cm^3	115,000	72,000	64,500	43,000
4	0.046	0.044	0.043	0.063
6	0.037	0.04	0.041	0.061
8	0.032	0.038	0.036	0.061
10	0.032	0.034	0.036	0.062
12.0	0.034	0.035	0.038	0.064

5.1.2.3 Curing Time

The froth was cured in the plastic mold at the room temperature ($27-35^\circ$C). Variation time from eight hours to twenty hours. The sponges were measured for the final foam density, and the result is represented in Figure 5.6. During the experiment, after sometime a layer was observed of liquid containing water, unreacted polyvinyl alcohol, formaldehyde, and sodium lauryl sulfate appearing at the bottom of the mold. The thickness of the layer increased until the foam completed cross-linking and the structures had become stabilized in about 18 hours. If the foam was washed with fresh water prior to 18 hours of curing time, its structure would disintegrate.
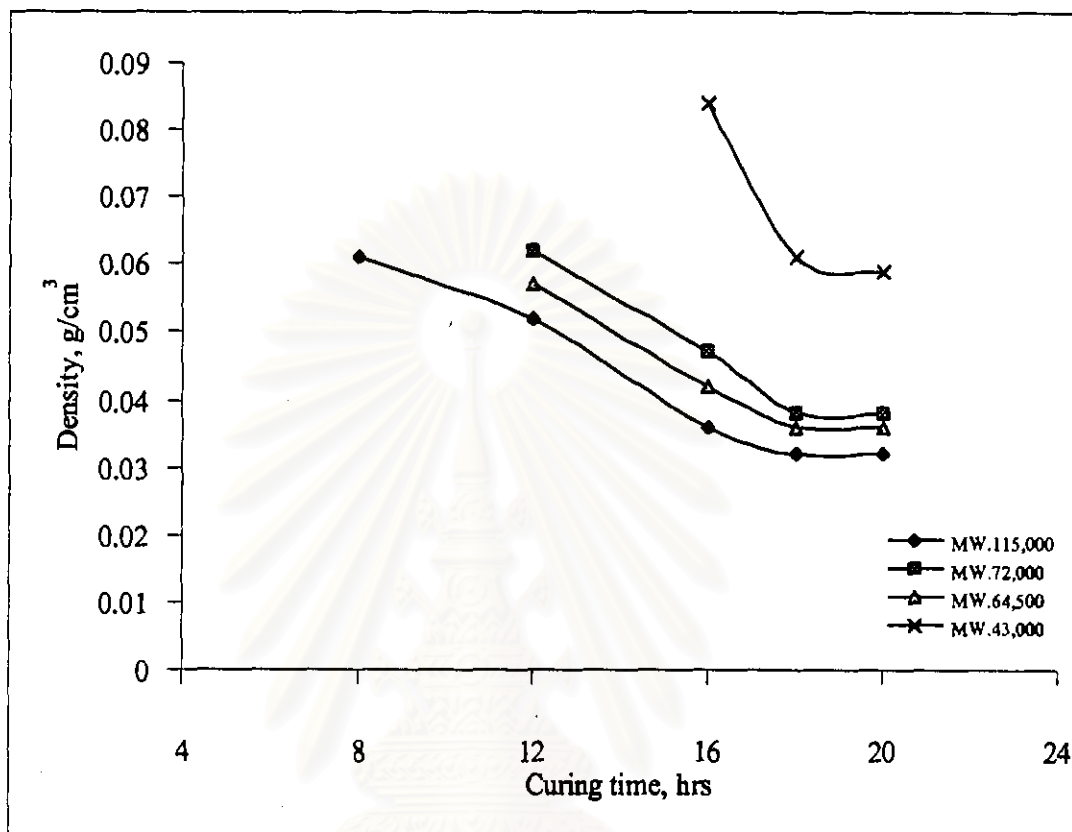
(based on data in Table 5.5)

Figure 5.5 Effect of acid concentration on final foam density

Table 5.6 Effect of curing time on final foam density

Formulation

polyvinyl alcohol [10% aqueous solution]	40 g
sulfuric acid [98% concentration]	8.0 cm^3
formaldehyde[37% aqueous solution]	8.0 cm^3
sodium lauryl sulfate	0.6 g

foam density, g/cm^3

MW. of PVA / curing time, hrs	115,000	72,000	64,500	43,000
8	0.061	0.093	-	-
12	0.052	0.062	0.057	-
16	0.036	0.047	0.042	0.084
18	0.032	0.038	0.036	0.061
20	0.032	0.038	0.036	0.059

(based on data from Table 5.6)

Figure 5.6 Effect of curing time on final foam density.

5.2 OPTIMUM COMPOSITION OF ACTIVATED CARBON-FILLED SPONGE

In the synthesis of activated carbon-filled sponge, the optimum composition of unfilled PVA sponge fond in 5.1 was used. Various samples were produced in which the amount of activated carbon added were varied in order to determine the optimum quantity of carbon.

The polyvinyl alcohol resin has the property of accepting high concentrations of fillers[8], and the polyvinyl-formal foam system has the same ability. Figures 5.7 and 5.8, show that large quantities of activated carbon can be incorporated in the process. There was no drastic collapse of the foam as activated carbon content was increased to 6.25 % by weight of the polyvinyl alcohol solution (about 2.5 g/40 g of PVA aqueous solution). The froth volume decreased and the density increased due to the mass of the activated carbon, but no collapsing structure occurred. Excessively increase amounts of the activated carbon, the froth volume would decrease and the reacting mass was hard, resulting in partial foam collapse and a higher-density foam was yielded.

