THE USE OF ANHYDROUS AMMONIA

FOR

ACID NEUTRALIZATION AND pH ADJUSTMENT

I N D E X

ACID NEUTRALIZATION AND pH ADJUSTMENT WITH ANHYDROUS AMMONIA

I. INTRODUCTION

The purpose of this technical bulletin is to discuss the use of anhydrous ammonia for pH adjustment and acid neutralization. We have attempted to strike a happy medium between a technical and a non-technical approach to these areas.

In many cases, the economics of replacing other bases with anhydrous ammonia are very favorable. Each situation should be analyzed individually. It is essential to obtain approval for a proposed anhydrous ammonia installation from the appropriate regulatory bodies.

II. ACID,BASE REVIEW

The terms "acid" and "base" will be used quite frequently within this booklet. One method of defining these terms follows:

ACID - any substance which can give up or donate a proton (hydrogen ion H^+) to any other substance. An acid is a proton donor.

Characteristics of acids

A. Acids have a sour taste.
B. Acids turn blue litmus paper red.
C. Acids neutralize bases.
D. pH's of acids range from 1 to just below 7.

BASE - any substance which can receive or accept a proton (hydrogen ion H^+) from any other substance. A base is a proton acceptor.

Characteristics of bases (alkalis)

A. Water solutions of bases feel soapy.
B. Bases have a bitter or alkaline taste.
C. Bases turn red litmus paper blue.
D. Bases neutralize acids.
E. pH's of bases range from just above 7 to 14.

Note: The strength of an acid or a base is measured in its ability to lose or gain protons respectively.

III. pH MEASUREMENT REVIEW

pH is a measure of the relative strengths of acids and bases.

pH	Relative Strength	Hydrogen Ion Concentration
1	Strong Acid	10^{-1}
2		10^{-2}
3		10^{-3}
4		10^{-4}
5		10^{-5}
6		10^{-6}
7	Neutral	10^{-7}
8		10^{-8}
9		10^{-9}
10		10^{-10}
11		10^{-11}
12		10^{-12}
13		10^{-13}
14	Strong Base	10^{-14}

IV. SOURCES OF INDUSTRIAL WASTE ACIDS

1. Industrial waste acid solutions that can create potentially expensive and labor-consuming problems to industry are created from a vast number of operations. Specifically, the following types of industries are originators of waste acid liquors. This is by no means a total list, but does indicate a basic group of industries which are involved:

   Petroleum refining operations
   Metallurgical and mining operations
   Chemical processing
   Wet battery manufacturing and rebuilding operations

2. A specific operation in the process of wire manufacture normally requires the removal of rust and scale by an operation known as "pickling". Sulfuric acid is normally used as a dilute solution dip for the rusted steel wire prior to drawing. The acid reacts with the iron oxide (rust) to form iron sulfate and water. The pickling solution slowly loses its strength as each batch of metal is treated and is finally discarded. At disposal point, the waste acid liquor usually contains from 1% - 3% free acid (by weight) and is still acidic enough to cause corrosion of sewerage facilities and contamination of municipal water or other surface water where the liquors are dumped.

V. INDUSTRIAL pH ADJUSTMENT

Anhydrous ammonia is used to increase pH in segments of the following industries:

1. Pharmaceutical
2. Ore Flotation
3. Food

This is by no means a total list, but does indicate a basic group of industries.

VI. CHEMICALS USED FOR ACID NEUTRALIZATION

Acid neutralization on an industrial scale is usually accomplished by the treatment of acidic solutions by the manual or automatically controlled addition of a basic (alkaline) compound. Depending upon the characteristics of the individual base, bases are added as solids, solutions, slurries, or in the case of anhydrous ammonia, as a liquid or a vapor. The following table provides a comparison between equivalent weights of various bases:

		POUNDS OF CHEMICAL EQUIVALENT TO ONE POUND OF THE FOLLOWING ACIDS:						
CHEMICAL	CHEMICAL FORMULA	100% CH_3COOH	CrO_3	$C_6H_8O_7.H_2O$	HCl	HNO_3	H_3PO_4	H_2SO_4
Anhydrous Ammonia	NH_3	0.28	0.34	0.24	0.47	0.27	0.52	0.35
Aqua Ammonia (29.4%)	NH_4OH	0.95	1.16	0.82	1.60	0.92	1.77	1.19
Calcium Carbonate	$CaCO_3$	0.84	1.00	0.72	1.38	0.80	1.53	1.02
Caustic Soda	NaOH	0.67	0.80	0.57	1.10	0.64	1.22	0.82
Slaked (Hydrated) Lime	$Ca(OH)_2$	0.62	0.74	0.53	1.02	0.59	1.13	0.76
Soda Ash	Na_2CO_3	0.88	1.06	0.76	1.45	0.84	1.62	1.08

EXAMPLES:

A. 0.47 pounds of NH_3 is equivalent to 1.0 pound of 100% HCl.

B. 1.53 pounds of $CaCO_3$ is equivalent to 1.0 pound of 100% H_3PO_4.

C. 1.08 pounds of soda ash is equivalent to 1.0 pound of 100% H_2SO_4.

Note: Neutralization of chromic acid will not alleviate the possible toxic effect of a heavy metal (chromium) on a biological waste treatment system. If chromic acid is present in the waste effluent, the method of treating this waste will have to be carefully discussed with appropriate regulatory bodies. The concentration of chromium as it reaches the waste treatment plant will be a factor in determining the treatment method.

EQUIVALENCY

One equivalent weight of an acid will completely react with one equivalent weight of a base. This is generally referred to as reaching equivalence. This does not mean that one pound of an acid will react with one pound of a base. One equivalent weight of hydrochloric acid, for example, is equal to 36.47 grams and one equivalent weight of anhydrous ammonia is equal to 17.0 grams.

A strong acid (such as hydrochloric acid) reacted with a strong base (such as sodium hydroxide) will theoretically reach equivalence at pH 7. A strong acid reacting with a weak base such as aqua ammonia will reach equivalence at pH 5. (Note: Aqua ammonia is mentioned because anhydrous ammonia reacts with water in the effluent to form aqua ammonia.) To raise the pH from 5 to 7 will require additional ammonia.

The equivalent weight comparisons were calculated on a theoretical basis. The possible buffering capacity of a waste acid solution was not taken into consideration.

EQUIVALENT WEIGHT COMPARISON

CHEMICAL	CHEMICAL FORMULA	1 POUND NH_3 EQUALS	1 POUND 29.4% NH_4OH EQUALS	1 POUND $CaCO_3$ EQUALS	1 POUND NaOH EQUALS	1 POUND $Ca(OH)_2$ EQUALS	1 POUND Na_2CO_3 EQUALS
Anhydrous Ammonia	NH_3	1.00 lb.	0.29 lb.	0.17 lb.	0.43 lb.	0.46 lb.	0.32 lb.
Aqua Ammonia	NH_4OH (29.4%)	3.40 lbs.	1.00 lb.	0.58 lb.	1.46 lbs.	1.56 lbs.	1.09 lbs.
Calcium Carbonate	$CaCO_3$	2.95 lbs.	0.86 lb.	1.00 lb.	1.25 lbs.	1.35 lbs.	0.95 lb.
Caustic Soda	NaOH	2.35 lbs.	0.69 lb.	0.40 lb.	1.00 lb.	1.08 lbs.	0.75 lb.
Slaked (Hydrated) Lime	$Ca(OH)_2$	2.18 lbs.	0.64 lb.	0.37 lb.	0.93 lb.	1.00 lb.	0.70 lb.
Soda Ash	Na_2CO_3	3.12 lbs.	0.92 lb.	0.53 lb.	1.33 lbs.	1.43 lbs.	1.00 lb.

EXAMPLES:

A. 1 pound of NH_3 is equivalent to 2.95 pounds of calcium carbonate.

B. 1 pound of NaOH will neutralize the same amount of acid as 1.33 pounds of soda ash.

SAMPLE PROBLEM: How many pounds of NH_3 are equivalent to 12,000 pounds of NaOH?

A company is currently using 12,000 lbs. of 100% NaOH per year to treat waste acid. From the chart, we see that one pound of NaOH is equivalent to 0.43 pounds of NH_3. Therefore, the answer is 12,000 lbs. x 0.43 or 5,160 pounds of NH_3 are equivalent to 12,000 pounds of NaOH.

VII. SAMPLE CALCULATION - NUMBER OF POUNDS OF BASE EQUIVALENT TO A GIVEN QUANTITY OF ACID

To calculate the required amount of base, the following facts must be known:

	SYMBOL
1. Number of gallons of acid solution	(A)
2. Specific gravity of acid solution	(B)
3. Identity of acid in solution	
4. Percent acid in solution, expressed as a decimal	(C)
5. Equivalent weight of base to be used for neutralization	(D)
6. Equivalent weight of acid in solution	(E)

The formula for this calculation would be

Number of pounds of base = 8.34(A)(B)(C)(D/E)

SAMPLE PROBLEM

How many pounds of anhydrous ammonia are equivalent to 100 gallons of a 4% sulfuric acid solution?

