TREATMENT OF CCA WASTE STREAMS FOR RECYCLING USES

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Summary

The laboratory study indicates that chromated copper arsenate solid wastes, generated by both wood treater or manufacturer, can be successfully extracted to produce streams that can be either used for the preparation of fresh CCA preservative or recycled to the metals industry. The prefered extraction fluid is an aqueous ammoniacal solution containing a metal chelating component, such as citrate or tartrate.

The burning of CCA treated wood was investigated. The laboratory study shows no chromium or copper losses and suggests that burning, done under conditions of limited oxygen and high temperatures, can result in arsenic volatilization approaching zero.

1. Introduction

Chromated copper arsenate has been and continues to be the most widely used wood preservative in the world. Sales in North America have been maintained in the 150,000,000 oxide pound levels for many years. For example, in 1990 this amount of preservative was used to treat 438 million cubic feet of timber (1). The composition of the preservative has been primarily the C-type, with a minor amount of CCA-A and negligible amounts of CCA-B.

The preservative has been shown to be the standard by which other preservatives are measured. It has a long history of excellent performance against fungal and insect attack, as well as limnoria and teredo attack when in marine use; and lifetime warrantees, for certain treated products, are given by manufacturers of the preservative. It is relatively leach resistant and thus performs well in outdoor and aquatic environments for many years. CCA stakes, put in ground contact in 1940 by the Forest Products Laboratory in Mississippi, continue to give good performance. Bell Labs have CCA utility poles in service, which were commissioned in the 40's.

Chromated copper arsenate has been shown to be a relatively safe and non-hazardous wood preservative. Vegetable garden studies have shown no CCA components are taken into the produce (2,3). Acute marine sediment toxicity studies with leachate from CCA pilings on a benthic organism, *Ampelisca abdita*, indicate that the pilings have little impact on aquatic life (4). Conversely, some researchers suggest CCA treated wood can show adverse phytotoxicity and aquatic effects (5,6).

The CCA wood treating industry has been proactive in responsible and safe use of the preservative with no proven environmental impact. In the U.S., waste streams generated

at the treating plant or manufacturing facilities are readily fixed such that these pass the U.S. Environmental Protection Agency's Toxic Characteristic Leach Procedure (TCLP) (7). However, with increasing costs of disposal, coupled with the popular recycling movement in North America, it may make good business and environmental sense to consider recycling of the CCA waste streams. Typically, these streams are contaminated soil, equipment, and sludges. A commercial process to recycle CCA/wood sugar treating tank sludge has been described (8). Soil washing with acid experiments have been performed in the laboratory with mixed success (9).

At present there are no environmental regulations in the U.S.for the disposal of CCA treated wood for the end user (10). These wastes are considered to be non-hazardous and are disposed of in non-hazardous waste sites or burned in conventional incinerators with other combustibles. However, there is growing concern by utility companies as to who will be ultimately responsible for the disposal of CCA treated poles. Adding to the redundant pole issue is the unwanted decking, etc. that will be considered demolition wood in the future. The number of waste disposal sites are decreasing and redundant poles, piling and lumber, being a large volume material, may not be accepted at the limited number of sites in the future.

Worldwide scientific and commercial communities have begun to discuss life cycle analyses and the final disposal of treated wood (11 - 13). Recycling the redundant treated wood in useful products/materials has been discussed (14 - 17). For the disposal of CCA treated wood three approaches have been tested in the laboratory/pilot plant. Sawdust and chips have been chemically extracted (18, 19), bioremediation to extract the CCA components from the wood has been reported (20, 21), and recent burning studies now appear in literature (22, 23).

This paper describes laboratory work directed at the generation feedstocks useful for either the preparation/manufacture of CCA preservative or other useful industrial products. The waste streams examined were: 1) contaminated soil from a CCA treating plant, 2) CCA manufacturing sludge, and 3) combustion of treated wood.

2. Experimental

2.1 Chemical Extraction of CCA Treater/Manufacturing Wastes

Two waste streams were obtained from the Conley Plant of Hickson Corporation. One was a sample obtained from a customer, eg treater waste, and was gray in color and comprised mostly of dirt or soil; while the other was from the Conley Plant and was dark green. Both materials were sized, using a 10 mesh Tyler screen, and dried at 105 C prior to chemical extraction. Typically, samples from treaters contain rocks, banding, pieces of wood, etc., making it necessary for sizing the samples for laboratory testing.

Chemical extraction experiments were performed in both conventional laboratory equipment/glassware and in a Bench Scale Reactor, Model N. 2000-Y-100-PFTN. Small scale extractions were done on 10 gram samples, using 50 mL polypropylene centrifuge tubes (Fisher 05-539-9) that were placed inside TCLP jars and tumbled for one hour at room temperature and 32 rpm. The tubes were centrifuged for 25 minutes and the extraction fluid decanted. Multiple washings were done on the waste stream. Large scale extractions were typically done using 300 grams of the waste stream. The extraction liquids from these larger experiments were filtered using fast flow glass filters. Analyses of the extracts, residues, and resulting TCLP tests were accomplished by Inductively Coupled Plasma (ICP), on a Thermal Jarrell Ash Polyscan 61E. Sulfuric acid and aqueous ammonia with and without metal chelating compounds (acetate, citrate, tartrate, glycinate) were used for the extractions.

For the Bench Scale Reactor, reaction time, temperature and pressure were varied with the ammoniacal extraction fluids. Temperature was monitored with a Love Controls Corporation potentiometer.

2.2 Burning of CCA Treated Wood

Burning studies were conducted with CCA treated southern yellow pine (SYP) sapwood sawdust. The retention was 2.3 pcf CCA-C oxides (dry basis) and the sample prepared by passing through a Wiley mill, fitted with a 10 Tyler mesh screen. The moisture content was measured by drying the sample for 16 hours at 105°C.

The burning experiments were done in a tube furnace, consisting of a 26 mm inner diameter by 710 mm quartz tube which was placed into a Multiple Unit Electric Furnace, Hevi Duty Electric Company, Type 123-T. The temperature was adjusted using a Powerstat, Type 116. The air flow through the assembly was monitored by U.S. Airgas rotameter, Series 941, Model 941-6. The temperature was measured with a type K thermocouple placed at the point of combustion and recorded by a Molytek, Model 2702-2-R-R.

The furnace was heated to the run temperature and the air flow was set at 150 standard cubic centimeter (scc) per minute. Approximately 2.0 grams of sawdust were placed in a porcelain combustion boat. On reaching the desired temperature the combustion boat was pulled into the heated zone of the furnace by means of a nichrome wire which went through a rubber septum (located at the opposite end of the combustion tube). The samples were in the heated zone for between 5 and 30 minutes.

To trap any vaporized materials, two 125 mL bubblers were placed in series. For burns that lasted between 5 - 7 minutes, the first bubbler was empty and the second contained between 50 to 100 mL of a 2.0 weight percent aqueous sodium hydroxide. For the remainder of these experiments, the first trap contained 50 mL of 6 mm glass beads and the second, 50 mL of a 2.0 weight percent solution of monoethanolamine.

After each experiment the combustion tube and traps were rinsed thoroughly. The solid residues were digested using conventional glassware and also a CEM Microwave Digester, Model MDS 2000. The digesting fluid was comprised of a mixture of concentrated hydrochloric and nitric acids in a 2:1 volume ratio, respectively. The solution were analyzed for the CCA components by an ICP spectrometer.

3. Results and Discussion

3.1 Chemical Extraction of CCA Treater/Manufacturing Wastes

Treater Wastes

A sample of CCA contaminated gray soil was obtained from a wood treater. The soil was sized, using a 10 mesh Tyler screen, so as to minimize sample variability in the laboratory. Two types of experiments were performed using ammoniacal solutions as the extractive fluid: 1) hot extractions in a pressure autoclave and 2) ambient temperature extractions in sealed centrifuge tubes.

In order to determine the CCA content of the soil, a 150.0 gram sample was extracted with 20 percent sulfuric acid three times followed by water washing twice. The results of these extractions (Table 1) indicate the waste stream contains 2.51 percent chromium, copper and arsenic or 4.05 percent oxides in the ration of 49.1% CrO_3, 22.5% CuO, and 28.4% As_2O_5.

The final weight of the extracted, filtered and dried soil sample was 116.9 grams. The CCA oxides extracted were 4.05 grams, indicating some 29.05 grams of additional soil was extracted. Due to the evolution of gas when the soil was extracted, it is believed this additional dissolution of material was due to reaction of dolomitic materials with the acid. This clearly shows the non-selectivity of acid extraction of soils. Also, if recycle into CCA was desired, acid treatment would dissolve iron, which is a problem in formulating CCA. High iron levels in CCA causes iron arsenates to precipitate in concentrate tanks and give rise to floc in CCA work tanks. In addition the high sulfate levels are unacceptable, giving higher conductivities, corrosion rates, etc.