Table 5.7 Effect of activated carbon content on froth volume.

Formulation

polyvinyl alcohol [10% aqueous solution]	40 g
sulfuric acid [98% concentration]	8.0 cm^3
formaldehyde[37% aqueous solution]	8.0 cm^3
sodium lauryl sulfate	0.6 g
activated carbon	variable

froth volume, cm^3

MW.of PVA / Activated carbon, g	115,000	72,000	64,500	43,000
2.0	250	240	240	200
2.5	240	220	230	180
3.0	210	200	210	160
3.5	180	190	190	140

Table 5.8 Effect of activated carbon content on final foam density.

Formulation as given in Table 5.7

foam density , g/cm^3

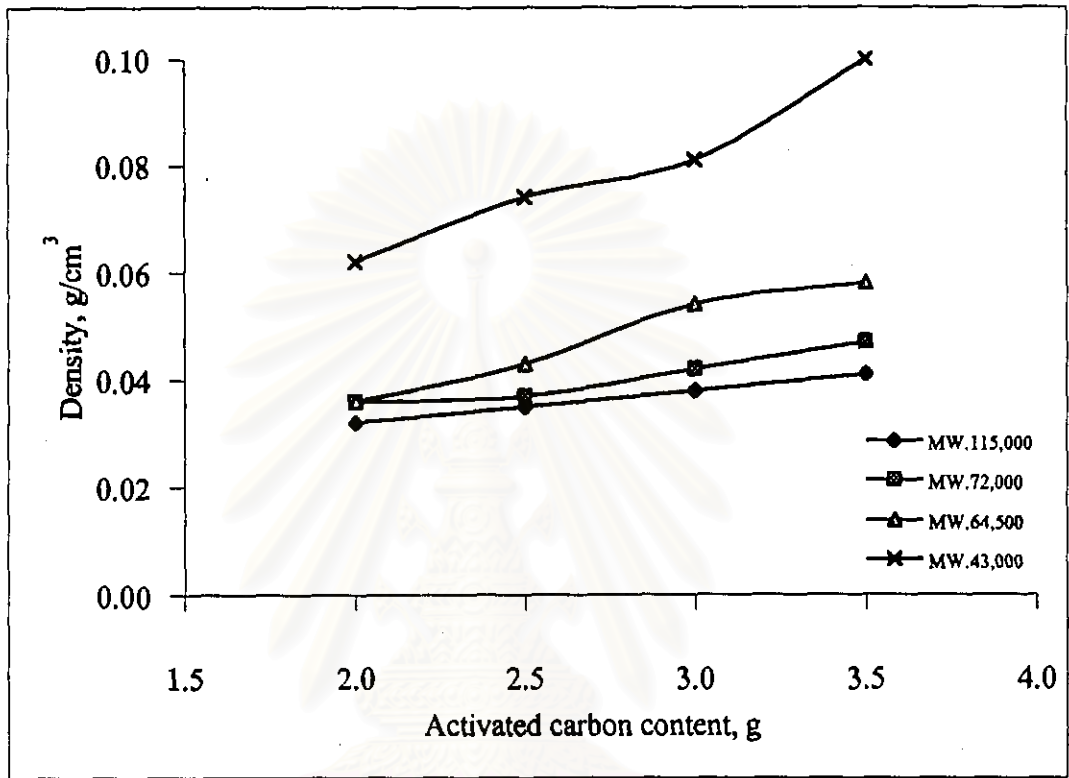| MW.of PVA / Activated carbon, g	115,000	72,000	64,500	43,000
2.0	0.032	0.036	0.036	0.062
2.5	0.035	0.037	0.043	0.074
3.0	0.038	0.042	0.054	0.081
3.5	0.041	0.047	0.058	0.1
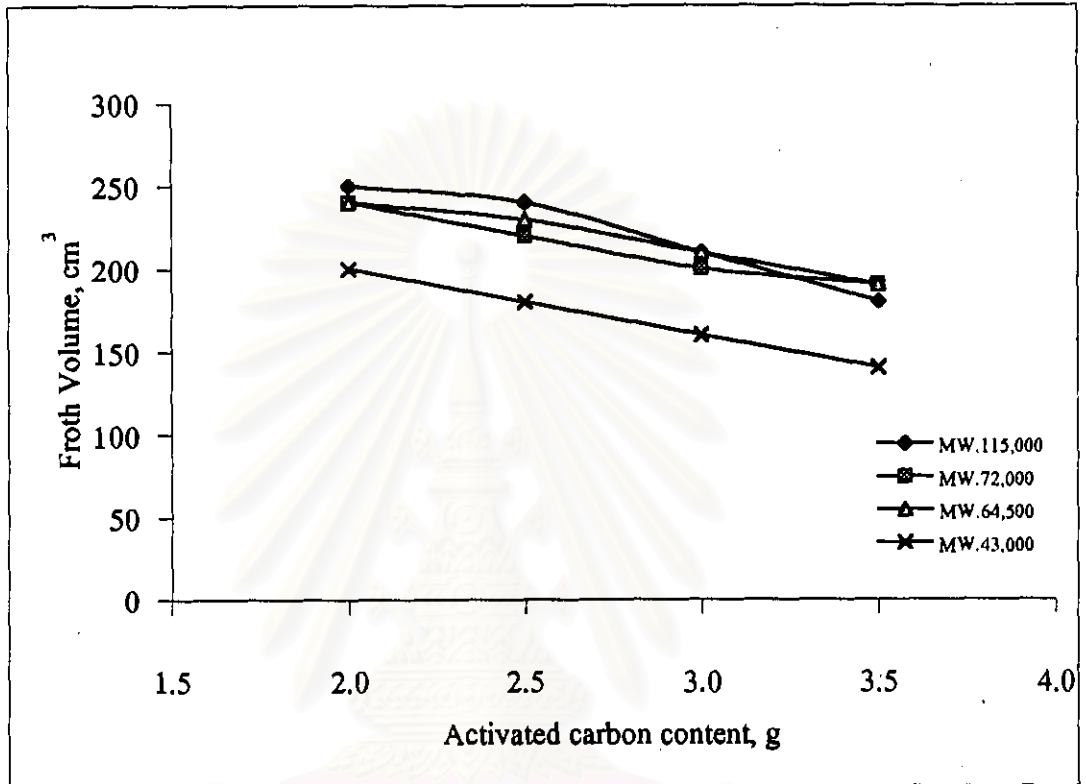
(based on data in Table 5.7)

