ENCLOSURE (B) 7

STUDIES ON MATERIALS RESISTANT TO CHLORINE COMPOUNDS

by

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LIST OF TABLES AND ILLUSTRATIONS

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SUMMARY

Studies were made with object described below:

1. To make clear the influence of water vapor on the corrosion of cast iron by HCl gas, and to find the necessary drying limit to prevent corrosion.

2. To find suitable materials for an HCl gas compressor and a liquid HCl vessel by testing the corrosion losses of some kinds of metals under those conditions.

3. To find a suitable material for the reaction vessel in the dichlor-ethane formation.

Results obtained were as follows:

1. Influence of water vapor content on corrosive properties of HCl gas.

   a. It is quite difficult to dry the HCl gas sufficiently to prevent the corrosion of a gas compressor made with cast iron.

   b. The gas dried through sulphuric acid towers is not sufficiently dry to prevent the corrosion of cast iron.

   c. Connecting an aluminum chloride tower has a considerable drying effect but is not completely satisfactory.

   d. Connecting metal towers such as iron or zinc in the drying train shows a large effect but is still not sufficient to keep the compressor in operation.

   e. It is not satisfactory to use cast iron as the compressor material.

2. Materials for HCl gas compressor and liquid HCl vessel.

   a. A steel bomb is suitable for the liquid HCl vessel.

   b. Silver based alloys, such as Ag-Sn, Ag-Sb, are suitable for the valve materials of the liquid HCl bomb.

   c. No entirely satisfactory material was found for the HCl gas compressor, but silver, nickel, copper and 18-8-2 chrome-nickel-molybdenum steel showed better results than cast iron.

3. Material for dichlor-ethane reaction vessel.

   a. Lead is the most suitable material for the reaction vessel.

   b. The purer the lead the better the results obtained.

   c. Silver-lined iron is the best for the lid of reaction vessel which has no contact with catalytic solution but which does contact the reaction gases.

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I. INTRODUCTION

It would be very convenient for both inorganic and organic industries, if liquid HCl manufacture reaches an industrial scale. It would decrease the neccessity of synthetic HCl installations even when HCl gas is needed in the reaction.

On this account, we tried formerly in this institute to operate an HCl gas compressor but because of the sticking of valves it was inevitably stopped within a few hours. The materials of the compressor used in the former experiment were:

Cylinder liners	semi-steel cast iron
Piston rings	cast iron
Lubricant	liquid paraffin

The HCl gas was made by the synthetic process and dried through two sulphuric acid towers filled with Raschig rings, and a tower filled with zinc granules. The zinc tower was afterwards replaced by an anhydrous aluminum chloride tower by the author.

For this report, the influence of the water vapor in HCl gas on the corrosion of cast iron was tested to see whether cast iron is useful as the compressor material. Corrosion tests of metals in HCl gas were made to find a suitable material for the HCl gas compressor. Studies were also made on the liquid HCl vessel.

In the dichlor-ethane formation, using such corrosive reagents as ferric chloride and water as the catalyst, hydrogen chloride, alcohol and dichlor-ethane as the reacting agents, and chlorine as the reactivator of the catalyst, the reaction proceeds at 130°C. It is difficult to find materials for the reaction vessel resistant to corrosion under such severe conditions. Even using such metals as Ta, Pt, W and other special alloys considered to be resistive to Cl-compounds it is questionable whether they are sufficiently resistant under these severe conditions. These metals also have disadvantages which condemn their practical use; i.e., some are too expensive, others cannot be worked easily. Non-metals such as stoneware are too fragile. Rubber lined iron vessels have no resistance under these conditions.

For these reasons, homogeneous lead linings have been in use up to this time for the vessels, but their resistance is not satisfactory.

For this report, some kinds of metals and alloys which are considered to have comparatively good resistance to hydrogen chloride were tested as to whether they are suitable as materials for the reaction vessel in the dichlor-ethane formation. The influence of minor constituents in lead were also tested.

These studies were started in May, 1944 and were in progress when the war ended.