To improve the selectivity of the extractive fluid, aqueous ammonia solutions were selected as useful candidates. The first set of experiments were conducted in an autoclave, so that ammonia losses would be minimized when the extractions were done a elevated temperatures. Transition metal chelating ligands were examined to aid in the CCA removal in soils. These experiments are given in Table 2.

Comparison of the final and initial weights indicates a 3 to 11 percent decrease in sample weight after extraction. Based on the acid extraction of the soil, the expected decrease would be 4.05 percent, assuming all the CCA components were removed. The larger than anticipated weight losses are probably due to sample work-up/filtration. The CCA analyses for these autoclave extractions are reported in Table 3.

Runs made at atmosphere pressure, e.g. zero psi, probably had ammonia losses. Ammonia appears to be selective toward removal of copper but the percent ammonia used and amount of liquid used show little impact of the percent copper removed. These results may be due to the experimental error in the system. Citrate and to a lesser extent tartrate ion seem to remove all three CCA components. The low arsenic removal, only about 40 percent, is thought to be due to the inherent iron content of the specific soil sample. Iron complexes arsenate, so as to make it insoluble in ammoniacal extractive liquids.

In order to obtain information on ammoniacal washing of CCA contaminated soil which would be of more commerical interest, a second series of extractions were carried out at ambient temperature in sealed containers. So as to minimize sample loss through sample handling/filtration, the extractions were performed in 50 mL plastic centrifuge tubes. Eight consecutive washings were done using water, aqueous ammonia, and aqueous ammonia solutions containing either citrate or tartrate ion. This type of washing could similate a backwashing extractive process. The description of these experiments appears in Table 4 and illustrated in Figures 1 to 3.

The results show that only minor amounts of arsenic and chromium are extracted with any of aqueous solutions and only about 50 percent of the copper by the ammoniacal citrate or tartrate solutions. These results may indicate that elevated temperatures and solution concentration changes will be required to properly extract the CCA components from this waste stream. The extracted solids were digested and analyzed by ICP spectrocopy. However, due to incomplete digestion of the residue, the extracted metals content plus the "analyzed" solids due not add up the "theory" values.

Manufacturing Wastes

A dark green CCA waste stream was obtained from Hickson Corporation Conley Plant. The material is rich in arsenic and copper and to a lesser extent chromium. It may arise by reaction of copper oxide and arsenic acid to give an in-trackable copper arsenate. Presently, the material is fixed so as to pass the U.S. EPA TCLP test (7). Without fixation the solid gives TCLP chromium and arsenic numbers of 1680 and 468 mg/kg, far above the maximum allowable limit for these metals of 5.0 mg/kg. Thus, fixation or extraction is necessary.

In order to determine the content of chromium, copper and arsenic in the waste, it was treated with four hot (90°C) washes of 20 percent sulfuric acid followed by two water washes. The results of treating a 100.0 gram sample (dry and sized through a Tyler 10 mesh screen) are reported in Table 5. As is seen from the table, the stream is nearly 50 percent CCA components.

This waste material was extracted with ammoniacal solutions in a laboratory autoclave. The experimental data are given in Table 6. The ligands or additives were added as the acid. Note that the solids from run 3 were filtered and re-extracted in run 4.

The ammoniacal extracts were dark green in color, indicating reduced chromium(III). The filter cakes were also dark green, suggesting incomplete extraction of the CCA components, particularly chromium(III). Analyses of the extracts by ICP, shown in Table 7, indicate the following chromium, copper and arsenic (as the oxides) had been removed.

Little difference was found for the selectivity of the ammoniacal additive or ligand. There may be a slight improvement in the extractive nature of the aqueous ammonia when glycinate ion is present, but it not certain as yet.

Samples of this manufacturing waste were extracted at ambient temperature using the polypropylene centrifuge tubes. Multiple washing were done with water, aqueous ammonia, and aqueous ammonia containing either citrate or tartrate ion. A total of eight extractions were performed with fresh solutions being introduced for each extraction. The extract solutions were analyzed by ICP. These analyses are reported in Table 8 and illustrated by Figures 4 to 6.

As is readily seen, water alone removes a a fairly large amount of chromium (73.1%) and small amounts of copper (13.5%) and arsenic(10.2%). The addition of ammonia greatly increases the copper/arsenic values, such that the values for chromium, copper and arsenic are 84.9, 76.6 and 68.5 percent, respectively. Ammonia solubilizes copper as the tetraminecopper complex, forms amine complexes with chromium, and provides a base necessary for arsenic removal. The addition of transition metal chelating complexes, such as citrate and tartrate ion, to the ammoniacal extractive solution enhance the solubility of chromium(III) and copper(II). Thus, the values for citrate and tartrate for chromium rise to 96.2 and 94.0 percent, respectively, and for copper to 88.3 and 86.1 percent, respectively. Note that with the increased solubility of chromium and copper there is an increase in the arsenic leached to slightly more than 80 percent. This suggests that the increased arsenic solubility was due to the dissolution of chromium/copper arsenate complexes.

The water alone extract was yellow in color, indicating chromium(VI) or chromate ion, whereas the ammoniacal extracts were a dark green color. The green color is due to the yellow chromium(VI) mixing with reduced chromium(III), which is green, and blue tetraminecopper(II) ion.

The solids from the ambient temperature extractions were microwave digested with nitric acid and analyzed by ICP. These results, along with those from the extraction data (Table 8), are given in Table 9. Although the results are not totally satisfying, they do indicate reasonable mass balance (unlike those for the treater waste experiment).

Burning of CCA Treated Wood

The volatilization of arsenic from arsenic containing metal streams is well known in the metals refining industry. Arsenic pentoxide is easily reduced to the trioxide, which can sublime at temperatures below the combustion temperature of wood. Thus, interest in the

fate of arsenic from the burning of wood treated with arsenicals began some forty years ago (24) and has proceeded to the present (22 - 29). The results of these studies, all conducted in excess air, have shown that between 10 and 80 percent arsenic is volatlized with little to no loss of chromium and copper. The amount of arsenic trioxide sublimed is dependent on the combustion temperature, the time at temperature, the amount of air flow during combustion, and the oxygen partial pressure in the air.

The CCA-C treated wood selected for the present study (22) was southern yellow pine (SYP). To obtain increased analytical accuracy for residues and volatiles, a high CCA retention was used. The analysis was 1.57, 1.04, and 1.44 percent chromium, copper, and arsenic, respectively. This calculates to 2.3 pcf (36.8 kg/m^3) with a balance of 46.2 CrO_3, 19.9 CuO, and 33.9 As_2O_5.

The result of the tube furnace experiments are summarized in Table 10. The color and final weight of the post combustion residue was dependent on the temperature and amount on time at temperature. Low weight residues (approximately 0.1 gram) were green in color while all others were either black or gray in color.

Assuming CCA-wood complexes result in the formation chromium(III) oxide, copper(II) oxide, and arsenic pentoxide, on burning, a CCA oxide residue of 0.058 grams per gram of wood is calculated. The calculation assumes no CCA losses by volatilization. Residues, having weights greater than 0.058 grams/gram of sawdust, would be expected to contain char, and therefore be black or gray in color.

The amount of air to combust one gram of wood to carbon dioxide and water is estimated at 5.0 grams. Dobbs (27, 28) and later McMahon (29) have suggested 4.3 and 6 grams of air per gram of wood, respectively. If, however, the combustion products are carbon monoxide and water, only 2.5 grams of air are required. Figure 7 illustrates the amount of air per gram of sawdust that passed through the tube furnace and the weight of the resulting residue. When the quantity of air is in the 2.5 to 3.0 grams per gram of sawdust range, the residue was green. When the amount of air passing over the sample was less than this value, the residues are gray to black, suggesting incomplete combustion of the carbonaceous material.

After each run the combustion tube and glass bead containing trap were rinsed with a 2 percent solution of either sodium hydroxide or monoethanolamine solution. These solutions, along with the second trap, which contained one of these solutions, were analyzed by ICP spectroscopy. Essentially, no chromium or copper was found in any of these solutions. Thus, only arsenic analyses are reported in Table 11. Note also the the bulk of the arsenic, 42 to 93 percent, was found in the exit portion (17 cm in length) of the combustion tube, suggesting volatilized arsenic trioxide does not "travel" very far.

