GARRETT

AIRESEARCH MANUFACTURING COMPANY

Los Angeles, California

SUPPORTING DEVELOPMENT FOR THE PRELIMINARY DESIGN OF AN INTERMEDIATE WATER RECOVERY SYSTEM

NAS 9-8460

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FORM 2377, 8-70

CONTENTS

SECTION 1

INTRODUCTION AND SUMMARY

This report summarizes the work done in Task A, Supporting Development, under Contract NAS 9-8460 for the preliminary design of an Intermediate Water Recovery System. The efforts reported herein were conducted during the latter part of 1968 and first half of 1969. The results of this effort provide an experimental base upon which Task B of the program will proceed. Task B will provide a preliminary design of a waste water recovery system that features a minimum of vehicle interface requirements and could be used on early flight programs where recovery of urine and wash and humidity condensate water may be desirable. The concept to be utilized is one that incorporates a forced circulation--flash evaporation loop in a vapor compression--distillation cycle. The basic process was investigated at AiResearch in 1967, utilizing company IR and D funds. The work covered in this report is an extension of that effort.

The supporting development effort was planned to include the identification of system and component areas which required particular concentration of development activity. Prototype models of critical components of the system--the compressor, phase separator, heat exchanger, and controls--were fabricated and tested. The components were then assembled into a system breadboard which was operated to establish system functional performance, operational characteristics, and the quality of product water.

The basic objective of the supporting development effort was to assure system functionality and to demonstrate the developmental status and overall system operational characteristics. These objectives were met, although the results of some efforts, particularly component development, indicate that more development effort is required before a flight prototype system can be fabricated. The following paragraphs briefly summarize the developmental status of the system.

Compressor: The compressor remains a major problem area requiring additional work. The vane positive displacement compressor received major emphasis but vane material problems make it doubtful that a satisfactory vane compressor can be produced. Satisfactory vane wear characteristis were obtained only at the expense of excessive power consumption. The diaphragm compressor, also investigated, shows promise but will require concentrated effort on mechanical design features, diaphragm design and life testing.

Phase Separator: The rotary-phase separator/brine circulating pump is a feasible and attractive concept requiring only detailed development work to improve the mechanical design of bearings, seals, etc., to assure long life and minimum power. Early problems in demistor plugging were solved with a redesign. Carry-over of contaminants appears to have been controlled adequately except when excessive foaming occurred--foaming caused by entrained gases suddenly expanding to low pressure after operation at sea level pressure. This phenomenon must be investigated; however, since actual operation should not require extensive exposure of the brine to high pressures, this problem will be precluded to a great extent.

Brine Heater/Condenser: The wick condensing/porous-plate gas trap side of this unit performed satisfactorily. Evidence was obtained that the brine-side heat transfer surface was controlling, and that laminar flow during high-brine concentrations affected the overall heat transfer of the unit. On two occasions, the brine-side tube did plug; due, it is thought, to this transition into laminar flow. Investigation of improved brine-side configurations will be required.

System Controls: The nucleonic principal for waste feed and density sensing brine-dump control was found to be an eminently satisfactory method of providing these critical control functions. Minor problems in solenoid valving were encountered but were easily corrected. The overall control scheme is considered to be essentially developed, except for detail optimization to the final design.

Product Water Quality Monitoring: Only simple and basic continuous monitoring schemes were utilized during testing, supplemented by detailed analysis after collection. Water conductivity was shown to be a sensitive and reliable indication of overall system performance, and can be considered a prime candidate for basic potability monitoring.

Overall System: Overall system developmental status is a function of the status of the subsystem areas noted above. The basic system concept is feasible and practical. Major development goals will be the improvement of thermal balance through improved insulation and reduction of power.

Section 2 through 6 of this report describe the efforts undertaken in major subsystem areas and the system test activity.

SECTION 2

COMPRESSOR DEVELOPMENT

INTRODUCTION

The vapor compressor problem statement was defined as follows at the initiation of the Phase A effort:

1. Performance: 1 lb/hr saturated steam at 1-psia to 1.25-psia inlet pressure (100° to 120°F evaporating temperature) at approximately 2/1 pressure ratio.
2. Mechanical Features: Clean, oil-free compression with low leakage seals for operation at pressures less than ambient.
3. Maximum mechanical and compression efficiency.
4. Maximum compactness and lightest possible weight.
5. Capability for short-term and low-cost development to a status suitable for operation on the breadboard system.

