CHAPTER IV

RESULTS AND DISCUSSIONS

Procedures

The experiments are conducted in a 250 ml. stirred batch reactor. The adsorbents are alumina, nickel, copper and nickel-copper adsorbents. Phenylarsineoxide and arsenic oxide are used as model compounds to represent organometallic and ionic forms of arsenic compounds. Diphenylmercury and mercuric chloride are used as model of organometallic and ionic form of mercury compounds. Toluene is used as solvent because of its high boiling point (maintains in liquid state) and its solubility for metal compounds. The operating conditions of all experiments are show in Table 4.1. After completion of each experiment, liquid sample and adsorbent are separated and kept to analyze for their characteristics.

Experiments in this study are classified into three sections.

1. Blank test is conducted to study adsorption of arsenic and mercury compounds on reactor wall.

2. Experimental error is conducted to study the repeatability of the experiments at the condition chosen.

3. Operating temperature, types of adsorbents and metal compound dependency are studied in section 3.

Tables 4.1 Operating conditions of all experiments

	Mercury	Arsenic
Compounds	1. Mercuric chloride 2. Diphenylmercury	1. Arsenic oxide 2. Phenylarsine oxide
Initial concentration (ppm)	1	10
Feed's volume (ml)	100	200
Adsorbent weight (g)	1	0.3
Temperature (^{o}C)	30,50,70	
Pressure	Atmosphere	
Contact time (mins)	60	
Feed (Solvent)	Toluene	

Results and Discussions

Blank test

The experiments in this section are conducted to study stability of each metal compound at adsorption temperatures and to verify adsorption of metal compounds on reactor wall. No adsorbent is used in this test and the conditions are summarized in Table 4.1 except. The concentration of mercury and arsenic after completion of the experiments are plotted with the operating temperature and shown in Figure 4.1 and Figure 4.2. The results show that concentration of mercuric chloride, arsenic oxide and phenylarsine oxides before and after the experiments are almost identical. It indicates that mercuric chloride, arsenic oxide and phenylarsine oxide are not adsorbed on the reactor wall and stable at operating temperature. Concentration of diphenylmercury after the completion of experiments is decreased about 15% from the beginning. This value is used as initial concentration in study of adsorption of diphenylmercury in the following section.

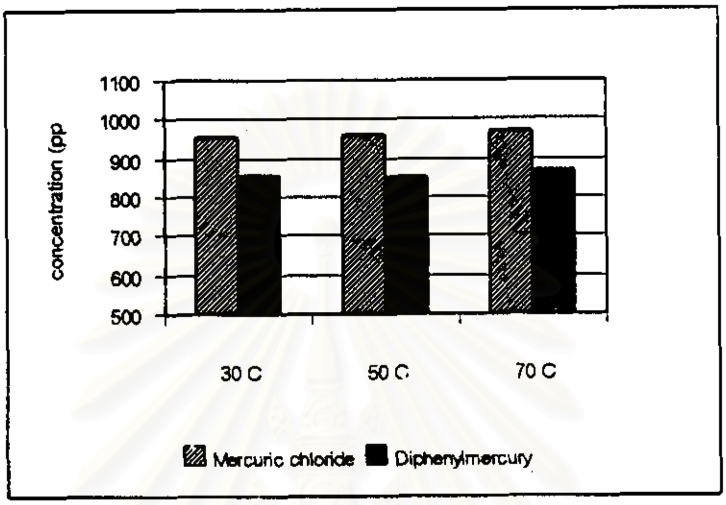

Figure 4.1 Amount of Mercury remaining using Blank test at various temperature

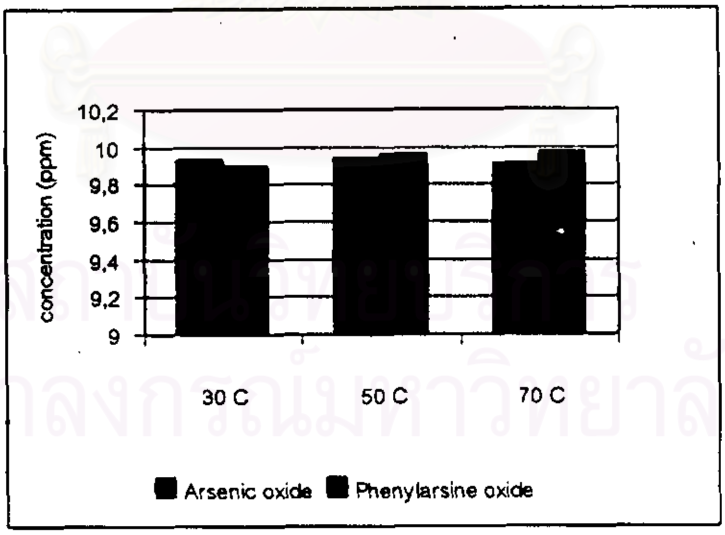

Figure 4.2 Amount of Arsenic remaining using Blank test at various temperature

Experimental Error

Several experiments are conducted to verify the repeatability of the experiments and to determine error limits over the whole ranges of the experiments. The experiments are operated at conditions shown in Tables 4.1. The adsorbent used is alumina adsorbent. The experiment is repeated 5 times at the same condition. Liquid samples are analyzed for their metal content. The results are shown in Table 4.2 while average concentration of mercury and percent deviation are calculated and shown in Tables 4.3. Maximum and minimum deviation of experiment are calculated according to the following equation:

$$\%\text{Maximum deviation} = \frac{\text{maximum conc.} - \text{average conc.} * 100}{\text{average conc.}}$$

$$\%\text{Minimum deviation} = \frac{\text{average conc.} - \text{minimum conc.} * 100}{\text{average conc.}}$$

From analysis it is certain that the values of remaining mercury deviate in the range of 17% for mercuric chloride removal, 11% for diphenylmercury, 30% for phenylarsine oxide removal, and 60% for arsenic oxide removal. Because the concentration of the metal compounds in liquid sample is rather low, small change in concentration cause high percentage deviation. Thus percent deviation calculated from remaining concentration of arsenic and mercury could not be used. Therefor the percent deviation calculated from percent removal of arsenic and mercury is suggested. Table 4.4 shows average percent removal of arsenic and mercury. Percent deviation calculated from percent removal is in the range of 2% for mercuric chloride study, 4% for diphenylmercury and below 0.06% for arsenic oxide and phenylarsine oxide. The results show that deviation of percent removal of arsenic oxide and phenylarsine oxide is low and can be neglected.

Table 4.2 Amount of arsenic and mercury remaining in adsorption repeatability study.

Temperature (°C)	Compounds	1 (ppb)	2 (ppb)	3 (ppb)	4 (ppb)	5 (ppb)
30	Mercuric chloride	48.51	40.15	50.28	55.31	46.35
	Diphenylmercury	355.7	360.9	385.6	332.0	351.2
	Arsenic oxide	11.54	10.21	13.25	9.77	10.1
	Phenylarsine oxide	44.72	50.88	40.32	45.63	47.86
50	Mercuric chloride	61.17	55.35	59.74	69.54	49.24
	Diphenylmercury	286.1	300.2	296.3	271.5	250
	Arsenic oxide	9.33	8.2	7.6	9.1	8.5
	Phenylarsine oxide	15.37	20.23	11.24	15.68	16.57
70	Mercuric chloride	156.4	160.6	173.5	149.6	152.3
	Diphenylmercury	224.3	240.6	210.6	238.0	220.5
	Arsenic oxide	1.83	3	2.8	0.8	1.03
	Phenylarsine oxide	10.52	9.57	8.23	11.05	8.99

Table 4.3 Average concentration and percent deviation of arsenic and mercury in adsorption repeatability study

Temperature (°C)	Compounds	Average concentration (ppb)	Maximum deviation (%)	Mininum deviation (%)
30	Mercuric chloride	48.1	14.9	16.6
	Diphenylmercury	357.2	7.9	6.7
	Arsenic oxide	11.0	20.7	11.0
	Phenylarsine oxide	45.9	10.9	12.1
50	Mercuric chloride	59.0	6.1	7.2
	Diphenylmercury	280.8	6.9	11.0
	Arsenic oxide	8.5	9.2	11.1
	Phenylarsine oxide	15.8	27.9	28.9
70	Mercuric chloride	158.5	9.5	5.6
	Diphenylmercury	226.8	6.1	7.2
	Arsenic oxide	1.9	58.6	57.7
	Phenylarsine oxide	9.7	14.2	7.1

Table 4.4 Average percent removal and percent deviation calculated from percent removal of arsenic and mercury in adsorption repeatability study

Temperature (°C)	Compounds	Average percent removal (%)	Maximum deviation of percent removal (%)	Minimum deviation of percent removal (%)
30	Mercuric chloride	95.2	0.84	0.76
	Diphenylmercury	64.3	3.75	4.40
	Arsenic oxide	99.9	0.012	0.023
	Phenylarsine oxide	99.5	0.06	0.05
50	Mercuric chloride	94.1	1.04	1.12
	Diphenylmercury	71.9	4.29	2.69
	Arsenic oxide	99.9	0.01	0.008
	Phenylarsine oxide	99.8	0.05	0.04
70	Mercuric chloride	84.2	1.06	1.79
	Diphenylmercury	77.3	2.1	1.79
	Arsenic oxide	99.9	0.011	0.011
	Phenylarsine oxide	99.9	0.01	0.01

Comparison of physical properties of adsorbent

Nickel, copper and nickel-copper adsorbents are prepared by dry impregnation of nickel nitrate and copper nitrate solutions on alumina support. After that, the adsorbents are calcined. The metals loaded on the adsorbents are in oxide form. Percent metal loading of nickel adsorbent and copper adsorbent are 2.5% by weight and total 5% by weight for nickel-copper adsorbent. All adsorbents are analyzed for their characteristics; surface area, pore volume, average pore diameter and pore size distribution by BET method. The results are compared with alumina support. Alumina support used was alumina activated neutral (Aldrich). The results are shown in Table 4.5 except data of pore size distribution are shown in appendix.

Table 4.5 Surface area, pore volume and average pore diameter of alumina and fresh adsorbents.

Adsorbents	Surface Area (m^2/g)	Pore Volume (cc/g)	Average Pore Diameter (A^o)
Al_2O_3	218.18	0.4539	83.21
Cu	156.00	0.2275	58.32
Ni	168.49	0.2467	58.57
Ni-Cu	149.8	0.2212	59.07

Comparison of surface area, pore volume and average pore diameter of alumina and impregnated adsorbents are shown in Figure 4.3 to Figure 4.5. The results show that total surface area, total pore volume and average pore diameter of adsorbent decrease significantly when metal was loaded on alumina. Figure 4.6 show the comparison of pore size distribution of each fresh adsorbent. It is observed that pore size between 80 A^o and 250 A^o is decreased while pore size between 20 A^o and 50 A^o is increased. The results can be explained by, metals loaded to adsorbent deposit on the surface area inside the pore or block the pore mouth cause pore to decrease in size.

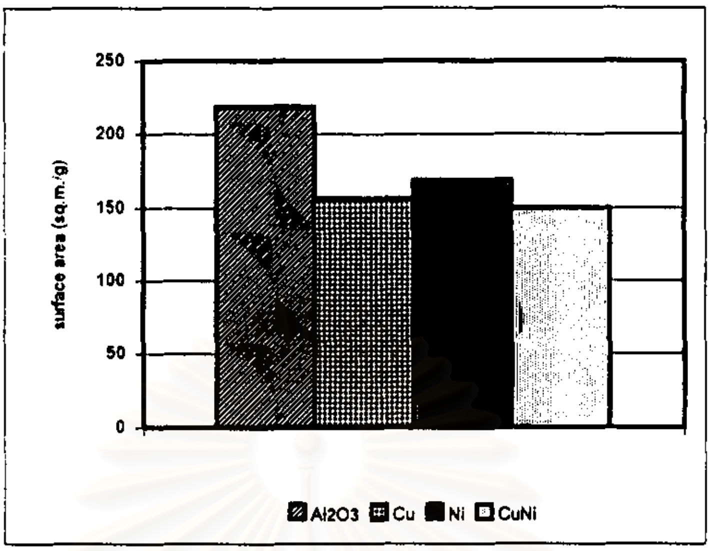

Figure 4.3 Comparison of total surface area between alumina and impregnated adsorbent.