To solve this problem we would use the formula stated above:

Number of pounds of base = 8.34(A)(B)(C)(D/E)

In this problem:

A (Number of gallons of solution)	= 100
B (Specific gravity of acid - 4% sulfuric)	= 1.0250
C (Percent acid in solution, expressed as a decimal)	= .04
D (Equivalent weight of base)	= 17.0
E (Equivalent weight of acid in solution)	= 49.04

Inserting the values into the formula gives the following results:

Number of pounds of base required for equivalency = 8.34(100)(1.0250)(0.04)(17/49.04)
= (8.34)(0.0410)(0.347)
= (39.194)(0.347)

Answer = 11.86

Therefore, 11.86 lbs. of NH_3 are equivalent to 100 gallons of a 4% solution of sulfuric acid.

Should you wish to calculate the amount of base necessary for equivalent to an acid, the following rounded-off figures will be of assistance:

EQUIVALENT WEIGHTS OF ACIDS:

Acetic	(CH_3COOH)	60.05
Chromic	(CrO_3)	50.00
Citric	($C_6H_8O_7.H_2O$)	70.00
Hydrochloric	(HCl)	36.47
Nitric	(HNO_3)	63.02
Phosphoric	(H_3PO_4)	32.68
Sulfuric	(H_2SO_4)	49.04

EQUIVALENT WEIGHTS OF BASES:

Anhydrous Ammonia	NH_3	17.00
Calcium Carbonate	$CaCO_3$	50.05
Caustic Soda	$NaOH$	40.00
Slaked (Hydrated) Lime	$Ca(OH)_2$	37.05
Soda Ash	Na_2CO_3	53.00

Note: To determine the amount of aqua ammonia (NH_4OH) necessary to neutralize a given amount of acids, calculate the pounds of anhydrous ammonia necessary for neutralization and multiply by the percentage of NH_3 concentration of the aqua divided into 100. For example, 1 pound of anhydrous ammonia is equal to 3.4 pounds of 29.4% aqua ammonia (100/29.4 = 3.4).

EQUIVALENT CONVERSION FACTORS (D/E RELATIONSHIP)

	CH_3COOH	CrO_3	$C_6H_8O_7.H_2O$	HCl	HNO_3	H_3PO_4	H_2SO_4
NH_3	0.28	0.34	0.24	0.47	0.27	0.52	0.35
$CaCO_3$	0.84	1.00	0.72	1.38	0.80	1.53	1.02
$NaOH$	0.67	0.80	0.57	1.10	0.64	1.22	0.82
$Ca(OH)_2$	0.62	0.74	0.53	1.02	0.59	1.13	0.76
Na_2CO_3	0.88	1.06	0.76	1.45	0.84	1.62	1.08

MISCELLANEOUS CONVERSION FACTORS

1. To convert pounds of NH_3 to gallons of NH_3 @ 70°F., divide pounds by 5.08.
2. To convert pounds of NH_4OH to gallons of NH_4OH @ 70°F., divide pounds by 7.50.

Tables in the following section give information on the amount of various bases required to neutralize specific acids. These values were calculated using the formula given in this section.

VIII. TABLES - QUANTITIES OF BASES EQUIVALENT TO GIVEN AMOUNTS OF ACID

ACETIC ACID
(CH_3COOH)
Molecular Weight 60.05

Percent Solution of Acetic Acid (CH_3COOH)	Pounds 100% Acetic Acid per 100 gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION					
			Lbs. Ammonia (NH_3)	Gals. Ammonia (NH_3)	Lbs. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Gals. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Lbs. Aqua Ammonia 29.4% NH_3 (NH_4OH)	Gals. Aqua Ammonia 29.4% NH_3 (NH_4OH)
0.1	0.834	0.9984	0.24	0.05	0.96	.13	0.80	0.11
0.2	1.668	0.9984	0.47	0.09	1.93	.25	1.60	0.21
0.3	2.502	0.9984	0.71	0.14	2.89	.38	2.41	0.32
0.4	3.336	0.9984	0.94	0.19	3.85	.51	3.21	0.43
0.5	4.170	0.9984	1.18	0.23	4.81	.63	4.01	0.54
0.6	5.004	0.9984	1.42	0.28	5.78	.76	4.81	0.64
0.7	5.838	0.9984	1.65	0.32	6.74	.89	5.62	0.75
0.8	6.672	0.9984	1.89	0.37	7.70	1.01	6.42	0.86
0.9	7.506	0.9984	2.12	0.42	8.67	1.14	7.22	0.96
1.0	8.340	0.9996	2.36	0.46	9.63	1.27	8.02	1.07
2.0	16.71	1.0012	4.73	0.93	19.30	2.54	16.08	2.14
3.0	25.10	1.0025	7.10	1.40	28.97	3.81	24.14	3.22
4.0	33.51	1.0040	9.49	1.86	38.72	5.10	32.27	4.30
5.0	41.96	1.0055	11.87	2.34	48.43	6.37	40.36	5.38
6.0	50.42	1.0069	14.26	2.81	58.18	7.66	48.48	6.46
7.0	58.90	1.0083	16.66	3.28	67.97	8.94	56.64	7.55
8.0	67.41	1.0097	19.07	3.75	77.81	10.24	64.84	8.65
9.0	75.94	1.0111	21.49	4.23	87.68	11.54	73.07	9.74
10.0	84.50	1.0125	23.91	4.71	97.55	12.84	81.29	10.84
11.0	93.07	1.0139	26.33	5.18	107.4	14.13	89.52	11.94
12.0	101.70	1.0154	28.77	5.66	117.4	15.45	97.82	13.04
13.0	110.30	1.0168	31.21	6.14	127.3	16.75	106.11	14.15
14.0	119.00	1.0182	33.66	6.63	137.3	18.07	114.44	15.26
15.0	127.60	1.0195	36.11	7.11	147.3	19.38	122.77	16.37
16.0	136.30	1.0209	38.57	7.59	157.4	20.71	131.14	17.49
17.0	145.00	1.0223	41.03	8.08	167.4	22.02	139.50	18.60
18.0	153.80	1.0236	43.50	8.56	177.5	23.35	147.90	19.72
19.0	162.50	1.0250	45.98	9.05	187.6	24.68	156.33	20.84
20.0	171.30	1.0263	48.46	9.54	197.7	26.01	164.76	21.97

ACETIC ACID
(CH_3COOH)
Molecular Weight 60.05

Percent Solution of Acetic Acid (CH_3COOH)	Pounds 100% Acetic Acid per 100 gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION			
			Lbs. Caustic Soda (NaOH)	Lbs. Slaked (Hydrated) Lime $Ca(OH)_2$	Lbs. Soda Ash (Na_2CO_3)	Lbs. Calcium Carbonate ($CaCO_3$)
0.1	0.834	0.9984	0.56	0.52	0.74	0.70
0.2	1.668	0.9984	1.11	1.10	1.47	1.38
0.3	2.502	0.9984	1.66	1.54	2.21	2.08
0.4	3.336	0.9984	2.22	2.06	2.94	2.78
0.5	4.170	0.9984	2.78	2.58	3.68	3.47
0.6	5.004	0.9984	3.33	3.09	4.42	4.16
0.7	5.838	0.9984	3.88	3.60	5.15	4.86
0.8	6.672	0.9984	4.44	4.12	5.89	5.55
0.9	7.506	0.9984	5.00	4.64	6.62	6.25
1.0	8.340	0.9996	5.55	5.15	7.36	6.95
2.0	16.71	1.0012	11.14	10.32	14.75	13.91
3.0	25.10	1.0025	16.73	15.50	22.15	20.94
4.0	33.51	1.0040	22.34	20.70	29.57	27.90
5.0	41.96	1.0055	27.97	25.91	37.02	34.93
6.0	50.42	1.0069	33.61	31.14	44.49	41.98
7.0	58.90	1.0083	39.26	36.38	51.97	49.03
8.0	67.41	1.0097	45.61	41.63	59.49	56.10
9.0	75.94	1.0111	50.62	46.90	67.01	63.20
10.0	84.50	1.0125	56.32	52.18	74.56	70.35
11.0	93.07	1.0139	62.04	57.49	82.14	77.50
12.0	101.70	1.0154	67.78	62.80	89.73	84.65
13.0	110.30	1.0168	73.53	68.13	97.34	91.80
14.0	119.00	1.0182	77.26	73.47	104.98	99.05
15.0	127.60	1.0195	85.07	78.82	112.61	106.2
16.0	136.30	1.0209	90.87	84.19	120.29	113.4
17.0	145.00	1.0223	96.67	89.57	127.98	120.7
18.0	153.80	1.0236	102.49	94.96	135.68	128.0
19.0	162.50	1.0250	108.33	100.38	143.42	135.3
20.0	171.30	1.0263	114.18	105.80	151.16	142.6