The ash or residue from each experiment was treated with nitric and hydrochloric acid mixtures in both conventional glassware and in a commercial microwave digester. Incomplete digestion was observed in all cases. (See Table 12.)

The microwave technique gives more complete digestions of the ash but solids still remain (although to a lesser extent). Calcination of transition metal oxides/compounds can cause the resulting solids to be insoluble in both acidic or basic solutions. Such appears to be the case with these residues. The lower levels of chromium and arsenic recovered by digestion suggest an intractable chromium/arsenic complex(es).

Previous burning studies (23 - 29) have shown that arsenic volatilization is directly proportional to the temperature of combustion, time at temperature, and oxygen partial pressure. Figure 8, which illustrates the McMahon et al. (29) data, shows these trends. Thurnau (30), studying arsenic calcination in other feedstocks, has found low oxygen partial pressures favor arsenic(III) and thus volatilization. The semi-commercial burning study by Thurnau has shown such an increase. It is well known that arsenic pentoxide, at sufficiently high temperatures, will decompose to arsenic trioxide and oxygen:

$$As_2O_5 \Longleftrightarrow As_2O_3 + O_2$$

Therefore, increases in oxygen might be expected to decrease the arsenic trioxide vaporized. However, since this is contrary to the results observed for the CCA burning studies, different solid state chemistry must be operational.

Examination of the arsenic volatilization versus temperature and time for this study is summarized in Table 13 and illustrated in Figure 9, which shows arsenic volatilization decreasing with increased temperature. These results are contrary to all previous studies. Linear regression analysis was performed on the data. The single data point at 900°C/30 minutes was ignored in this analysis since it was an obvious outlier. The results of the regression are given in Table 14.

The correlation factor, R^2, is quite good. Using the equation:

Arsenic Volatilized, % = Slope(Temperature, °C) + Constant

A calcination temperature can be calculated for the times given above where no arsenic volatilization occurs. This temperature is 1080, 1170, and 1230°C for the combustion times of 6, 15 - 20, and 30 minutes, respectively. Therefore, little or no arsenic would be predicted to volatalize at temperatures above 1100°C.

The formation of transition metal arsenides is the suspected reason for the results found in this study. The thermodynamics and kinetics are such that these arsenides would be expected (31) to form at the higher combustion or calcination temperatures. Additional laboratory work is underway to identify the solids in the residues, particularly those formed at the high temperatures.

4. Conclusions

Acid extraction of CCA waste streams can successfully remove the CCA components; however, the resulting solutions can not be readily recycled. Ammoniacal extraction techniques have shown promise. This latter route offers the advantage that ammonia can be stripped from extracts to generate solids which can be more readily used in the CCA recycle process. Waste materials will require multistage extraction processing to insure "complete" remove of the CCA components.

The laboratory burning of CCA treated wood has shown that it may be possible to burn this material with little or no arsenic volatilization. Arsenic losses are predicted to approach zero at temperatures in excess of 1100^{o}C and with limited oxygen for combustion. Thus, a commerical furnace used for the burning of CCA treated wood may not require the extensive baghouse and filters normally needed when calcining arsenic containing streams. The study also determined that no chromium or copper was volatilized.

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6. References

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TABLE 1. ACID EXTRACTION OF TREATER SOIL			
EXTRACTION, mL	CrO_3, g	CuO, g	As_2O_5, g
315 sulfuric	1.75	0.79	1.01
225 sulfuric	0.15	0.07	0.08
65 sulfuric	0.06	0.03	0.04
215 water	0.03	0.02	0.02
100 water	0.00	0.00	0.00
Total	1.99	0.91	1.15

TABLE 2. AMMONIACAL EXTRACTION OF TREATER SOIL AUTOCLAVE EXTRACTION: ELEVATED TEMPERATURES

	Sample Wt., g				Soln. Wt., g			
	Pressure							
RUN	INITIAL	FINAL	NH_3	WATER	% NH_3	LIGAND	psi	MINS.
1	600	577	1240	1100	4.15	NONE	0	15
2	300	290	815	500	2.45	NONE	0	15
3	300	287	1000	310	4.85	NONE	30	15
4	300	289	950	420	4.85	NONE	30	85
5	300	285	520	390	4.85	NONE	35	65
6	300	281	1000	320	11.1	NONE	50	50
7	300	282	530	375	4.95	NONE	13	115
8	300	290	690	400	4.95	ACETATE*	45	45
9	300	282	560	360	4.88	ACETATE	50	60
10	300	266	800	375	4.88	CITRATE	0	15
11	300	269	730	430	4.88	CITRATE	50	65
12	300	272	1000	475	5.02	TARTRATE	0	15
13	210	187	615	0	3.70	GLYCINATE	25	15

*INDICATES RUN WAS DONE USING 10.0 GRAMS OF AMMONIUM ACETATE. ALL OTHERS CONTAINED 20.0 GRAMS OF AMMONIUM ACETATE, CITRIC ACID, TARTARIC ACID, OR GLYCINE.

TABLE 3. AMMONIACAL EXTRACTION OF TREATER SOIL AUTOCLAVE EXTRACTION: ELEVATED TEMPERATURES

RUN	LIGAND	CrO_3, %	CuO %	As_2O_5, %
1	NONE	4.3	4.2	2.4
2	NONE	6.8	4.8	6.3
3	NONE	1.4	15.2	0.7
4	NONE	0.3	37.5	3.3
5	NONE	0.3	52.0	2.0
6	NONE	0.7	50.0	2.0
7	NONE	0.3	35.4	2.1
8	ACETATE*	0.3	62.5	1.1
9	ACETATE	0.4	33.3	0.5
10	CITRATE	91.3	89.6	40.0
11	CITRATE	97.1	89.6	41.3
12	TARTRATE	55.1	64.6	12.0
13	GLYCINATE	2.6	62.5	3.2

*SEE FOOTNOTE FOR TABLE 2.

TABLE 4. AMMONIACAL EXTRACTION OF TREATER WASTE AT AMBIENT TEMPERATURES

REAGENT	EXTRACTION NO.	CrO_3, %	CuO, %	As_2O_5, %
WATER	1	1.00	0.04	0.00
	2	0.54	0.16	0.10
	3	0.39	0.19	0.12
	4	0.40	0.14	0.10
	5	0.27	0.14	0.10
	6	0.31	0.13	0.09
	7	0.27	0.20	0.14
	8	0.22	0.18	0.13
	TOTAL	3.38	1.17	0.78
AMMONIA, 3.6%	1	2.95	9.40	0.92
	2	1.04	5.37	0.88
	3	0.62	3.85	0.83
	4	0.69	3.93	0.93
	5	0.37	2.45	0.68
	6	0.40	2.44	0.75
	7	0.28	1.27	0.53
	8	0.25	1.17	0.44
	TOTAL	6.60	29.87	5.96
AMMONIA, 3.6% PLUS CITRATE	1	4.33	29.51	2.50
	2	1.82	11.41	1.85
	3	1.26	5.67	1.54
	4	1.70	4.16	2.02
	5	0.98	2.15	1.18
	6	1.87	2.03	1.99
	7	0.86	0.97	0.90
	8	0.66	0.62	0.68
	TOTAL	13.49	56.51	12.65
AMMONIA, 3.5% PLUS TARTRATE	1	3.24	24.94	1.26
	2	1.24	9.98	1.08
	3	0.83	5.24	1.00
	4	1.19	4.27	1.30
	5	0.61	2.20	0.79
	6	1.20	2.15	1.27
	7	0.60	1.03	0.69
	8	0.48	0.68	0.52
	TOTAL	9.40	50.49	7.91

TABLE 5. ACID EXTRACTION OF MANUFACTURING WASTE			
EXTRACTION, mL	CrO_3, g	CuO, g	As_2O_5, g
200 sulfuric	8.77	10.80	22.64
210 sulfuric	0.55	0.68	1.99
210 sulfuric	0.13	0.11	0.34
150 sulfuric	0.09	0.07	0.18
250 water	0.03	0.02	0.04
200 water	0.01	0.02	5.19
TOTAL OR PERCENT	9.58	11.70	25.19

TABLE 6. AMMONIACAL EXTRACTION OF MANUFACTURING WASTE								
	Sample Wt., g		Soln. Wt., g				Pressure	
RUN	INITIAL	FINAL	NH_3	WATER	NH_3, %	LIGAND	psi	MINS.
1	210	187	1430	0	4.15	GLYCINATE	16	30
2	300	251	1550	2010	2.45	CITRATE	36	45
3	300	226	710	2220	4.85	TARTRATE #1	0	15
4	226	152	710	1640	4.85	TARTRATE #2	23	30