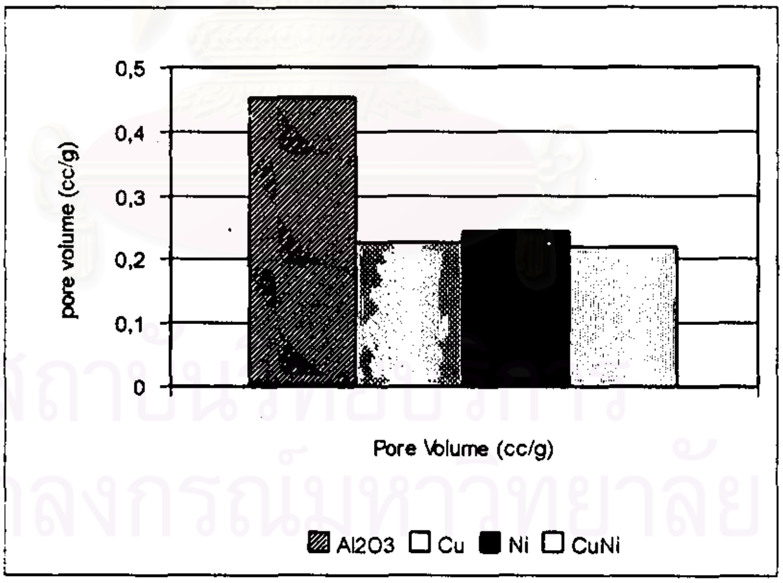

Figure 4.4 Comparison of total pore volume between alumina and impregnated adsorbent.

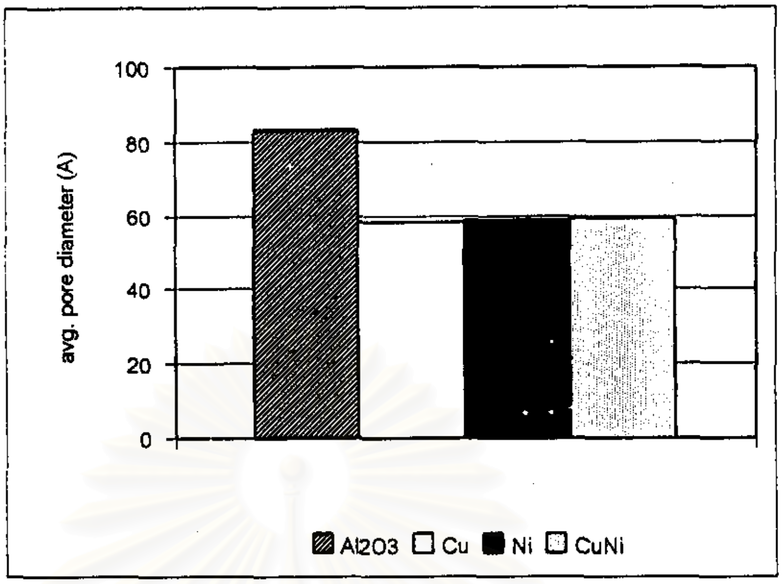

Figure 4.5 Comparison of pore average diameter between alumina and fresh adsorbent.

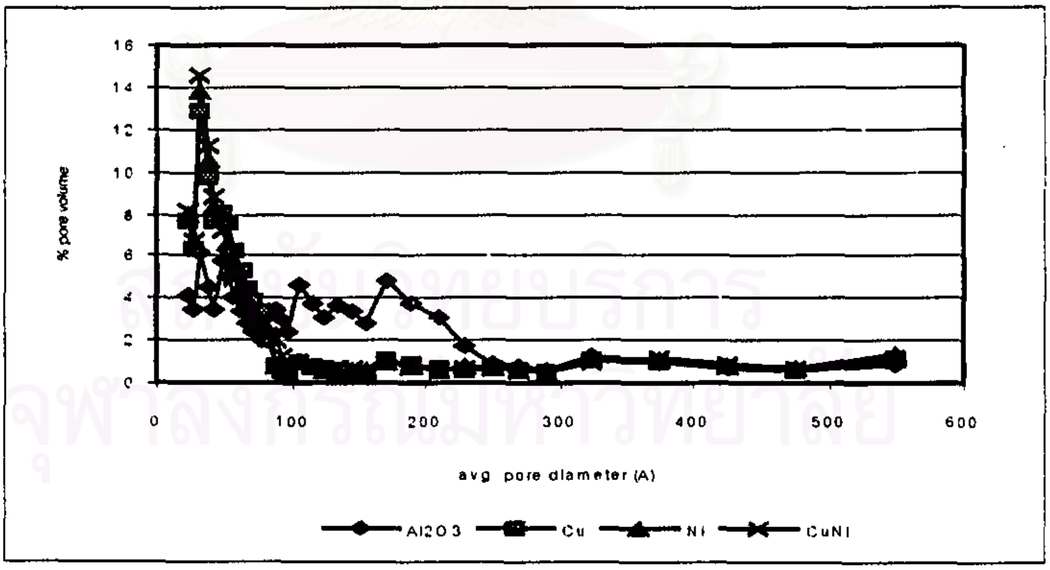

Figure 4.6 Comparison of pore size distribution between alumina and impregnated adsorbents.

Adsorption by alumina adsorbent

Twelve experiments are conducted to study the adsorptivity of mercury and arsenic compounds on alumina adsorbent. Alumina adsorbent is neutral activated alumina (Aldrich). Experimental results are shown in Table 4.6 to 4.9 except results of pore size distribution are shown in Appendix A.

Table 4.6 shows the amount of mercuric chloride, diphenylmercury, arsenic oxide and arsenic oxide which remain in toluene and the amount which have been removed are shown in Table 4.7. Spent adsorbents are analyzed in order to determine the quantity of arsenic and mercury which are adsorbed. Table 4.8 shows the arsenic and mercury content of spent alumina adsorbent. Amount of arsenic and mercury on the adsorbents are shown in micrograms of arsenic or mercury per gram of alumina adsorbent. It is found that the amount of arsenic and mercury removed from liquid sample are almost equal to the amount of arsenic and mercury found on the adsorbents.

Table 4.6 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsien oxide remaining in study of adsorption by alumina adsorbent at various temperatures.

Compounds	30°C (ppb)	50°C (ppb)	70°C (ppb)
Mercuric chloride	48.5	61.2	156.4
Diphenylmenmercury	355.7	286.1	224.4
Arsenic oxide	11.5	9.3	1.8
Phenylarsine oxide	44.7	15.4	10.5

Table 4.7 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsine oxide removed from toluene in study of adsorption by alumina adsorbent at various temperatures.

Compounds	30°C (µg)	50°C (µg)	70°C (µg)
Mercuric chloride	82.4	81.3	73.5
Diphenylmemercury	42.8	54.2	48.8
Arsenic oxide	1731	1731	1731
Phenylarsine oxide	1728	1730	1731

Table 4.8 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsine oxide on the adsorbents in study of adsorption by alumina adsorbent at various temperatures.

Compounds	30°C		50°C		70°C	
	µg/ g ads.	µg	µg/ g ads.	µg	µg/ g ads.	µg
Mercuric chloride	77.1	77.1	77.6	77.6	71.0	71.0
Diphenylmemercury	36.6	36.6	37.8	37.8	36.5	36.5
Arsenic oxide	5503	1651	5473	1642	5503	1651
Phenylarsine oxide	4803	1441	4893	1468	4930	1479

Table 4.9 Surface area and pore volume of spent adsorbent in study of arsenic and mercury removal by alumina adsorbent.

	Surface area (m^2/g)			Pore volume (cc/g)		
	30°C	50°C	70°C	30°C	50°C	70°C
Mercuric chloride	196.7	185.3	178.1	0.397	0.351	0.315
Diphenylmercury	153.5	149.9	155.1	0.318	0.317	0.332
Arsenic oxide	177.1	167.6	190.5	0.364	0.342	0.414
Phenylarsine oxide	192.4	189.2	194.2	0.374	0.375	0.380

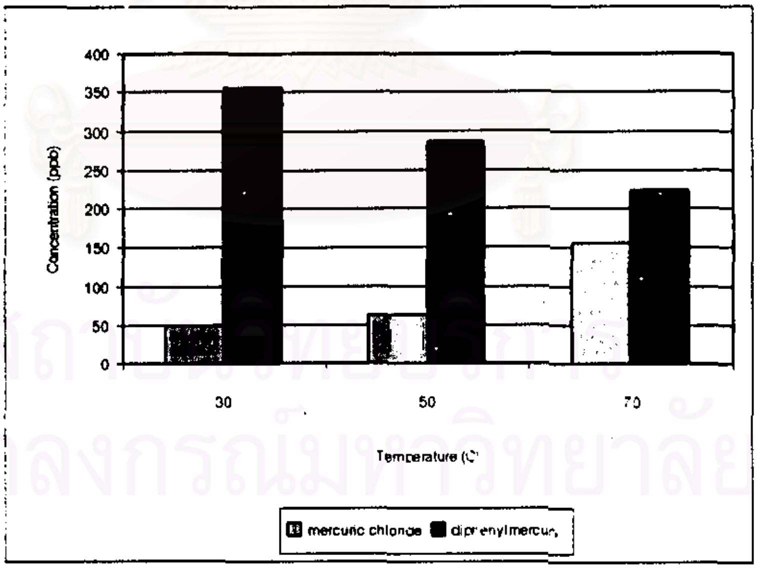

Figure 4.7 Amount of mercuric chloride and diphenylmercury remaining in study of adsorption on alumina adsorbent at various temperatures.

Adsorption of mercury compounds on alumina adsorbent

Figure 4.7 shows the amount of mercuric chloride and diphenylmercury remaining in study of removal of mercury by alumina adsorbent. Percent removals of mercury are calculated and shown in Table 4.10. From the result of mercuric chloride removal, remaining concentration of mercury in liquid sample at each operating temperature are 49 ppb, 61 ppb and 156 ppb from initial concentration of 1,000 ppb with 95%, 94% and 84% removal. It is found that percent removal of mercuric chloride decreases with increasing temperature. Concentrations of diphenylmercury with operating temperatures are 356 ppb, 284 ppb and 226 ppb, corresponding to 58%, 67% and 73% removal. Degree of diphenylmercury removal increases with increasing temperature. The results also show that mercuric chloride can be adsorbed by alumina adsorbent with higher efficiency than diphenylmercury. This indicates that properties of mercury compounds strongly affect the adsorption of mercury on adsorbents.

In this study, diphenylmercury which is classified as an organo mercury compounds can be partially removed by adsorption on alumina adsorbent. On a contrary, Yamada (1995), who studied adsorption of organo mercury compound mentioned that mercury compounds, especially organo mercury compounds, can not be adsorbed on any types of adsorbents but it can be decomposed and converted into elementary mercury, then it is adsorbed on suitable adsorbent. In his study, the decomposition of mercury compounds was conducted at temperatures of 165 to 300°C. In this study, adsorption experiments were conducted at temperatures less than 70°C in which diphenylmercury were not expected to decompose. Even though, structure of mercury compound adsorbed on the surface of the alumina adsorbent can not be identified, it is believed that diphenylmercury in this study does not decompose upon adsorption but it adsorbs directly on to alumina surface.

Mercuric chloride, which is classified as ionic mercury compounds, can be adsorbed on alumina adsorbent. Remy (1956) mentioned that mercuric chloride is different from other metal chloride. Metal chloride, when dissolves into water, it decomposes to metal ions and chloride ions but does not mercuric chloride. This is accord with other authors such as Biscarini (1971) and Gomez (1997). Thus mercuric chloride is directly adsorb on alumina surface.

Mercury deposition of alumina adsorbent causes its surface area and pore volume to decrease. Percent decreases of surface area and pore volume of spent alumina adsorbent are shown in Table 4.11. It is found that percent decrease of surface area and pore volume of spent adsorbent in diphenylmercury removal are more than in mercuric chloride removal while percent removal of mercuric chloride is more than diphenylmercury. It indicates that alumina adsorbent show higher efficiency in removal of mercuric chloride than diphenylmercury. Figure 4.8 and 4.9 show comparison of pore size distribution between fresh and spent alumina adsorbent in study of mercuric chloride removal and diphenylmercury removal respectively. From the result, there is slightly different in pore size distribution between fresh and spent adsorbent. Percentage of large pore decrease while percentage of small pore increase. The increase in the number of small pore is due to mercury deposition on large pore lead to decrease in pore size.

Table 4.10 Percent removal of mercuric chloride and diphenylmercury in study of adsorption on alumina adsorbent at various temperatures.

Compounds	30°C (%)	50°C (%)	70°C (%)
Mercuric chloride	95.1	93.9	84.4
Diphenylmercury	64.4	77.6	71.4

Table 4.11 Percent decrease of surface area and pore volume of spent alumina adsorbent in study of adsorption of mercuric chloride and diphenylmercury.

