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Energy Systems

CANDIDATE CHEMICAL SYSTEMS FOR AIR COOLED,
SOLAR POWERED, ABSORPTION AIR CONDITIONER DESIGN

PART III - LITHIUM SALTS WITH ANTI-FREEZE ADDITIVES

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PART III - LITHIUM SALTS WITH ANTI-FREEZE ADDITIVES

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This report is submitted as one portion of the work agreed upon in Letter Contract EG-77-C-03-1587 (SAC 2) between the Department of Energy and Energy Systems Division, Carrier Corporation.

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SUMMARY

The two most promising "anti-solidification" additives which have been identified are ethanolamine and ethylene glycol. Considerations of viscosity, corrosion, crystallization temperature and vapor pressure have led to a selection of lithium bromide - ethylene glycol - water as the basis of a prototype air-cooled machine, with the lithium bromide/ethylene glycol ratio being 4.5.

Using what appear to be reasonable heat exchanger approach temperatures, cycle thermal COP's of 0.7^+ appear possible at the specified design point, based on solution properties which were determined with "qualification accuracy".

The prototype, delivering 10,000 watts of cooling, has a calculated parasitical electrical load of about 175 watts (theoretical) to drive the internal fans and pumps, equivalent to about a 0.5 horsepower motor.

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1-0 INTRODUCTION

In the two earlier sections of this report, we looked at a variety of alternate chemical systems in the hopes of finding new chemical combinations which would give air-cooled, absorption cycles with acceptable thermodynamic performance and requisite stability of the chemical system. Two candidate systems were identified, but with important reservations.

Many other searches, in addition to the Carrier Corporation Research Division Program which has served as the primary input to this report, have been made with no really definitive identification of a new candidate system. Among the more imaginative of these systematic searches is the one done by Arthur D. Little, Inc.* A relatively recent survey is the review by R. K. Swartman, et al.,** of the University of Western Ontario. The associated bibliography includes references to many of the earlier searches.

Because no new candidate system was found which did not present almost as many new problems as solutions to old problems, our Carrier search eventually wound up attempting to find an additive which would modify the properties of the well known lithium bromide-water system to render it suitable for air cooling.

As discussed in the first volume of this report, the restriction on the use of lithium bromide is its limited solubility in water. To

* "An Investigation of Possible New Absorption Cooling Cycles," Arthur D. Little, Inc. Report to the American Gas Association(C-64617) New York, 1963.

** Swartman, R.K.; Ha, V; Newton, A.J. "Survey of Solar Powered Refrigeration" ASME Publication 73-WA/Sol. Paper presented as ASME Winter Annual Meeting, Detroit (1973).

absorb water vapor from a chiller at 7°C into an absorber operating at 49°C requires a lithium bromide concentration of about 65%, which is virtually saturated. Any perturbation of the operating conditions, such as a sudden drop in absorber temperature due to a sharp cold front or a rain shower, could drive the absorber, or solution heat exchanger, across the saturation line and solidify the solution filling that component. What is therefore required of an additive is that it should shift the solidification line towards higher concentration without raising the refrigerant vapor pressure or diminishing the heat transfer properties by an intolerant amount.

Many candidate "anti-solidification" or "anti-freeze" additives have been suggested over the years, generally selected on the basis of high boiling point and the existence of strongly polar groups to give them miscibility with water and solvent power for ionic solutes. Such studies were carried out by Paul Lynch of Trane Corporation* and by W. R. Hainsworth** and others on behalf of Arkla-Servel.***

2-0 EXPERIMENTAL PROGRAM

Aminoethanol, ethylene glycol, aminobutanol, diethylaminoethanol, bis (methoxyethoxy) ethyl ether, dimethylformamide, propylene carbonate, t-butyl phosphate, diethylene glycol, tri-ethyleneglycol, triethanolamine and ethylene diamine were used as additives to lithium bromide and lithium

* For example, see Patent 3,296,814 and Patent 3,388,557 to R. J. Modahl and assigned to the Trane Company.

** Hainsworth, W.R. "Refrigerants and Absorbents" Refrigerating Engineer: 48, 87 (1949).

*** U. S. Patent 3,626,708 Awarded to Chester C. Lyon and assigned to Arkla Industries, Inc.

chloride aqueous solutions. The three criteria used for fluid selection were: high boiling point, high dielectric constant and commercial availability at reasonable cost.

In most cases very viscous solutions were obtained and such additives were rejected with no further attention. The only solvents found which formed solutions of lower vapor pressure and correspondingly lower crystallization temperature in comparison to lithium bromide water were (in order of effectiveness in the vapor pressure-crystallization relationship):

Aminoethanol
Ethylene Glycol
Ethylene Diamine
Diethylaminoethanol
Bis (methoxyethoxy) Ethyl Ether

The first three constitute a natural grouping representable by the generalized formula $R - (CH_2) - (CH_2) - R$ where R can be either an amino group or a hydroxyl group.

Further screening of these candidate systems was done by measurement of the film side heat transfer coefficient by means of a simulated single absorber tube in equipment which will not be described in detail in this report. Suffice it to say that this apparatus, and the means used to reduce the data collected, has been repeatedly demonstrated to be in very close agreement with the actual performance measured in complete absorption machines.

2-1.1 Vapor Pressure/Crystallization Results

A series of Duhring plots follow which show the variation of saturation temperature with absorbent concentration and solution temperature for additions of various amounts of ethanolamine or ethylene

glycol to the system lithium bromide-water. Where no crystallization lines are shown, the solubility limits are outside the limits of the graph.

Figures 1, 2 and 3 deal with the system lithium bromide-aminoethanol-water at lithium bromide/aminoethanol ratios of 2.65 to 3.88. Figure 4 shows the vapor pressure behavior of lithium bromide-ethylene glycol-water at a lithium bromide/glycol ratio of 3.72, directly comparable to the ethanolamine additive in Figure 2. Comparing these two we note:

1. Slightly higher vapor pressure for aminoethanol at similar absorbent concentrations.
2. A lower slope for the aminoethanol Duhring plot. Since the slope is determined by the ratio $\Delta H_{\text{solution}} / \Delta H_{\text{water}}$, we conclude that the aminoethanol weakens the $\text{Li}^+ - \text{H}_2\text{O}$ bond more than does ethylene glycol.
3. Viscosities of the aminoethanol solutions are higher than the viscosities of the corresponding ethylene glycol solutions. This suggests that the aminoethanol bonds much more tightly, and probably with more bridging between ion clusters, to lithium ions than does the ethylene glycol, an observation consistent with items (1) and (2).