Figure 5.7 Effect of activated carbon content on froth volume

(based on data in Table 5.8)

Figure 5.8 Effect of activated carbon content on final foam density

5.3 CHARACTERISATION AND TESTING OF PERFORMANCE OF SPONGE

5.3.1 PORE SIZE AND UNIFORMITY

Specification of the testing specimen is presented in Table 5.9. Porosity and pore distribution were measured by Scanning Electro Microscope (SEM). Sample photographs were shown on Figures 5.9 to 5.14. From these figures the porosity may be used to predict the actual pore size range. The one important parameter that affects porosity and pore distribution is the molecular weight of polyvinyl alcohol. Comparing Figures 5.9 through 5.14, The larger the molecular weight, the smaller is the pore size. Figure 5.9 for molecular weight of about 115,000 the resultant sponge has a relatively small pore size, but less uniformity. Figure 5.10 and 5.11 for molecular weight of about 72,000 the resultant sponge exhibits a relatively large non-uniform pore size of 0.5 to 1.5 millimeters. The molecular weight of the polyvinyl alcohol about 64,500, in Figure 5.12 and 5.13, are the desire molecular weight since it has been found that improved uniformity of pore size can be obtain therewith. The uniformly medium pore size is between 0.5 to 1.0 millimeters. Figure 5.14 for molecular weight of about 43,000, the resultant sponge exhibits less porosity as well as less uniformity.

5.3.2 RESISTANCE TO AIR FLOW

Pressure drop across the sample of sponge was investigated using the testing unit in Figure 4.3. The volumetric flow rate of sample air was varied to 31.28, 26.97, and 23.77 cm^3/sec. Table 5.9 shows the formulations for each specimen number in Figure 5.15. Figure 5.15 shows the plots of measured pressure drop versus air volumetric flow rate. It clearly shows that pressure drop increases as air flow rate increases. The pressure drop varies inversely with pore size, which in turn varies

Table 5.9 Specification of testing specimen.

Formulation

polyvinyl alcohol [10% aqueous solution]	40 g
sulfuric acid [98% concentration]	8.0 cm^3
formaldehyde[37% aqueous solution]	8.0 cm^3
sodium lauryl sulfate	0.6 g

Specimen	Molecular weight	Activated carbon, g
No.1	115,000	0
No.2	115,000	2.5
No.3	72,000	0
No.4	72,000	2.5
No.5	72,000	2.0
No.6	64,500	0
No.7	64,500	2.0
No.8	64,500	2.5
No.9	43,000	0
No.10	43,000	2.5