Compounds	Surface area (%)			Pore volume (%)		
	30°C	50°C	70°C	30°C	50°C	70°C
Mercuric chloride	9.9	15.1	18.4	12.5	22.6	30.6
Diphenylmercury	29.6	31.3	28.9	30.0	30.2	26.9

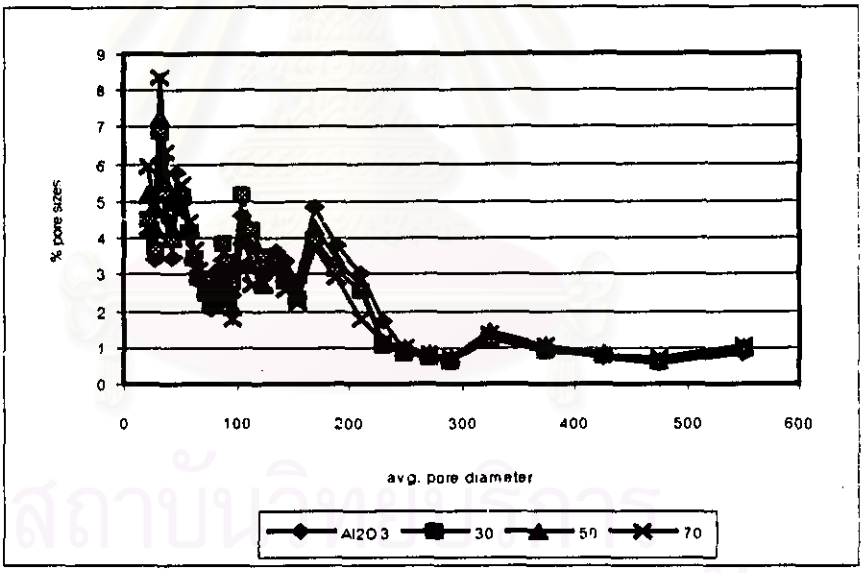

Figure 4.8 Comparison of pore size distribution between fresh and spent alumina adsorbent in study of removal of mercuric chloride.

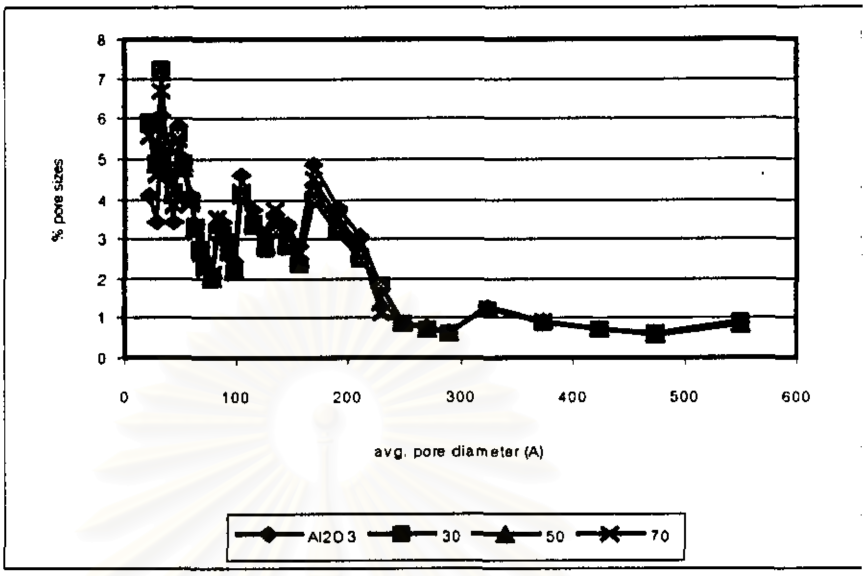

Figure 4.9 Comparison of pore size distribution between fresh and spent alumina adsorbent in study of removal of diphenylmercury.

Table 4.12 Amount of mercury removed per gram of alumina adsorbent

Compounds	30°C (μg /g)	50°C (μg /g)	70°C (μg /g)
Mercuric chloride	82.4	81.3	73.1
Diphenylmercury	55.8	67.2	61.8

Table 4.13 Amount of mercury removed per surface area of alumina adsorbent

Compounds	30°C ($\mu g/m^2$)	50°C ($\mu g/m^2$)	70°C ($\mu g/m^2$)
Mercuric chloride	0.3777	0.3726	0.3348
Diphenylmercury	0.2577	0.3079	0.2833

Amount of mercury removed per gram of alumina adsorbent and amount of mercury per surface area of alumina adsorbent are calculated in order to study efficiency of adsorbent on removal of mercury compounds. Table 4.12 shows calculated amount of mercury removed per gram of alumina adsorbent. The results show that amount of mercuric chloride removed per gram of adsorbent is more than amount of diphenylmercury removed per gram of adsorbent. Table 4.13 shows amount of mercury removed per surface area of alumina adsorbent. The amount of mercury removed per surface area of adsorbent is rather low. Because, initial concentration of mercury compounds in toluene is low compare with surface area of alumina adsorbent. In study of diphenylmercury, both amount of mercury removed per gram of adsorbent and amount of mercury removed per surface area of adsorbent are less than in mercuric chloride study.

Adsorption of arsenic compounds on alumina adsorbent

The experimental results of arsenic oxide and phenylarsine oxide removal by alumina adsorbent are shown in Figure 4.10 and percent removal of arsenic compound are calculated and shown in Table 4.14. In the study of removal of arsenic oxide on alumina adsorbent, it is found that concentration of arsenic at operating temperature is 12 ppb, 9 ppb and 2 ppb from initial concentration of 10 ppm (10,000 ppb), corresponding to 99.9%, 99.9% and 99.9% removal. In study of phenylarsine oxide, remaining concentration at operating temperature are 45 ppb, 15 ppb and 11 ppb, corresponding to 99.6%, 99.8% and 99.9% removal. The results indicate that almost all of arsenic in feed of both studies is removed. In addition, it is found that percent removal of both arsenic oxide and phenylarsine oxide tends to increase with temperature increase.

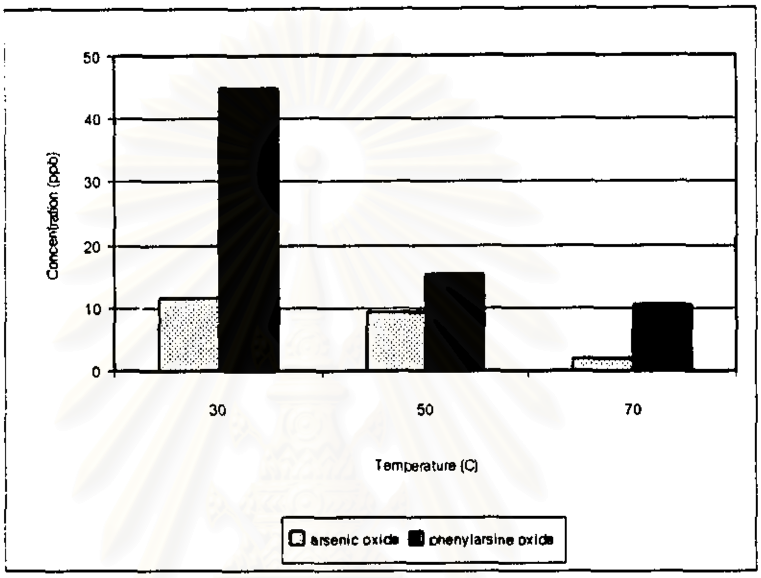

Figure 4.10 Amount of arsenic oxide and phenylarsine oxide remaining in study of adsorption on alumina adsorbent at various temperature

Table 4.14 Percent removal of arsenic oxide and phenylarsine oxide in study of adsorption on alumina adsorbent at various temperatures

Compounds	30°C (%)	50°C (%)	70°C (%)
Arsenic oxide	99.9	99.9	99.9
Phenylarsine oxide	99.6	99.8	99.9

Table 4.15 Percent decrease of surface area and pore volume of spent of alumina adsorbent in study of adsorption of arsenic oxide and phenylarsine oxide.

Compounds	Surface area (%)			Pore volume (%)		
	30°C	50°C	70°C	30°C	50°C	70°C
Arsenic oxide	18.8	23.2	12.7	19.8	24.7	8.8
Phenylarsine oxide	11.8	13.3	11.0	17.7	17.4	16.3

Table 4.15 show calculated percent decrease of surface area and pore volume of spent alumina adsorbent. The results show that percent decrease of both surface and pore volume of arsenic oxide are more than that of phenylarsine oxide. Decrease in surface area and pore volume result from deposition of arsenic on the adsorbent. Figure 4.11 to 4.12 show the pore size distribution of fresh and spent alumina adsorbent in study of arsenic oxide and phenylarsine oxide removal. It is found that there is slight decrease in pore size between 240 A and 120 A in both studies.

Table 4.16 Amount of arsenic removed per gram of alumina adsorbent

Compounds	30°C (μg/g)	50°C (μg/g)	70°C (μg/g)
Arsenic oxide	5770	5770	5773
Phenylarsine oxide	5760	5769	5770

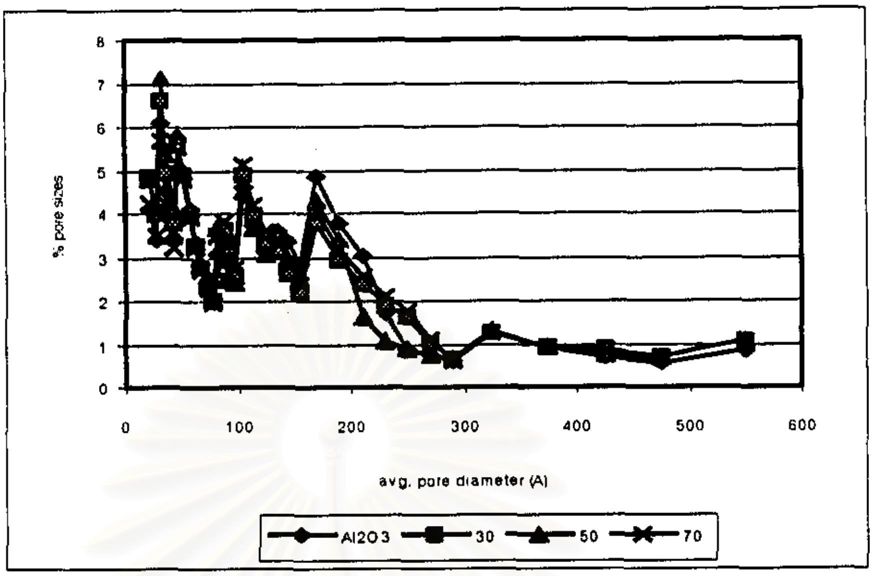

Figure 4.11 Comparison of pore size distribution between fresh and spent alumina adsorbent in study of removal of arsenic oxide.

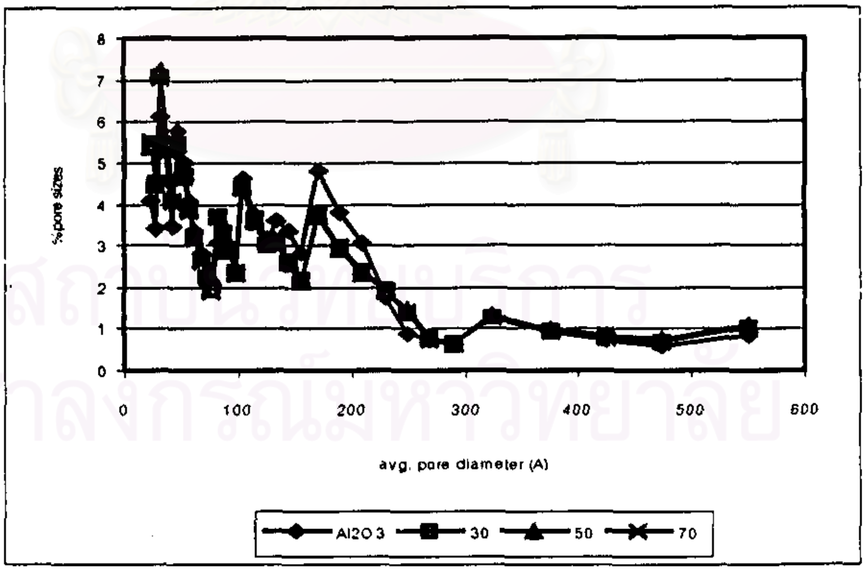

Figure 4.12 Comparison of pore size distribution between fresh and spent alumina adsorbent in study of removal of phenylarsine oxide.

Table 4.17Amount of arsenic removed per surface area of alumina adsorbent

Compounds	30°C (µg/m^2)	50°C (µg/m^2)	70°C (µg/m^2)
Arsenic oxide	26.5	26.5	26.5
Phenylarsine oxide	26.4	26.4	26.5

Amount of arsenic removed per gram of adsorbent and amount and amount of arsenic removed per surface area of adsorbent are calculated and shown in Table 4.16 o 4.17 Both amount of arsenic removed per gram of adsorbent and amount of arsenic removed per surface area of adsorbent in arsenic oxide and phenylarsine oxide removal by alumina adsorbent are much more than those of mercuric chloride and diphenylmercury removal. Thus it can be concluded that alumina can remove arsenic compounds with higher efficiency than remove mercury compounds.