Figure 5 shows the effect of adding aminoethanol to the system lithium chloride-water. It is immediately evident that this system, too, possesses solubility-vapor pressure data making it suitable for air cooled absorption. No follow up was made since no obvious advantage was seen over the use of the more familiar bromide salt. It remains an area for further exploration for possible secondary performance or cost gains after the technical and economic feasibility of lithium bromide-additive-water has been shown.

A number of observations, including dynamic heat transfer measurements in our absorber simulator, led us to conclude that the viscosity of ethanolamine solutions was enough higher than that of ethylene glycol solutions that the latter was the preferred additive. A series of solutions in which the ratio lithium bromide/ethylene glycol was altered was studied to ascertain the optimum value of this ratio. Increasing the amount of anti-solidification additive generally moved the crystallization curve more than did lesser amounts but at the cost of rapidly increasing viscosity and, hence, poorer heat transfer behavior which tended to eat up the gains by increased subcooling in the absorber. These did not appear to be a well developed optimum composition but on a semi-intuitive basis the optimum was felt to be somewhere between a lithium bromide-ethylene glycol ratio of 4 and 5, and the decision was made to select 4.5 as the ratio to be used in further development.

Figures 6, 7 and 8 present vapor pressure and solidification data for lithium bromide-ethylene glycol-water solutions at the selected working ratio of 4.5 and at bracketing ratios of 4.15 and 5.0.

Table 1 contains the equations, derived by least squares from raw experimental data, used to generate these Duhring plots. The average deviation between experimental points and the loci of these equations is in the order of 0.5-1.0°C.

Table 2 contains strong and weak solution concentrations and also the units of mass flow of the strong solution per unit mass of refrigerant flow in a typical cycle.

47 0702

TO THE INCH ± 0.01 INCHES
PER FULL & LESSER CO. PART IN U.S.

SATURATION TEMPERATURE (°C)

47 0702

K&E 11 X 10 TO THE INCH 10 X 15 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

SATURATION TEMPERATURE (°C)

47 0702

K&E 10 X 10 TO THE INCH • 10 X 15 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

TABLE I

LiBr/Aminoethanol 2.65

$$T_{\text{sat}} = 0.862 T_{\text{sol}} - (1.91 [x] - 101.5)$$

LiBr/Aminoethanol 2.88

$$T_{\text{sat}} = (1.105 - 0.00337 [x]) T_{\text{sol}} - (1.590 [x] - 77.85)$$

LiBr/Aminoethanol 3.72

$$T_{\text{sat}} = (0.8744) T_{\text{sol}} - (1.874 [x] - 90.44)$$

LiCl/Aminoethanol 1.51

$$T_{\text{sat}} = (0.00153 [x] + 0.8598) T_{\text{sol}} - (1.417 [x] - 49.89)$$

LiBr/Ethylene Glycol 3.72

$$T_{\text{sat}} = 0.9567 T_{\text{sol}} - (1.972 [x] - 90.4)$$

LiBr/Ethylene Glycol 4.15

$$T_{\text{sat}} = (1.3274 - 0.006341 [x]) T_{\text{sol}} - (2.049 [x] - 73.29)$$

LiBr/Ethylene Glycol 4.5

$$T_{\text{sat}} = (1.3603 - 0.00679 [x]) T_{\text{sol}} - (1.976 [x] - 68.66)$$

LiBr/Ethylene Glycol 5.0

$$T_{\text{sat}} = (1.421 - 0.00751 [x]) T_{\text{sol}} - (1.991 [x] - 64.20)$$

where: T_{sat} = Saturation Temperature, °C

T_{sol} = Solution Temperature, °C

$[x]$ = Weight Percent Solute (salt + additive)

TABLE IICOMPARATIVE SOLUTION DATA (120°C COLLECTOR)

<u>Absorbent</u>	<u>117/55</u> <u>Strong Sol.</u>	<u>49/7</u> <u>Weak Sol.</u>	<u>kg str/kg H₂O</u>
LiBr/Glycol 4.15	73.7%	65.8%	8.33
LiBr/Glycol 5.00	72.85%	65.8	9.33
LiBr/Glycol 4.5	73.9%	67.2%	10.0
LiBr/Am. Eth. 2.65	77.1%	71.6	13.0
LiBr/Am. Eth. 3.72	73.5%	67.4	5.03
LiBr/Glycol 3.72	74.75%	66.1	7.64
LiBr/Am. Eth. 2.88	76.65	71.20	13.06
LiCl/Am. Eth. 1.51	76.8%	63.4%	4.73

2-1.2 Other Numerical Data

In order to calculate cycle performances with some confidence and also to do preliminary sizing of machine components, some auxiliary data were collected and that relevant to the use of the lithium bromide/ethylene glycol 4.5 ratio absorbent is summarized below.

Specific heats were determined by plunging a tared copper mass, heated to 120°C, into a weighed amount of solution contained in a small Dewar flask. The increase in temperature of the solution could then be related to the specific heat of the solution. The heat capacity contribution of the Dewar flask, thermometer and stirring ring were previously measured by plunging the copper mass into distilled water of the same volume as the solution. The specific heat can be expressed between 55 and 75 weight percent solute as:

$$C_p = 4.18 - 0.0327 [x] \text{ kJ/kg}$$

with a reliability no worse than $\pm 5\%$.

Heats of dilution were measured by adding weighed amounts of water to known masses of solution, measuring the temperature rise and then relating this measured temperature rise to the quantity of heat liberated through the heat capacity of the system, measured as above. Determined in this manner, the numbers are necessarily approximate as seen from the raw laboratory results listed below.

		<u>[x] Mean</u>	<u>ΔH Btu/# H_2O</u>
58.0% LiBr	54.5%	68.74	144
57.2	55.35	68.77	122
61.0	58.7	73.14	129
59.6	58.5	72.16	130
58.5	57.5	70.88	134
59.7	58.1	71.98	90

Since no discernible concentration variation was present, ΔH_D was considered constant over the range used at 125 Btu/lb of water added, or in conventional S.I. units, 290 kJ/kg of water added.

Some viscosity data were taken with an Ostwald viscosimeter, as tabulated below:

<u>% LiBr</u>	<u>% Glycol</u>	<u>Ratio</u>	<u>[x]</u>	<u>T, °C</u>	<u>Viscosity, Pa·s</u>
53.35	13.33	4.0	66.68	49	0.0081
55.72	13.70	4.1	69.42	51	0.0178
58.88	14.72	4.0	73.60	52	0.0267
				66	0.0210
61.46	15.36	4.0	76.82	66	0.0298

A large body of film side heat transfer data was taken for absorber performance, not all of which is still retrievable. One series of data was collected in a 22 ton absorption chiller and the following are typical values abstracted from this data.