CHROMIC ACID
(CrO_3)
Molecular Weight 100.01

Percent Solution of Chromic Acid (CrO_3)	Pounds 100% Chromic Acid per 100 Gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION					
			Lbs. Ammonia (NH_3)	Gals. Ammonia (NH_3)	Lbs. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Gals. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Lbs. Aqua Ammonia 29.4% NH_3 (NH_4OH)	Gals. Aqua Ammonia 29.4% NH_3 (NH_4OH)
0.1	0.84	1.001	0.28	0.06	1.16	.15	0.97	0.13
0.2	1.68	1.001	0.57	0.11	2.32	.30	1.93	0.26
0.3	2.52	1.001	0.85	0.17	3.48	.46	2.90	0.39
0.4	3.36	1.001	1.14	0.22	4.63	.61	3.86	0.52
0.5	4.20	1.004	1.42	0.28	5.81	.76	4.84	0.65
0.6	5.04	1.004	1.71	0.34	6.97	.92	5.81	0.77
0.7	5.88	1.004	1.99	0.39	8.13	1.07	6.78	0.90
0.8	6.72	1.004	2.28	0.45	9.29	1.22	7.74	1.03
0.9	7.56	1.004	2.56	0.50	10.45	1.38	8.71	1.16
1.0	8.40	1.006	2.85	0.56	11.64	1.53	9.70	1.29
2.0	16.92	1.014	5.75	1.13	23.46	3.09	19.55	2.61
3.0	25.65	1.022	8.69	1.71	35.47	4.67	29.56	3.94
4.0	34.38	1.030	11.68	2.30	47.65	6.27	39.71	5.30
5.0	43.35	1.038	14.72	2.90	60.06	7.90	50.05	6.67
6.0	52.32	1.045	17.78	3.50	72.54	9.54	60.45	8.06
7.0	61.55	1.053	20.90	4.11	85.27	11.22	71.06	9.48
8.0	70.77	1.060	24.04	4.73	98.08	12.91	81.74	10.90
9.0	80.28	1.068	27.25	5.36	111.2	14.63	92.65	12.35
10.0	89.79	1.076	30.51	6.01	124.5	16.38	103.7	13.83
11.0	99.65	1.085	33.84	6.66	138.1	18.17	115.1	15.35
12.0	109.5	1.093	37.20	7.32	151.8	19.97	126.5	16.87
13.0	119.6	1.102	40.63	8.00	165.8	21.81	138.1	18.41
14.0	129.7	1.110	44.06	8.67	179.8	23.65	149.8	19.97
15.0	140.1	1.119	47.60	9.37	194.2	25.55	161.8	21.57
16.0	150.5	1.127	51.14	10.07	208.7	27.46	173.9	23.19
17.0	161.3	1.136	54.77	10.78	223.5	29.40	186.2	24.83
18.0	172.0	1.145	58.45	11.51	238.5	31.38	198.7	26.49
19.0	183.1	1.154	62.19	12.24	253.7	33.38	211.4	28.19
20.0	194.1	1.161	65.96	12.96	269.1	35.40	224.3	29.91

CHROMIC ACID
(CrO_3)
Molecular Weight 100.01

Percent Solution of Chromic Acid (CrO_3)	Pounds 100% Chromic Acid per 100 Gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION			
			Lbs. Caustic Soda (NaOH)	Lbs. Slaked (Hydrated) Lime $Ca(OH)_2$	Lbs. Soda Ash (Na_2CO_3)	Lbs. Calcium Carbonate ($CaCO_3$)
0.1	0.84	1.001	0.67	0.62	0.88	0.88
0.2	1.68	1.001	1.34	1.24	1.77	1.67
0.3	2.52	1.001	2.00	1.86	2.66	2.51
0.4	3.36	1.001	2.67	2.47	3.54	3.34
0.5	4.20	1.004	3.35	3.10	4.44	4.19
0.6	5.04	1.004	4.02	3.72	5.32	5.03
0.7	5.88	1.004	4.69	4.34	6.21	5.86
0.8	6.72	1.004	5.36	4.96	7.10	6.70
0.9	7.56	1.004	6.03	5.58	7.99	7.54
1.0	8.40	1.006	6.71	6.22	8.89	8.40
2.0	16.92	1.014	13.53	12.53	17.92	16.92
3.0	25.65	1.022	20.46	18.95	27.10	25.60
4.0	34.38	1.030	27.49	25.46	36.42	34.40
5.0	43.35	1.038	34.62	32.07	45.88	43.32
6.0	52.32	1.045	41.83	38.75	55.43	52.40
7.0	61.55	1.053	49.18	45.55	65.16	61.55
8.0	70.77	1.060	56.58	52.40	74.96	70.80
9.0	80.28	1.068	64.13	59.40	84.97	80.25
10.0	89.79	1.076	71.79	66.50	95.12	89.85
11.0	99.65	1.085	79.63	73.76	105.5	99.65
12.0	109.5	1.093	87.52	81.07	116.0	109.5
13.0	119.6	1.102	95.60	88.55	126.7	119.6
14.0	129.7	1.110	103.7	96.03	137.4	129.8
15.0	140.1	1.119	112.0	108.7	148.4	140.2
16.0	150.5	1.127	120.3	111.4	159.4	150.6
17.0	161.3	1.136	128.9	119.4	170.8	161.2
18.0	172.0	1.145	137.5	127.4	182.2	172.0
19.0	183.1	1.154	146.3	135.5	193.9	183.1
20.0	194.1	1.163	155.2	148.8	205.6	194.2

CITRIC ACID
$(C_6H_8O_7.H_2O)$
Molecular Weight 210.1

Percent Solution of Citric Acid $C_6H_8O_7.H_2O$	Pounds 100% Citric Acid per 100 Gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION					
			Lbs. Ammonia (NH_3)	Gals. Ammonia (NH_3)	Lbs. Aqua Ammonia 24.5% NH_3 NH_4OH	Gals. Aqua Ammonia 24.5% NH_3 NH_4OH	Lbs. Aqua Ammonia 29.4% NH_3 (NH_4OH)	Gals. Aqua Ammonia 29.4% NH_3 (NH_4OH)
0.1	0.84	1.005	0.20	0.04	0.83	.11	0.69	0.09
0.2	1.68	1.005	0.41	0.08	1.66	.22	1.38	0.18
0.3	2.52	1.005	0.61	0.12	2.49	.33	2.07	0.28
0.4	3.36	1.005	0.81	0.16	3.31	.44	2.76	0.37
0.5	4.20	1.019	1.03	0.20	4.19	.55	3.50	0.47
0.6	5.04	1.019	1.23	0.24	5.04	.66	4.20	0.56
0.7	5.88	1.019	1.44	0.28	5.88	.77	4.89	0.65
0.8	6.72	1.019	1.64	0.32	6.71	.88	5.59	0.75
0.9	7.56	1.019	1.85	0.36	7.55	.99	6.29	0.84
1.0	8.40	1.0037	2.03	0.40	8.27	1.09	6.88	0.92
2.0	16.81	1.0074	4.07	0.80	16.59	2.18	13.82	1.84
3.0	25.35	1.0112	6.12	1.20	24.98	3.29	20.82	2.78
4.0	33.88	1.0149	8.19	1.61	33.43	4.40	27.86	3.72
5.0	42.55	1.0188	10.28	2.02	41.94	5.52	34.95	4.66
6.0	51.21	1.0227	12.39	2.44	50.55	6.65	42.13	5.62
7.0	60.02	1.0268	14.51	2.86	59.20	7.79	49.33	6.58
8.0	68.83	1.0309	16.64	3.28	67.89	8.93	56.58	7.54
9.0	77.78	1.0351	18.80	3.70	76.70	10.09	63.92	8.52
10.0	86.72	1.0392	20.97	4.13	85.56	11.26	71.30	9.51
11.0	95.76	1.0431	23.16	4.56	94.49	12.43	78.74	10.50
12.0	104.8	1.0470	25.36	4.99	103.5	13.62	86.22	11.50
13.0	114.0	1.0510	27.56	5.43	112.4	14.79	93.70	12.49
14.0	123.2	1.0549	29.81	5.87	121.6	16.00	101.4	13.52
15.0	132.6	1.0591	32.07	6.31	130.8	17.18	109.0	14.53
16.0	142.0	1.0632	34.34	6.76	140.1	18.43	116.8	15.57
17.0	151.5	1.0675	36.64	7.21	149.5	19.67	124.6	16.61
18.0	161.0	1.0718	38.94	7.66	158.9	20.91	132.4	17.65
19.0	170.7	1.0762	41.26	8.12	168.3	22.14	140.3	18.71
20.0	180.4	1.0805	43.61	8.58	177.9	23.40	148.3	19.77