TABLE 7. AMMONIACAL RESULTS FOR MANUFACTURING WASTE				
RUN	LIGAND	CrO_3, %	CuO %	As_2O_5, %
1	GLYCINATE	56.5	55.6	61.9
2	CITRATE	55.9	37.0	42.4
3	TARTRATE #1	52.3	41.3	56.0
4	TARTRATE #1	38.1	43.5	37.9
3 & 4	TOTAL	90.4	84.8	93.9

TABLE 8. AMMONIACAL EXTRACTION OF MANUFACTURING WASTE AT AMBIENT TEMPERATURES

REAGENT	EXTRACTION NO.	CrO_3, %	CuO, %	As_2O_5, %
WATER	1	58.5	7.98	2.81
	2	10.6	2.27	1.91
	3	2.37	0.99	1.43
	4	0.74	0.66	1.20
	5	0.40	0.52	0.95
	6	0.15	0.37	0.69
	7	0.27	0.40	0.69
	8	0.10	0.30	0.56
	TOTAL	73.1	13.5	10.2
AMMONIA, 3.8%	1	62.8	47.22	33.0
	2	12.7	14.5	14.3
	3	4.03	6.88	8.86
	4	2.05	2.95	4.62
	5	1.26	2.14	3.24
	6	0.81	1.01	1.65
	7	0.67	1.22	1.80
	8	0.51	0.66	1.04
	TOTAL	84.8	76.6	68.5
AMMONIA, 3.3% PLUS CITRATE	1	66.4	50.5	37.5
	2	14.1	18.4	18.7
	3	6.37	8.79	11.7
	4	2.61	3.86	5.07
	5	1.97	2.23	3.50
	6	0.69	0.91	1.11
	7	1.34	0.95	2.00
	8	0.52	0.46	0.73
	TOTAL	94.0	86.1	80.4
AMMONIA, 3.2% PLUS TARTRATE	1	68.2	51.8	37.3
	2	14.1	18.5	18.7
	3	6.79	9.46	12.6
	4	2.46	3.76	4.86
	5	2.12	2.42	3.72
	6	0.67	0.96	1.11
	7	1.41	1.00	2.11
	8	0.48	0.47	0.73
	TOTAL	96.2	88.3	81.0

TABLE 9. MATERIAL BALANCE: EXTRACTION OF MANUFACTURING WASTE

	EXTRACTED, %			RESIDUE, %			TOTAL, %		
	CrO_3	CuO	As_2O_5	CrO_3	CuO	As_2O_5	CrO_3	CuO	As_2O_5
WATER	7.00	1.58	2.58	3.46	12.21	22.58	10.36	13.79	25.11
AMMONIA	8.13	8.96	17.26	1.87	1.50	4.62	10.00	10.46	21.88
AMMONIA PLUS CITRATE	9.00	10.07	20.24	1.29	0.47	2.84	10.29	10.54	23.08
AMMONIA PLUS TARTRATE	9.22	10.34	20.40	1.27	0.57	2.68	10.50	10.91	23.08
SULFURIC ACID EXTRACTION							9.58	11.70	25.19

TABLE 10. CCA TREATED SYP BURNING EXPERIMENTS

RUN	TEMP., °C	TIME, MINS.	SAMPLE WEIGHT, g	
			INITIAL	FINAL
1	600	18	2.39	0.18
2	600	20	1.97	0.33
3	680	6	2.16	0.66
4	700	6	2.34	0.73
5	700	30	2.10	0.11
6	800	6	2.46	0.84
7	800	30	2.29	0.13
8	900	6	2.82	0.16
9	900	30	2.52	0.11
10	1000	15	2.14	0.35
11	1000	30	2.33	0.09

TABLE 11. ANALYSES OF VOLATILES: ARSENIC					
	ARSENIC VOLATILIZED, G				
RUN	TUBE	1ST TRAP	2ND TRAP	TOTAL	PERCENT
1	0.0046	0.0008	0.0019	0.0072	20.9
2	0.0042	0.0006	0.0005	0.0050	17.6
3	0.0027	0.0002	0.0000	0.0029	9.3
4	0.0028	0.0002	0.0000	0.0030	8.9
5	0.0047	0.0006	0.0002	0.0056	18.5
6	0.0016	0.0003	0.0004	0.0023	6.5
7	0.0039	0.0012	0.0001	0.0052	5.8
8	0.0009	0.0002	0.0007	0.0017	4.2
9	0.0005	0.0004	0.0002	0.0012	3.3
10	0.0021	0.0003	0.0003	0.0027	8.0
11	0.0012	0.0004	0.0002	0.0018	5.8

TABLE 12. MATERIAL BALANCE FOR CCA TREATED SYP BURNING

	METALS RECOVERED, %		
RUN	Cr	Cu	As
1*	68.5	70.5	74.4
2	18.1	40.3	48.6
3*	88.8	85.5	89.4
4*	84.2	73.7	88.1
5	10.6	60.0	61.9
6*	125	128	88.4
7	6.7	69.9	60.3
8*	71.1	102	66.0
9	1.8	26.2	22.3
10*	17.8	42.9	20.5
11	3.9	50.0	23.4

* SAMPLE DIGESTED IN A MICROWAVE DIGESTER.

TABLE 13. ARSENIC VOLATILIZATION, PERCENT

	TIME - MINUTES		
TEMPERATURE, °C	6	15 - 20	30
600		20.9	
600		17.9	
680	9.3		
700	8.9		18.5
800	6.5		15.8
900	4.2		3.3
1000		5.8	8.0

TABLE 14. LINEAR REGRESSION OF ARSENIC VOLATILIZATION VERSUS TEMPERATURE			
TIME, MINUTES	SLOPE	CONSTANT	R^2
5 - 7	-0.0233	25.2	0.999
15 - 20	-0.0340	39.8	0.965
30	-0.0356	43.7	0.993

Ammoniacal Extraction of Chromium

Treater Waste - Ambient Temp.