Absorber Heat Transfer Data

Ratio LiBr/Glycol = 4.5; Cooling Water 30°C; Heat Transfer

Additive: Octanol-1

<u>[x]</u>	<u>Mean Temp. Diff. (°C)</u>	<u>U (overall) Includes water side and metal</u>
67.59	14.6	1193 w m ⁻² K ⁻¹
69.67	17.1	1119
72.84	19.2	1068
73.09	18.7	1125

2-1.3 Corrosion Testing

Included as Appendix "A" is a copy of a corrosion study of the systems Lithium bromide-ethylene glycol/aminoethanol-water. As seen, the ethylene glycol system seems to be quite satisfactory from this point of view and the aminoethanol system, while corroding more rapidly, is still well under the rule of thumb acceptability of 10 milligrams per square decimeter per day which is commonly used in absorption work.

The recommendation that a recirculating test loop be set up to more clearly match the actual operating conditions of an absorption machine was accepted. Such a test loop was built, loaded with lithium bromide-ethylene glycol-water and operated continuously for one year. No significant corrosion or any absorbent decomposition products were noted during the test period or when the loop was torn down. Unfortunately no documentation of this test was done because of termination of the program.

3²0 CYCLE CALCULATIONS, LiBr/GLYCOL = 4.5

Contract EG-77-03-1587 (SAC-2) proposes that the rating conditions of an air-cooled absorption chiller shall be: ambient temperature be 35°C (95°F), chilled water temperature be 7.0°C (45°F) and that the hot water be delivered from the collectors at 110°C (230°F). These conditions are recognized as somewhat arbitrary and in reviewing the project the Department of Energy spokesmen emphasized that they should not be allowed to adversely affect equipment development.

In Figure 9 are shown the estimated operating conditions for a lithium bromide-ethylene glycol-water (ratio = 4.5) cycle under the contractual rating conditions. The heat exchanger approach temperatures are those which we consider good, but attainable in high efficiency commercial equipment. The liquid-liquid heat exchanger, which as was seen in part 1 of this report is a very critical component with respect to cycle COP, was kept at a level of 70% out of deference to the known high viscosity of the solutions involved. Data used in the cycle calculations were taken from the material in 2-1.1 and 2-1.2 of this report, supplemented by refrigerant data taken from Keenan and Keyes.* While some of the data is recognized as less reliable than might be desired, the small sum of the energies (4% of Q_E) around the cycle gives some reassurance.

In general the results of this cycle analysis are very encouraging, and comparing these with equivalent numbers for a water-cooled lithium bromide cycle show no particular causes for pessimism in setting

*"Thermodynamic Properties of Steam" J.H. Keenan and F.G. Keyes. John Wiley & Sons, New York (1944).

FIGURE 9

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CYCLE CALCULATION CARROL 4.5

SAC-2 Rating Condition:
 95°F amb., 230° firing
 water, 45°F chilled water

1. Refrigerant Superheated Vapor
2. Ref. Condensate (purge neglected)
3. Ref. Vapor (bleed neglected)
4. Weak Sol. to HX
5. Weak Sol. to Gen.
6. Strong Sol. to HX
7. Strong Sol. to Abs.

Ambient 35°C Approach 12°C
 Chiller 7°C (flash evaporator)
 Firing Water 110°C, Gen. Appr. 3°C

Point	Temp. °C	[X] LiBr/Gl = 4.5	W kg/kg-ref.	h kJ/kg	Wh kJ/kg-ref	Dew Point °C	Q in kJ W _R = 1 kg	WR = 15.6 kg/ 10,000 W cooling
1	107	0	1.00	2698		49	Q _C = 2501	Q _C = 10.8kW
2	47	0	1.00	197		49	Q _E = 2313	Q _E = 10.0kW
3	7	0	1.00	2510		7	Q _G = 3216	Q _G = 13.9kW
4	49	67.0	13.2	C _P = 1.99 kJ/kg-°C		7	Q _A = 2942	Q _A = 12.8kW
5	83	67.0	13.2			49	COP = 0.72	
6	107	72.5	12.2	C _P = 1.81 kJ/kg-°C		49	Q _A /Q _E = 1.27	
7	66	72.5	12.2			7	Q _G /Q _E = 1.39	

$$(1) \text{ Dew Point} = 35^\circ + 12^\circ + 2^\circ (\text{superheat}) = 49^\circ$$

$$\text{Generator Temp} = 110^\circ - 3^\circ = 107^\circ\text{C}$$

$$(7) R_{WK} = 72.5 / (72.5 - 67.0) = 13.2 \text{ kg/kg refrigerant}$$

$$Q_{st. \max} = (107 - 49) \times 12.2 \times 1.81 = 1281 \text{ kJ/kg ref.}$$

$$Q_{HX} = 70\% \times 1281 = 897 \text{ kJ/kg ref.} \quad t_7 = 66^\circ\text{C}$$

$$= 897 = 1.99 \times 13.2 \times (t_5 - 49) \quad t_5 = 83^\circ\text{C}$$

$$Q_G = 13.2 \text{ kg (67\%)} \rightarrow 12.2 \text{ kg (72.5\%)} + 1 \text{ kg ref. (} t = 83^\circ\text{)}$$

$$1 \text{ kg ref. (} \mathcal{L}, 83^\circ\text{)} \rightarrow 1 \text{ kg ref. (} v, 107^\circ\text{)}$$

$$12.2 \text{ kg (72.5\%)} 81^\circ \rightarrow 107^\circ$$

$$\Delta H = 290 \text{ kJ}$$

$$\Delta H = 2352 \text{ kJ}$$

$$\Delta H = 574 \text{ kJ}$$

$$Q_G = 3216$$

$$Q_A = 1 \text{ kg ref (} v, 7^\circ\text{)} \rightarrow 1 \text{ kg ref (} \mathcal{L}, 49^\circ\text{)}$$

$$1 \text{ kg ref. dissolved in 72.5\% absorbent}$$

$$12.2 \text{ kg (72.5\%)} 66^\circ\text{C} \rightarrow 49^\circ\text{C}$$

$$\Delta H = 2277 \text{ kJ}$$

$$\Delta H = 290 \text{ kJ}$$

$$\Delta H = 375 \text{ kJ}$$

$$Q_A = 2942 \text{ kJ}$$

$$\text{Approximate pump power } (9455.6) \times \frac{13.2 \times 15.6}{1500 \times 3600} = 0.4 \text{ watts solution pump.}$$

out to build a working prototype machine.