II. DETAILED DESCRIPTION

A. Corrosion of Metals by Wet HCl Gas - Statically.

1. Description of apparatus.

The corrosion vessel shown in Fig. 1(B)7 contains in the bottom 35 or 40% hydrochloric acid, and above it test pieces were placed in contact with the acid vapor. The humidities of the hydrochloric acid vapors are shown in Table I(B)7.

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Table I(B)7

HUMIDITIES OF HYDROCHLORIC ACID VAPORS

Acid (%)	Temp. (°C)	Partial V.P. (mm Hg)		Humidity (%)
		H_2O	HCl	
40	20 35 30	2.00 2.88 4.09	399 515 627	0.50 0.56 0.65
35	20 25 30	3.42 4.88 6.70	75.0 100 130	4.4 4.7 4.9

2. Test procedure.

a. The influence of surface condition on the corrosion of cast iron was tested.

b. The influence of time on the corrosion of cast iron was tested.

c. The corrosion resistance of some kinds of metals and alloys were compared. Constituents of metals and alloys used in the tests are as shown below.

Table II(B)7

COMPOSITION OF IRON AND STEEL USED IN CORROSION TEST

	T.C.	Si	Mn	S	P
Cast iron	3.90	2.12	1.68	0.09	0.35
Steel	0.20	0.05	0.56	0.04	0.04

Table III(B)7

COMPOSITION OF METALS AND ALLOYS USED IN CORROSION TEST

Silver .... chemical pure silver
Copper .... electrolytic copper
Nickel .... electrolytic nickel
Ag-Cu(1) .... Ag 95; Cu 5
Ag-Cu(2) .... Ag 72; Cu 28
Ag-Sb .... Ag 96.8; Sb 3.2
Ag-Sn .... Ag 89; Sn 10.3
Brass ....Cu 64.0; Zn 36.4
Bronze .... Cu 85.7; Sn 10.3; Zn 4.0
Cu-Ni .... Cu 75; Ni 25
Constantan .... Cu 58.5; Ni 40; Fe 1; Mn 0.5
18-8 steel .... Cr 16.33; Ni 7.52
18-8-2Mo steel .... Cr 18; Ni 8; Mo 2.3
13 Cr steel .... Cr 11.95; C 0.05

The dimensions of the test pieces are as follows:

Metals other than silver and silver based alloys: 20x50mm
Silver and its alloys: 1x20x50mm

ENCLOSURE (B)7

3. Experimental results.

The experimental results are recorded in Tables IV(B)7, V(B)7, and VI(B)7.

4. Discussion.

It is clear from Table IV(B)7 that corrosion is largely dependent on the surface condition. Corrosion is great when the surface is uneven and decreases with the surface smoothness.

Observing the corrosion of cast iron, it was observed that iron chloride is formed on the surface as the corrosion proceeds, and by its hygroscopic nature it absorbs the humidity in HCl gas so that the surface of the test piece is covered with a saturated iron chloride solution. This markedly decreases the corrosion of the test piece as with time. Discussion of the corrosion of metals and alloys in wet static HCl gas are included in Enclosure (B)4.

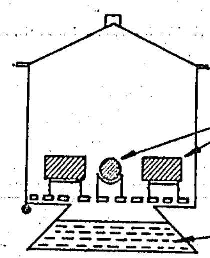

Figure 1(B)7

CORROSION VESSEL, STATIC TYPE

Table IV(B)7

DIFFERENCES DUE TO THE SURFACE CONDITION OF TEST PIECE
(test piece cast iron, liquid phase 35%HCl, room temp, 25°C)

Surface conditions	Time (min)	Corrosion loss		
		mg/dm²	mg/dm²day	Average (mg/dm²day)
Polished	210	102 99	699 679	689
Wiped off the corrosion product of test piece	210	67 59	459 405	432
Wiped off the corrosion product of test piece once more	210	65 57	446 390	418

ENCLOSURE (B)7

Table V(B)7

DIFFERENCE DUE TO THE TIME OF EXPOSURE

(test piece cast iron, liquid phase 35%HCl, room temp. 25°C)