inversely with PVA molecular weight. This observation does not apply for sponge No.10. This is due to non-uniformity of pore size and pore distribution of the sponge No.10. However, it can be concluded that the pressure drop across the sponge is very little, so that it may be used as facemask.
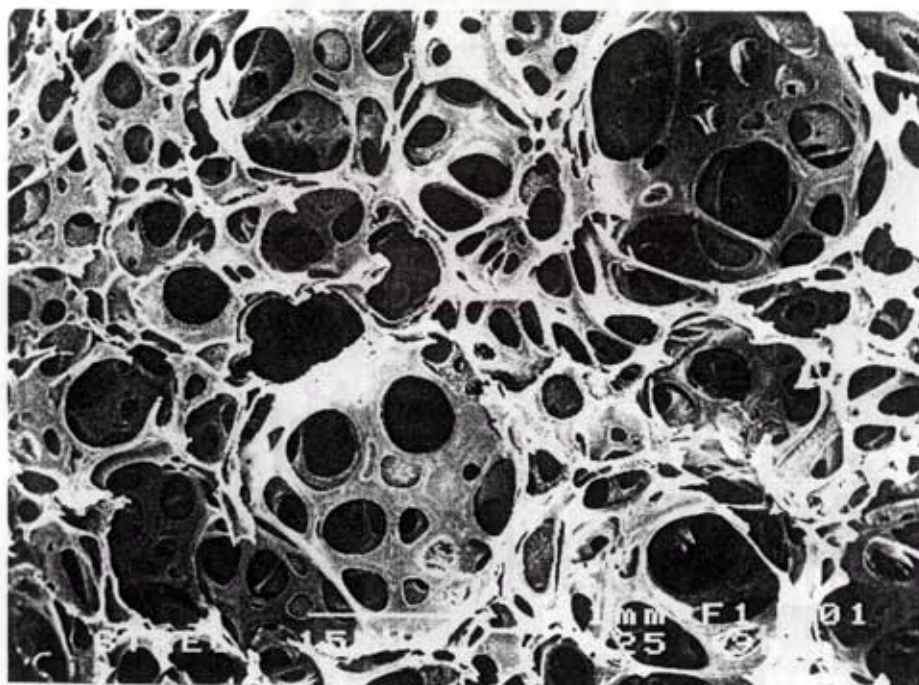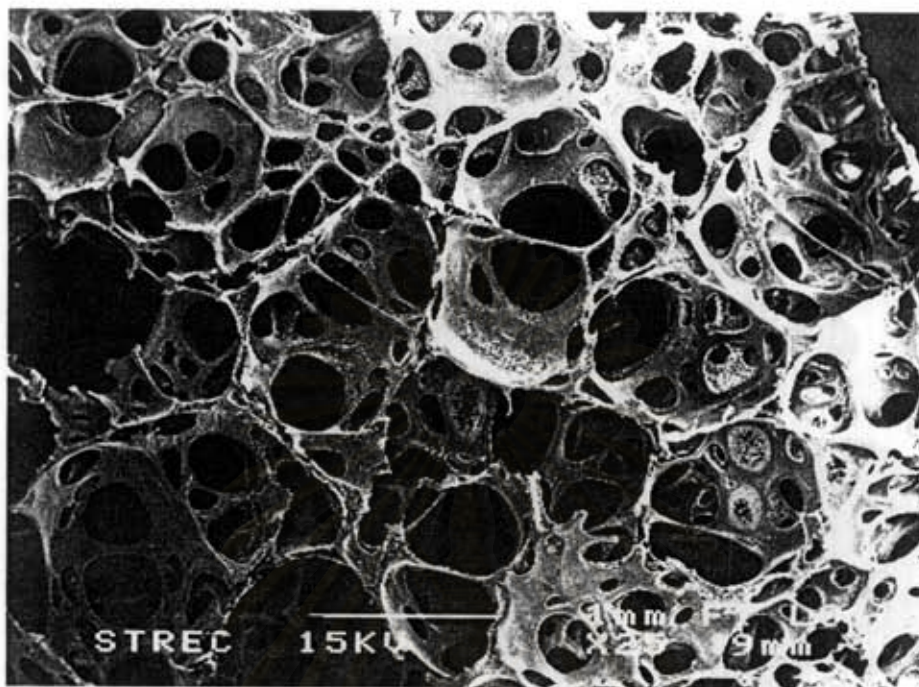
Figure 5.9 Photographs of specimen No.1

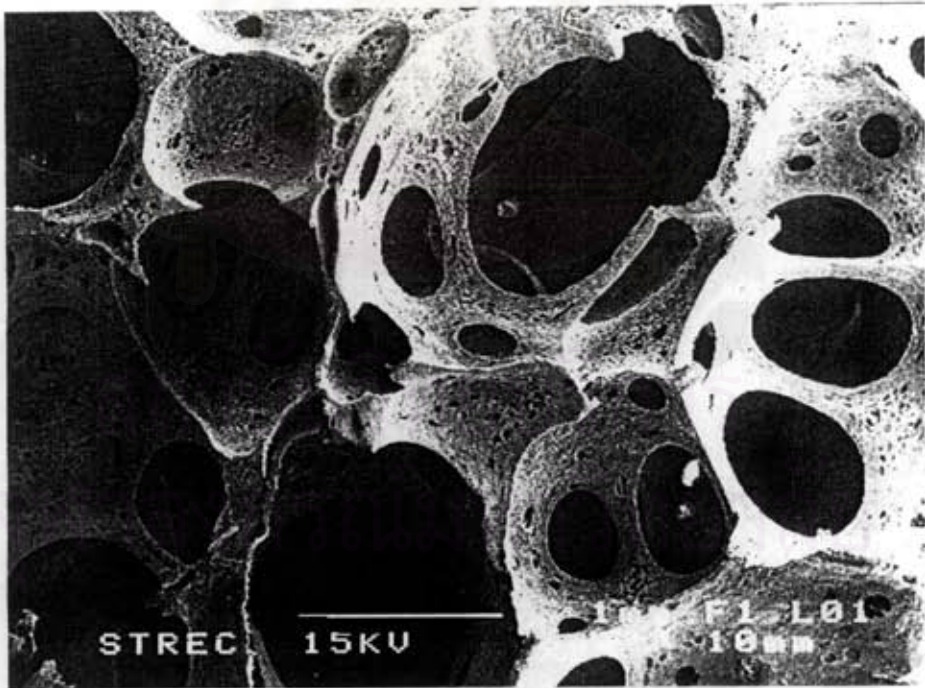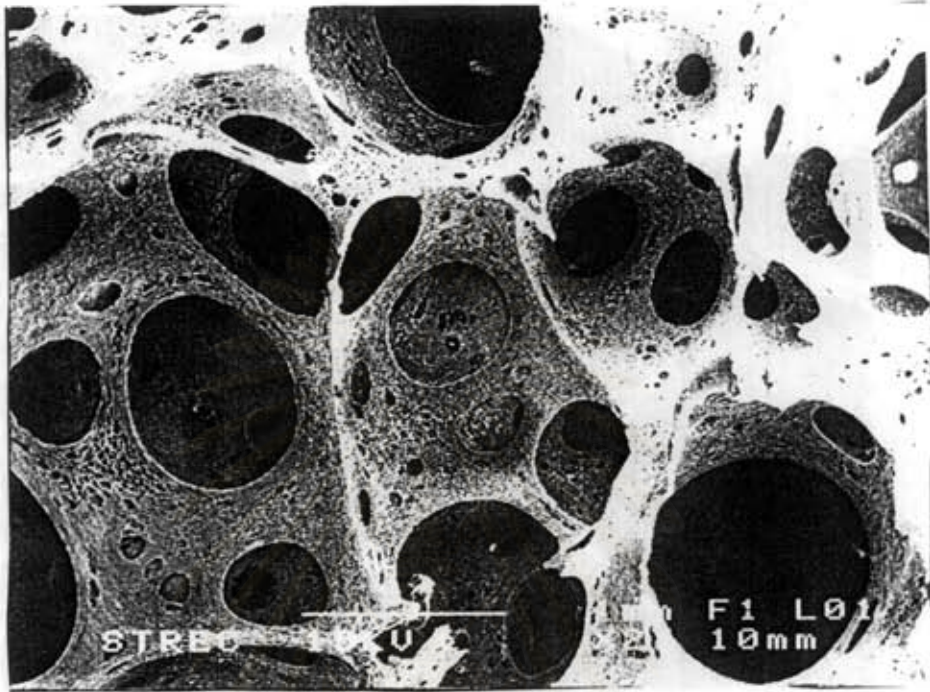(PVA sponge from PVA reactant of molecular weight of about 115,000)