<u>QUANTITY</u>	<u>CARRIER-BONNEVILLE SOLAR CHILLER, WATER COOLER</u>	<u>PROPOSED AIR COOLED SOLAR ABSORPTION CHILLER</u>
COP	0.71	0.72
$Q_{\text{abs}}/Q_{\text{evap}}$	1.33	1.28
$Q_{\text{gen}}/Q_{\text{evap}}$	1.41	1.39
$Q_{\text{cond}}/Q_{\text{evap}}$	1.06	1.08
$Q_{\text{HX}}/Q_{\text{evap}}$	.50	.39
kg strong sol./kg ref.	18.5	12.2

Absorption cycles are generally very sensitive to changes in heat rejection temperature. In Figure 10 we have done a partial cycle calculation to see what would happen to this cycle if the ambient were allowed to increase from 30°C to 40°C, as might be encountered in parts of the southwest. It was assumed that the collector temperature would also rise the same amount as the ambient, to 120°C. The chiller temperature remained at 70°C, the pumping rate stayed the same and the heat exchanger efficiency remained at 70%. As we see, the COP drops to 0.56 but, a more serious problem, the capacity drops to 2.76kw mostly due to the drop in concentration spread.

Should it be necessary to maintain capacity up to such elevated ambient temperatures, we would either increase the pumping rate (two speed motor, for example) or more likely develop a control circuit which would allow the chilled water temperature to rise with ambient since dehumidification is not apt to be important in such a desert environment.

CYCLE CALCULATION CARROL 4.5

Hot Day Operation Ambient $T = 40^{\circ}\text{C}$
 Firing Water 115°C , Chilled Water 7°C .

Assume: Strong solution flow
 remains at $15.6 \times 12.2 =$
 190 kg/hour . Condenser
 and absorber, 12°C approach
 Generator, 3°C approach.

Point	Temp. $^{\circ}\text{C}$	X % LiBr/Gly = 4.5	W kg/kg-ref.	h kJ/kg	Wh kJ/kg-ref	Dew Point $^{\circ}\text{C}$	Q in kJ $W_R = 1 \text{ kg}$	$W_{\text{str}} = 190 \text{ kg/hr}$ $W_R = 4.31 \text{ kg/hr}$
1	112	0	1.00	2705		54	$Q_C = 2488$	$Q_E = 2.76 \text{ kW}$
2	52	0	1.00	217		54	$Q_E = 2295$	
3	7	0	1.00	2512		7	$Q_G = 4078$	
4	54	70.5	45.1	$C_P = 1.88 \text{ kJ/kg-}^{\circ}\text{K}$		7	$Q_A =$	
5	93.7	70.5	45.1			54	$\text{COP} = 0.56$	
6	112	72.1	44.1	$C_P = 1.83 \text{ kJ/kg-}^{\circ}\text{K}$		54		
7	71.4	72.1	44.1			6		

$$P \text{ (high side)} = 14.8 \text{ kPa} \quad P \text{ (low side)} = 1.0 \text{ kPa}$$

$$R_{\text{WK}} = 72.1 / (72.1 - 70.5) = 45 \text{ kg/kg ref.}$$

$$Q_{\text{HX(max)}} = (112 - 54) \times 1.83 \times 44.1 = 4681 \text{ kJ/kg ref.}$$

$$\text{at } 70\% \text{ HX efficiency} \quad Q_{\text{HX}} = 3277 \text{ kJ/kg ref.}$$

$$t_7 = 112 - 0.7 (112 - 54) = 71.4$$

$$3277 = 1.83 \times (t_5 - 54) \times 45.1$$

$$t_5 = 93.7$$

$$Q_G = 45.1 \times (112 - 93.7) \times 1.88$$

$$45.1 \text{ kg } (72.1) \rightarrow 44.1 \text{ kg } (70.5) + 1 \text{ kg } \text{H}_2\text{O}$$

$$1 \text{ kg ref. } (\ell, 112^{\circ}) \rightarrow 1 \text{ kg ref. } (v, 112)$$

$$\Delta H = 1552 \text{ kJ}$$

$$\Delta H = 290 \text{ kJ}$$

$$\Delta H = 2236$$

$$Q_G = 4078$$

The above calculations assumed that air at ambient temperature would pass through both condenser and absorber coils. In practice this probably would not be desirable since it would increase the fan horsepower and probably also the initial cost. Usually these two components are placed in series. The disadvantage of this arrangement is that one of the components, usually the condenser, must operate at higher temperature. In Figure 11 is presented a cycle calculation in which a series arrangement of absorber and condenser is used but which allows an extra 10°C (to 120°C) in the temperature of the collectors. Except for a small increase in absorber loading, this change does not appear to compromise the cycle.

Obviously many different cycle calculations will be required to select among the various design variables that must be chosen. These will be included in a later report covering the design of a specific piece of hardware.

FIGURE 11

CYCLE CALCULATION CARROL 4.5

Condenser downstream of absorber. Raise generator to 117°C, collector to 120°C

1. Superheated Ref. Vapor
2. Liquid Refrigerant
3. Saturated Ref. Vapor
4. Weak Sol. to HX
5. Weak Sol. to Gen.
6. Strong Sol. to HX
7. Strong Sol. to Abs.

No rectifier needed. Neglect thermal effects of Gen liquid bleed stream and condenser vapor purge stream.

Point	Temp. °C	[X] Wt % abs.	W kg/kg-ref.	h kJ/kg	Wh kJ/kg-ref	Pressure kPa	Dew Pt °C	Q kJ/kg-ref	Q' (Q _{ref} =10kW 15.78 kg/hr ref)
1	117	0	1.00	2713.4		15.73	55	Q _E =2280	10 kW
2	55	0	1.00	229.6		15.73	55	Q _A =2958	13.97 kW
3	7	0	1.00	2510		1.0	7	Q _G =3160	13.86 kW
4	49	67.2	11.03	C _P = 1.99 kJ/kg-°C		1.0	7	Q _C =2484	10.89 kW
5		67.2	11.03	C _P = 1.77 kJ/kg-°C		15.73	55		
6	117	73.9	10.03			15.73	55	COP=0.72	
7	69.4	73.9	10.03			1.0	7		

$$Q_E = (2) - (3) = 2280 \text{ kJ}$$

$$Q_{\text{Strong}} = (117 - 49) \times 10.03 \times 1.77 = 1207.2$$

$$Q_{\text{wk}} = (117 - 49) \times 11.03 \times 1.99 = 1492.6$$

$$Q_{\text{HX}} = 70\% \times 1207.2 = 845 \text{ kJ/kg. refrigerant}$$

$$t_7 = -0.70 (117 - 49) + 117 = 69.4$$

$$845 = 11.03 \times 1.99 (t_5 - 49)$$

$$t_5 = 87.5^\circ\text{C}$$

$$Q_A = (2510 - 204) + 290 + (69.4 - 49) 1.77 \times 10.03 = 2958$$

$$Q_G = (2713.4 - 490.7) + 290 + (117 - 87.5) 1.99 \times 11.03 = 3160.2$$

$$Q_C = 2484$$

4-1 POSSIBLE MACHINE CONFIGURATION

We anticipate the use of vertical absorber and condenser tubes, one or two rows deep, placed in series in the airstream, absorber coil first. The refrigerant would be flash cooled in a flash chamber to 7°C, pumped through the air coil and returned to the flash chamber at 13°C. While this means that the air coil is part of the vacuum system, this is compensated by a temperature saving in the collectors (elimination of ΔT across heat exchanger), by elimination of heat exchanger surface and by elimination of a chilled water pump.