Surface condition	Time (min.)	Corrosion loss		
		mg/dm^2	$mg/dm^2 day$	Average ($mg/dm^2 day$)
Polished	60	38 33	919 799	859
Wiped off the corrosion product of test piece	60	29 25	696 596	646
Wiped off the corrosion product of test piece once more	900	148 135	237 216	227

Table VI(B)7

CORROSION OF METALS AND ALLOYS IN HYDROCHLORIC ACID VAPOR

Test piece	Conc. of HCl in liquid phase (%)	Temp. (°C)	Time (hr)	Surface Condition	Corrosion loss	
					mg/dm^2	$mg/dm^2 day$
Silver	45	5	15x24	polished	334	22
Ag-Cu(1)	40 35	25-29	24	Wiped off the corrosion produced on the test piece after testing in presence of dry and wet HCl gas (Table 10)	- 28 - 31	- 28 - 31
Ag-Cu(2)	40 35				- 23 70	- 23 70
Ag-Sb	40 35				- 4.5 - 34	- 4.5 - 34
Ag-Sn	40 35				26 - 7.8	26 - 7.8
Copper	40 35				- 51 847	- 51 847
Steel	40 35		48		194 194	97 97
Cast Iron	40 35				780 367	390 184
18-8 Steel	40 35		48 24		548 433	274 433
18-8-2Mo Steel	40 35		48 24		259 356	130 356
Bronze	35	20-25	48		3080	1540
Nickel	35				148	74
Cu-Ni	35				4630	2315
Constantan	35		24		2340	2340
13 Cr Steel	35				583	583

(- means increase in weight after corrosion)

ENCLOSURE (B)7

B. Corrosion of Metals by Dry and Wet HCl Gas - Dynamically.

1. Description of apparatus.

~~The apparatus is shown in Fig. 2(B)7.~~

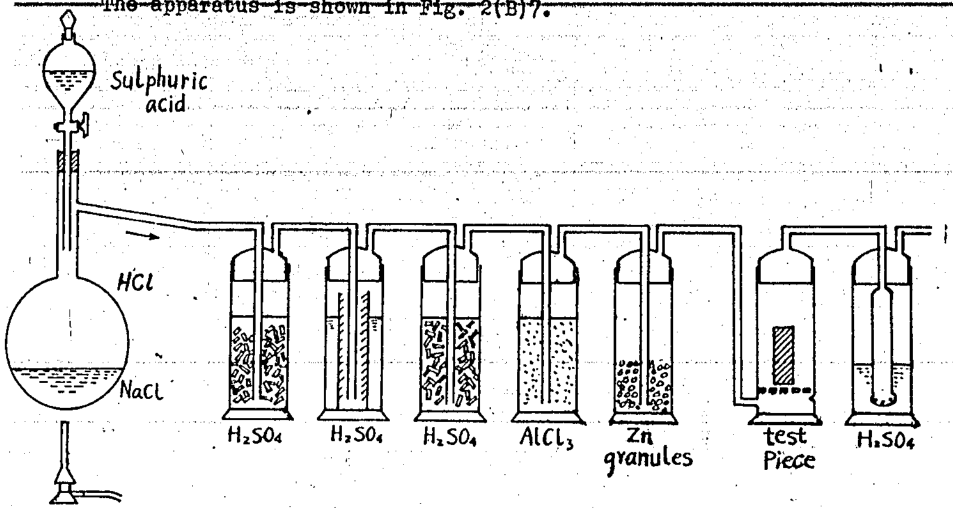

Figure 2(B)7
CORROSION TEST, DYNAMIC

HCl gas was generated by Le Blanc's method and the concentration of sulphuric acid used was 85%.

Three sulphuric acid towers were used to dry the gas. The first and the third tower contained 200cc and the second tower contained 300cc of acid. The 1st and the 3rd towers were filled with Rashig's rings, and the 2nd tower was an Ichinose washing bottle by which the velocity of the gas was controlled. The depth of liquid in each tower was about 10cm.

The aluminum chloride tower was filled with anhydrous aluminum chloride, and the layer of drying agent was about 10cm. The zinc tower contained about 35g of zinc granules and its thickness was about 5cm. The tests were made at room temperature and the velocity of HCl flow was about 200 cc/min.