Adsorption by copper adsorbent

Removal of arsenic and mercury compounds by copper adsorbent are studied in this section. Copper adsorbent is prepared by dry impregnation of copper on alumina. Metal content of copper is 2.5wt%. Experimental results are shown in Table 4.18 to 4.21.

Table 4.18 shows the amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsine oxide which remain in toluene and the amount which have been removed are shown in Table 4.19. Spent adsorbents are analyzed in order to determine the quantity of arsenic and mercury which are adsorbed. Table 4.20 shows the arsenic and mercury content of spent alumina adsorbent. It is found that the amount of arsenic and mercury removed from liquid sample are almost equal to the amount of arsenic and mercury found on the adsorbents.

Table 4.18 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsien oxide remaining in the study of adsorption on copper adsorbent at various temperatures

Compounds	30°C (ppb)	50°C (ppb)	70°C (ppb)
Mercuric chloride	76.7	89.2	110.7
Diphenylmemercury	633	413	312
Arsenic oxide	36.1	42.4	15.2
Phenylarsine oxide	20.5	12.2	8.5

Table 4.19 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsien oxide removed from toluene in the study of adsorption on copper adsorbent at various temperatures

Compounds	30°C (μg)	50°C (μg)	70°C (μg)
Mercuric chloride	80.0	78.9	77.0
Diphenylmemercury	31.7	59.5	49.2
Arsenic oxide	1728	1728	1730
Phenylarsine oxide	1730	1730	1731

Table 4.20 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsine oxide on the adsorbents in study of adsorption by copper adsorbent at various temperatures

Compounds	30°C		50°C		70°C	
	μg/ g ads.	μg	μg/ g ads.	μg	μg/ g ads.	μg
Mercuric chloride	77.1	77.1	77.6	77.6	71.0	71.0
Diphenylmemercury	36.6	36.6	37.8	37.8	36.5	36.5
Arsenic oxide	5503	1651	5473	1642	5503	1651
Phenylarsine oxide	4803	1441	4893	1468	4930	1479

Table 4.21 Surface area and pore volume spent adsorbent in study of arsenic and mercury removal by copper adsorbent.

Compounds	Surface area (m^2/g)			Pore volume (cc/g)		
	30°C	50°C	70°C	30°C	50°C	70°C
Mercuric chloride	142.9	134.9	134.6	0.205	0.197	0.197
Diphenylmercury	113.5	90.9	127.2	0.168	0.146	0.184
Arsenic oxide	138.1	138.4	146.4	0.200	0.204	0.215
Phenylarsine oxide	154.8	152.6	148.5	0.216	0.212	0.208

Adsorption of mercury compounds on copper adsorbent

The experimental results of adsorption of mercury on copper adsorbent are shown in Figure 4.13. Percent removals of mercury are calculated and shown in Table 4.22. The results show that concentration of mercury at operating temperature in study of mercuric chloride are decreased to 76 ppb, 89 ppb and 110 ppb, corresponding to 92%, 91% and 89% removal. The concentration slightly increases when temperature of adsorption increases. In study of diphenylmercury concentration of mercury are decreased to 633 ppb, 431 ppb and 312 ppb, corresponding to 37%, 69% and 57% removal. It indicates that concentration of diphenylmercury is decrease with temperature increases. Comparison between concentration of mercury in this section and in the adsorption on alumina section found that remaining concentration of mercury in adsorption on copper adsorbent is more than in adsorption of alumina adsorbent. As describe in adsorption of alumina adsorbent section mercuric chloride and diphenylmercury directly adsorb on to copper surface.

Percent decrease of total surface area and total pore volume spent copper adsorbents are shown in Table 4.23. The results show that percent decrease of total surface area and total pore volume of adsorbent in diphenylmercury study are more than in mercuric chloride study. As previous mentioned remaining concentration of mercuric chloride is less than of diphenylmercury. Thus the efficiency of copper adsorbent on removal of mercuric chloride is higher than on removal of diphenylmercury. Figure 4.14 to 4.15 show the pore size distribution of fresh and spent copper adsorbents. Data of surface area distribution and pore volume distribution of fresh and spent copper adsorbents are shown in Appendix A. It is apparent that there is slightly different of pore size distribution between fresh and spent adsorbent. This means that mercury adsorption is distributed through every pore size of adsorbent.

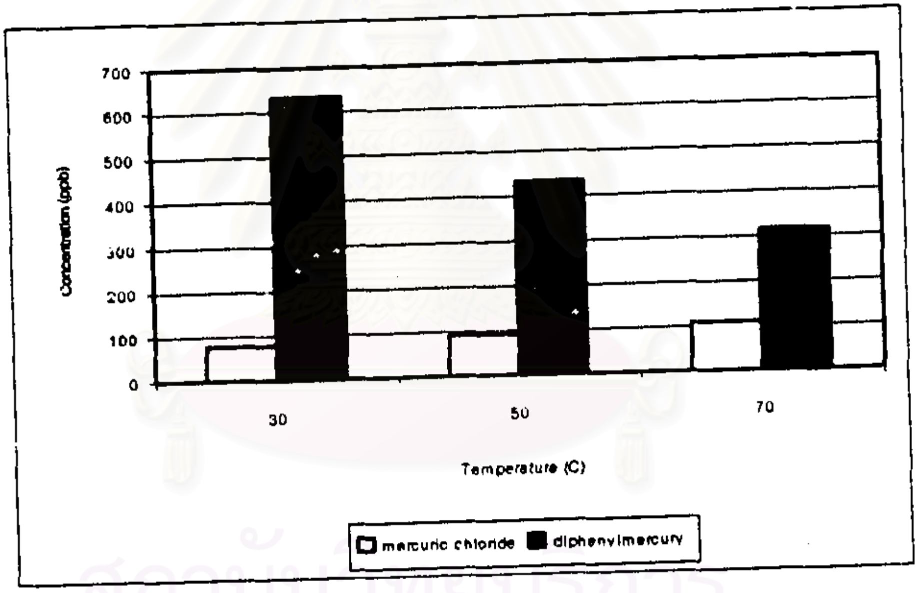

Figure 4.13 Amount of mercuric chloride and diphenylmercury remaining in study of adsorption on copper adsorbent at various temperature

Table 4.22 Percent removal of mercuric chloride and diphenylmercury in study of adsorption on copper adsorbent.

Compounds	30°C (%)	50°C (%)	70°C (%)
Mercuric chloride	92.3	91.1	88.9
Diphenylmercury	36.7	68.8	56.8

Table 4.23 Percent decrease of surface area and pore volume of spent copper adsorbent in study of adsorption of mercuric chloride and diphenylmercury

Compounds	Surface area (%)			Pore volume (%)		
	30°C	50°C	70°C	30°C	50°C	70°C
Mercuric chloride	8.4	13.5	13.7	10	13.6	13.4
Diphenylmercury	27.2	41.8	18.5	26	35.8	19.1

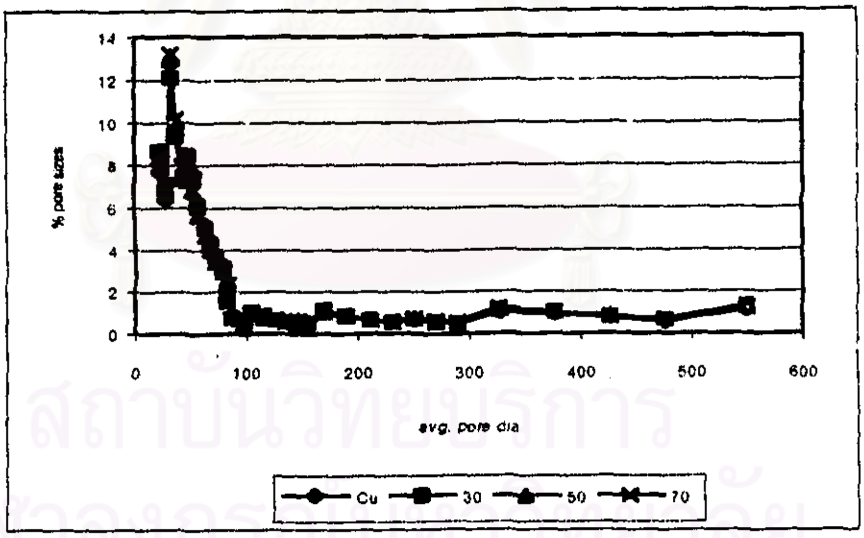

Figure 4.14 Comparison of pore size distribution between fresh and spent copper adsorbent in study of removal of mercuric chloride

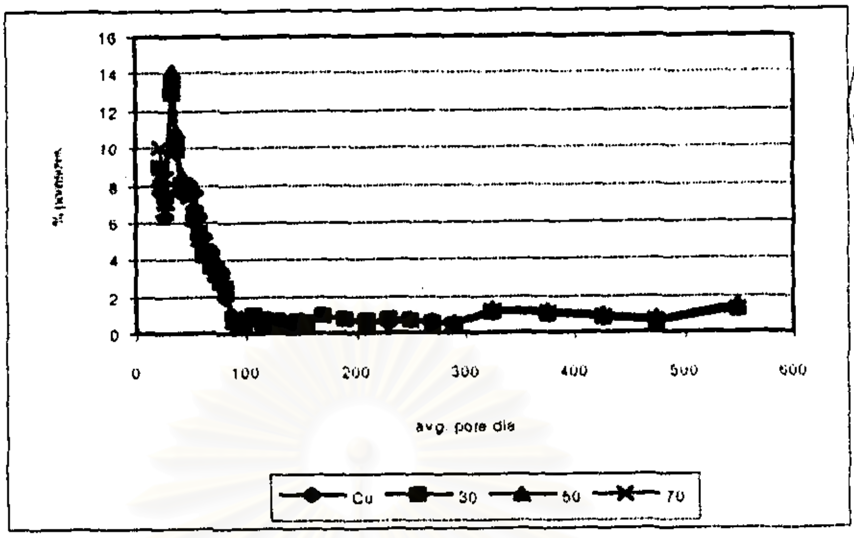

Figure 4.15 Comparison of pore size distribution between fresh and spent copper adsorbent in study of removal of diphenylmercury

Table 4.24 Amount of mercury removed per gram of copper adsorbent

Compounds	30°C (μg/g)	50°C (μg/g)	70°C (μg/g)
Mercuric chloride	80.0	78.9	77.0
Diphenylmercury	31.7	59.5	49.2

Table 4.25 Amount of mercury removed per surface area of copper adsorbent

Compounds	30°C ($\mu g/m^2$)	50°C ($\mu g/m^2$)	70°C ($\mu g/m^2$)
Mercuric chloride	0.5126	0.5056	0.4937
Diphenylmercury	0.2035	0.3817	0.3155

Amount of mercury removed per gram of adsorbent and amount of mercury per surface area of adsorbent are calculated and shown in Table 4.24 and Table 4.25 respectively. Comparison between copper and alumina adsorbent show that amount of mercury removed per surface area of copper adsorbent in study of mercuric chloride is about 1.5 times the amount of mercury removed per surface area of alumina adsorbent. This indicates that copper adsorbent can remove mercury more than alumina adsorbent if they have equal total surface area. In the study of diphenylmercury, amount of mercury removed per surface area of copper adsorbent is almost equal the amount of mercury removed per surface area of alumina adsorbent. This indicates that both copper adsorbent and alumina adsorbent show almost equal efficiency in diphenylmercury removal.

Adsorption of arsenic compounds on copper adsorbent

Figure 4.16 shows the result of study of arsenic oxide and phenylarsine oxide. Because initial concentration of arsenic is very high compared with concentration in product, thus percent removal of arsenic is calculated from the remaining concentration. The percent removals of arsenic in study of both arsenic oxide and phenylarsine oxide are shown in Table 4.26. The experiment results of both arsenic oxide and phenylarsine oxide show that the remaining concentration of arsenic of all experiments are very low and percent removal is more than 99.5%. It shows that almost all of arsenic in feed is removed by copper adsorbent. In addition, the remaining concentration of arsenic of both arsenic oxide and phenylarsine oxide is tended to decrease when temperature of adsorption increases. The spent copper adsorbent is measured the stoichiometry of copper-arsenic compounds by X-ray Diffraction (XRD). Figure 4.17 shows the XRD result of spent copper adsorbent. It shows that arsenic is interacted with copper and formed to copper arsenide (Cu_2As).