Figure 5.10 Photographs of specimen No.3

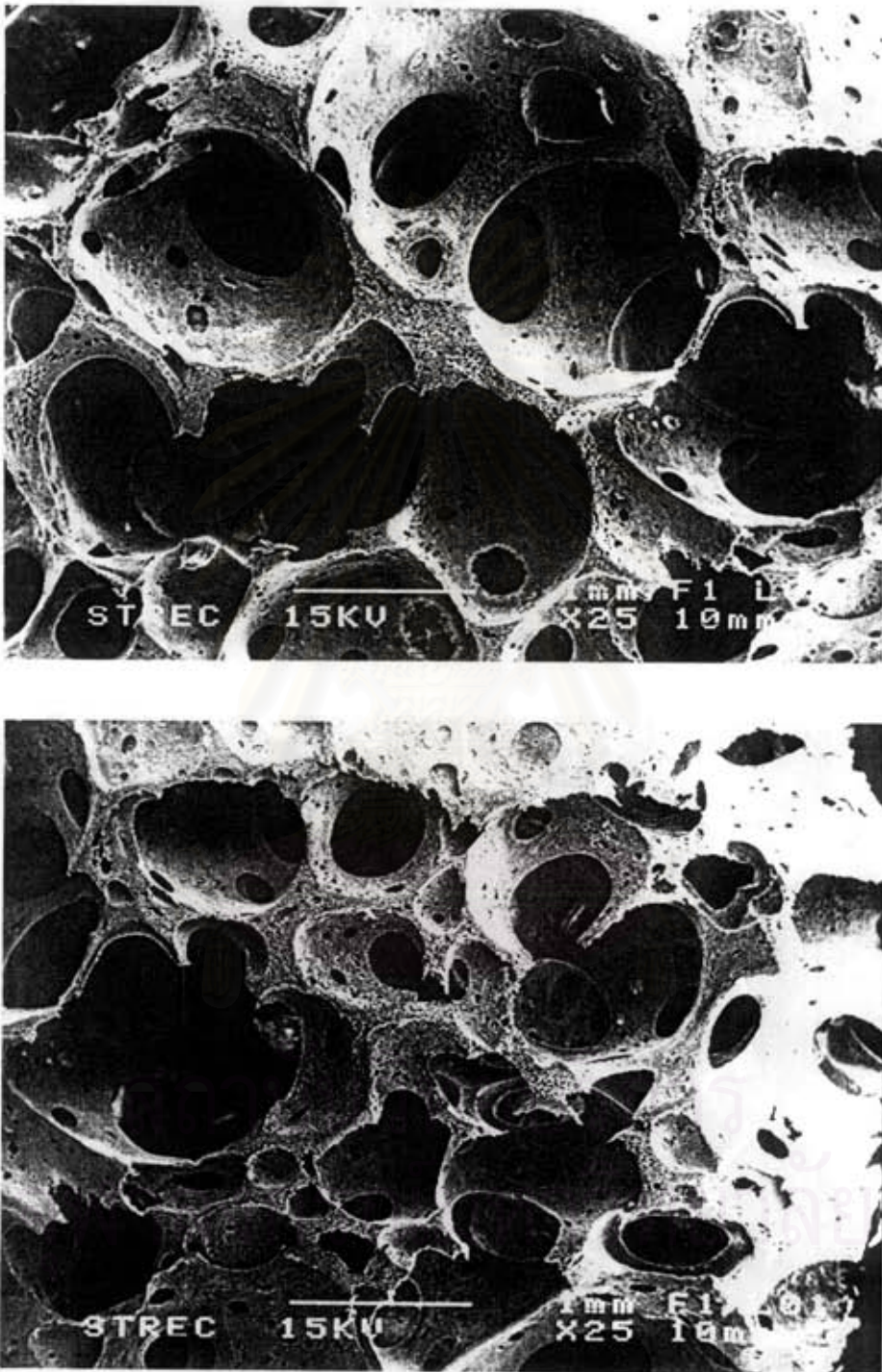(PVA sponge from PVA reactant of molecular weight of about 72,000)