2. Test procedure.

Tests are made under 3 conditions.

a. Varying the drying method for HCl gas, the corrosion of cast iron was tested. (See Table XII(B)7)

b. Drying the gas with three sulphuric acid towers, the corrosion of metals and alloys were tested.

c. After drying with sulphuric acid, the gas was introduced into the corrosion vessel which contained saturated (nearly 45%) HCl acid in the bottom (Fig. 3(B)7), and the corrosion of metals and alloys was tested. For this case the humidity in the gas is about 0.04%.

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The constituents of metals and alloys used in these tests are shown in Tables II(B)7, and III(B)7.

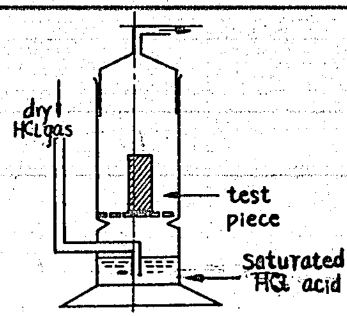

Figure 3(B)7

CORROSION VESSEL

3. Experimental results.

The experimental results are recorded in Tables 8, 9, and 10.

Table VII(B)7

METHODS OF DRYING HCL GAS

No.	Drying Method			
1	is not dried			
2	is dried through	three	85%	sulphuric acid towers
3			98%	
4			85%	sulphuric acid towers and one aluminum chloride tower
5			98%	
6	contacts 35 cm^2 iron piece	before H_2SO_4	dried like No.	4
7				5
8		after H_2SO_4		4
9				5
10	is dried through one $CaCl_2$ tower	before H_2SO_4	dried like No.	5
11	contact 35 cm^2 iron piece			10
12	is dried through one zinc tower after			5

(Calcium chloride tower contains about a 10 cm thickness of anhydrous $CaCl_2$)

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Table VIII(B)7

CORROSION OF CAST IRON BY HCL GAS DRIED BY DIFFERENT METHODS
(Room temp. 20-25°C)

Surface Condition	Drying Method	Time (min)	Corrosion Loss		
			mg/dm^2	mg/dm^2day	Average (mg/dm^2day)
Polished	1	180 210 360	80 93 154	640 640 620	633
	2	140 210	172 281	1770 1927	1849
	3	200 210	82 88	590 603	597
	4	210	98 80	672 548	610
	5		55 54	377 370	374
	6		66	453	453
	7		48	329	329
	8		46 73	315 501	408
	9		32 34	219 233	226
	10	250 240	54 66	311 396	354
	11	180 360	24 31	192 124	158
	12	210	41 41	281 281	281
Polished (HCl is generated by 98/H_2SO_4)	5		17	117	117

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Table IX(B)7

CORROSION OF METALS AND ALLOYS IN DRY HCL GAS
(Room temp. 20-22°C)

Test Piece	Surface Condition	Time (hr)	Corrosion Loss	
			mg/dm^2	mg/dm^{2}day
Silver	Polished	6	7.6	34
	Wiped off the corr. prod. of test piece	25	10.1	9.7
Ag-Cu(1)	Polished	6	43.5	174
	Wiped off the corr. prod. of test piece	25	−14.1	−14
Ag-Cu(2)	Polished	6	12.5	50
	Wiped off the corr. prod. of test piece	25	34.4	33
Ag-Sb	Polished	6	25.9	104
	Wiped off the corr. prod. of test piece	25	7.8	7.5
Ag-Sn	Polished	6	30.0	120
	Wiped off the corr. prod. of test piece	25	3.9	3.7
Copper	Polished	6	6.7	27
	Wiped off the corr. prod. of test piece	25	29.3	28
Brass	Polished	6	191	762
	Wiped off the corr. prod. of test piece	25	89.5	86
Nickel	Polished	6	0.0	0
	Wiped off the corr. prod. of test piece	25	29.8	29
Steel	Polished	6	27.8	111
	Wiped off the corr. prod. of test piece	25	94.0	90
Cast Iron	Polished	6	25.9	104
	Wiped off the corr. prod. of test piece	25	69.0	66
18-8 Steel	Polished	6	7.5	30
	Wiped off the corr. prod. of test piece	25	66.8	64
18-8-2Mo Steel	Polished	6	11.1	44
	Wiped off the corr. prod. of test piece	25	43.4	42