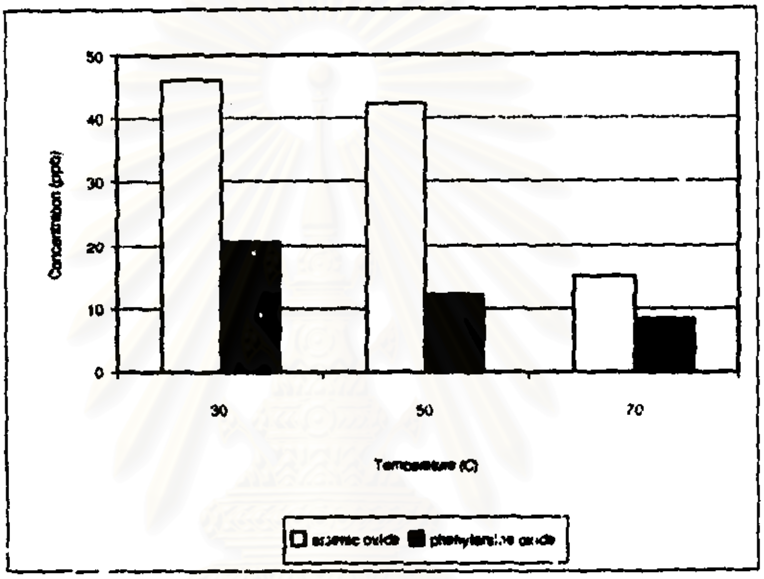

Figure 4.16 Amount of arsenic oxide and phenylarsine oxide remaining in study of adsorption on copper adsorbents

Table 4.26 Percent removal of arsenic oxide and phenylarsine oxide in study of adsorption on copper adsorbent at various temperatures

Compounds	30°C (%)	50°C (%)	70°C (%)
Arsenic oxide	99.5	99.6	99.8
Phenylarsien oxide	99.8	99.9	99.9

Table 4.27 Percent decrease of surface area and pore volume of spent copper adsorbent in study of adsorption of arsenic oxide and phenylarsine oxide

Compounds	Surface area (%)			Pore volume (%)		
	30°C	50°C	70°C	30°C	50°C	70°C
Arsenic oxide	11.5	11.3	6.16	12.0	10.4	5.5
Phenylarsine oxide	0.77	2.17	4.83	5.13	6.9	8.4

Percent decreases of surface area and pore volume of fresh and spent alumina are shown in Table 4.27. It is found that percent decreases in both surface area and pore volume of spent copper in study of phenylarsine oxide are less than in study of arsenic oxide. Decreasing of surface area and pore volume result from deposit of mercury on adsorbent. Figure 4.18 to 4.19 shows the pore size distribution of fresh and spent copper adsorbent. From the Figure, it is apparent that there is slight different of pore size distribution between fresh and spent adsorbent.

Table 4.28 Amount of arsenic removed per gram of copper adsorbent

Compounds	30°C (μg/g)	50°C (μg/g)	70°C (μg/g)
Arsenic oxide	5760	5761	5768
Phenylarsine oxide	5767	5769	5771

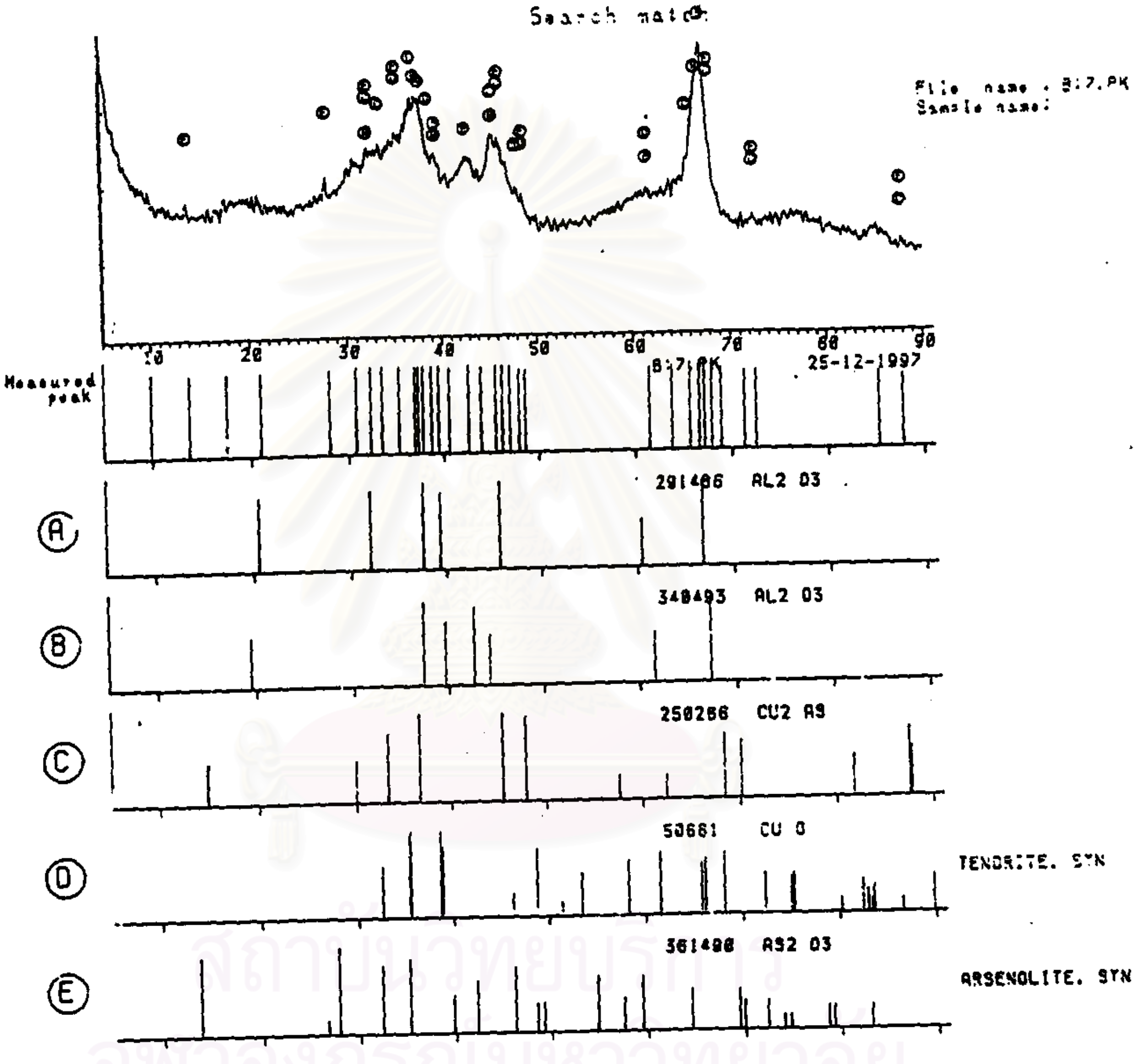

Figure 4.17 XRD pattern of spent copper adsorbent on phenylarsine oxide study

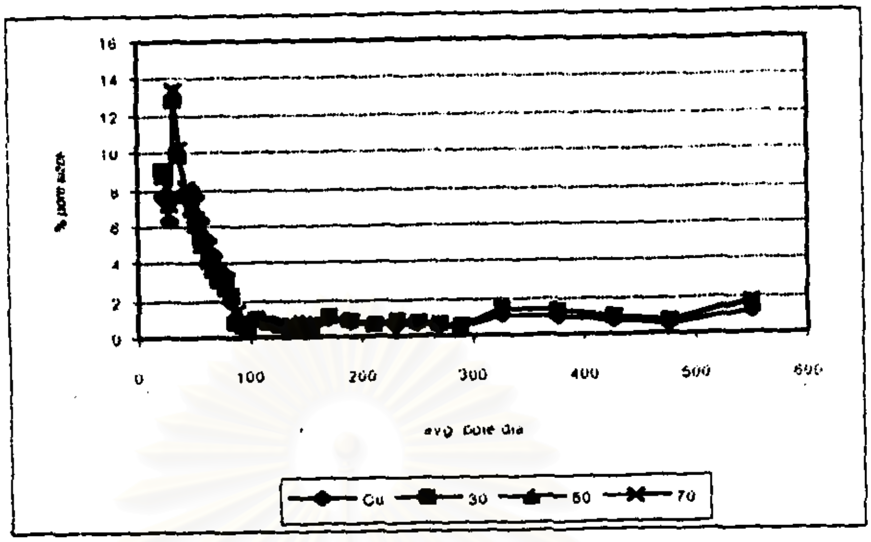

Figure 4.18 Comparison of pore size distribution between fresh and spent copper adsorbent in study of removal of arsenic oxide.

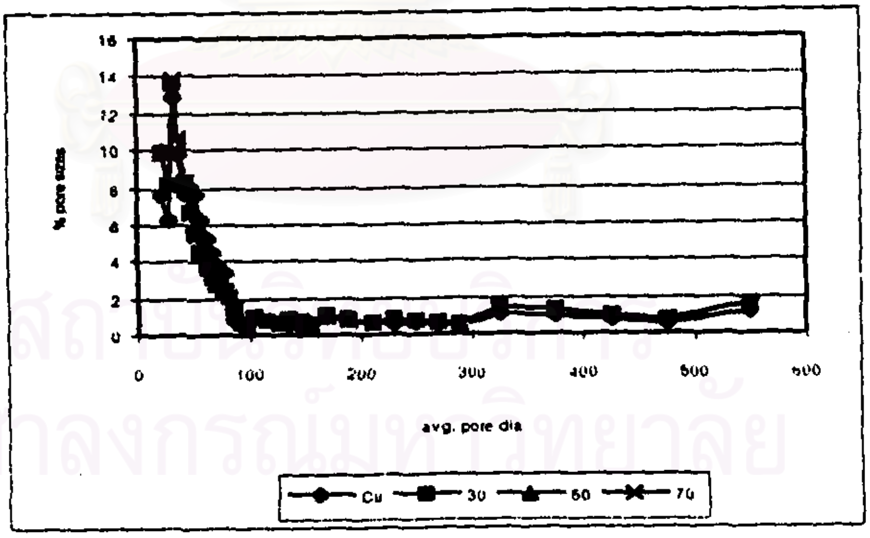

Figure 4.19 Comparison of pore size distribution between fresh and spent copper adsorbent in study of removal of arsenic oxide

Table 4.29 Amount of arsenic removed per surface area of copper adsorbent

Compounds	30°C (μg/m^2)	50°C (μg/m^2)	70°C (μg/m^2)
Arsenic oxide	36.9	36.9	37
Phenylarsine oxide	37	37	37

Amount of arsenic removed per gram of adsorbent and amount and amount of arsenic removed per surface area of adsorbent are calculated and show in Table 4.28 to 4.29. Both amount of arsenic removed per gram of adsorbent and amount of arsenic removed per surface area of adsorbent of arsenic compounds removal on copper adsorbent are much higher than in study of mercury compound removal. Thus it can be concluded that copper adsorbent has higher efficiency in removal of arsenic compounds than removal of mercury compounds. Comparison between copper adsorbent and alumina adsorbent show that amount of arsenic removed per gram adsorbent of copper adsorbent is almost equal to amount of arsenic removed per gram adsorbent of alumina adsorbent. While amount of arsenic removed per surface area of adsorbent of copper adsorbent is more than that of alumina adsorbent. This indicates that copper adsorbent show higher efficiency in removal of arsenic compounds than mercury compounds but both adsorbents show high efficiency in removal of arsenic compounds.

Adsorption by nickel adsorbent

This section, the experiments are conducted to study the adsorption of mercury and arsenic compounds on nickel adsorbent. Nickel adsorbent used is 2.5% loading of nickel on neutral alumina (Aldrich).

Table 4.30 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsine oxide remaining in study of adsorption on nickel adsorbent at various temperatures

Compounds	30°C (ppb)	50°C (ppb)	70°C (ppb)
Mercuric chloride	101.7	138.4	183.3
Diphenylmemercury	487	463	349
Arsenic oxide	38.9	30.5	31.3
Phenylarsine oxide	37.3	20.9	2.05

Table 4.31 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsine oxide removed from toluene in study of adsorption on nickel adsorbent at various temperatures

Compounds	30°C (μg)	50°C (μg)	70°C (μg)
Mercuric chloride	77.8	74.6	70.7
Diphenylmemercury	44.4	46.5	56.4
Arsenic oxide	1728	1729	1729
Phenylarsine oxide	1729	1730	1731

Table 4.32 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsine oxide on the adsorbents in study of adsorption by nickel adsorbent at various temperatures

Compounds	30°C		50°C		70°C	
	µg/ g ads.	µg	µg/ g ads.	µg	µg/ g ads.	µg
Mercuric chloride	77.1	77.1	77.6	77.6	71.0	71.0
Diphenylmenmercury	36.6	36.6	37.8	37.8	36.5	36.5
Arsenic oxide	5503	1651	5473	1642	5503	1651
Phenylarsine oxide	4803	1441	4893	1468	4930	1479

Table 4.33 Surface area and pore volume of spent nickel adsorbent in study of arsenic and mercury removal by nickel adsorbent.