Figure 5.11 Photographs of specimen No.4

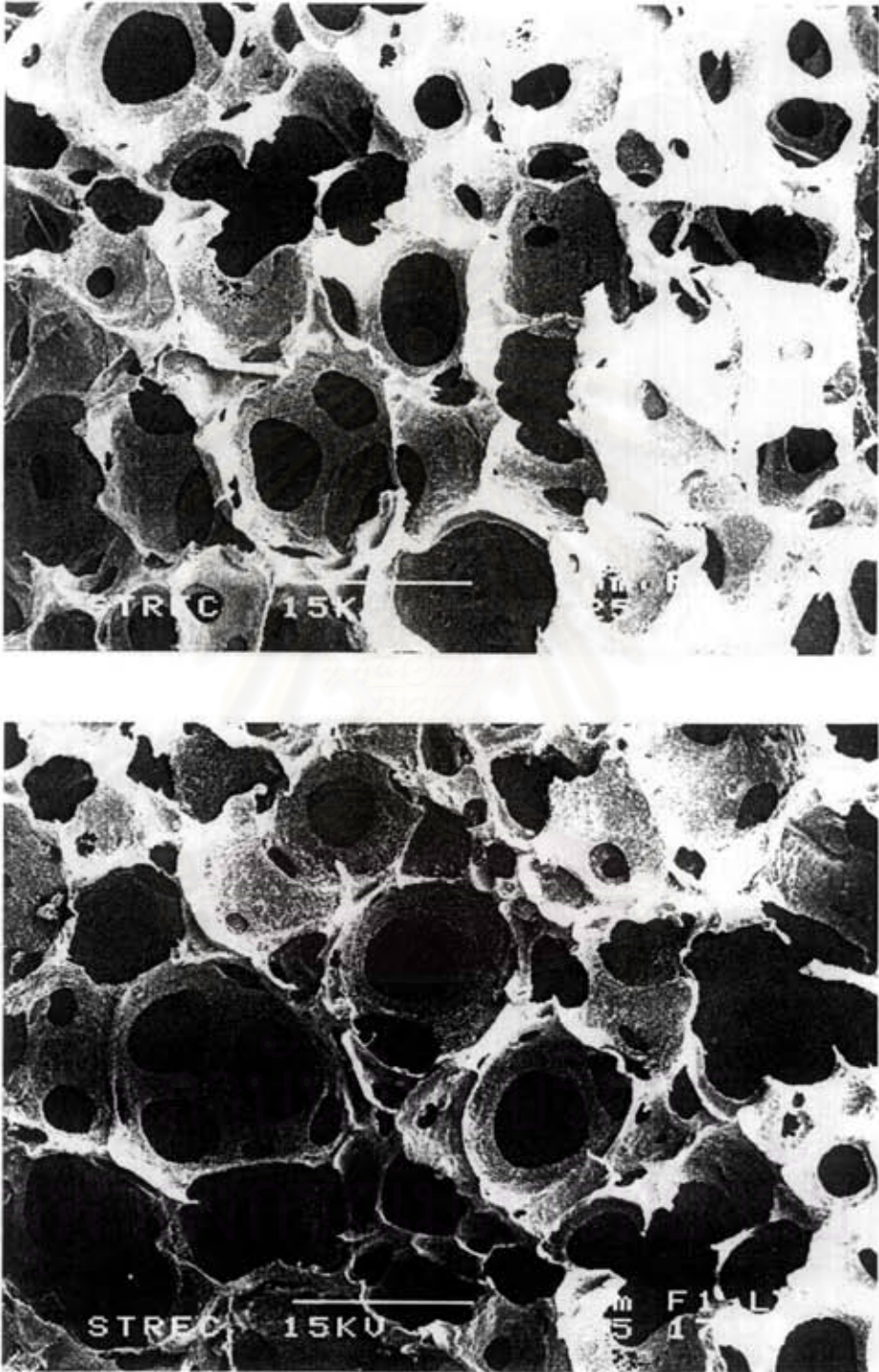(Activated carbon-filled sponge from PVA reactant of molecular weight of about 72,000)