ENCLOSURE (B)7

Table X(B)7

CORROSION OF METALS AND ALLOYS IN WET HCL GAS
(Contact with vapor of 45% HCl, Room Temp. 20-22°C)

Test Piece	Surface Condition	Time (hr)	Corrosion Loss	
			mg/dm²	mg/dm²day
Silver	Wiped off the corrosion product on the test piece after the dry gas corrosion tests.	25	5.0	4.8
Ag-Cu(1)			-29.5	-28
Ag-Cu(2)			39.6	38
Ag-Sb			-7.9	-7.6
Ag-Sn			-30.1	-29
Copper			39.6	38
Brass			294	282
Nickel			21.3	20
Steel			134	129
Cast Iron			190	181
18-8 Steel			83.9	81
18-8-2Mo Steel			59.7	57

4. Discussion.

The HCl dried through 85% sulphuric acid towers corrodes the cast iron to a far greater extent than when the gas is not dried. The corrosion with gas dried by 98% sulphuric acid is appreciable, even though it shows a little decrease compared to the case when the gas is not dried. Connection of an aluminium chloride tower gives good results and the corrosion loss greatly decreases.

A very effective method to decrease the humidity in HCl gas is to contrast the gas with metals whose chlorides are very hygroscopic, such as iron. Contact with iron after drying the gas with sulphuric acid shows better results than when the gas contacts it before drying with sulphuric acid. A zinc tower shows the same effect as iron to HCl gas, and this is a result of the hygroscopic nature of the corrosion product, zinc chloride.

Connection of a calcium chloride tower shows little effect in decreasing the humidity of the gas, but is effective in preventing the dilution of sulphuric acid. However, when accompanied by contact with iron the corrosion of the test piece shows a considerable decrease.

The corrosion by the gas generated with 98% sulphuric acid is far less than that by the gas generated with 85% acid. This shows the poor efficiency of sulphuric acid towers.

Corrosion resistance of silver is great both to dry and wet HCl gas.

Corrosion in Ag-Cu alloys is greater than in silver, but its fine corrosion product acts as a protective coating. These alloys have a tendency to increase their weight by corrosion. Silver-copper alloy rich in copper shows a poor result in wet HCl gas.

Ag-Sb alloy shows better results than Ag-Cu alloys. It also forms a protective coating.

Ag-Sn alloy condenses moisture on its surface even in dry HCl due to the hygroscopic nature of its corrosion product, stannous chloride, but the corrosion loss is small.

Copper shows good results in dry HCl gas. Its corrosion product is fine and sticks to the surface, but its corrosion loss greatly increases following the increase in water vapor content in HCl gas, and the corrosion product strips off easily.

Next to silver, nickel has good resistance to HCl gas. The corrosion loss of nickel increases slightly with the increase in humidity of the gas.

Alloys such as brass, bronze, constantan, etc., show poor results in the corrosion tests. Selective corrosion was recognized in such alloys.

Humidity in HCl gas has little effect on the corrosion of steel as long as electrolytic corrosion on steel does not occur.

Cast iron shows better results in dry HCl gas than steel, but with increasing humidity the corrosion loss becomes greater than that of steel.

18-8 chrome nickel steel shows good resistivity to dry HCl gas, but is badly corroded in wet HCl gas.

18-8-2 chrome-nickel-molybdenum steel shows better results than 18-8 chrome-nickel steel, but corrosion is high in wet HCl gas.

13 Cr steel shows poor results in either wet or dry HCl.

C. Material for Liquid HCl Vessel.

1. Description of apparatus.

The test piece was placed in a autoclave made of 18-8 chrome nickel steel. The HCl gas dried by sulphuric acid was introduced into the autoclave, which was dipped in liquid air for 30 minutes. The valve was closed, and the autoclave was placed at room temperature.

2. Test procedure.

Tests in liquid HCl were made with steel only. The analytical data of the steel are shown in Table II(B)7. Dimensions of the test piece were 3 x 5 x 50 mm.