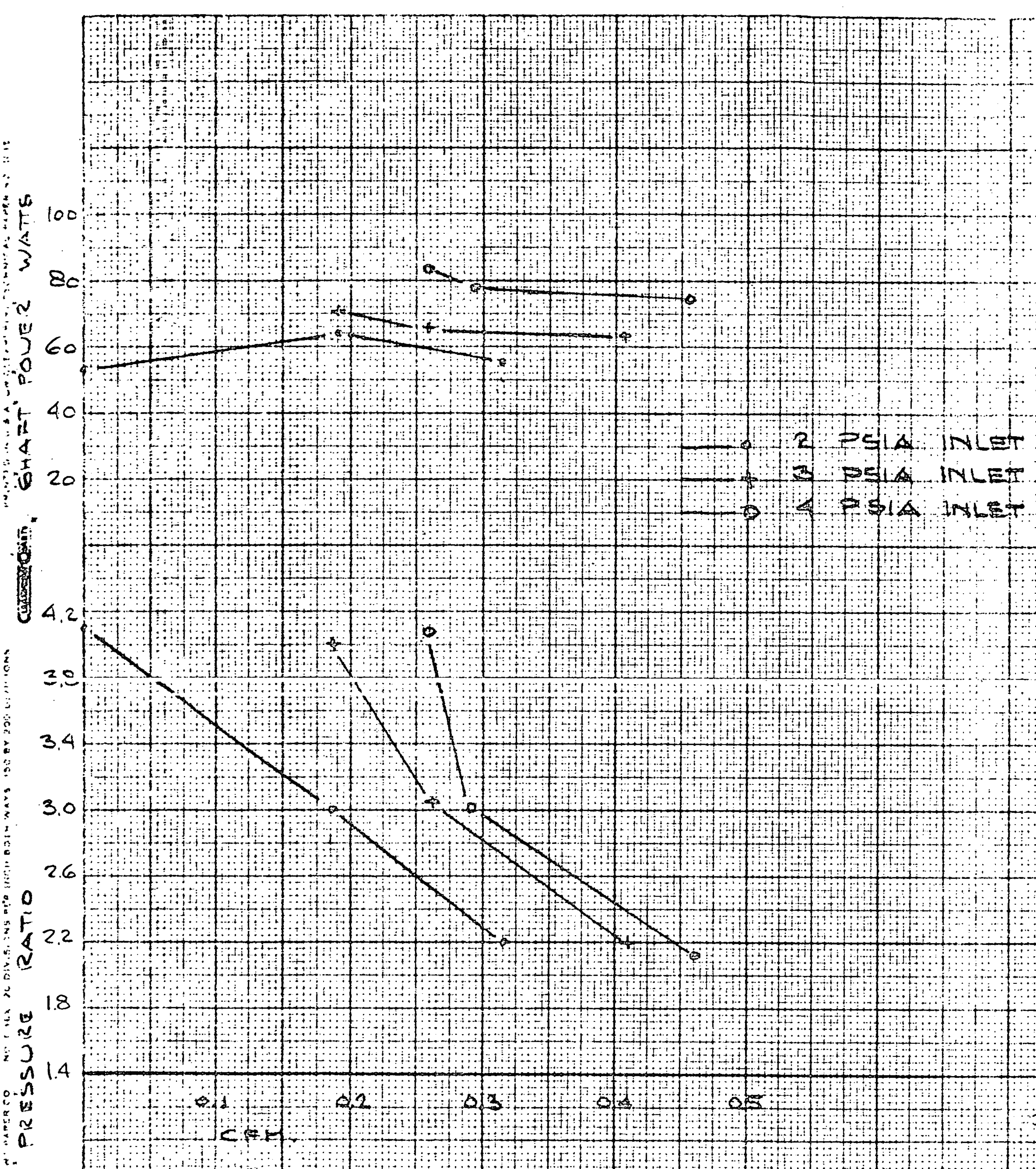
Based on preliminary investigation, two types of machines were considered as potentially meeting these requirements: a diaphragm-type positive displacement machine and a vane-rotary type.

Initial Investigation

To obtain basic performance data on these two classes of compressors, commercial models of each were obtained and tested. Findings, in summary, were as follows:

Diaphragm Compressor

The Dia laboratory-type diaphragm compressor was found to have extremely low volumetric and overall compression efficiency. Figure 2-1 shows measured performance of the unit. It was impossible to obtain data at inlet pressures below 2-psia; volumetric efficiency apparently drops with inlet pressure to such an extent that flow at pressures below 2-psia was essentially zero.



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UNIT NO.

PERFORMANCE OF DIA TYPE 45 MOD. 08-423-71 DIAPHRAGM COMPRESSOR.

Figure 2-1

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Page 2-2

GARRETT AIRESEARCH MANUFACTURING COMPANY

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Analysis of the power draw of this unit was difficult due to the effect of pulsating torque and the reversed pressure differential across the diaphragms, caused by an ambient pressure crankcase and sub-atmospheric operation. Special techniques were developed utilizing photographic recording of oscilloscope traces of a torque transducer to estimate shaft power requirements. Review of this data showed that overall compression efficiency was quite low--less than 10 percent for all runs and as low as 2 to 3 percent at 2-psia inlet pressures. Attempts at isolating losses to determine reasons for this low efficiency were only partly successful. Table 2-1 summarizes the distribution estimated.