This system, using two pumps, will adjust concentrations to match varying conditions since it is possible to store water or solution. The central system will be on - off, but with pumps running on a time switch to provide declining load in going to "off" conditions.

The first model may be bulky; about 1.25m wide, 2m high and 0.3m deep; suitable for integration into or against an outside wall. Size reduction would be undertaken subsequently.

4-1.1 Evaporator

This could comprise a flash chamber built with a 0.6m length of 25cm pipe as a shell. Refrigerant would be introduced through a spray header with two or three nozzles. Refrigerant vapor could be conveyed to the absorber through a 10cm vapor duct at each end of the spray chamber.

The air coil would be a fairly conventional copper tube with aluminum fins, but because of the need of holding a vacuum would have

some constructional restrictions such as no soft solder joints.

4-1.2 Absorber

A suggested design was 20 tubes 0.75m long, 2.86cm O.D., 0.09cm wall, aluminum fins, 5.5 fins/cm, one row, with tube spacing 6.0cm. Tubes could be headered in parallel with 10cm pipe header. Because of the impossibility of keeping the header perfectly horizontal in actual installation, the tubes would have to be divided into several groups and each group fed solution independently if uniform distribution is to be maintained. Several methods of distribution have been used in the past and some "cut and try" is evidently going to be needed when the absorber design is finalized.

One practical problem that will be met is that finned tubes of the size needed are not common.

4-1.3 Condenser

To match airflow, the condenser should have the same face area as the absorber, and since similar vapor volumes are involved, will probably use the same tube size. Because the inside thermal resistance in the condenser will be only a fraction of that encountered in the absorber ($\sim 10,000$ vs $1,000 \text{ Wm}^{-2}\text{K}$) it may be possible to use shorter tubes or otherwise effect economies in construction.

For the first working model it will be expedient to use a condenser coil identical to the absorber and then worry about cost reduction possibilities in later models.

4-1.4 Generator

Several options are available. First unit will be designed as shell and tube heat exchanger with solar heated water inside the tubes. The weak solution pumped up from the absorber will be brought into contact with the tubes in shallow trays built around each layer of generator tubes. Absorbent solution will feed into the top tray, overflow the opposite end into the second tray, etc. Such a method will decrease submergence losses and will permit counterflow rather than crossflow operation of the generator. Again, this will result in temperature savings in the solar collector.

Associated with the generator will be a "separator", a small chamber containing a section of mesh or blade eliminators. This separator function can usually be combined with the vapor duct leading to the condenser header.

4-1.5 Solution Heat Exchanger

This design is complicated by the low head available from generator to absorber and by the solution viscosity which will limit heat transfer coefficients. What is needed is a lot of cheap surface, particularly on the strong solution side.

Probably the best approach is the classic flat plate design. One provisional design comprises eleven hot passages and ten cold passages with plate size 0.2 x 0.64 metre, giving nearly 3m^2 of surface and an estimated overall heat transfer coefficient of $136 \text{ Wm}^{-2}\text{K}^{-1}$.

4-1.6 Pumps

The basic pump requirements can be met with a centrifugal pump at 3500rpm or less. Choice of commercially available models becomes somewhat less when the criteria of hermeticity and reliability are applied. Low NPSH is highly desirable since machine height is increased by the NPSH requirements.

The pump flow and head requirements are:

1. Evaporator pump: To supply 10kw of cooling at a temperature change of 5 - 6°C will require a flow of about $4.3 \times 10^{-4} \text{ m}^3/\text{s}$ at a pressure drop (depending upon location and size of air coil) of 30 to 60 kPa for a theoretical pump power of the order of 25w.
2. Solution pump: The primary flow will be in the order of $3.3 \times 10^{-5} \text{ m}^3/\text{s}$ with perhaps twice this flow needed to operate the purge. Pressure drop around the solution circuit will be of the order of 30kPa, leading to a theoretical pump power of 3 watts. For purging purpose the pump should be able to supply a pressure above atmospheric at very low flow requirement.

4-1.7

The fan power is highly dependent upon the design of the absorber and condenser coils and upon the temperature approach desired. A balance must be made between the amount of surface used and the fan power

which is permitted. On some coil designs which have been evaluated on paper it appears that a theoretical fan power of about 150 watts is a good first compromise which would involve perhaps a 0.5 horsepower fan motor.

APPENDIX A

INTER-OFFICE LETTER

TO DR. W. J. BIERMANN (A)

FROM M. HEINRICHS

DATE 3/29/68

MR. H. F. KELLER (A)

OFFICE RDC

MR. D. P. GAFFNEY (B)

DR. C. A. JOHNSON (B)

SUBJECT CORROSION AND STABILITY TESTING
OF ORGANIC LiBr SYSTEMS

MR. R. N. STENERSON (B)

MR. J. R. BOURNE (B)

DR. E. R. ZABOLOTNY (B)

MR. E. M. GREELEY (B)

DR. D. J. SANDELL (C)

"Pot type" corrosion testing was undertaken in early November to evaluate the corrosivity and stability of two organic - LiBr - water systems. The two organic constituents employed in our tests were aminoethanol and ethyleneglycol. The results are given in tabular form. The experimental procedures employed in evaluating these two systems are nearly identical to those employed for LiBr solutions alone and are adequately described in Technical Report 9-1015-03, Report No. 1, February, 1967.

The first set of values recorded under the heading Weight loss or gain in mgs for the eight coupons employed are those obtained by cleaning the coupons with a detergent solution and a soft brush. The average weight loss for the four specimens in the vapor phase and the four, number 5-8, submerged in solution are given in the second line. The third line gives the weight loss in mgs recorded after cathodic cleaning of the specimens and again the average loss values are recorded in the fourth line. The last number given in the column for exposure time gives the cumulative hours for exposure at temperature.