3. Experimental results.

The experimental results are recorded in Table XI(B)7.

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CORROSION OF STEEL IN LIQUID HYDROGEN CHLORIDE

Table XI(B)7
~~(room temp. 15-20°C)~~
(test piece: steel)

Surface Condition	Time (hr)	Corrosion Loss	
		mg/dm²	mg/dm²day
Polished	120	190	38
Wiped off the corr. prod. of test piece	200	70	8

4. Discussion.

The surface of steel dipped in liquid HCl is more matted when compared with the surface of steel exposed to the vapor.

D. Material for Dichlor-Ethane Vessel.

1. Description of apparatus.

The apparatus is shown in Fig. 4(B)7. The first corrosion vessel made of stoneware contains 500g of $FeCl_3 \cdot 6H_2O$ as a catalyst for the reaction, and the second is empty. Both vessels are placed in oil thermostat, the temperature of which is kept at 130°C. HCl gas generated by Le Blanc's method and alcohol vapour are led into the first vessel and the reacted gas goes out from the second vessel. This process continues 5 hours and then the flow of HCl gas and alcohol are stopped and chlorine gas is introduced into the first vessel for 5 hours.
These processes are alternated for 40 hours. Constituents of metals and alloys tested in this experiment are as follows:

ALLOYS AND METALS TESTED AS DICHLOR-ETHANE VESSELS
Table XII(B)7

Test Piece	Constituents	Dimension (mm)
Silver	Chemical pure silver	1 x 20 x 50
Pb-Sb(1)	Sb 0.2%	20 ø x 50
Pb-Sb(2)	Sb 5.0%	
Tungsten	Pure tungsten wire	1 ø x 50

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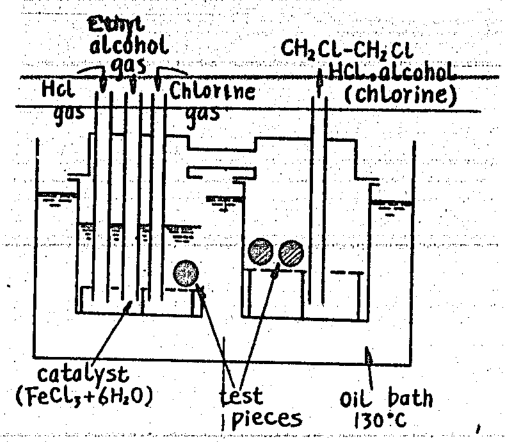

Figure 4(B)7

DICHLOR-ETHANE CORROSION TEST

Table XIII(B)7

COMPOSITION OF LEAD SPECIMENS TESTED IN DICHLOR-ETHANE APPARATUS
(Dimension of test pieces 20mm x 50mm)

Test Piece	Silica	Cu	Fe	Bi	Zn	As	Sb	Sn	Cd	Ni	Pb
Lead(1)	0.002	0.001	0.007	0.004	0.005	-	-	-	-	-	99.981%
Lead(2)	0.001	0.001	0.003	0.006	0.001	-	0.001	0.019	-	0.005	99.963
Lead(3)	Ag 0.33 %										
Lead(4)	Cu 0.20										
Lead(5)	Bi 0.17										
Lead(6)	Sn 0.31	Was added to lead (1)									
Lead(7)	Sb 0.20										
Lead(8)	As 0.15										
Lead(9)	Cd 0.13										
Lead(10)	Zn 0.15% was added to lead(1)										

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2. Test procedure.

The corrosion was tested both in the liquid and gaseous phases.

a. A comparison between different metals and alloys was made.

b. The influence of minor constituents in lead was tested.

3. Experimental results.

The experimental results are recorded in Table XIV(B)7.

Table XIV(B)7

CORROSION OF METALS AND ALLOYS

Test Piece	Time (hr)	Corrosion Loss			
		Liquid Phase		Gaseous Phase	
		mg/dm^2	mg/dm^2day	mg/dm^2	mg/dm^2day
Lead (1)	40	2368	1420	1218	732
Pb-Sb(1)		4077	2443	3164	1900
Pb-Sb(2)		4591	2755	3032	1820
Silver		2831	1698	21	13
Tungsten		57	34	0	0

4. Discussion.

Tungsten has a good resistivity for corrosion in the dichlor-ethane forming reaction. This is especially true in the gaseous phase where no corrosion loss was found.
Silver shows poor results in the liquid, but in the gaseous phase it shows very good results.