CITRIC ACID
($C_6H_8O_7.H_2O$)
Molecular Weight 210.1

Percent Solution of Citric Acid ($C_6H_8O_7.H_2O$)	Pounds 100% Citric Acid per 100 gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION			
			Lbs. Caustic Soda (NaOH)	Lbs. Slaked (Hydrated) Lime $Ca(OH)_2$	Lbs. Soda Ash (Na_2CO_3)	Lbs. Calcium Carbonate ($CaCO_3$)
0.1	0.84	1.005	0.48	0.44	0.63	0.60
0.2	1.68	1.005	0.96	0.89	1.27	1.20
0.3	2.52	1.005	1.44	1.33	1.90	1.80
0.4	3.36	1.005	1.92	1.77	2.54	2.40
0.5	4.20	1.019	2.43	2.25	3.22	3.04
0.6	5.04	1.019	2.91	2.70	3.86	3.64
0.7	5.88	1.019	3.40	3.15	4.50	4.25
0.8	6.72	1.019	3.88	3.60	5.15	4.86
0.9	7.56	1.019	4.37	4.05	5.79	5.47
1.0	8.40	1.0037	4.78	4.43	6.34	5.98
2.0	16.81	1.0074	9.59	8.89	12.72	12.01
3.0	25.35	1.0112	14.45	13.38	19.15	18.09
4.0	33.88	1.0149	19.33	17.91	25.63	24.21
5.0	42.55	1.0188	24.26	22.47	32.16	30.38
6.0	51.21	1.0227	29.22	27.07	38.74	36.60
7.0	60.02	1.0268	34.23	31.71	45.37	42.86
8.0	68.83	1.0309	39.27	36.38	52.07	49.18
9.0	77.78	1.0351	44.36	41.10	58.81	55.55
10.0	86.72	1.0392	49.49	45.85	65.61	61.95
11.0	95.76	1.0431	54.64	50.62	72.44	68.40
12.0	104.8	1.0470	59.84	55.44	79.33	74.95
13.0	114.0	1.0510	65.04	60.25	86.22	81.45
14.0	123.2	1.0549	70.35	65.17	93.26	88.10
15.0	132.6	1.0591	75.66	70.09	100.3	94.75
16.0	142.0	1.0632	81.02	75.07	107.4	101.4
17.0	151.5	1.0675	86.45	80.09	114.6	108.2
18.0	161.0	1.0718	91.87	85.12	121.8	115.0
19.0	170.7	1.0762	97.36	90.19	129.1	121.9
20.0	180.3	1.0805	102.9	95.13	136.4	128.8

HYDROCHLORIC ACID
(HCl)
Molecular Weight 36.46

Percent Solution of Hydrochloric Acid (HCl)	Pounds 100% Hydrochloric Acid per 100 Gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION					
			Lbs. Ammonia (NH_3)	Gals. Ammonia (NH_3)	Lbs. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Gals. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Lbs. Aqua Ammonia 29.4% NH_3 (NH_4OH)	Gals. Aqua Ammonia 29.4% NH_3 (NH_4OH)
0.1	0.837	1.0005	0.39	0.08	1.58	.21	1.32	0.18
0.2	1.675	1.0005	0.78	0.15	3.17	.42	2.64	0.35
0.3	2.511	1.0005	1.17	0.23	4.76	.63	3.96	0.53
0.4	3.348	1.0005	1.56	0.31	6.35	.84	5.29	0.70
0.5	4.185	1.0016	1.95	0.38	7.94	1.04	6.62	0.88
0.6	5.022	1.0016	2.34	0.46	9.53	1.25	7.94	1.06
0.7	5.859	1.0016	2.73	0.54	11.12	1.46	9.26	1.24
0.8	6.696	1.0016	3.11	0.61	12.71	1.67	10.59	1.41
0.9	7.533	1.0016	3.50	0.69	14.29	1.88	11.91	1.59
1.0	8.37	1.0032	3.90	0.77	15.91	2.09	13.26	1.77
2.0	16.83	1.0082	7.84	1.54	31.98	4.21	26.65	3.55
3.0	25.41	1.0132	11.81	2.32	48.18	6.34	40.15	5.35
4.0	33.99	1.0181	15.83	3.12	64.59	8.50	53.82	7.18
5.0	42.73	1.0230	19.88	3.91	81.11	10.67	67.59	9.01
6.0	51.47	1.0279	23.97	4.72	97.80	12.87	81.50	10.87
7.0	60.37	1.0328	28.10	5.53	114.6	15.08	95.54	12.74
8.0	69.27	1.0376	32.26	6.35	131.6	17.32	109.7	14.63
9.0	78.34	1.0450	36.55	7.20	149.1	19.62	124.3	16.57
10.0	87.41	1.0474	40.71	8.01	166.1	21.86	138.4	18.45
11.0	96.66	1.0524	44.99	8.86	183.6	24.16	153.0	20.40
12.0	105.9	1.0574	49.30	9.70	201.1	26.46	167.6	22.35
13.0	115.3	1.0625	53.68	10.57	219.0	28.82	182.5	24.33
14.0	124.7	1.0675	58.06	11.43	236.9	31.17	197.4	26.32
15.0	134.3	1.0726	62.54	12.31	255.2	33.58	212.6	28.35
16.0	143.9	1.0776	67.01	13.19	273.4	35.97	227.8	30.37
17.0	153.65	1.0827	71.53	14.08	291.8	38.39	243.2	32.43
18.0	163.4	1.0878	76.10	14.98	310.5	40.86	258.7	34.49
19.0	173.35	1.0929	80.71	15.89	329.3	43.33	274.4	36.59
20.0	183.3	1.098	85.32	16.80	348.1	45.80	290.1	38.68

HYDROCHLORIC ACID
(HCl)
Molecular Weight 36.46

Percent Solution of Hydrochloric Acid (HCl)	Pounds 100% Hydrochloric Acid per 100 Gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION			
			Lbs. Caustic Soda (NaOH)	Lbs. Slaked (Hydrated) Lime $Ca(OH)_2$	Lbs. Soda Ash (Na_2CO_3)	Lbs. Calcium Carbonate ($CaCO_3$)
0.1	0.837	1.0005	0.92	0.85	1.21	1.14
0.2	1.674	1.0005	1.83	1.70	2.42	2.29
0.3	2.511	1.0005	2.75	2.54	3.64	3.44
0.4	3.348	1.0005	3.66	3.39	4.85	4.58
0.5	4.185	1.0016	4.58	4.24	6.07	5.74
0.6	5.022	1.0016	5.50	5.09	7.28	6.88
0.7	5.859	1.0016	6.41	5.94	8.50	8.02
0.8	6.696	1.0016	7.33	6.79	9.71	9.17
0.9	7.533	1.0016	8.25	7.64	10.92	10.32
1.0	8.37	1.0032	9.18	8.50	12.16	11.48
2.0	16.83	1.0082	18.45	17.09	24.44	23.08
3.0	25.41	1.0132	27.81	25.76	36.83	34.80
4.0	33.99	1.0181	37.25	34.50	49.34	46.61
5.0	42.73	1.0230	46.80	43.34	61.98	58.60
6.0	51.47	1.0279	56.43	52.26	74.74	70.60
7.0	60.37	1.0328	66.14	61.25	87.60	82.75
8.0	69.27	1.0376	75.95	70.34	100.6	95.00
9.0	78.34	1.0450	86.05	79.70	114.0	107.6
10.0	87.41	1.0474	95.82	88.75	126.9	119.9
11.0	96.66	1.0524	105.9	98.09	140.3	132.5
12.0	105.9	1.0574	116.1	107.5	153.7	145.2
13.0	115.3	1.0625	126.4	117.0	167.4	158.1
14.0	124.7	1.0675	136.7	126.6	181.0	171.0
15.0	134.3	1.0726	147.2	136.3	195.0	184.2
16.0	143.9	1.0776	157.7	146.1	208.9	197.4
17.0	153.65	1.0827	168.4	156.0	223.0	210.7
18.0	163.4	1.0878	179.1	165.9	237.3	224.2
19.0	173.35	1.0929	190.0	176.0	251.7	237.7
20.0	183.3	1.0980	200.9	186.0	266.0	251.3

NITRIC ACID
(HNO_3)

Molecular Weight 63.02

Percent Solution of Nitric Acid (HNO_3)	Pounds 100% Nitric Acid per 100 Gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION					
			Lbs. Ammonia (NH_3)	Gals. Ammonia (NH_3)	Lbs. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Gals. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Lbs. Aqua Ammonia 29.4% NH_3 (NH_4OH)	Gals. Aqua Ammonia 29.4% NH_3 (NH_4OH)
0.1	0.838	1.0005	0.22	0.04	0.92	.12	0.76	0.10
0.2	1.676	1.0005	0.45	0.09	1.84	.24	1.53	0.20
0.3	2.514	1.0005	0.68	0.13	2.75	.36	2.30	0.31
0.4	3.352	1.0005	0.90	0.18	3.67	.48	3.06	0.41
0.5	4.190	1.0018	1.13	0.23	4.60	.60	3.83	0.51
0.6	5.028	1.0018	1.35	0.27	5.52	.73	4.60	0.61
0.7	5.866	1.0018	1.58	0.31	6.43	.85	5.36	0.71
0.8	6.704	1.0018	1.80	0.36	7.36	.97	6.13	0.82
0.9	7.542	1.0018	2.03	0.40	8.27	1.09	6.90	0.92
1.0	8.38	1.0036	2.26	0.44	9.21	1.21	7.67	1.02
2.0	16.84	1.0091	4.54	0.89	18.52	2.44	15.43	2.06
3.0	25.40	1.0146	6.85	1.35	27.94	3.68	23.28	3.10
4.0	34.05	1.0201	9.18	1.81	37.45	4.93	31.21	4.16
5.0	42.79	1.0256	11.53	2.27	47.04	6.19	39.20	5.23
6.0	51.63	1.0312	13.92	2.74	56.79	7.47	47.33	6.31
7.0	60.57	1.0369	16.32	3.21	66.59	8.76	55.49	7.40
8.0	69.61	1.0427	18.76	3.69	76.54	10.07	63.78	8.50
9.0	78.75	1.0485	21.23	4.18	86.62	11.40	72.18	9.62
10.0	87.98	1.0543	23.71	4.67	96.74	12.73	80.61	10.75
11.0	97.32	1.0602	26.23	5.16	107.0	14.08	89.18	11.90
12.0	106.8	1.0661	28.78	5.66	117.4	15.45	97.85	13.05
13.0	116.3	1.0721	31.35	6.17	127.9	16.83	106.6	14.21
14.0	126.0	1.0781	33.95	6.68	138.5	18.22	115.4	15.39
15.0	135.7	1.0842	36.58	7.20	149.2	19.63	124.4	16.59
16.0	145.6	1.0903	39.24	7.72	160.1	21.07	133.4	17.79
17.0	155.5	1.0964	41.92	8.25	171.0	22.50	142.5	19.00
18.0	165.6	1.1026	44.64	8.79	182.1	23.96	151.8	20.24
19.0	175.8	1.1088	47.39	9.33	193.4	25.45	161.1	21.48
20.0	186.1	1.1150	50.16	9.87	204.7	26.93	170.5	22.73