The weight losses for mild steel exposed to 60:20:20: LiBr-aminoethanol water are given in Table 1. The average weight loss observed for the specimens submerged in solution, show the lowest weight losses occurring for the solutions with LiNO_3 and 2-ethylehexylamine as additives. The lower losses observed for these are, however, not considered to be low enough to be of significance. In general, the weight losses are observed to be indifferent to additions of inhibitor or additive to the solution. The coupon weight losses after brushing with detergent are only slightly less than the loss after cathodic cleaning. There was very little scale or protective coating on these submerged coupons. This behavior was reported for the submerged specimens in the ethyleneglycol LiBr water system which had large LiOH additions. Apparently, the basic solutions obtained with the aminoethanol solutions or the ethyleneglycol solutions with large alkali additions do not allow protective film formation. This means that the corrosion would continue indefinitely at a rate likely determined by the rate of the cathodic process.

Some of the erratic results observed for the vapor phase specimens may be due to the same phenomenon. The spotty appearance of some of the

vapor phase specimens suggested that these coupons had been in, at least periodic contact, with the solution. The vapor phase weight losses suggest that 2-ethylhexylamine has accelerated attack in the vapor phase.

Lithium nitrate shows only a very slight improvement in corrosion behavior compared to lithium molybdate and uninhibited solutions. It does, however, decrease the total pressure of hydrogen produced in the initial hours of exposure.

The results obtained for mild steel specimens exposed to LiBr - ethyleneglycol - water = 60:20:20 are given in Tables 2 and 3. From the results recorded in Table 2, we see that addition of lithium hydroxide to the solution causes an increase in weight of metal lost. In addition as mentioned earlier, the protective coating formation on the metal surface decreases as the alkali concentration increases.

The results in Table 3 show that the inhibitor seems to be without any effect on the total metal weight losses observed for the specimens. On the other hand, addition of 2-ethylhexylamine reduces the losses observed for the vapor phase specimens. A metal loss of 20 mgs per specimen corresponds to an average corrosion rate of 0.84 mdd for the exposure time used in Table 3. These results must, therefore, be considered as very encouraging for the ethyleneglycol-LiBr-water system. On the other hand, since the corrosion rates for the aminoethanol system fall well below the acceptable value of 10 mdd, one cannot rule it out as unacceptable.

Two solution samples from CR-333 and CR-334 were checked for nitrate content subsequent to exposure. The analytical results showed these two as having 3.8 and 3.0 ppm of NO_3^- respectively. Thus, the inhibitor has been consumed by some process but did not show any inhibitive effect. The decomposition products for the nitrate include N_2O and N_2 . The total pressure produced as a result of complete decomposition of the nitrate to nitrogen gas would be 1.2" of Hg.

The gas samples withdrawn from the containers were scanned with the infracord. These, with the exception of CR-361, did not show any gaseous decomposition products of the organic constituents. A C-H stretching frequency at 3.4μ was observed for CR-361. In order to get better sensitivity, Mr. Ed Greeley employed a flame ionization detector which is approximately a hundred-fold more sensitive than the thermal conductivity cell. In addition, a new column which had superior resolution for the hydrocarbons was employed for these latter analysis. Employing these sensitive techniques, one was able to detect hydrocarbons in the gaseous phase. These are not reported as percentage values but simply as relative amounts of these constituents that were found. Thus the column with $\text{C}_1 \text{ C}_2 \text{ C}_3 \text{ C}_4 \text{ C}_x$ has numbers 1, 2, 3, 4 and 0. The $\text{C}_1 \text{ C}_2$ etc. refers to the number of carbon atoms in the hydrocarbon with x being unknown and the relative order of amounts found as 1, 2, 3 etc. 0 means none present and 1 refers to the constituent as being most abundant, 2 is the next most abundant

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etc. These values or quantities of hydrocarbons found in the gaseous phase do not, in my opinion, show significant decomposition. Future work, however, should try to establish a better determination for the absolute rate of decomposition.

I understand that these systems are still being considered as candidates for new absorption systems. I would, therefore, recommend that:

- 1) A recirculating loop similar to that used in evaluating C46 be built and operated under the best estimate for design conditions that are available for the ethyleneglycol - LiBr water system.
- 2) Further "pot type" tests be initiated to evaluate other possible inhibitors for the aminoethanol system. These inhibitors would belong to the classes capable of producing a sulphide film instead of an oxide film, and would include amongst others thiourea, thiocyanates and mercaptobenzo-thiazole.

MH/je

Mann

TABLE 1

[illegible]

TABLE 1 (Cont'd.)

Experiment #	Exposure Time	Pressure /hrs.	Gas Analysis					Inhibitor	Additive	* Weight Loss or Gain of Specimens in mgs								
			H ₂	O ₂	N ₂	N ₂ O	C ₁ : C ₂ C ₃			1	2	3	4	5	6	7	8	
							C ₄											C _x
CR-334	193.5	3.61	Bal	0.04	4.95	yes		3000 ppm LiNO ₂	1% 2-ethyl- hexanol	-1.2	-2.9	-1.8	-3.6	-159.0	-154.1	-145.4	-143.2	
	474.5	19.46	Bal	0.01	0.47					21.3	22.1	20.3	23.8	168.7	160.8	152.2	148.1	
	977.0	4 psig	Bal	0.01	0.09								21.9				157.4	
	1504.0	12 psig	Bal	----	----													
	3148																	
CR-335	193.5	10.72	Bal	0.02	2.15			300 ppm Li ₂ MoO ₄	1% 2-ethyl- hexanol	-3.2	-0.7	-4.3	+4.3	-150.1	-146.9	-149.2	-146.8	
	474.5	26.92	Bal	0.04	0.22								-1.0				-148.2	
	977.0	4 psig	Bal	----	0.07		23401			23.0	20.8	23.7	28.3	163.5	156.0	160.1	158.5	
	1504.0	8 psig	Bal	0.02	0.07							23.7					159.5	
	3148																	
CR-336	193.5	10.38	Bal	0.06	6.77			300 ppm Li ₂ MoO ₄	1% 2-ethyl- hexanol	+0.7		-18.1	-3.7	-148.1	-149.6	-137.9	-138.3	
	474.5	19.42	Bal	0.01	0.79								-7.0				-143.4	
	977.0	24.65	Bal	0.02	0.12					16.4		38.3	22.5	155.0	158.3	143.4	142.9	
	1504.0	8 psig	Bal	----	----								25.7				149.9	
	3148																	
CR-337	193.5	8.91	Bal	0.06	1.58			---	1% 2-ethyl- hexylamine	+0.5	-64.6	-40.3	-80.6	-148.8	-147.6	-139.1	-137.8	
	474.5	28.35	Bal	0.01	0.64								-46.2				143.3	
	977.0	10 psig	Bal	0.01	0.10		12000			15.5	78.0	53.6	89.1	157.6	153.7	146.2	143.7	
	1504.0	20 psig	Bal	----	----								59.0				150.3	
	3148																	
CR-338	193.5	11.5	Bal	----	0.49			---	1% 2-ethyl- hexylamine	-22.3	-17.5	-35.3	-3.1	-146.0	-141.1	-135.2	-134.1	
	474.5	4 psig	Bal	----	0.02								-19.0				-137.8	
	977.0	10 psig	Bal	----	0.04					48.4	53.5	110.5	56.0	150.2	152.2	143.3	141.6	
	1504.0	26 psig	Bal	0.04	0.17								66.8				146.8	
	3148																	