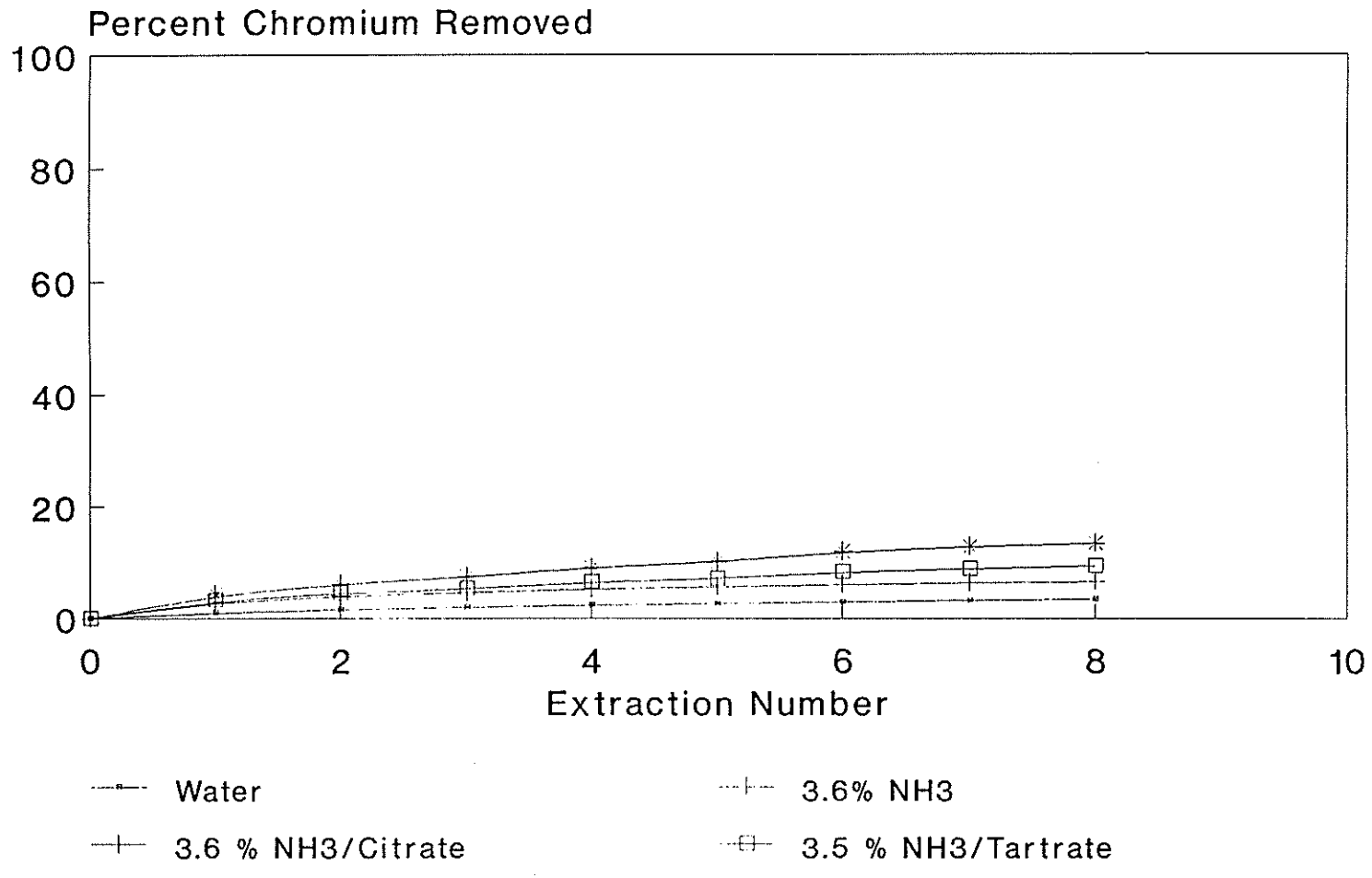


FIGURE 1

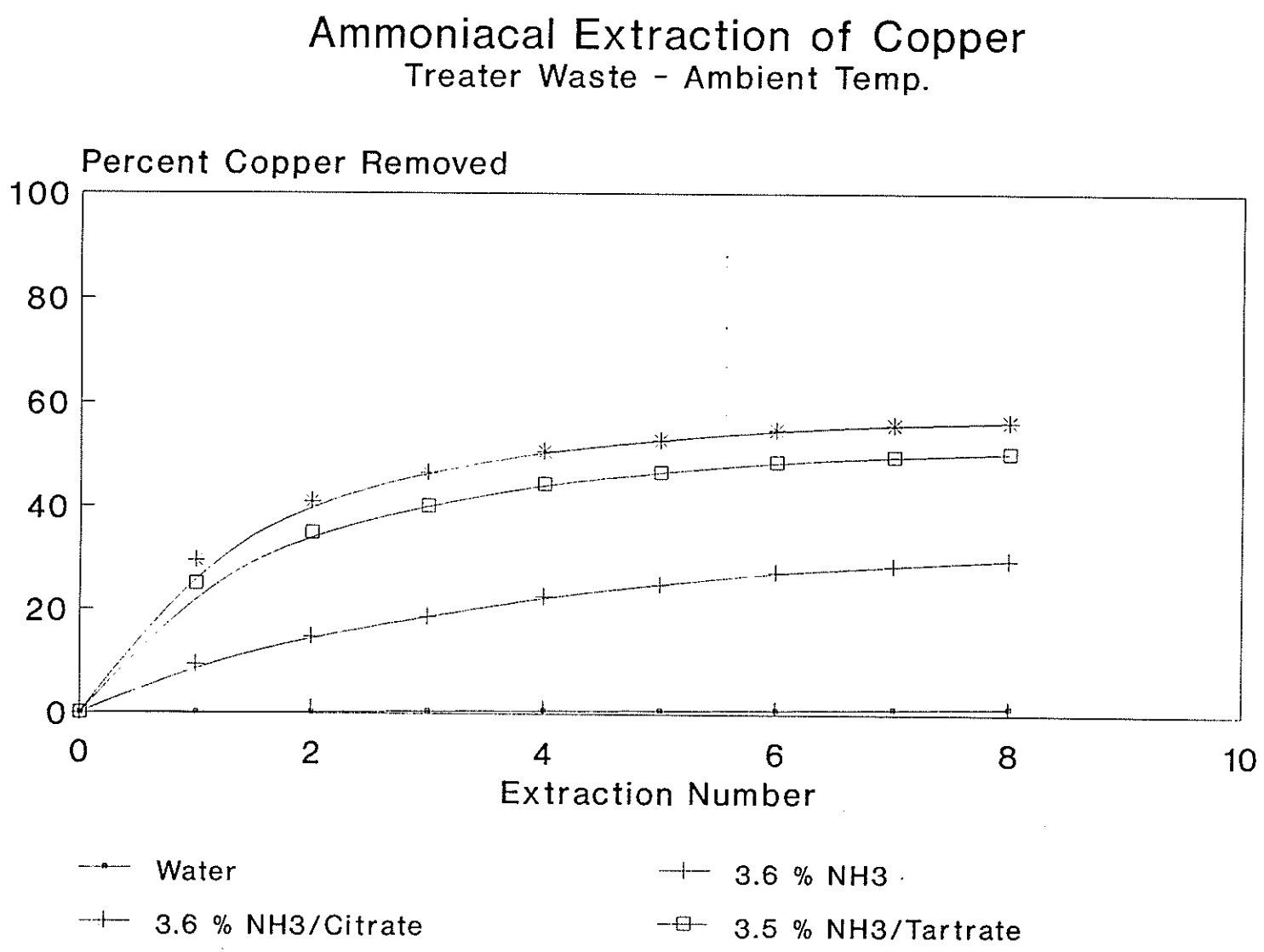

Ammoniacal Extraction of Copper
Treater Waste - Ambient Temp.
Percent Copper Removed
100
80
60
40
20
0
0
2
4
6
8
10
Extraction Number
Water
3.6 % NH3
3.6 % NH3/Citrate
3.5 % NH3/Tartrate

FIGURE 2

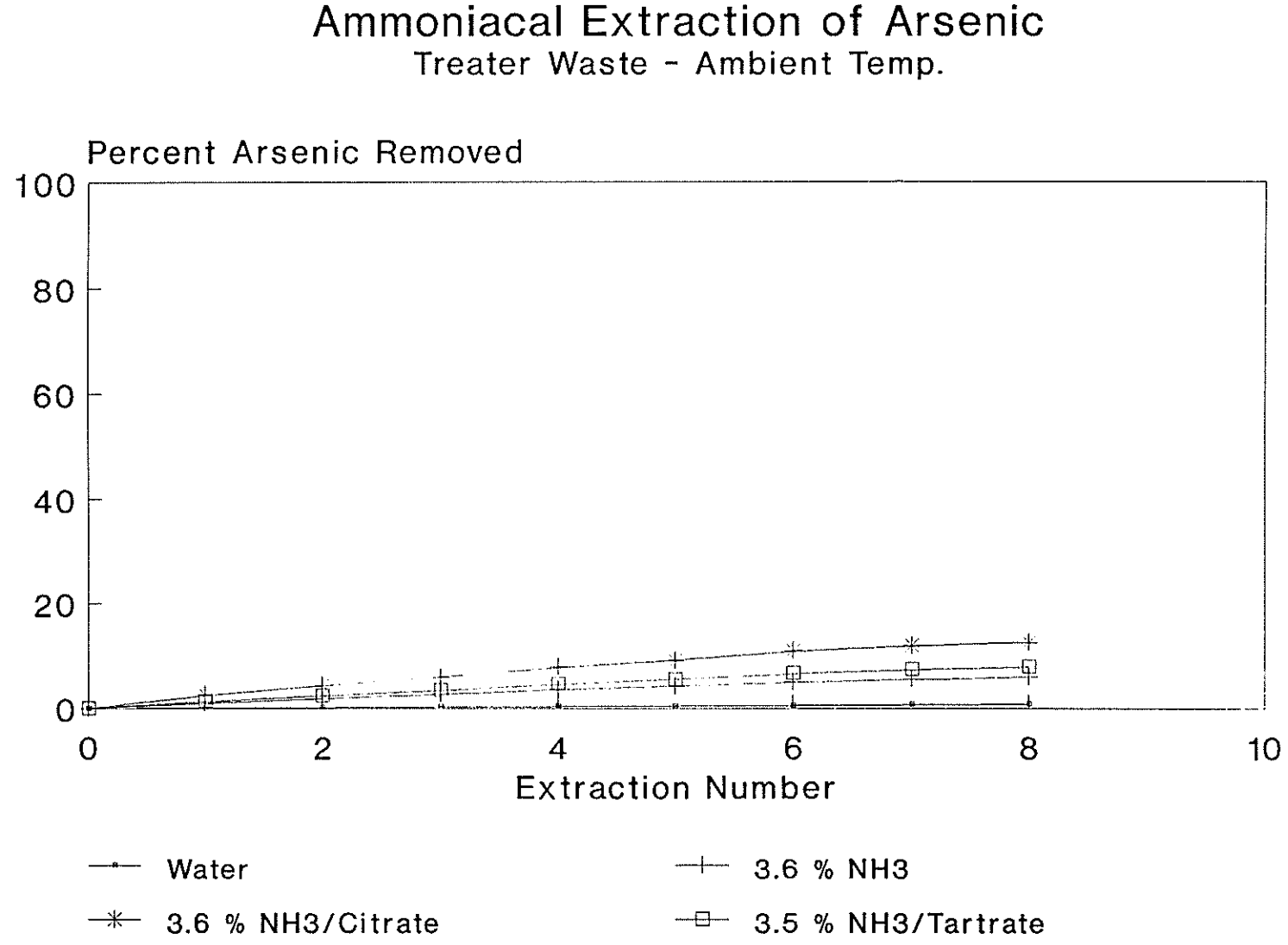

Ammoniacal Extraction of Arsenic
Treater Waste - Ambient Temp.
Percent Arsenic Removed
100
80
60
40
20
0
0
2
4
6
8
10
Extraction Number
Water
3.6 % NH3
3.6 % NH3/Citrate
3.5 % NH3/Tartrate