NITRIC ACID
(HNO_3)
Molecular Weight 63.02

Percent Solution of Nitric Acid (HNO_3)	Pounds 100% Nitric Acid per 100 gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION			
			Lbs. Caustic Soda (NaOH)	Lbs. Slaked (Hydrated) Lime $Ca(OH)_2$	Lbs. Soda Ash (Na_2CO_3)	Lbs. Calcium Carbonate ($CaCO_3$)
0.1	0.838	1.0005	0.53	0.49	0.70	0.33
0.2	1.676	1.0005	1.06	0.98	1.40	0.66
0.3	2.514	1.0005	1.59	1.47	2.10	0.99
0.4	3.352	1.0005	2.12	1.96	2.81	1.32
0.5	4.190	1.0018	2.65	2.46	3.51	1.66
0.6	5.028	1.0018	3.18	2.95	4.22	1.99
0.7	5.866	1.0018	3.71	3.44	4.92	2.32
0.8	6.704	1.0018	4.24	3.93	5.62	2.65
0.9	7.542	1.0018	4.78	4.42	6.32	2.98
1.0	8.38	1.0036	5.32	4.92	7.04	3.32
2.0	16.84	1.0091	10.69	9.90	14.15	6.68
3.0	25.40	1.0146	16.12	14.93	21.35	10.08
4.0	34.05	1.0201	21.61	20.00	28.62	13.51
5.0	42.79	1.0256	27.16	25.15	35.97	16.98
6.0	51.63	1.0312	32.77	30.34	43.40	20.46
7.0	60.57	1.0369	38.44	35.59	50.91	24.03
8.0	69.61	1.0427	44.18	40.91	58.51	27.62
9.0	78.75	1.0485	49.97	46.28	66.19	31.25
10.0	87.98	1.0543	55.84	51.70	73.95	69.80
11.0	97.32	1.0602	61.76	57.19	81.80	77.20
12.0	106.8	1.0661	67.70	62.69	89.67	84.70
13.0	116.3	1.0721	73.81	68.35	97.76	92.25
14.0	126.0	1.0781	79.93	74.02	105.87	99.95
15.0	135.7	1.0842	86.13	79.75	114.06	107.6
16.0	145.6	1.0903	92.39	85.55	122.36	115.6
17.0	155.5	1.0964	98.71	91.40	130.73	123.4
18.0	165.6	1.1026	105.11	97.33	139.20	131.4
19.0	175.8	1.1088	111.57	103.31	147.76	139.5
20.0	186.1	1.1150	118.10	109.36	156.41	147.7

PHOSPHORIC ACID
(H_3PO_4)
Molecular Weight 98.04

Percent Solution of Phosphoric Acid (H_3PO_4)	Pounds 100% Phosphoric Acid per 100 Gal. Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION					
			Lbs. Ammonia (NH_3)	Gals. Ammonia (NH_3)	Lbs. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Gals. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Lbs. Aqua Ammonia 29.4% NH_3 (NH_4OH)	Gals. Aqua Ammonia 29.4% NH_3 (NH_4OH)
0.1	0.838	1.0005	0.43	0.08	1.77	0.23	1.48	0.20
0.2	1.676	1.0005	0.87	0.17	3.54	0.46	2.95	0.39
0.3	2.514	1.0005	1.30	0.26	5.31	0.70	4.43	0.59
0.4	3.352	1.0005	1.74	0.34	7.08	0.93	5.90	0.79
0.5	4.190	1.0019	2.17	0.43	8.86	1.17	7.38	0.98
0.6	5.028	1.0019	2.61	0.51	10.64	1.40	8.86	1.18
0.7	5.866	1.0019	3.04	0.60	12.41	1.63	10.34	1.38
0.8	6.704	1.0019	3.48	0.68	14.18	1.86	11.82	1.58
0.9	7.542	1.0019	3.91	0.77	15.95	2.10	13.29	1.77
1.0	8.38	1.0038	4.35	0.86	17.76	2.34	14.80	1.97
2.0	16.84	1.0092	8.75	1.72	35.72	4.70	29.76	3.97
3.0	25.45	1.0146	13.20	2.60	53.86	7.09	44.88	5.98
4.0	34.05	1.0200	17.70	3.48	72.22	9.50	60.18	8.02
5.0	42.84	1.0255	22.24	4.38	90.74	11.94	75.62	10.08
6.0	51.62	1.0309	26.82	5.28	109.4	14.39	91.19	12.16
7.0	60.60	1.0365	31.47	6.20	128.4	16.89	107.0	14.27
8.0	69.57	1.0420	36.15	7.12	147.5	19.41	122.9	16.39
9.0	78.73	1.0476	40.89	8.05	166.8	21.95	139.0	18.53
10.0	87.89	1.0532	45.68	8.99	186.4	24.53	155.3	20.71
11.0	97.25	1.0590	50.52	9.94	206.1	27.12	171.8	22.91
12.0	106.6	1.0647	55.41	10.91	226.1	29.75	188.4	25.12
13.0	116.2	1.0706	60.37	11.88	246.3	32.41	205.3	27.37
14.0	125.8	1.0764	65.36	12.87	266.7	35.09	222.2	29.63
15.0	135.55	1.0824	70.41	13.86	287.3	37.80	239.4	31.92
16.0	145.3	1.0884	75.52	14.87	308.1	40.54	256.8	34.24
17.0	155.4	1.0946	80.70	15.89	329.3	43.33	274.4	36.59
18.0	165.4	1.1008	85.93	16.92	350.6	46.13	292.2	38.96
19.0	175.5	1.1071	91.21	17.95	372.1	48.96	310.1	41.35
20.0	185.8	1.1134	96.57	19.01	394.0	51.84	328.3	41.77

PHOSPHORIC ACID
(H_3PO_4)
Molecular Weight 98.04

Percent Solution of Phosphoric Acid (H_3PO_4)	Pounds 100% Phosphoric Acid per 100 Gal. Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION			
			Lbs. Caustic Soda (NaOH)	Lbs. Slaked (Hydrated) Lime $Ca(OH)_2$	Lbs. Soda Ash (Na_2CO_3)	Lbs. Calcium Carbonate ($CaCO_3$)
0.1	0.838	1.0005	1.02	0.95	1.35	1.78
0.2	1.676	1.0005	2.04	1.89	2.71	2.56
0.3	2.514	1.0005	3.06	2.84	4.06	3.84
0.4	3.352	1.0005	4.09	3.78	5.41	5.11
0.5	4.190	1.0019	5.11	4.74	6.78	6.40
0.6	5.028	1.0019	6.14	5.69	8.13	7.68
0.7	5.866	1.0019	7.16	6.63	9.49	8.96
0.8	6.704	1.0019	8.18	7.58	10.84	10.24
0.9	7.542	1.0019	9.20	8.53	12.20	11.52
1.0	8.38	1.0038	10.25	9.49	13.58	12.82
2.0	16.84	1.0092	20.60	19.09	27.30	25.68
3.0	25.45	1.0146	31.08	28.79	41.18	38.89
4.0	34.05	1.0200	41.65	38.59	55.20	52.10
5.0	42.84	1.0255	52.34	48.49	69.36	65.50
6.0	51.62	1.0309	63.15	58.62	83.68	79.00
7.0	60.60	1.0365	74.06	68.62	98.15	92.65
8.0	69.57	1.0420	85.09	78.84	112.8	106.4
9.0	78.73	1.0476	96.24	89.17	127.5	120.4
10.0	87.89	1.0532	107.5	99.61	142.5	134.5
11.0	97.25	1.0590	118.9	110.2	157.6	148.8
12.0	106.6	1.0647	130.4	120.8	172.7	163.1
13.0	116.2	1.0706	142.1	131.7	188.3	177.8
14.0	125.8	1.0764	153.8	142.5	203.9	192.5
15.0	135.55	1.0824	165.7	153.5	219.6	207.4
16.0	145.3	1.0884	177.8	164.7	235.5	222.4
17.0	155.4	1.0946	190.0	176.0	251.7	237.7
18.0	165.4	1.1008	202.3	187.5	268.1	253.2
19.0	175.5	1.1071	214.7	198.9	284.5	268.6
20.0	185.8	1.1134	227.3	210.6	301.2	284.4