* Area of metal specimen is 19.45 cm²

TABLE 2

CORROSION DATA FOR MILD STEEL EXPOSED TO
60:20:20 ETHYLENEGLYCOL-LiBr-WATER at 280°F

Experiment #	Exposure Time/hrs	Pressure ins of Hg	Gas Analysis					Inhibitor	*Weight Loss or Gain of Specimens in mgs								
			H ₂	O ₂	N ₂	N ₂ O	C ₁ C ₂ C ₃ C ₄ C _x		Additive	1	2	3	4	5	6	7	8
CR-343	165.0	4.65	Bal	0.04	1.39				1.19%	-58.1	-7.1	-135.0	-321.7	-146.7	-136.3	-132.3	-137.2
	449.0	13.29	Bal	--	0.02				LiOH			66.7					-138.1
	1224.0	31.00	Bal	--	--					80.6	21.1	174.9	363.0	161.1	150.9	145.6	147.3
	1192.0	6 psig	Bal	0.03	0.12		21304					92.2					151.2
	3030.0																
CR-344	165.0	4.57	Bal	0.01	1.91				1.19%	-7.6	-8.2	-10.1	-11.5	-148.8	-147.5	-153.3	-129.6
	449.0	11.80	Bal	--	0.03				LiOH			-9.3					-147.3
	1224.0	25.00	Bal	--	--					29.8	16.6	32.7	27.7	162.8	170.0	162.0	139.4
	1192.0	8 psig	Bal	0.04	0.14							26.7					158.5
	3030.0																
CR-345	165.0	5.27	Bal	0.03	2.79					-65.5	-127.1	-101.2	-147.8	-99.9	-61.6	-123.3	-108.9
	449.0	16.59	Bal	--	0.08				0.94%				-110.4				-98.4
	1224.0	6 psig	Bal	--	0.03				LiOH	109.0	166.0	122.7	170.8	157.5	147.7	137.5	135.4
	1192.0	21 psig	Bal	0.04	0.17							142.1					144.5
	3030.0																
CR-346	165.0	4.14	Bal	0.01	1.17					-23.7	-29.8	-31.8	-205.4	-66.6	-83.2	-65.8	-89.5
	449.0	15.20	Bal	--	0.02				0.94%								-75.8
	1224.0	4 psig	Bal	--	0.03				LiOH	83.4	73.3	54.9	246.4	153.6	151.2	133.9	144.6
	1192.0	15 psig	Bal	0.07	0.24												145.6
	3030.0																
CR-347	165.0	6.90	Bal	1.05	8.92				0.69%		-8.0	-11.6	-23.0	-84.7	-85.1	-78.2	-106.8
	449.0	17.16	Bal	0.07	0.19				LiOH				-14.2				-88.7
	1224.0	27.10	Bal	--	0.07					28.4	34.3	57.2	152.0	149.9	140.1	148.2	
	1192.0	7 psig	Bal	0.04	1.61							-40.0					147.5
	3030.0																
CR-348	165.0	5.30	Bal	0.01	1.51					-0.7	-10.5	-21.8	-23.8	-62.4	-37.7	-49.4	-67.9
	449.0	14.60	Bal	0.18	0.66				0.69%				-14.2				-54.6
	1224.0	27.25	Bal	--	0.01				LiOH	14.8	22.9	44.5	48.8	132.9	128.0	121.5	118.7
	1192.0	8 psig	Bal	0.03	0.15							32.7					125.3
	3030.0																

* Area of metal specimen is 19.45 cm²

TABLE 2 (Cont'd.)

Experiment #	Exposure Time/hrs	Pressure ins. of Hg	Gas Analysis					Inhibitor	*Weight Loss or Gain of Specimen in mgs								
			H ₂	O ₂	N ₂	N ₂ O	C ₁ C ₂ C ₃ C ₄ C _x		Additive	1	2	3	4	5	6	7	8
CR-349	165.0	10.55	Bal	12.5	86.0												
	449.0	7.62	Bal	0.22	2.45				0.44%	-4.9	+2.4	-2.7	-1.0	-4.5	-4.6	-6.2	-7.1
	1224.0	10.82	Bal	0.06	0.35				LiOH	36.0	11.1	22.9	-1.4	13.9	13.8	26.9	-5.6
	1192.0	9.42	Bal	0.07	0.30								10.7				42.9
	3030.0												20.2				24.4
CR-350	165.0	4.02	Bal	0.04	1.24												
	449.0	11.87	Bal	0.24	1.38				0.44%	+2.4	+9.9	-13.6	-4.0	+4.3	-3.7	-0.9	-2.0
	1224.0	23.30	Bal	--	0.37				LiOH	18.4	28.4	44.7	-1.3	83.7	94.5	84.0	-0.6
	1192.0	26.92	Bal	0.02	0.08								17.6				126.8
	3030.0												27.3				97.2
CR-351	165.0	4.97	Bal	0.01	1.24												
	449.0	10.00	Bal	--	0.06				0.19%	+14.3	+19.7	+8.8	+17.8	+12.3	+16.8	+19.0	+21.9
	1224.0	17.50	Bal	0.21	0.89				LiOH	41.2	57.6	37.9	+15.1	24.5	29.2	56.5	+17.5
	1192.0	17.09	Bal	0.04	0.12		32401						51.3				69.6
	3030.0												47.0				44.9
CR-352	165.0	5.71	Bal	0.74	24.2												
	449.0	10.64	Bal	0.02	1.68					+20.1	+1.7	-1.3	-13.2	+10.3	+11.9	+18.2	+25.0
	1224.0	20.82	Bal	2.45	18.0				0.19%	90.6	45.4	97.7	+1.8	27.2	24.9	54.8	+16.3
	1192.0	11.85	Bal	5.30	76.0				LiOH				94.4				58.7
	3030.0												82.0				41.4