FIGURE 3

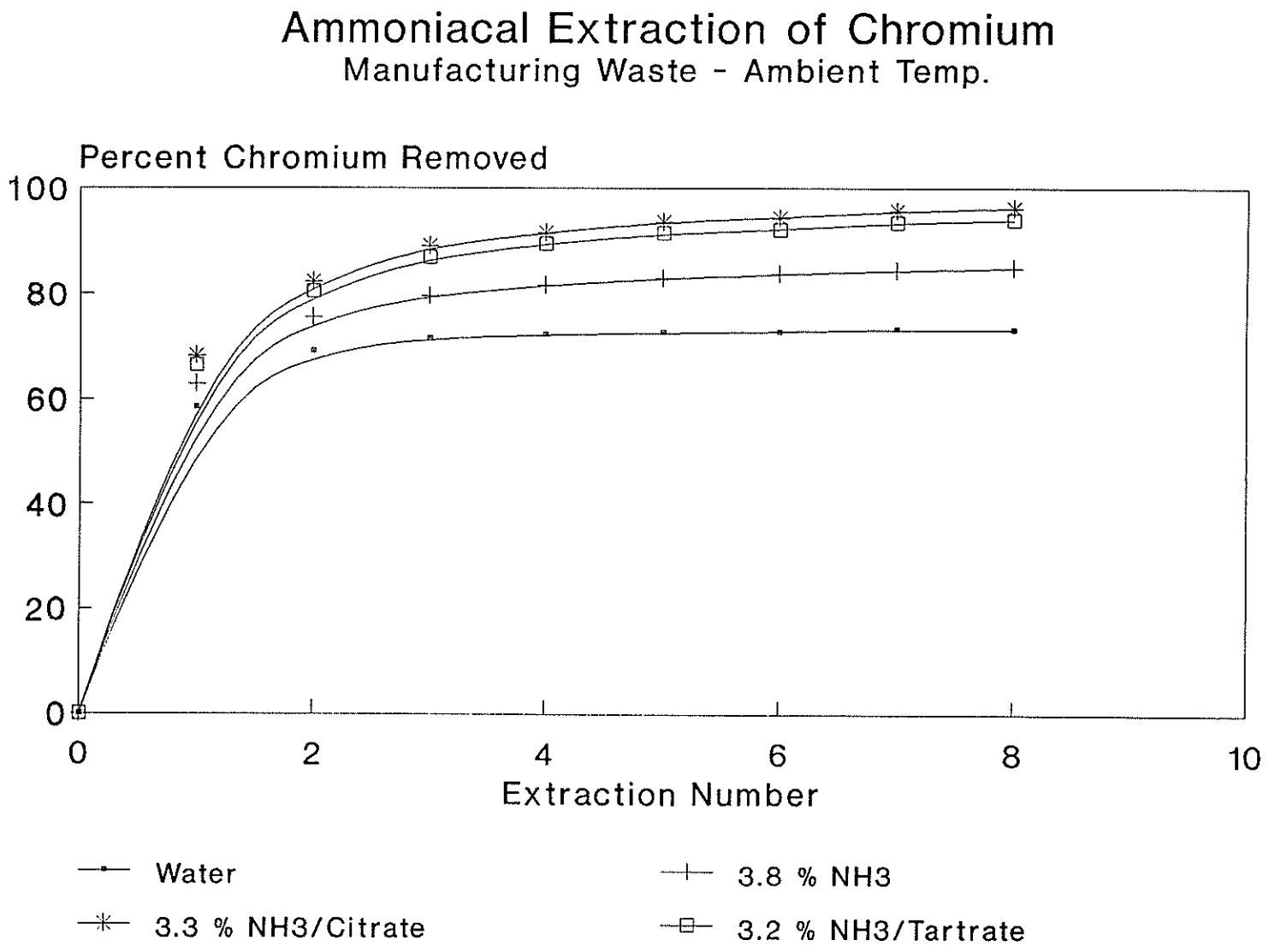

Ammoniacal Extraction of Chromium
Manufacturing Waste - Ambient Temp.
Percent Chromium Removed
100
80
60
40
20
0
0
2
4
6
8
10
Extraction Number
Water
3.8 % NH3
3.3 % NH3/Citrate
3.2 % NH3/Tartrate

FIGURE 4

Ammoniacal Extraction of Copper

Manufacturing Waste - Ambient Temp.