	Surface area (m^2/g)			Pore volume (cc/g)		
	30°C	50°C	70°C	30°C	50°C	70°C
Mercuric chloride	143.2	141.6	139.4	0.194	0.215	0.190
Diphenylmercury	128.1	131.7	126.3	0.180	0.184	0.175
Arsenic oxide	144.4	133.7	148.4	0.203	0.191	0.199
Phenylarsine oxide	164.7	156.6	139.4	0.223	0.203	0.190

Amount of arsenic and mercury on spent adsorbent is analyzed. Table 4.31 shows the results of mercury and arsenic content on spent adsorbent. The results show amount of arsenic and mercury found the spent adsorbent is almost equal the amount of arsenic and mercury removed from liquid sample. This means that mercury and arsenic is adsorbed on the adsorbent.

Adsorption of mercury compounds on nickel adsorbent

The experiment results of mercuric chloride and diphenylmercury removal by nickel adsorbent are shown in Figure 4.29. Percent removals of mercury are calaulated and shown in Table 4.34. In the study of mercuric chloride, concentration of mercury remaining in solution at operating temperature is 102 ppb, 138 ppb and 183 ppb from initial concentration of 1,000 ppb, corresponding to 90%, 86% and 82% removal. Concentration of mercury increases when temperature increases from 30°C to 70°C. Remaining concentration of diphenylmercury is 487 ppb, 463 ppb and 349 ppb with 51%, 53% and 65% removal. As copper and alumina adsorbent, remaining concentration in study of diphenylmercury is much more than in study of mercuric chloride. The result also found that remaining concentration of mercury in adsorption on nickel are more than in adsorption on copper adsorbent and alumina adsorbent.

Table 4.34 Percent removal of mercuric chloride and diphenylmercury in study of adsorption on nickel adsorbent

Compounds	30°C (%)	50°C (%)	70°C (%)
Mercuric chloride	89.8	86.2	81.7
Diphenylmercury	51.3	53.7	65.1

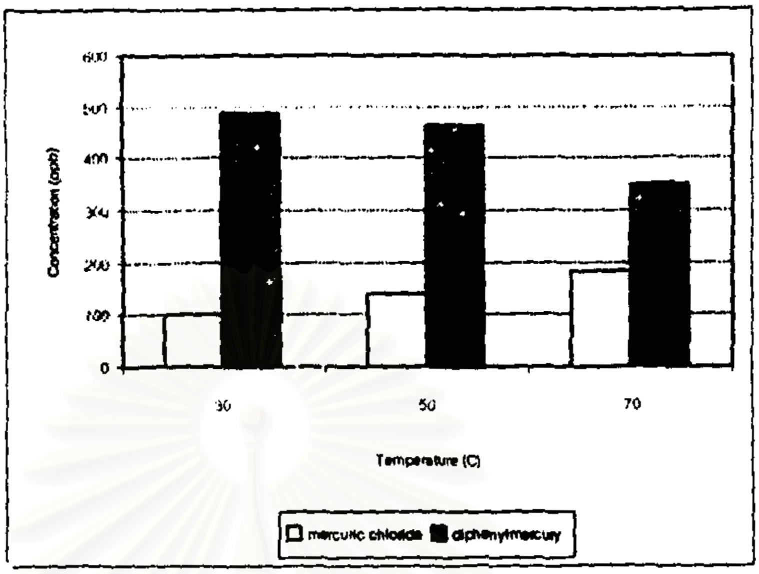

Figure 4.20 Amount of mercuric chloride and diphenylmercury remaining in study of adsorption on nickel adsorbent at various temperature

Table 4.35 Percent decrease of surface area and pore volume of spent nickel adsorbent in study of adsorption of mercuric chloride and diphenylmercury

Compounds	Surface area (%)			Pore volume (%)		
	30°C	50°C	70°C	30°C	50°C	70°C
Mercuric chloride	15.0	15.9	17.2	21.3	13.0	22.9
Diphenylmercury	24.0	21.8	25.1	27.2	25.3	29.1

Table 4.35 shows percent decrease of surface area and pore volume of fresh and spent nickel which operated at temperature from 30°C to 70°C. The results show that percent decreases of both total surface area and total pore volume in study of diphenylmercury are more than that of mercuric chloride.

Figure 4.21 to 4.22 shows the pore size distribution fresh and spent nickel adsorbent. There are slightly changes in pore size distribution.

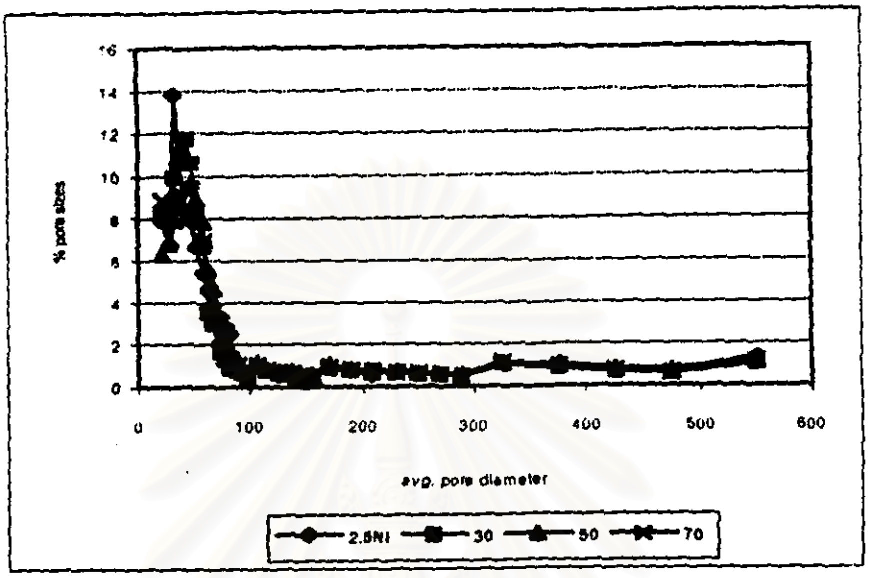

Figure 4.21 Comparison of pore size distribution between fresh and spent nickel adsorbent in study of removal of mercuric chloride.

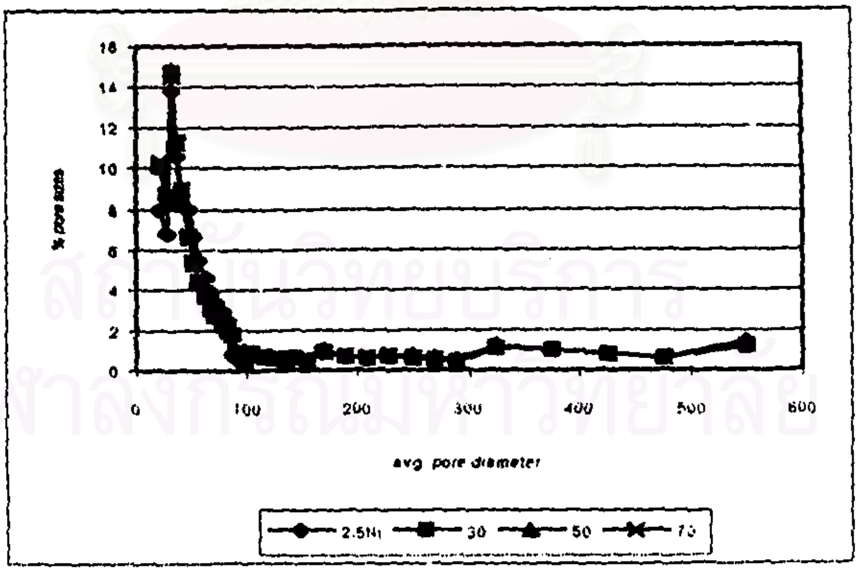

Figure 4.22 Comparison of pore size distribution between fresh and spent nickel adsorbent in study of removal of diphenylmercury.

Table 4.36 Amounts of mercury removed per gram of nickel adsorbent

Compounds	30°C (μg /g)	50°C (μg /g)	70°C (μg /g)
Mercuric chloride	78.2	75.5	72
Diphenylmercury	22.2	35.3	31.6

Table 4.37 Amount of mercury removed per surface area of nickel adsorbent

Compounds	30°C ($\mu g/m^2$)	50°C ($\mu g/m^2$)	70°C ($\mu g/m^2$)
Mercuric chloride	0.5222	0.5039	0.4808
Diphenylmercury	0.1479	0.2345	0.2112

Table 4.36 shows amounts of mercury removed per gram of adsorbent and Table 4.37 shows amount of mercury per surface area of adsorbent. The results show that amount of mercury removed per gram of adsorbent is about 70 μg/g adsorbent for mercuric chloride removal and 50μg/g adsorbent for diphenylmercury removal while the amount of mercury removed per surface area of adsorbent is rather low (below $0.5\mu g/m^2$.). As previous mentioned, the initial concentration of mercury compounds in toluene is low compare with surface area of adsorbent. Furthermore, the results also show that both amount of mercury removed per gram of adsorbent and amount of mercury removed per surface area of adsorbent in study of mercuric chloride is more than in study of diphenylmercury. The previous mentioned show that nickel adsorbent can show

higher efficiency on removing of mercuric chloride than removing of diphenylmercury.

Comparison between nickel and alumina adsorbent, it was found that amount of diphenylmercury removed per surface area of both adsorbent is almost equal while amount of mercuric chloride removed per surface area of nickel adsorbent is slightly more than alumina adsorbent. This indicates that nickel adsorbent show higher efficiency in removal of mercuric chloride than alumina adsorbent. Comparison between nickel adsorbent and copper adsorbent show that amount of mercury removed per gram of nickel adsorbent in study of mercuric chloride is less than that of copper adsorbent. Amount of mercury removed per surface area of nickel adsorbent is closely to amount of mercury removed per surface area of copper adsorbent. This show that copper adsorbent show higher efficiency in removal of mercury compounds than nickel, especially for mercury in ionic form.

Adsorption of arsenic compounds on nickel adsorbent

Figure 4.23 shows the experiment results of arsenic oxide and phenylarsine oxide removal by nickel adsorbent. Table 4.38 shows the calculated percent removal of arsenic and mercury. It is found that concentration of arsenic oxide and phenylarsine oxide is below 40 ppb from initial concentration of 10 ppm (10,000 ppb), corresponding to more than 99.6% removal which can be concluded that almost all of arsenic is removed. The results also show that percent removal of arsenic compounds by nickel adsorbent tend to decrease when temperature of adsorption increases.

Table 4.35 Percent removal of mercury in the study of arsenic oxide and phenylarsine oxide adsorption on nickel adsorbent

Compounds	30°C (%)	50°C (%)	70°C (%)
Arsenic oxide	99.6	99.7	99.7
Phenylarsine oxide	99.6	99.8	99.9

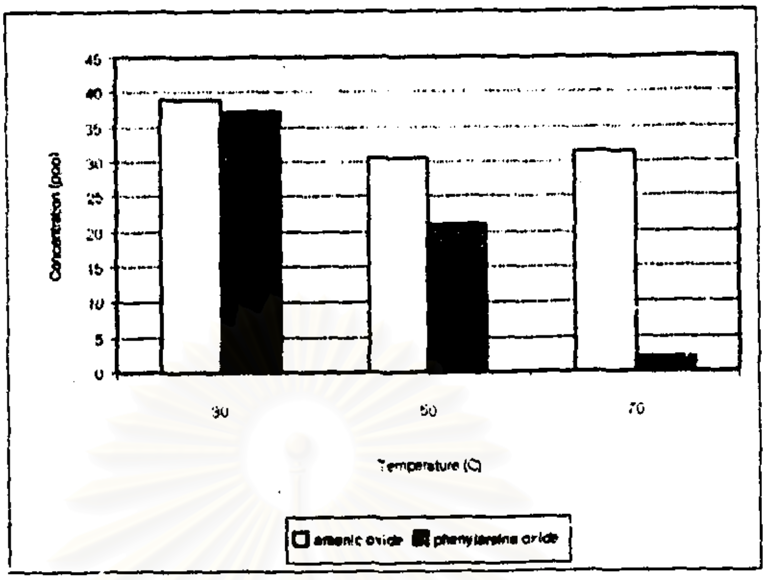

Figure 4.23 Amount of arsenicoxide and phenyiarsine oxide in study of adsorption on nickel adsorbent

Table 4.39 Percent decrease of surface area and pore volume of spent of nickel adsorbent in study of adsorption of arsenic oxide and diphenylmercury

Compounds	Surface area (%)			Pore volume (%)		
	30°C	50°C	70°C	30°C	50°C	70°C
Arsenic oxide	14.3	20.6	11.9	17.7	22.7	19.1
Phenylarsine oxide	2.2	7.1	17.3	9.9	17.9	22.9

After each experiment, spent adsorbents are analyzed for their characterization including total surface area, total pore volume and pore size distribution. Table 4.36 shows the results of characterization of spent adsorbent. It is found that surface area and pore volume is slightly decrease. The results show that percent decrease of surface area and pore volume in study arsenic oxide is more than that of phenylarsine oxide study. Decrease in surface area and pore volume result from adsorption of arsenic on the adsorbent. Figure 4.24 to 4.25

show pore size distribution of fresh and spent nickel adsorbents. From the result it is apparent that there is different of pore surface area distribution and pore volume distribution between fresh and spent adsorbent.