SULFURIC ACID
(H_2SO_4)
Molecular Weight 98.08

Percent Solution of Sulfuric Acid (H_2SO_4)	Pounds 100% Sulfuric Acid per 100 gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION					
			Lbs. Ammonia (NH_3)	Gals. Ammonia (NH_3)	Lbs. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Gals. Aqua Ammonia 24.5% NH_3 (NH_4OH)	Lbs. Aqua Ammonia 29.4% NH_3 (NH_4OH)	Gals. Aqua Ammonia 29.4% NH_3 (NH_4OH)
0.1	0.839	1.0005	0.29	0.06	1.18	.16	0.98	0.13
0.2	1.678	1.0005	0.58	0.11	2.36	.31	1.97	0.26
0.3	2.517	1.0005	0.87	0.17	3.54	.47	2.95	0.39
0.4	3.356	1.0005	1.16	0.23	4.72	.62	3.94	0.52
0.5	4.195	1.0025	1.45	0.28	5.92	.78	4.93	0.66
0.6	5.034	1.0025	1.74	0.34	7.10	.94	5.92	0.79
0.7	5.873	1.0025	2.03	0.40	8.29	1.09	6.90	0.92
0.8	6.712	1.0025	2.32	0.46	9.47	1.25	7.89	1.05
0.9	7.551	1.0025	2.61	0.51	10.65	1.40	8.88	1.18
1.0	8.39	1.0051	2.91	0.57	11.86	1.56	9.89	1.32
2.0	16.89	1.0118	5.86	1.15	23.90	3.14	19.91	2.65
3.0	25.50	1.0184	8.84	1.74	36.08	4.75	30.06	4.01
4.0	34.22	1.0250	11.86	2.34	48.39	6.37	40.32	5.38
5.0	43.05	1.0317	14.93	2.94	60.91	8.01	50.76	6.77
6.0	52.00	1.0385	18.03	3.55	75.56	9.94	61.30	8.17
7.0	61.06	1.0453	21.17	4.17	86.37	11.36	71.98	9.60
8.0	70.25	1.0522	24.36	4.80	99.39	13.08	82.82	11.04
9.0	79.55	1.0591	27.59	5.43	112.6	14.81	93.81	12.51
10.0	88.97	1.0661	30.85	6.07	125.9	16.56	104.89	13.99
11.0	98.51	1.0731	34.16	6.72	139.4	18.34	116.14	15.49
12.0	108.2	1.0802	37.51	7.38	153.0	20.13	127.53	17.00
13.0	118.0	1.0874	40.91	8.05	166.9	21.96	139.09	18.55
14.0	127.9	1.0947	44.35	8.73	180.9	23.80	150.79	20.11
15.0	137.9	1.1020	47.84	9.42	195.2	25.68	162.66	21.69
16.0	148.1	1.1094	51.37	10.11	209.6	27.57	174.66	23.29
17.0	158.4	1.1168	54.94	10.81	224.2	29.50	186.80	24.91
18.0	168.9	1.1243	58.57	11.53	239.0	31.44	199.14	26.55
19.0	179.5	1.1318	62.23	12.25	253.9	33.40	211.58	28.21
20.0	190.2	1.1394	65.95	12.98	269.1	35.40	224.23	29.90

SULFURIC ACID
(H_2SO_4)
Molecular Weight 98.08

Percent Solution of Sulfuric Acid (H_2SO_4)	Pounds 100% Sulfuric Acid per 100 gal. of Solution	Specific Gravity	QUANTITY OF CHEMICAL EQUIVALENT TO 100 GALLONS OF ACIDIC SOLUTION			
			Lbs. Caustic Soda (NaOH)	Lbs. Slaked (Hydrated) Lime $Ca(OH)_2$	Lbs. Soda Ash (Na_2CO_3)	Lbs. Calcium Carbonate ($CaCO_3$)
0.1	0.839	1.0005	0.68	0.63	0.90	0.85
0.2	1.678	1.0005	1.36	1.26	1.80	1.70
0.3	2.517	1.0005	2.04	1.89	2.70	2.55
0.4	3.356	1.0005	2.72	2.52	3.61	3.40
0.5	4.195	1.0025	3.41	3.16	4.52	4.27
0.6	5.034	1.0025	4.09	3.79	5.42	5.12
0.7	5.873	1.0025	4.78	4.42	6.33	5.98
0.8	6.712	1.0025	5.46	5.06	7.23	6.82
0.9	7.551	1.0025	6.14	5.69	8.14	7.68
1.0	8.39	1.0051	6.84	6.34	9.06	8.55
2.0	16.89	1.0118	13.77	12.76	18.25	17.22
3.0	25.50	1.0184	20.79	19.26	27.54	26.00
4.0	34.22	1.0250	27.90	25.85	36.96	34.89
5.0	43.05	1.0317	35.10	32.52	46.50	43.90
6.0	52.00	1.0385	42.41	39.29	56.18	53.05
7.0	61.06	1.0453	49.79	46.13	65.96	62.25
8.0	70.25	1.0522	57.28	53.07	75.89	71.65
9.0	79.55	1.0591	64.87	60.10	85.94	81.15
10.0	88.97	1.0661	72.55	67.22	96.11	90.75
11.0	98.51	1.0731	80.33	74.43	106.42	100.4
12.0	108.2	1.0802	88.22	81.73	116.87	110.3
13.0	118.0	1.0874	96.21	89.13	127.45	120.3
14.0	127.9	1.0947	104.30	96.63	138.17	130.4
15.0	137.9	1.1020	112.49	104.22	149.03	140.8
16.0	148.1	1.1094	120.80	111.92	160.03	151.0
17.0	158.4	1.1168	129.21	119.71	171.17	161.5
18.0	168.9	1.1243	137.72	127.60	182.45	172.2
19.0	179.5	1.1318	146.35	135.59	193.88	183.0
20.0	190.2	1.1394	155.08	143.68	205.44	193.9

IX. PRODUCT ADVANTAGES OF USING ANHYDROUS AMMONIA FOR ACID NEUTRALIZATION

A. Ammonia (itself) adds no additional salts to the solution. Some commonly used neutralizers create solid precipitates and sludges which, in turn, must be handled as bulk waste. The use of contract disposal crews and equipment is expensive and inconvenient in a great many instances. Also, the use of highly skilled process control personnel to accomplish disposal or neutralization of waste acids is usually costly and disrupts operations.

B. Ammonia may be used for other processes in the plant:

1. Whiteprinting
2. Heat Treating Atmospheres
3. Source Gas for N_2, H_2 and Forming Gas
4. General Purpose pH Control
5. Chemical Processing

C. Ammonia is clean:

1. No spilled material from broken bags or leaky drums.
2. No cluttered storage area.

D. Ammonia provides fast neutralization. Since an ammonia system is essentially one of a liquid or vapor entering a liquid, the reaction time is less than the system in which a solid is introduced into the liquid. Faster reaction time makes more accurate control possible with less waste.

X. DISADVANTAGES OF USING ANHYDROUS AMMONIA FOR ACID NEUTRALIZATION

1. In some cases neutralization costs can be high for processes with large quantities of waste acids.

2. Addition of nitrogenous substances to sanitation systems or bodies of water are being restricted in some areas. Ammonia nitrogen and nitrates facilitate algae growth.

3. Some ammonium salts formed as neutralization by-products are reactive.

4. Anhydrous ammonia increases the chlorine demand of the effluent.

When discussing a proposed anhydrous ammonia neutralization system with a regulatory agency, make available any technical information that is requested. It is better to get any problems resolved before the system is installed.

XI. NEUTRALIZATION OF MIXED ACIDS WITH ANHYDROUS AMMONIA

In situations where more than one acid is present in the effluent, the amount of base necessary for neutralization can be determined experimentally. If facilities are not available at the plant, an outside lab can easily make this determination.

XII. TYPICAL NEUTRALIZATION REACTIONS USING ANHYDROUS AMMONIA

Neutralization of an acid occurs when it is combined with a base. An acid destroys the basic properties of a base and vice versa. The neutralization reaction usually results in the formation of a salt.

An example of the reaction of anhydrous ammonia neutralization of sulfuric acid is shown below:

(Ammonia)		(Sulfuric Acid)		(Ammonium Sulfate)
$2NH_3$	+	H_2SO_4	$\longrightarrow$	$(NH_4)_2SO_4$

A few typical reactions of ammonia with aqueous acid solutions are indicated below to demonstrate the reaction product obtained in acid neutralization with anhydrous ammonia.