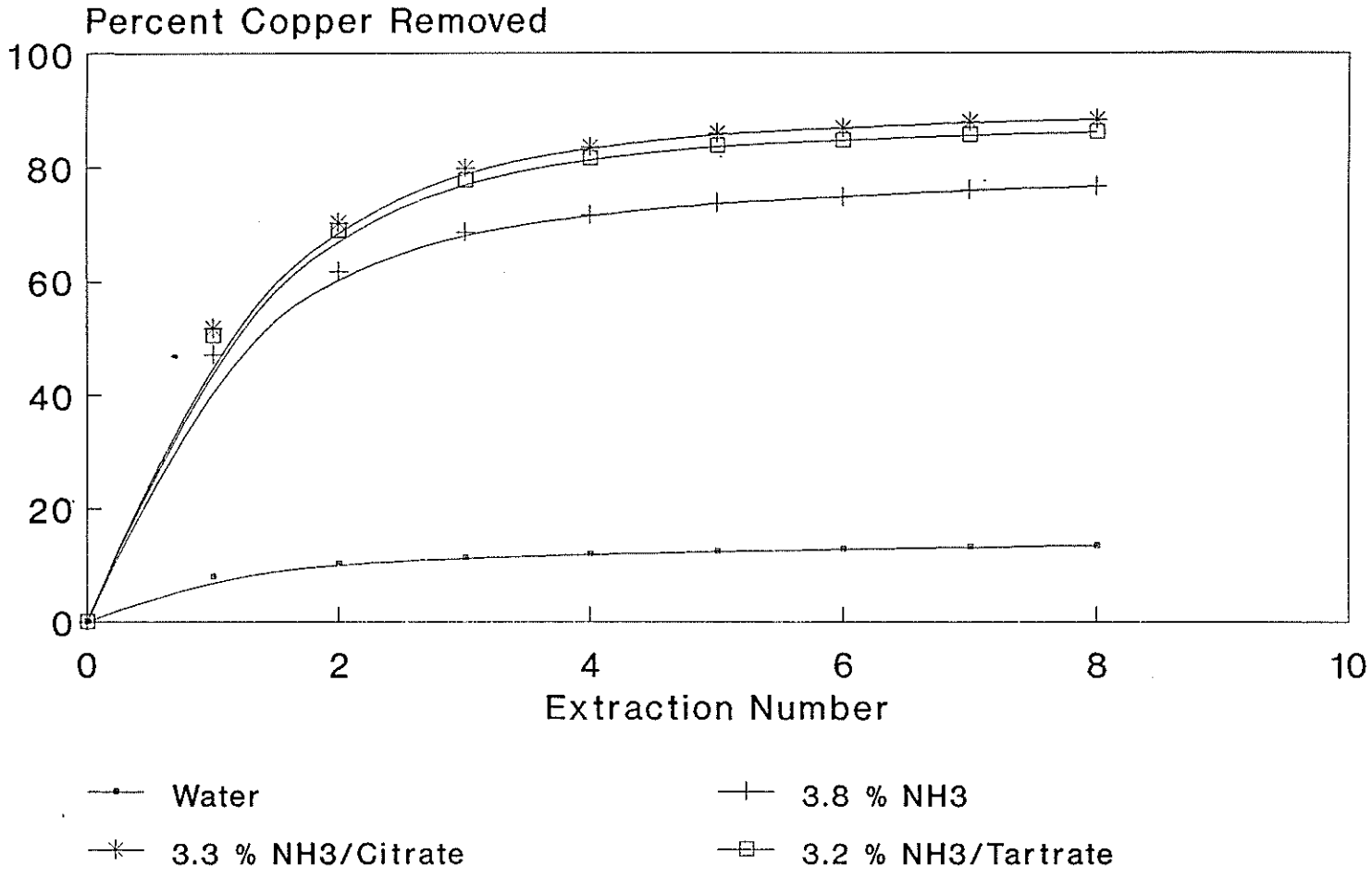


FIGURE 5

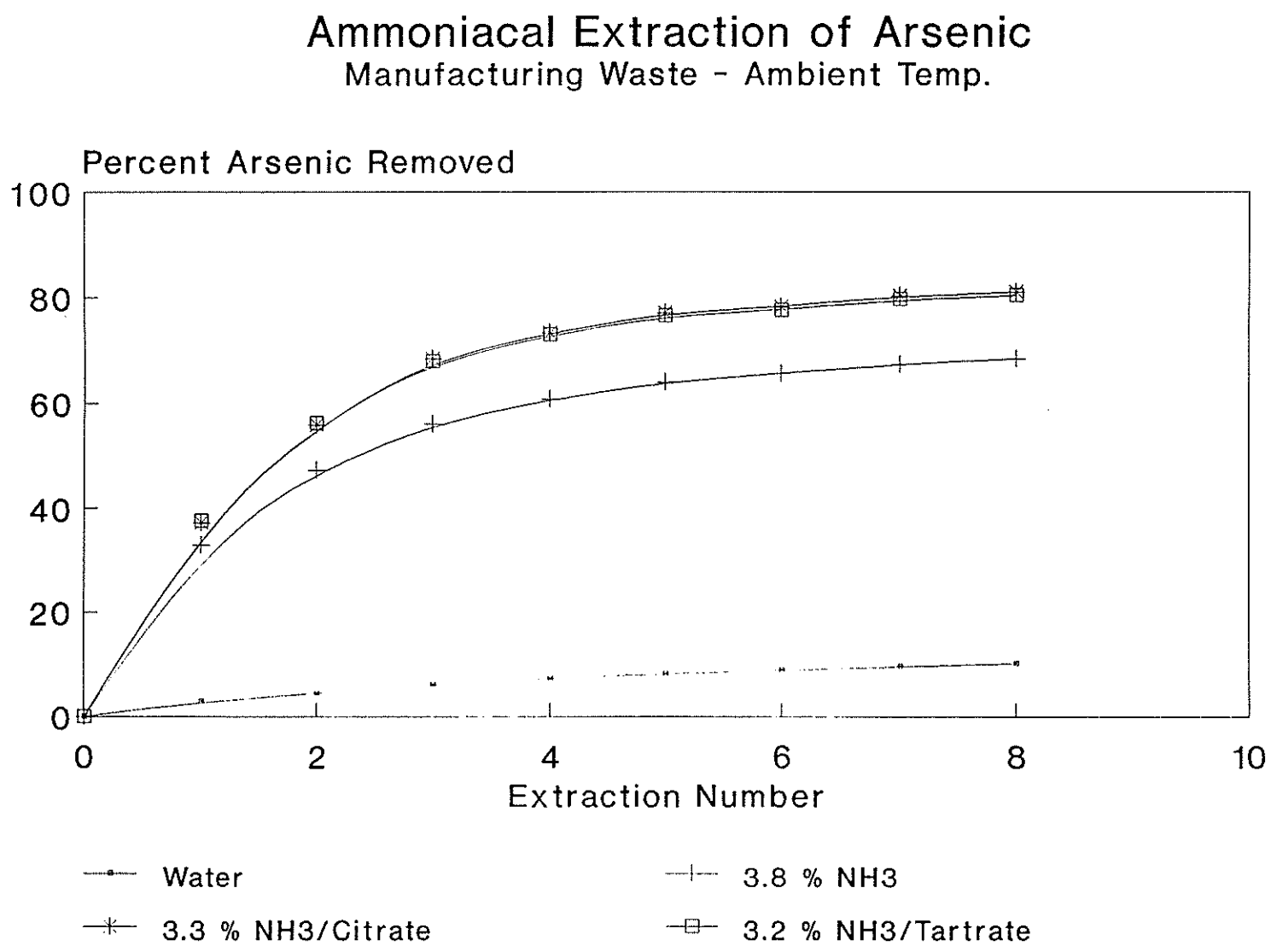

Ammoniacal Extraction of Arsenic
Manufacturing Waste - Ambient Temp.
Percent Arsenic Removed
100
80
60
40
20
0
0
2
4
6
8
10
Extraction Number
Water
3.8 % NH3
3.3 % NH3/Citrate
3.2 % NH3/Tartrate