Corrosion resistance of antimonial lead is very poor under these conditions.

The presence of minor constituents in lead shows a bad influence on lead corrosion. Especially, the existence of As and Sb in lead causes excessive corrosion both in liquid and gaseous phase. The presence of Bi has comparatively small effect on lead corrosion.

Lead (2) used in the 3rd Naval Fuel Depot as the material for reaction vessel in dichlor-ethane formation, shows a worse result than Lead (1).

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Table XV(B)7

THE INFLUENCE OF MINOR CONSTITUENTS IN LEAD

Test Piece	Time (hr)	Corrosion Loss			
		Liquid Phase		Gaseous Phase	
		mg/dm²	mg/dm²day	mg/dm²	mg/dm²day
Lead (1)	40	2076	1237	657	392
Lead (2)		3072	1833	1843	1102
Lead (3)		2570	1536	2067	1234
Lead (4)		2641	1577	1850	1103
Lead (5)		2446	1461	877	523
Lead (6)		3036	1812	978	585
Lead (7)		3999	2383	2592	1547
Lead (8)		3740	2232	2826	1687
Lead (9)		3143	1879	2178	1300
Lead(10)		2595	1550	2750	1641

III. CONCLUSIONS:

A. In the actual operation of an HCl gas compressor, the corrosion product will be wiped off continuously, and the surface condition will be exactly similar to one which is continuously polished with emery paper. For this reason, the corrosion loss in such a case will be far greater than the one shown in this report. The corrosion loss of cast iron by dried HCl gas is about 200 mg/dm²day disregarding entirely the influence of defacement. Actually, the removal of ferrous chloride film due to the rubbing of iron surface results in the formation of a new active surface, and the formation of scrap will increase the formation of ferrous chloride and the defacement of iron as much as ten or more times. These corrosion products mixed with lubricant cause the sticking of valves, and make it impossible to keep the compressor in motion. Therefore, the use of cast iron as the compressor material is not suitable.

B. HCl gas is very hygroscopic. This makes it difficult to dry the gas to the extent necessary to keep the compressor in motion using ordinary drying agents which are in industrial use. Metal towers such as iron or zinc have a great efficacy in decreasing the humidity of HCl gas, but these metals will lose their efficacy when a saturated metal chloride solution is formed on the surface of the metals. Furthermore, it is questionable whether a metal drying tower will keep its great efficacy after a prolonged continuous flow of the gas as with an HCl gas compressor.

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C. No completely satisfactory material was found for the HCl gas compressor. Even silver and its alloys which show good resistance for HCl gas were corroded considerably when the surfaces were polished. Silver, copper, nickel and 18-8-2 chrome nickel molybdenum steel show relatively good resistance to HCl gas. The practical tests of these metals as the compressor materials will be worthwhile and interesting.

D. The use of a lubricant which has a low viscosity such as liquid paraffin greatly accelerates the defacement of cylinder liners and piston rings. Thus its use as the lubricant in the compressor should be avoided. Lubricating oils suitable to the HCl gas compressor must have high viscosity, stability to the gas, and low solubility of the gas.

E. From the appearance of test pieces the use of steel bombs for liquid HCl vessels may be satisfactory, though the determination of suitability should be done after measuring its mechanical strength after corrosion.

F. Silver and its alloys have good corrosion resistance even in wet HCl gas, and they are suitable for the valve material of the liquid HCl bomb. Silver is too soft for the valve material, so Ag-Sb and Ag-Sn alloys are better than silver.

G. Homogeneous lead linings are best for the reaction vessel in dichlorethane formation. The purer lead gives better results.

Tungsten has a very good resistivity for this condition, but its practical use is out of the question. Silver has a very good resistivity if there is not contact with the catalytic solution but only contact with the reaction gases. Therefore, silver-lined cast iron is suitable for the lid of the reaction vessel.