Ammonia + Water $NH_3 + H_2O \longrightarrow NH_4OH$ (Ammonium Hydroxide)

Ammonia + Phosphoric Acid $2NH_3 + H_3PO_4 \longrightarrow (NH_4)_2HOP_4$ (Diammonium Phosphate)

Ammonia + Hydrochloric Acid $NH_3 + HCl \longrightarrow NH_4Cl$ (Ammonium Chloride)

Ammonia + Sulfuric Acid $2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$ (Ammonium Sulfate)

Ammonia will react with certain metallic salts in aqueous solutions to produce precipitates of metallic hydroxides as shown below:

$$2H_2O + FeSO_4 + 2NH_3 \longrightarrow (NH_4)_2SO_4 + Fe(OH)_2$$

XIII. EQUIPMENT FOR ACID NEUTRALIZATION

Equipment requirements for acid neutralization with ammonia can vary from a very simple manual system to a more complex, fully automatic electronic system. If neutralization is done on a batch basis, a manual system with a portable pH meter should be adequate if proper records are kept. The design of a neutralization system should be approved by all concerned regulatory agencies.

Complete information about automated systems tailored to a specific requirement is available from the following instrumentation manufacturers:

Analytical Measurements
490 Morris Avenue
Summit, N. J.

Honeywell, Inc.
1100 Virginia Drive
Ft. Washington, Pa. 19034

Foxboro Company
220 Neponset Avenue
Foxboro, Mass. 02035

Leeds & Northrup
4901 Stenton Avenue
Philadelphia 44, Pa.

Mr. W. A. Lang
Fischer & Porter Co.
100 Warminster Avenue
Warminster, Pa. 18974

This is not intended to be a complete listing of instrumentation manufacturers.

The following type of control systems can be used for acid neutralization:

A. Pneumatic System - Control valve actuated by air pressure. If an air line is not available, cylinders of compressed air may be used. Control range plus or minus one pH unit.

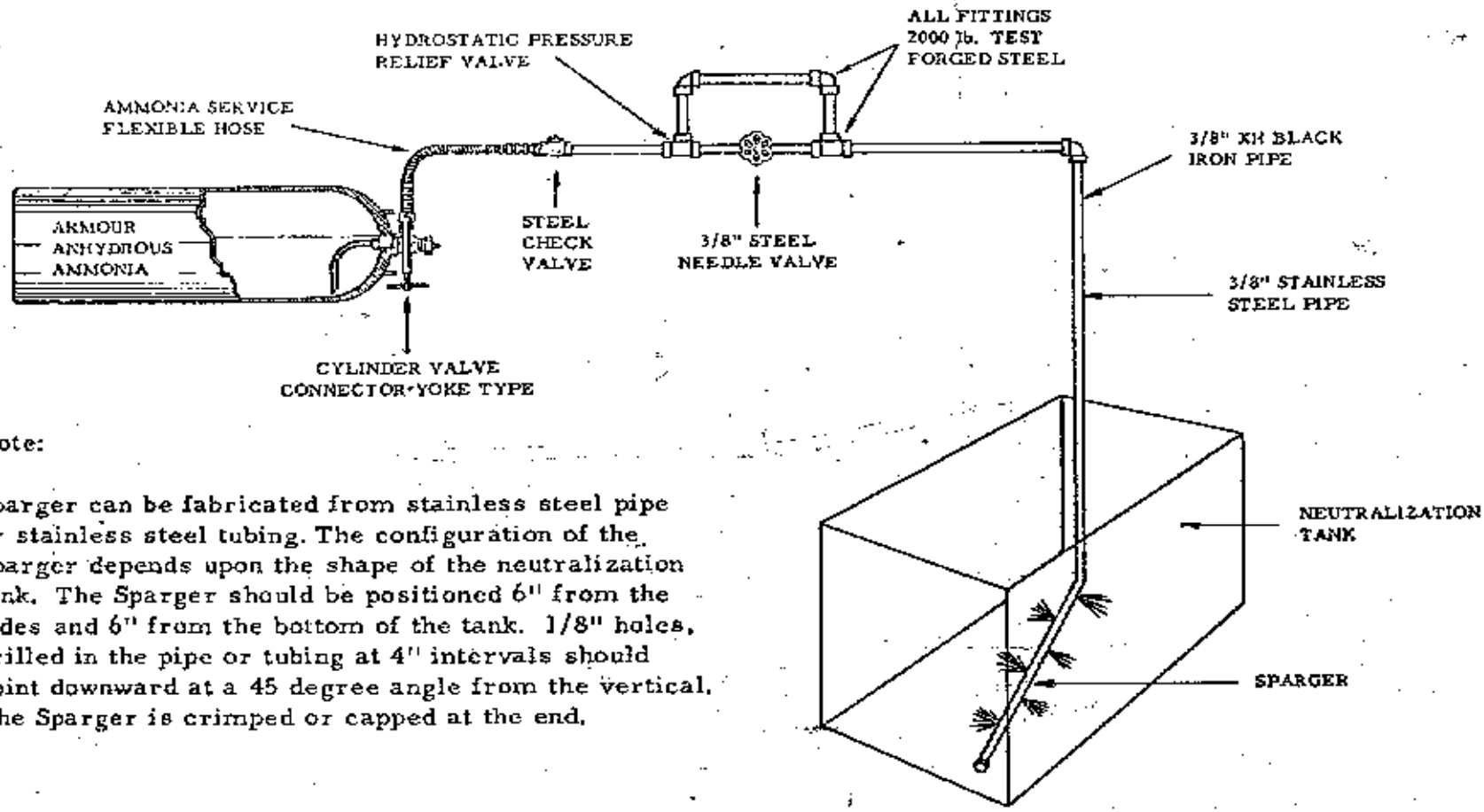
B. On-Off System - Control valve actuated by electricity. Control range plus or minus one pH unit.

C. Time Proportioning System - Control valve actuated by electric timer. Control range plus or minus one pH unit.

D. Position Proportioning System - Position of control valve seat actuated by electricity. Control range plus or minus 0.2%.

ANHYDROUS AMMONIA NEUTRALIZATION SYSTEM USING CYLINDER AMMONIA

Figure 1



Note:

Sparger can be fabricated from stainless steel pipe or stainless steel tubing. The configuration of the Sparger depends upon the shape of the neutralization tank. The Sparger should be positioned 6" from the sides and 6" from the bottom of the tank. 1/8" holes, drilled in the pipe or tubing at 4" intervals should point downward at a 45 degree angle from the vertical. The Sparger is crimped or capped at the end.

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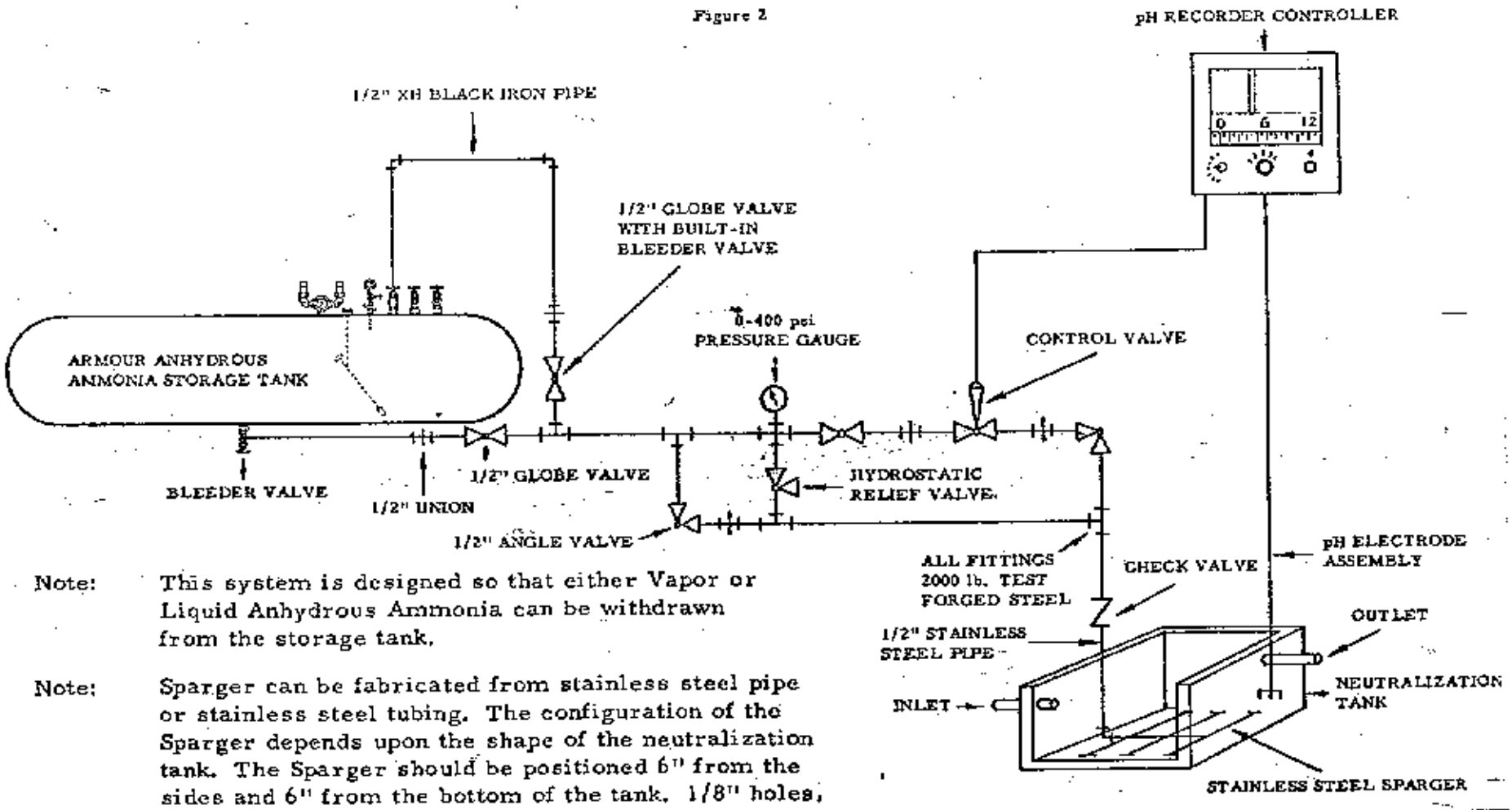
ANHYDROUS AMMONIA NEUTRALIZATION SYSTEM USING BULK AMMONIA