FIGURE 6

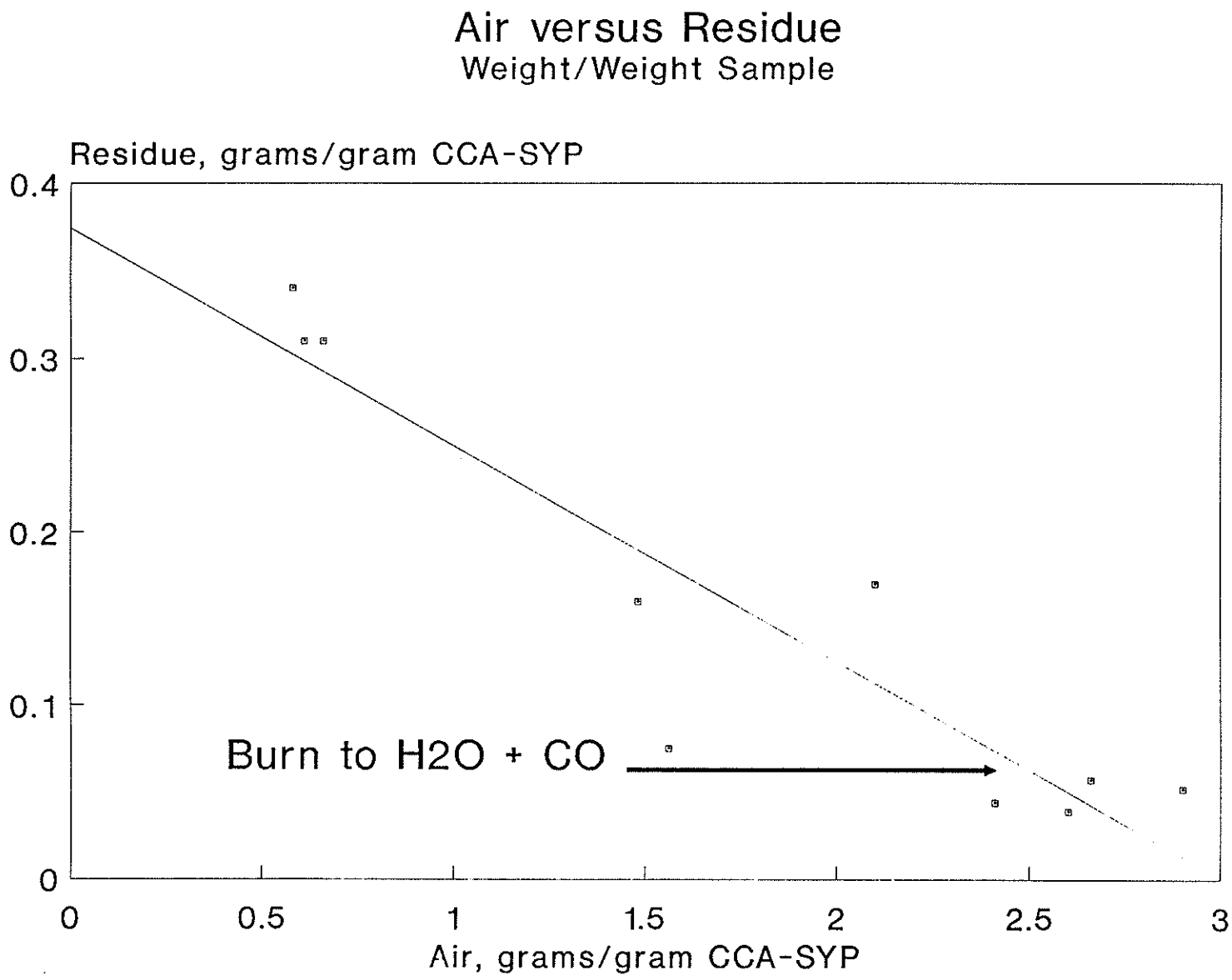
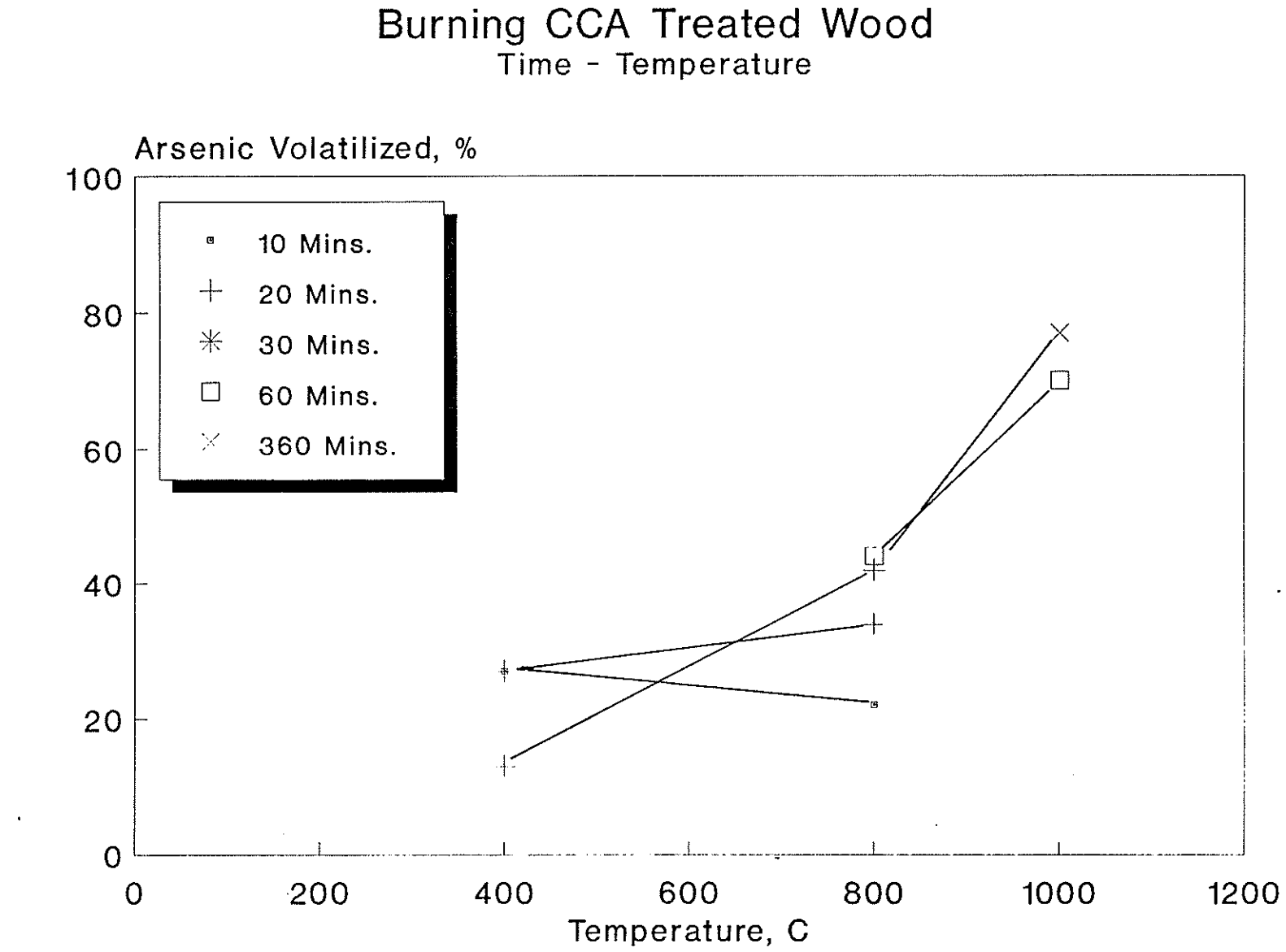

Air versus Residue
Weight/Weight Sample
Residue, grams/gram CCA-SYP
0.4
0.3
0.2
0.1
0
Burn to H2O + CO
0
0.5
1
1.5
2
2.5
3
Air, grams/gram CCA-SYP

FIGURE 7



McMahon, Bush, and Woolson (1986)

FIGURE 8

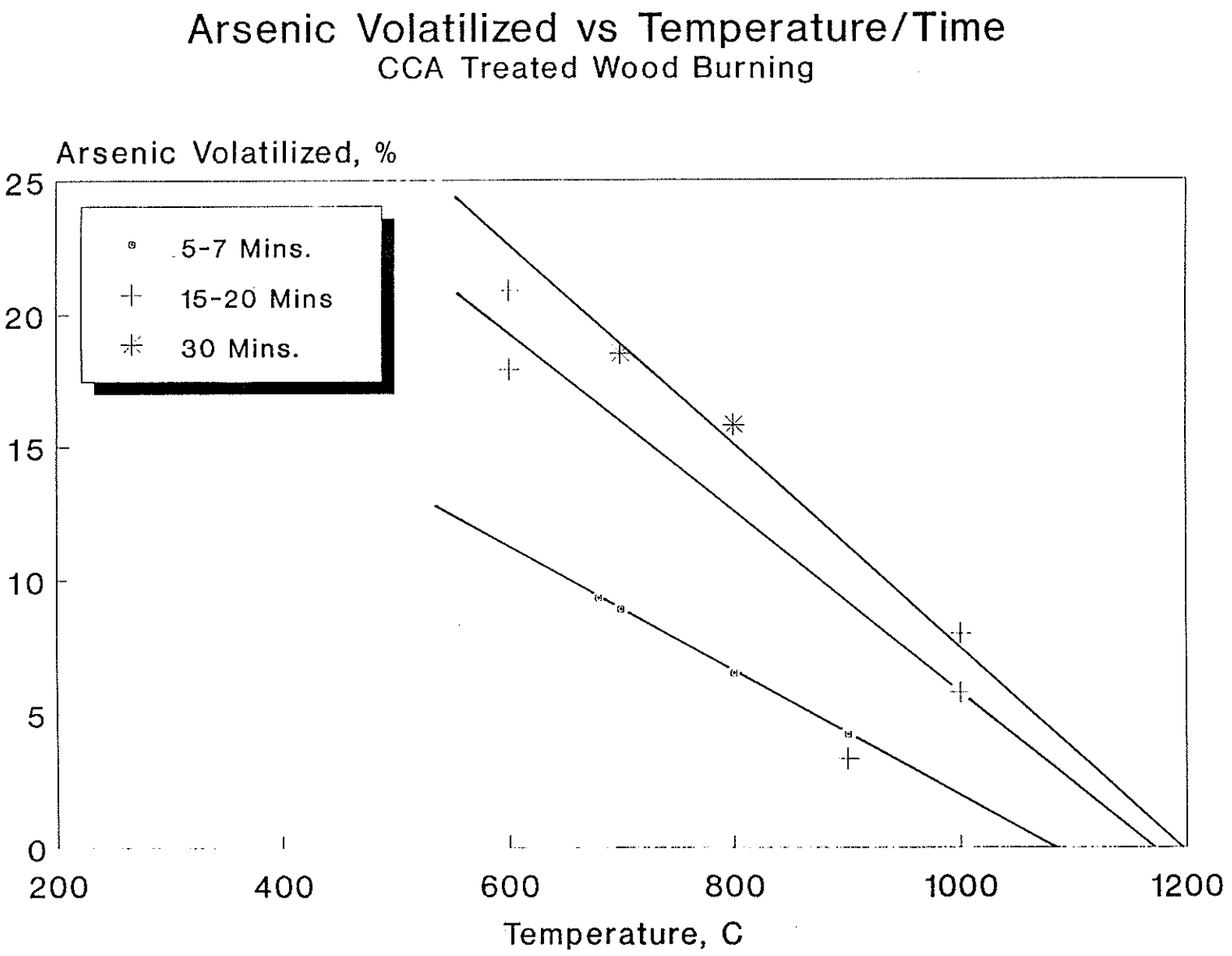

Arsenic Volatilized vs Temperature/Time
CCA Treated Wood Burning
Arsenic Volatilized, %
25
20
15
10
5
0
5-7 Mins.
15-20 Mins
30 Mins.
200
400
600
800
1000
1200
Temperature, C

FIGURE 9