* Area of metal specimen is 19.45cm²

TABLE 3

CORROSION DATA FOR MILD STEEL EXPOSED TO
60:20:20 ETHEYLENEGLYCOL-LiBr WATER at 280°F

Experi- ment #	Exposure Time/hrs	Pressure ins of Hg	Gas Analysis					Inhibitor	Additive	*Weight Loss or Gain of Specimen in mgs							
			H ₂	O ₂	N ₂	N ₂ O	C ₁ C ₂ C ₃ C ₄ C _x			1	2	3	4	5	6	7	8
CR-353	282.0	7.45	Bal	0.01	1.05				1%	-67.3	-8.1	+20.7	+18.4	-6.0	-5.4	-1.6	-4.3
	1143.5	9.53	Bal	0.02	0.15				2-ethyl-	137.8	56.6	84.1	-9.1	16.4	15.5	20.8	-4.3
	1504.5	9.72	Bal	--	--		32401		hexanol				67.6				21.4
	2930.0												86.5				
CR-354	282.0	7.45	Bal	0.01	0.64				1%	+27.5	+23.3	+31.6	+26.9	-3.6	-3.9	-4.2	-3.5
	1143.5	10.17	Bal	0.01	0.08				2-ethyl-	92.0	99.1	111.4	+27.3	17.3	14.8	16.2	-3.8
	1504.5	18.84	Bal	--	--				hexanol				107.2				16.1
	2930.0												102.6				16.1
CR-355	282.0	14.06	Bal	10.35	79.9			300ppm	1%	-22.8	-2.5	-25.2	-21.4	-4.5	-4.1	-4.5	-2.7
	1143.5	10.26	Bal	2.45	76.2				2-ethyl-	99.3	86.1	79.0	-18.0	14.1	11.8	12.6	-3.9
	1504.5	17.40	Bal	5.79	63.2		21000	LiNO ₃	hexanol				94.3				11.5
	2930.0												89.7				12.5
CR-356	282.0	7.21	Bal	0.03	1.30			300ppm	1%	+19.2		+11.7	+7.5	-3.1	-3.2	-4.8	-8.2
	1143.5	17.17	Bal	--	0.06				2-ethyl-	66.8		51.7	33.7	12.8	13.2	19.2	-4.8
	1504.5	21.19	Bal	--	--			LiNO ₃	hexanol								21.2
	2930.0																16.6
CR-357	282.0	8.53	Bal	--	0.74			300ppm	1%	+24.6		+21.7	+27.4	-7.9	-4.7	-5.5	-4.5
	1143.5	11.25	Bal	--	0.07				2-ethyl-	75.1		73.0	83.7	18.4	15.4	16.5	-5.6
	1504.5	15.45	Bal	--	--		21300	Li ₂ MoO ₄	hexanol								17.0
	2930.0																16.8

* Area of metal specimen is 19.45 cm²

TABLE 3 (Cont'd.)

Experiment #	Exposure Time/hrs	Pressure ins of Hg	Gas Analysis					Inhibitor	Additive	*Weight Loss or Gain of Specimen in mgs							
			H ₂	O ₂	N ₂	N ₂ O	C ₁ C ₂ C ₃ C ₄ C _x			1	2	3	4	5	6	7	8
CR-358	282.0	9.39	Bal	0.20	1.52			300ppm	1%	+25.4	+23.2	+35.9	+27.0	-1.0	-0.1	-1.2	-1.7
	1143.5	12.77	Bal	0.01	0.09				2-ethyl-				+27.9				-1.0
	1504.5	16.47	Bal	--	--			Li ₂ MoO ₄	hexanol	81.9	73.3	79.0	81.6	21.8	24.0	31.6	30.1
	2930.0												78.9				26.9
CR-359	282.0	2.53	Bal	0.01	2.43				1%	-0.9	-0.9	-3.6	-0.5	-5.6	-3.3	-6.1	-3.2
	1143.5	4.35	Bal	0.02	0.40				2-ethyl-				-1.5				-4.5
	1504.5	2.78	Bal	--			31402		hexylamine	7.6	7.2	13.0	9.2	11.4	10.4	15.3	10.3
	2930.0												9.2				11.7
CR-360	282.0	1.60	Bal	0.24	1.89				1%	-5.0	-2.4	-49.4	-2.4	-4.8	-3.5	-4.8	-3.3
	1143.5	5.55	Bal	0.17	36.4				2-ethyl-				-14.8				-4.1
	1504.5	3.80	Bal	0.07	0.48				hexylamine	25.0	21.3	57.8	9.0	8.7	7.9	9.4	8.1
	2930.0												28.3				8.5
CR-361	282.0	10.18	Bal	0.41	87.9	yes		300ppm	1%	-1.7	-2.0	-5.2	-2.5	-10.3	-16.4	-33.2	-10.6
	1143.5	4.16	Bal	0.06	66.5			LiNO ₂	2-ethyl-				-2.8				-17.6
	1504.5	5.22	Bal	--	0.15		00000		hexylamine	6.2	7.2	13.1	9.3	20.9	29.7	51.4	22.5
	2930.0												8.9				31.1
CR-362	282.0	1.39	Bal	1.32	59.7	yes		300ppm	1%	-0.8	-1.0	-1.5	-1.5	-4.9	-5.9	-5.0	-9.3
	1143.5	5.50	Bal	0.02	2.41			LiNO ₂	2-ethyl-				-1.2				-6.3
	1504.5	3.88	Bal	--	0.09				hexylamine	6.5	6.6	6.7	8.0	10.4	11.3	10.1	16.1
	2930.0												6.9				12.0

* Area of metal specimen is 19.45 cm²

TABLE 3 (Cont'd.)

Experiment #	Exposure Time/hrs	Pressure ins of Hg	Gas Analysis					Inhibitor	Additive	*Weight Loss or Gain of Specimen in mgs							
			H ₂	O ₂	N ₂	N ₂ O	Q C ₂ C ₃ C ₄ C _x			1	2	3	4	5	6	7	8
CR-363	282.0	5.73	Bal	1.02	63.1			300ppm Li ₂ MoO ₄	1% 2-ethyl- hexylamine	-2.7	-2.0	-2.4	-2.0	-8.4	-6.5	-7.0	-6.2
	1143.5	8.92	Bal	0.01	0.39								-2.3				-7.0
	1504.5	3.79	Bal	--	--		21403			10.9	9.8	13.2	10.4	20.2	17.8	18.9	16.7
	2930.0												11.1				18.4
CR-364	282.0	4.67	Bal	0.06	0.99			300ppm Li ₂ MoO ₄	1% 2-ethyl- hexylamine	-0.1	-1.1	+0.9	-0.9	-8.1	-12.0	-7.2	-7.6
	1143.5	8.11	Bal	0.01	0.14								-0.3				-8.7
	1504.5	3.80	Bal	--	--					11.0	10.2	5.4	7.4	18.1	24.1	17.4	17.9
	2930.0												8.5				19.4

* Area of metal specimen is 19.45 cm²