Figure 5.12 Photographs of specimen No.6

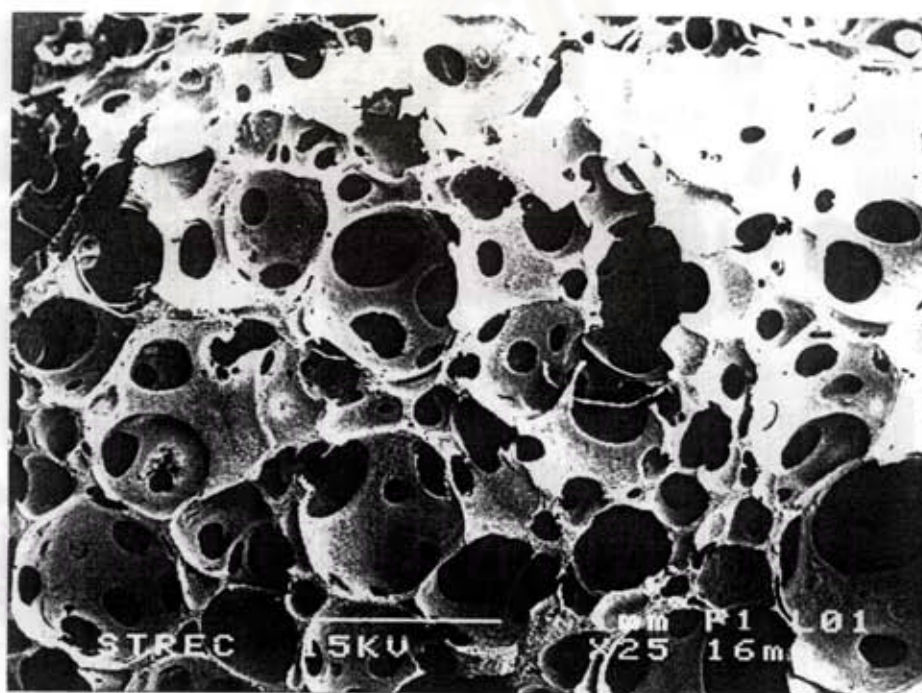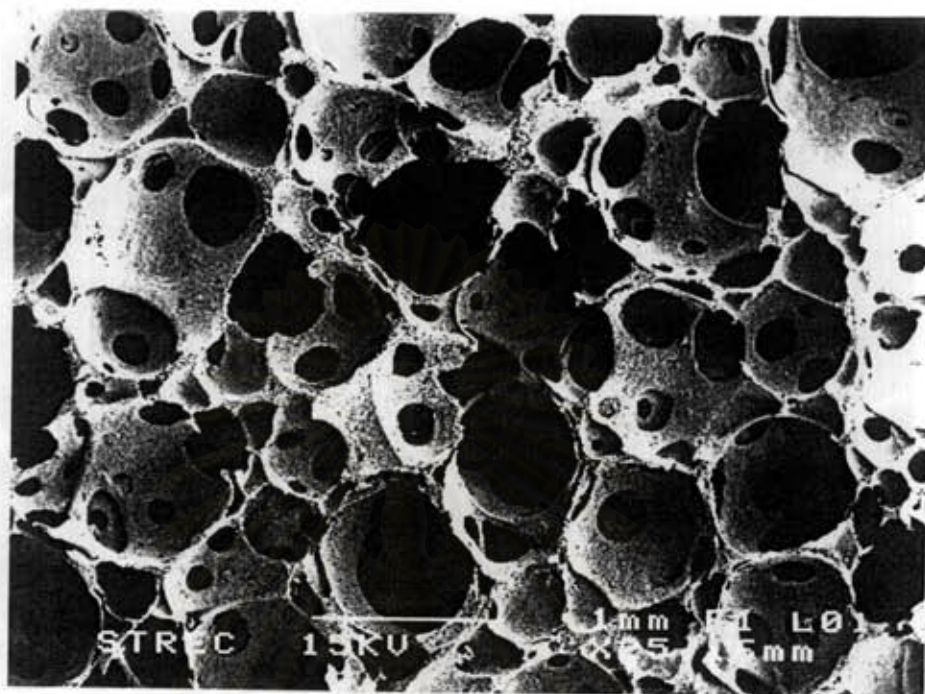(PVA sponge from PVA reactant of molecular weight of about 64,500)

Figure 5.13 Photographs of specimen No.8

(Activated carbon-filled sponge from PVA reactant of molecular weight of about 64,500)
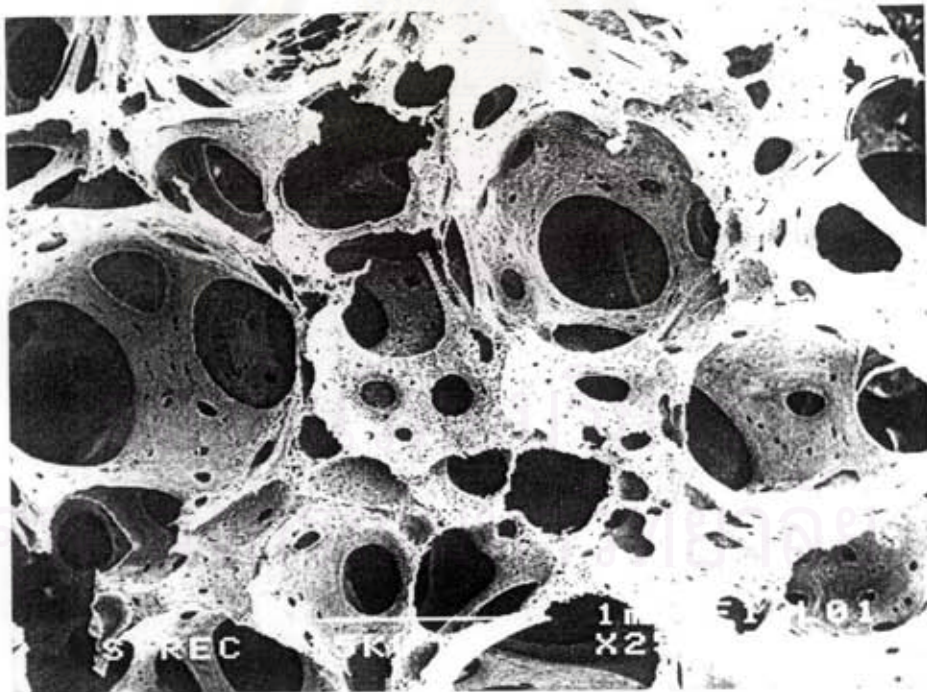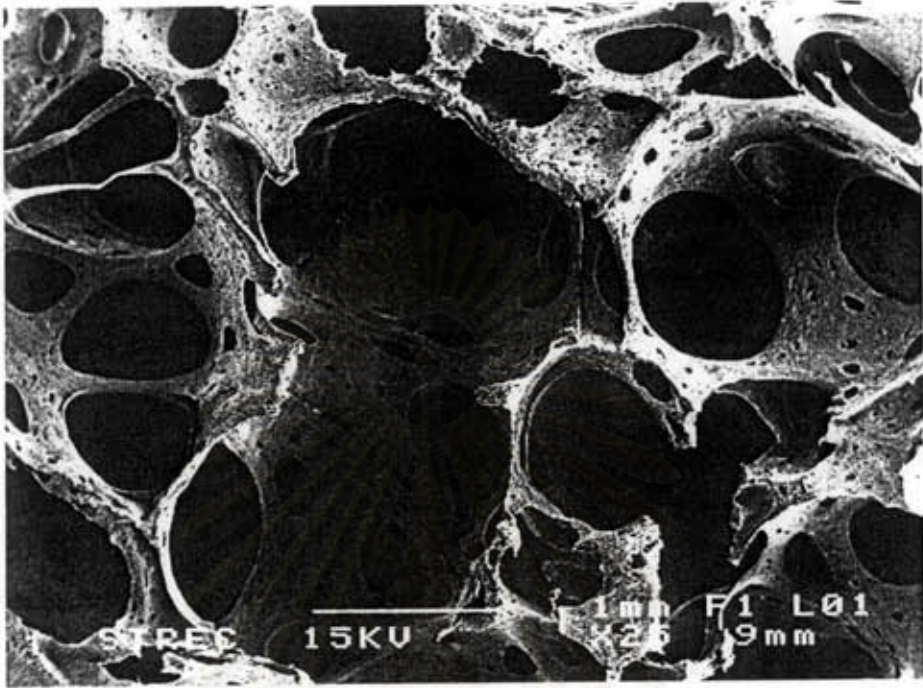
Figure 5.14 Photographs of specimen No.10