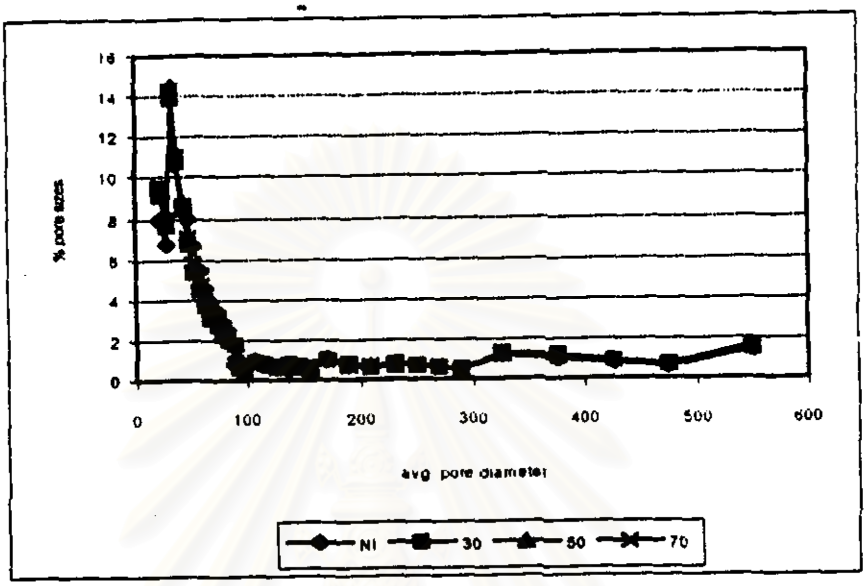

Figure 4.24 Comparison of pore size distribution between fresh and spent nickel adsorbent in study of removal of arsenic oxide.

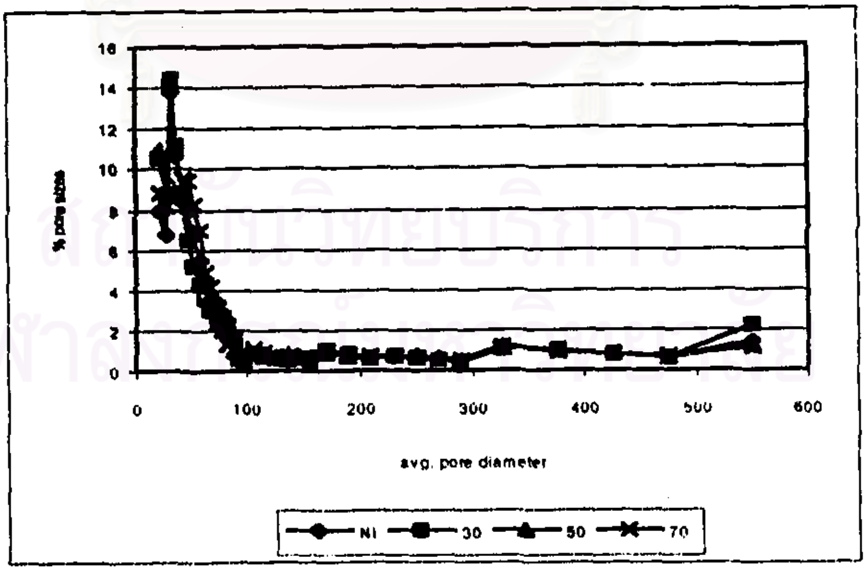

Figure 4.25 Comparison of pore size distribution between fresh and spent nickel adsorbent in study of removal of phenylarsine oxide.

Table 4.40 Amounts of arsenic removed per gram of nickel adsorbent

Compounds	30°C (μg/g)	50°C (μg/g)	70°C (μg/g)
Arsenic oxide	5750	5754	5754
Phenylarsine oxide	5750	5760	5772

Table 4.41 Amounts of arsenic removed per surface area of nickel adsorbent

Compounds	30°C ($\mu g/m^2$)	50°C ($\mu g/m^2$)	70°C ($\mu g/m^2$)
Arsenic oxide	34.1	34.2	34.2
Phenylarsine oxide	34.1	34.2	34.3

Amount of arsenic removed per gram of adsorbent and amount and amount of arsenic removed per surface area of adsorbent are calculated and show in Table 4.49 to 4.41. Both amount of arsenic removed per gram of adsorbent and amount of arsenic removed per surface area of adsorbent of arsenic oxide and phenylarsine oxide removal on nickel adsorbent are high because of high efficiency in removal of arsenic compounds. The value of arsenic removed per gram and arsenic removed per surface area of adsorbent are much higher than that of mercuric chloride and diphenylmercury. Thus it can be concluded that nickel have higher efficiency for removal of arsenic compounds than removal of mercury compounds.

Comparison between nickel, copper and alumina adsorbent show that amount of arsenic removed per surface area of adsorbent increase in the following order: copper adsorbent > nickel adsorbent > alumina adsorbent. The result shows that copper adsorbent shows highest efficiency in removal of mercury compounds.

Adsorption by nickel-copper adsorbent

From the above mentioned, we can conclude that nickel and copper can remove mercury and arsenic with high efficiency. Thus this section will be focused on the effect of bimetallic compounds adsorbents if both nickel and copper are presenting together. Adsorbent used is nickel-copper adsorbent which prepared by first impregnated by copper solution and by nickel solution in the latter. In order to prove that arsenic and mercury is adsorbed on nickel-copper adsorbent. Spent adsorbents are analyzed for their arsenic and mercury content and result is shown in Table 4.42. The amount of arsenic and mercury is shown in liquid concentration. The results show that amount of arsenic and mercury found on the adsorbent is almost equal amount of arsenic and mercury removed from liquid sample. This means that arsenic and mercury is removed by nickel-copper adsorbents.

Table 4.42 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsien oxide remaining in the study of adsorption on nickel-copper adsorbent at various temperatures

Compounds	30°C (ppb)	50°C (ppb)	70°C (ppb)
Mercuric chloride	96.76	128.4	168.3
Diphenylmemercury	744	593	634
Arsenic oxide	35.9	32.9	37.6
Phenylarsine oxide	34.0	36.2	36.1

Table 4.43 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsien oxide removed from toluene in the study of adsorption on nickel-copper adsorbent at various temperatures

Compounds	30°C (μg)	50°C (μg)	70°C (μg)
Mercuric chloride	78.2	75.5	72.0
Diphenylmemercury	22.1	35.2	31.6
Arsenic oxide	1728	1729	1729
Phenylarsine oxide	1729	1729	1729

Table 4.44 Amount of mercuric chloride, diphenylmercury, arsenic oxide and phenylarsine oxide on the adsorbents in study of adsorption by copper adsorbent at various temperatures

Compounds	30°C		50°C		70°C	
	μg/ g ads.	μg	μg/ g ads.	μg	μg/ g ads.	μg
Mercuric chloride	77.1	77.1	77.6	77.6	71.0	71.0
Diphenylmemercury	20.0	20.0	37.8	37.8	36.5	36.5
Arsenic oxide	5503	1651	5473	1642	5503	1651
Phenylarsine oxide	4803	1441	4893	1468	4930	1479

Table 4.45 Surface area and pore volume spent nickel-copper adsorbent

Compounds	Surface area (m^2/g)			Pore volume (cc/g)		
	30°C	50°C	70°C	30°C	50°C	70°C
Mercuric chloride	133.7	135.0	135.5	0.181	0.190	0.191
Diphenylmercury	116.0	119.4	125.8	0.165	0.170	0.177
Arsenic oxide	133.0	138.5	138.6	0.188	0.195	0.196
Phenylarsine oxide	131.9	136.4	135.1	0.205	0.208	0.214

Adsorption of mercury compounds on nickel-copper adsorbent

The experiment results of adsorption of mercury on nickel-copper adsorbent are shown in Figure 4.26. Percent removals of mercury are calculated and shown in Table 4.46. The results show that concentration of mercuric chloride at each operating temperature is decreased to 97 ppb, 128 ppb and 168 ppb, corresponding to 90%, 87% and 83% removal. The concentration of mercury increase with temperature of adsorption. In study of diphenylmercury concentration of mercury at operating temperature is decreased to 744 ppb, 634 ppb and 593 ppb, corresponding to 25%, 36% and 41% removal. The change in concentration of mercury in both studies is more than percent deviation shown in experimental error section. Comparison between concentration of mercury in this section and in the adsorption on nickel adsorbent and copper adsorbent found that remaining concentration of mercury in adsorption on nickel-copper adsorbent is more than that of both nickel adsorbent and copper adsorbent.

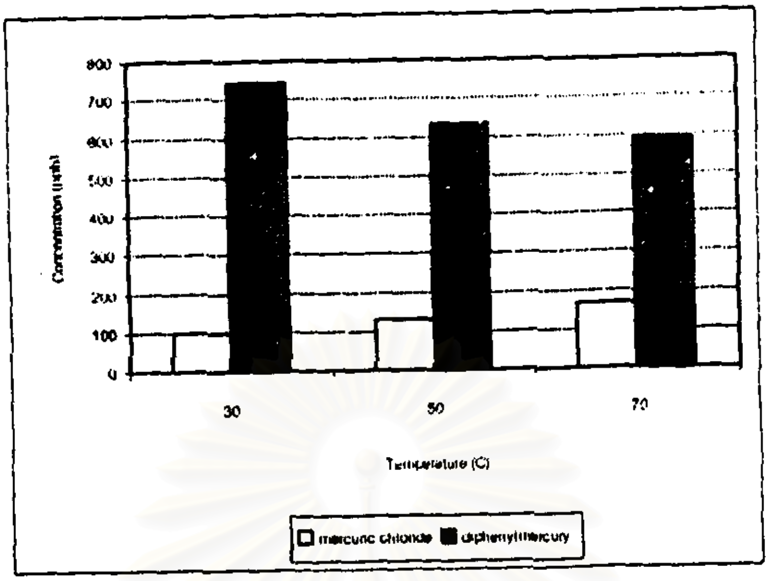

Figure 4.26 Amount of mercuric chloride and diphenylmercury in study of adsorption on nickel-copper adsorbents at various temperature

Table 4.46 Percent removal of mercuric chloride and diphenylmercury in study of adsorption on nickel-copper adsorbent

Compounds	30°C (%)	50°C (%)	70°C (%)
Mercuric chloride	90.3	87.2	83.2
Diphenylmercury	25.6	40.7	36.5

Table 4.47 Percent decrease of total surface area and total pore volume of spent nickel-copper adsorbent in study of removal of mercuric chloride and diphenylmercury.

Compounds	Surface area (%)			Pore volume (%)		
	30°C	50°C	70°C	30°C	50°C	70°C
Mercuric chloride	10.8	9.8	9.6	18.2	13.9	13.4
Diphenylmercury	22.5	20.3	16.0	25.4	23.2	20.0

Percent decrease of total surface area and total pore volume spent copper adsorbents are shown in Table 4.47. The results show that percent decrease of total surface area and total pore volume of adsorbent in diphenylmercury study are more than in mercuric chloride study. Figure 4.27 to 4.28 shows the surface area distribution and pore volume distribution of fresh and spent nickel-copper adsorbents. From the result it is apparent that there is slightly different of pore surface area distribution and pore volume distribution between fresh and spent adsorbent. This means that mercury adsorption was distributed on every pore size of adsorbent.

In order to compare the efficiency of nickel-copper adsorbent with nickel and copper, amounts of mercury removed per gram of adsorbent and amount of mercury per surface area of nickel-copper adsorbent are calculated and shown in Table 4.48 and Table 4.49.