Figure 2



Note: This system is designed so that either Vapor or Liquid Anhydrous Ammonia can be withdrawn from the storage tank.

Note: Sparger can be fabricated from stainless steel pipe or stainless steel tubing. The configuration of the Sparger depends upon the shape of the neutralization tank. The Sparger should be positioned 6" from the sides and 6" from the bottom of the tank. 1/8" holes, drilled in the pipe or tubing at 4" intervals should point downward at a 45 degree angle from the vertical. The Sparger is crimped or capped at the end.

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8-66

Figure I shows a basis system layout for an acid neutralization system using anhydrous ammonia cylinders. Figure II shows a basic acid neutralization system using bulk anhydrous ammonia. Each system should be designed to fit the requirements of a specific situation. The Sparger design is dependent upon the size and shape of the neutralization pit. It is generally desirable to locate the pH electrode near the neutralization pit outlet.

XIV. SYSTEM ADVANTAGES OF USING ANHYDROUS AMMONIA FOR ACID NEUTRALIZATION

A. Ammonia systems are simple. Since ammonia is stored under pressure, no transfer equipment is necessary and no external agitation is required in the neutralizing pit.

B. Ammonia systems are reliable. With its own "built in" pressure system, no outside power source is required to operate transfer pumps, etc. High reliability is the result of system simplicity and minimum manpower requirement for the system's operation.

C. Ammonia systems are inexpensive;

1. Minimum equipment requirement.

2. Minimum handling and labor requirement.

3. Minimum maintenance due to reduced corrosion of piping, controls, etc.

4. Minimum space requirement for total system.

D. Ammonia systems are flexible. Equipment layouts can be simple and inexpensive for manual operation, or completely automatic electronic systems can be installed.

XV. LIQUID ANHYDROUS AMMONIA VS. VAPOR ANHYDROUS AMMONIA FOR ACID NEUTRALIZATION

Acid neutralization systems that require the addition of large quantities of anhydrous ammonia over a short period of time will use liquid anhydrous ammonia. The factor that limits the usage of vapor anhydrous ammonia for this situation is the rate of vaporization of liquid ammonia. As anhydrous ammonia liquid vaporizes at its surface, it is cooled due to the fact that

evaporation is a cooling process. If one attempts to draw an excessively large amount of vapor from an anhydrous ammonia container, the temperature of the anhydrous ammonia liquid and consequently the pressure of the vapor will be reduced to the point where essentially no more vapor will be transferred from the container.

It is easier and less expensive (from an equipment viewpoint) to meter vapor anhydrous ammonia than it is to meter liquid anhydrous ammonia.

APPENDIX

A-1 PHYSICAL PROPERTIES OF ANHYDROUS AMMONIA

Under conditions of ordinary pressure and temperature, ammonia is a stable, pungent colorless gas. When compressed and cooled, ammonia condenses to a mobile colorless liquid about 60% as dense as water.

Molecular Symbol	NH_3
Molecular Weight	17.032
Boiling Point at 1 Atmosphere	-28°F (-33.35°C)
Melting Point at 1 Atmosphere	-107.9°F (-77.7°C)
Critical Temperature	271.4°F
Critical Pressure	1657 psia
Rel. density of vapor compared to dry air at 32°F and 1 atmosphere	.5963
Vapor density at -28°F (-33.35°C) 1 Atmosphere	.05555 lb/cu.ft.
Spec. Grav. of Liquid at -33.35°C as compared to water at 4°C	.6819
Liquid density at -28°F and 1 Atmosphere	42.57 lb/cu.ft.
Specific Volume of Vapor at 32°F (0°C) and 1 Atmosphere	20.78 cu.ft./lb.
Explosive limits in Air, % by Volume	16-25%
Explosive Limits in Oxygen, % by Volume	15-79%
Ignition Temperature (Iron Bomb)	1204°F (651°C)
Ignition Temperature (Quartz Bomb)	1562°F (850°C)
Specific Heat, Cp (1 atm, 60°F)	.52 Btu/lb/°F
Cv (1 atm, 60°F)	.40 Btu/lb/°F
Light Sensitivity	None
Appearance	Colorless
Odor	Pungent
Heat of Fusion at -75°C	108.3 cal/g
Heat of Vaporization (1 atm at -28°F)	589.3 Btu/lb
Viscosity -28°F (liquid)	.26 cp
Viscosity 32°F (vapor)	.00926 cp

A-2 CHEMICAL PROPERTIES

Common metals are not affected by dry ammonia. Moist ammonia will not corrode iron or steel, but will react rapidly with copper, brass, zinc, and many alloys, especially those containing copper. Only iron or steel should be used for ammonia containers, fittings, and piping, except that fabricated equipment made of certain non-ferrous alloys may be used.

A-3 CHEMICAL REACTIONS

Ammonia is a highly reactive chemical forming ammonium salts in reactions with inorganic and organic acids; amides in reaction

esters, acid anhydrides, acyl halides, carbon dioxide, or sulfonyl chlorides; amines in reactions with halogen compounds or oxygen containing compounds such as poly-hydric phenols, alcohols, aldehydes and aliphatic ring oxides.

A-4 PHYSIOLOGICAL EFFECTS OF AMMONIA

1. Ammonia vapor is not poisonous, but due to its high solubility in water, it does have a very irritating action on the mucous membrane of the eyes, nose, throat and lungs. Fortunately, since its sharp pungent odor serves as a warning signal, very small concentrations of ammonia in air are readily detected. Prolonged exposure to air containing 100 ppm of ammonia is not harmful, but breathing air containing from 5,000 to 10,000 ppm of ammonia may cause sudden death from spasm or inflammation of the larynx. Concentrations exceeding 700 ppm of ammonia vapor will cause irritation of the eyes and permanent injury may result if immediate remedial measures are not taken. Ammonia's high solubility in water causes it to irritate any skin surface where moisture has accumulated.

2. The tabulation below shows the physiological response to various concentrations of ammonia.

PHYSIOLOGICAL EFFECTS OF AMMONIA
(Henderson and Haggard)

	Part of Ammonia per Million Parts of Air (by Volume)
Least detectable odor	53
Maximum concentration allowable for prolonged exposure	100
Maximum concentration allowable for short exposure (1/2 to 1 hour)	300-500
Least amount causing immediate irritation to the throat	408
Least amount causing immediate irritation to the eyes	698
Least amount causing coughing	1,720
Dangerous for even short exposure (1/2 Hour)	2,500 - 4,500
Rapidly fatal for short exposure	5,000 - 10,000

3. Since liquid ammonia vaporizes readily and has a great affinity for water, it may cause severe injury to the skin by freezing the tissue and subjecting it to caustic action. The sympton of such a burn is practically the same as those of a thermal burn.

GENERAL REFERENCE MATERIAL

1. Waste Acid Problems? Pamphlet #101
   Armour Industrial Nitrogen Division

2. Measurement and Control of pH and Conductivity - Bulletin PIB-4
   Honeywell

3. The Industrial pH Handbook -
   Beckman Instruments

4. Measurement and Automatic Control of pH
   Honeywell

   Note: Booklets 3 and 4 are identical except for the title and the cover.

5. Principles and Applications of Industrial pH Measurement -
   Beckman Instruments

6. pH Control in Industrial Waste Treatment -
   Beckman Instruments

7. The Measurement and Automatic Control of pH -
   Leeds and Northrup Co. - Technical Publication EN-96(1)

EQUIVALENT ACID NEUTRALIZING CAPACITY

ANHYDROUS AMMONIA	1	lb.
AQUA AMMONIA, AMMONIUM HYDROXIDE	3.40	lb.
CAUSTIC SODA, 50% LIQUID	4.76	lb.
CAUSTIC SODA, DRY FLAKE, BEAD, ETC.	2.35	lb.
SODA ASH	3.12	lb.
BURNT LIME, 95%	1.77	lb.
LIMESTONE, 90%	3.28	lb.