(Activated carbon-filled sponge from PVA reactant of molecular weight of about 43,000)
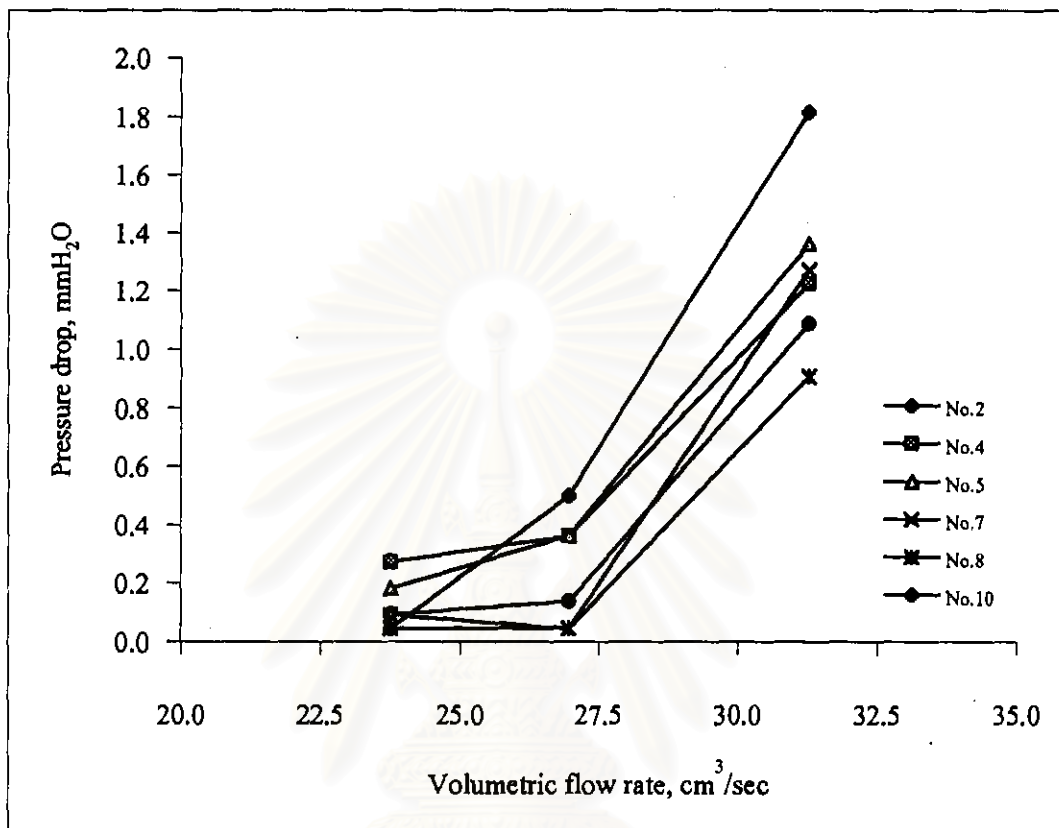
Figure 5.15 Pressure drop across the sponge of 3 mm thickness.

5.3.2 AIR POLLUTANT ADSORPTION ABILITY

Hexane was used to represent an air-borne pollutant. Air was mixed with hexane before it flow through the sponge specimen, the air flow rate was $31 \text{ cm}^3/\text{sec}$. Adsorption of hexane by the sponge was determined by measuring the concentrations of hexane in the up stream and down stream air by gas chromatograph. The result of the experiment is presented in Table 5.10.

Among the sponges studied, the sponge specimen No.8 (made from PVA of 64,500 MW.) showed the best adsorbing performance. This may be due to the uniformity of medium pore size of the specimen No.8. Sponge specimen No.4 which contains more activated carbon performs better than sponge specimen No.5. Comparing to the activated carbon packed column of 3 millimeters in thickness, the specimen No.8 adsorbed about 84 % less hexane.

Table 5.10 Hexane adsorption ability of activated carbon-filled sponge

specimen	Hexane concentration in up stream air, ppm	Percent hexane adsorbed, %
Blank	0.702	2.1
Packed column	0.643	97.4
No. 1	0.016	70.9
No.2	0.041	59.4
No.3	0.075	82.1