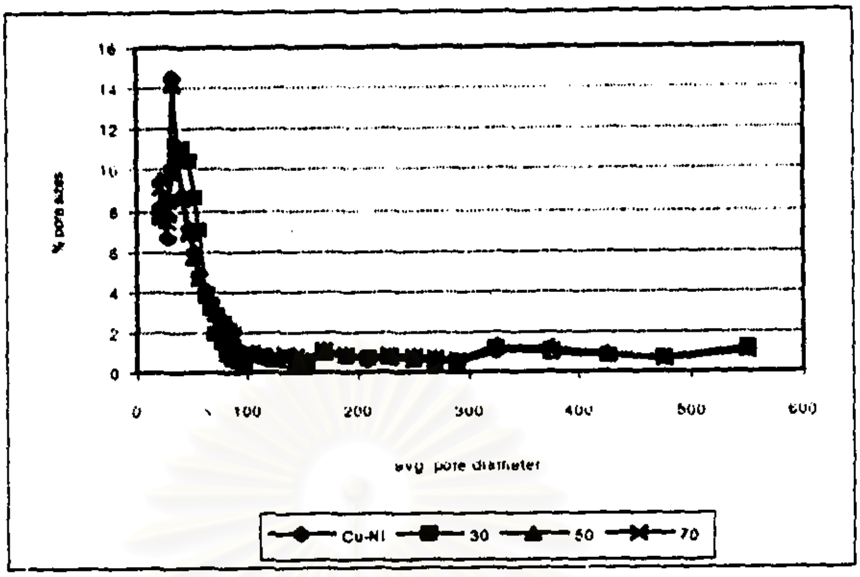

Figure 4.27 Comparison of pore size distribution between fresh and spent nickel-copper adsorbent in study of removal of mercuric chloride.

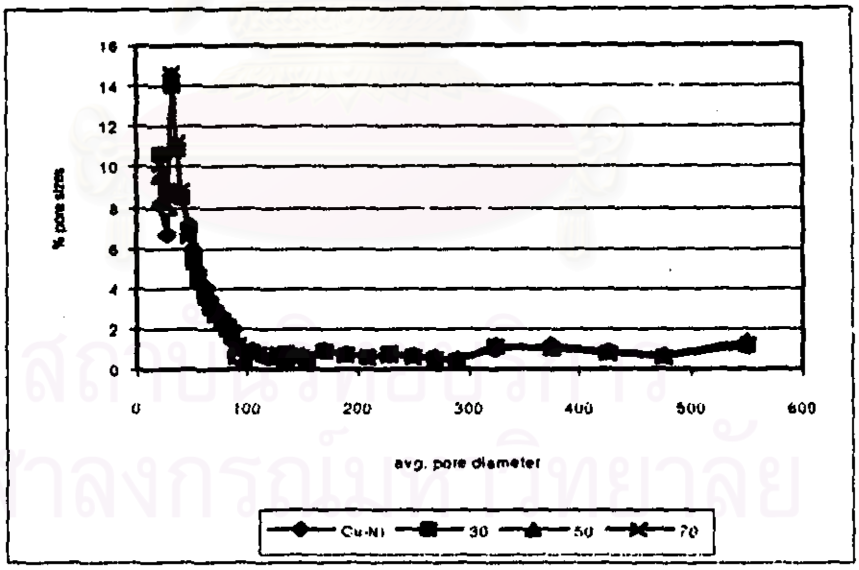

Figure 4.28 Comparison of pore size distribution between fresh and spent nickel-copper adsorbent in study of removal of diphenylmercury.

Table 4.48 Amount of mercury removed per gram of nickel-copper adsorbent

Compounds	30°C (μg /g)	50°C (μg /g)	70°C (μg /g)
Mercuric chloride	78.2	75.5	72.0
Diphenylmercury	22.2	35.3	31.6

Table 4.49 Amount of mercury removed per surface area of nickel-copper adsorbent

Compounds	30°C ($\mu g/m^2$)	50°C ($\mu g/m^2$)	70°C ($\mu g/m^2$)
Mercuric chloride	0.5222	0.5039	0.4808
Diphenylmercury	0.1749	0.2354	0.2112

The results show that amount of mercury removed per gram of adsorbent in study of mercuric chloride is almost identical for all temperature of each mercury compound while the amount of mercury removed per surface area of adsorbent is rather low. Because the initial concentration of mercury compounds in toluene is low compare with surface area of adsorbent. In diphenylmercury study both amount of mercury removed per gram of adsorbent and amount of mercury removed per surface area of adsorbent is less than in study of mercuric chloride study.

Comparison of nickel-copper with copper and nickel adsorbent show that amount of mercury removed per surface area of nickel-copper adsorbent in study of mercuric chloride is more than the amount of mercury removed per surface area of nickel and copper adsorbent. This show that nickel-copper adsorbent can show higher efficiency in removing of mercuric chloride than nickel and copper adsorbent if they have equal surface area. In the study of diphenylmercury, amount of mercury removed per surface area of nickel-copper adsorbent is less than the amount of mercury removed per surface area of nickel and copper adsorbent. These show that both nickel-copper adsorbents show lower efficiency in removal of diphenylmercury than nickel and copper adsorbent.

Adsorption of arsenic compounds on nickel-copper adsorbent

Figure 4.29 shows the result of study of arsenic oxide and phenylarsine oxide. Because initial concentration of arsenic is very high compared with concentration in product, thus percent removal of arsenic is calculated from the remaining concentration. The percent removals of arsenic in study of both arsenic oxide and phenylarsine oxide are shown in Table 4.50. The experiment results of both arsenic oxide and phenylarsine oxide show that the remaining concentration of arsenic are very low and percent removal is more than 99.5%.

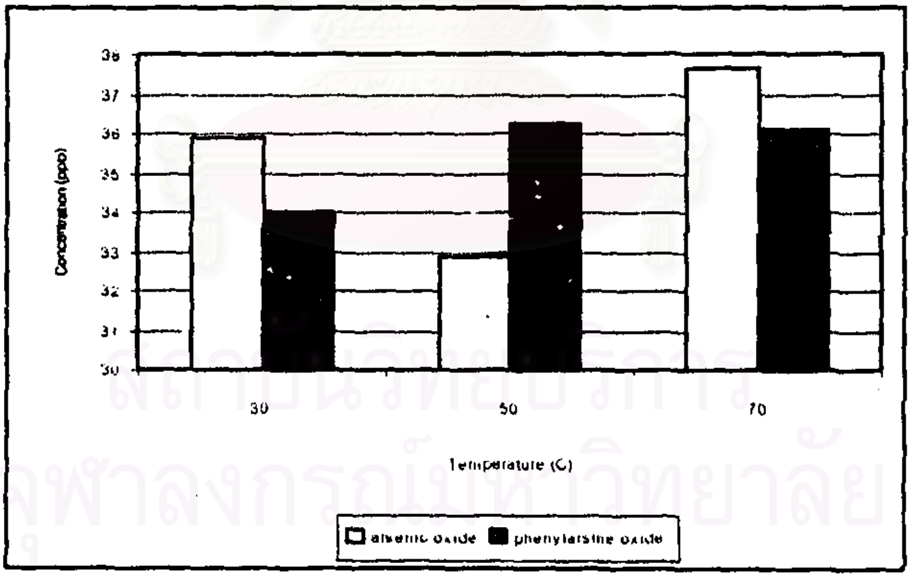

Figure 4.29 Amount of arsenic oxide and phenylarsine oxide in study of adsorption on nickel-copper adsorbents at various temperature

Table 4.50 Percent removal of arsenic oxide and phenylarsine oxide in the study of adsorption on nickel-copper adsorbents

Compounds	30°C (%)	50°C (%)	70°C (%)
Arsenic oxide	99.6	99.7	99.6
Phenylarsine oxide	99.7	99.6	99.6

Table 4.51 Percent decrease of total surface area and total pore volume of spent nickel-copper adsorbent in study of removal of arsenic compounds.

Compounds	Surface area (%)			Pore volume (%)		
	30°C	50°C	70°C	30°C	50°C	70°C
Arsenic oxide	11.2	7.5	7.5	15.0	11.7	11.5
Phenylarsine oxide	11.2	8.9	9.8	7.2	5.9	3.5

Percent decrease of total surface area and total pore volume of fresh and spent alumina are shown in Table 4.51. It was found that percent decrease in both total surface area and total pore volume of spent copper in study of phenylarsine oxide is less than in study of arsenic oxide. Decreasing of surface area and pore volume result from deposit of mercury on adsorbent. Figure 4.30 to 4.31 shows the surface area distribution and pore volume distribution of fresh and spent copper adsorbent. From the figure, it is apparent that there is slightly different of pore surface area distribution and pore volume distribution between fresh and spent adsorbent. This may result from arsenic distribute to every pore size of adsorbent.

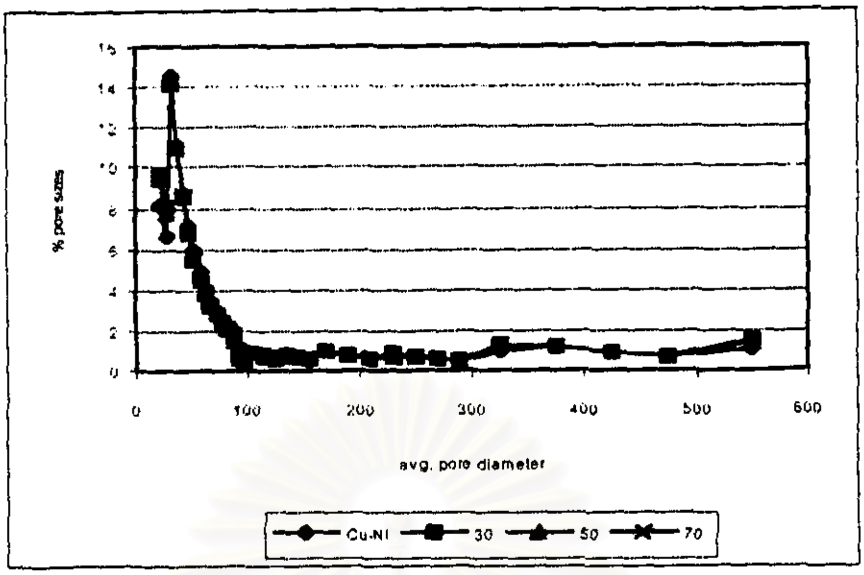

Figure 4.30 Comparison of pore size distribution between fresh and spent nickel-copper adsorbent in study of removal of arsenic oxide.

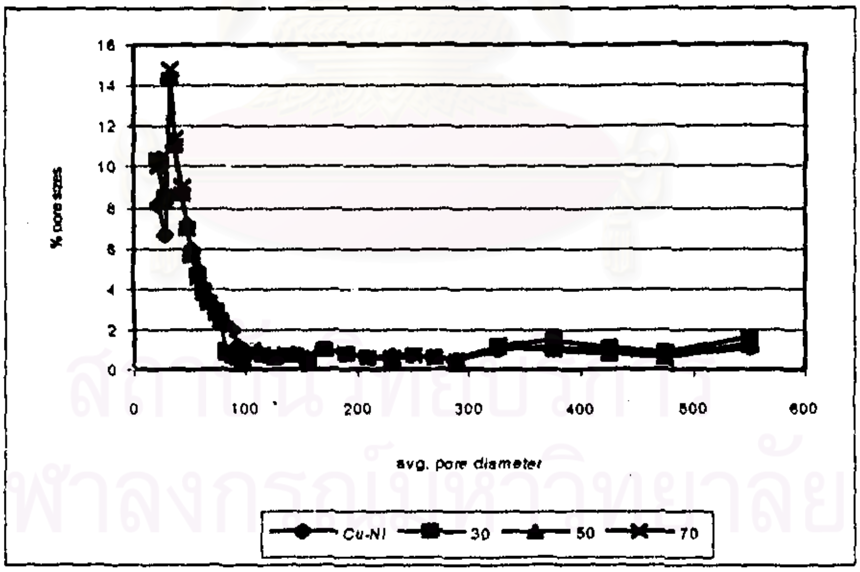

Figure 4.31 Comparison of pore size distribution between fresh and spent nickel-copper adsorbent in study of removal of phenylarsine oxide.

Table 4.52 Amount of arsenic removed per gram of nickel-copper adsorbent

Compounds	30°C (μg/g)	50°C (μg/g)	70°C (μg/g)
Arsenic oxide	5763	5764	5762
Phenylarsine oxide	5764	5762	5763

Table 4.53 Amount of arsenic removed per surface area of nickel-copper adsorbent

	30°C	50°C	70°C
Arsenic oxide	38.5	38.5	38.5
Phenylarsine oxide	38.5	38.5	38.5

Amount of arsenic removed per gram of adsorbent and amount and amount of arsenic removed per surface area of adsorbent are calculated and show in Table 4.52 to 4.53.

Comparison of nickel-copper adsorbent with nickel adsorbent and copper adsorbent show that amount of arsenic removed per gram adsorbent of nickel-copper adsorbent is nearly equal to amount of arsenic removed per gram adsorbent of nickel and copper adsorbent. While amount of arsenic removed per surface area of nickel-copper adsorbent is more than that of nickel and copper adsorbent. This indicates that nickel-copper adsorbent can shower higher efficiency in removal of arsenic than nickel and copper adsorbent