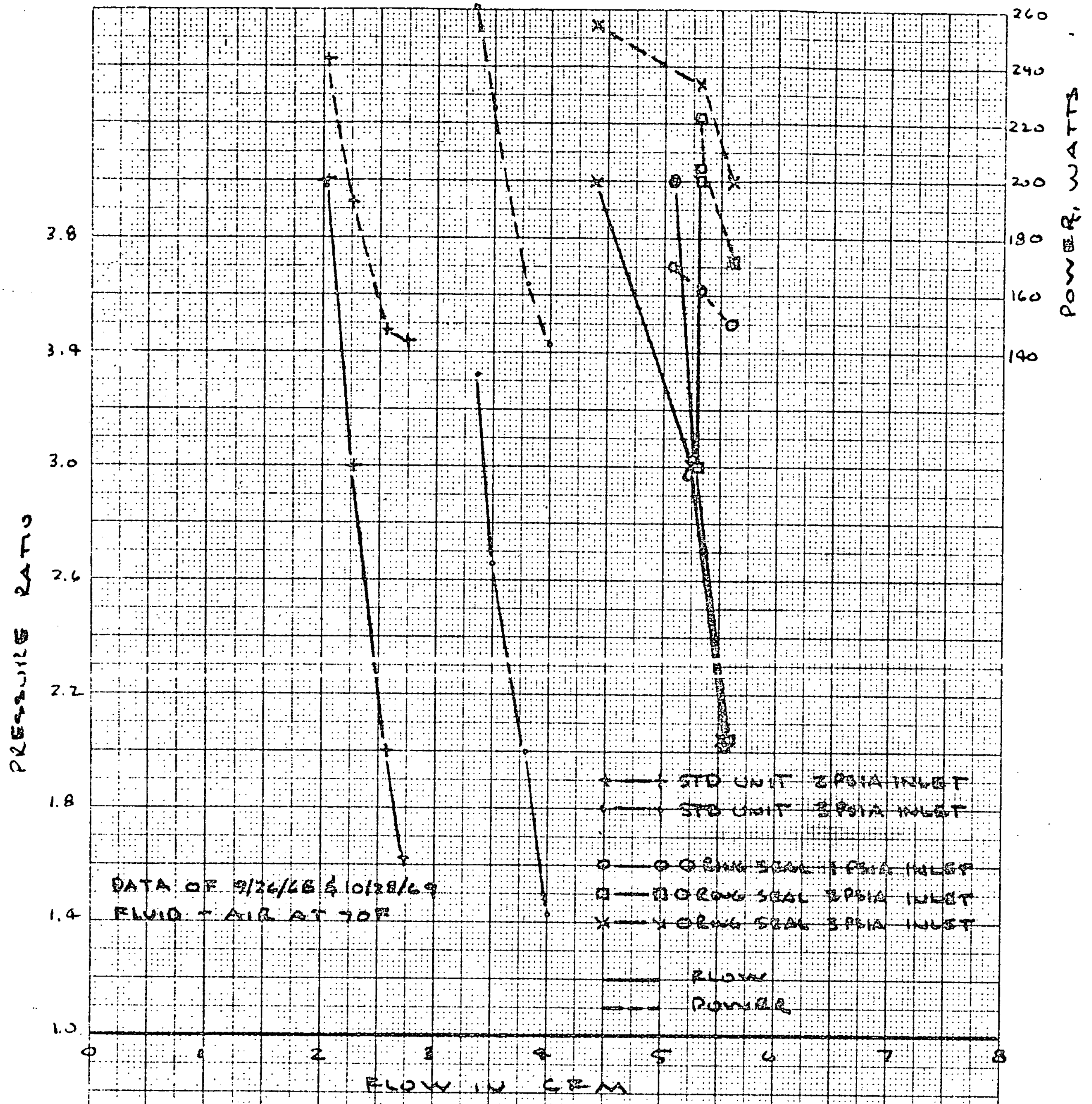
TABLE 2-1

DISTRIBUTION OF POWER FOR DIA, TYPE G-5, COMPRESSOR

Flow	0.31 lb/hr
Inlet Pressure	1.98 psia
Outlet Pressure	3.95 psia
Ideal Compression	1.5 watts
Actual Compression	8 watts
Bearing Loss	9 watts
Diaphragm Loss	28 watts
Reverse ΔP Loss	12 watts
Total Power	57 watts
Overall Efficiency	2.6 percent

Vane Compressor

A Gast commercial dry vacuum pump was tested to determine its performance as a compressor. Initial tests showed a large drop in flow as inlet pressure decreased, indicating either volumetric efficiency drop-off or leakage into the compressor, since flow measurements were made at the inlet. As with the diaphragm compressor, flow at inlet pressures below 2-psia was practically zero. Simultaneous measurement of inlet and outlet flow confirmed that shaft leakage was appreciable. The compressor was reworked with a set of simple '0' ring seals on the shaft. Measured flow performance was markedly improved, although power remained high due to the friction loss of the '0' ring seals. Data before and after application of the '0' ring seals is shown on Figure 2-2.



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PERFORMANCE OF GAST MODEL 0740 S/N 38-117578 VANE COMPRESSOR AT 1750 RPM

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Figure 2-2

Prototype Compressors

Diaphragm Compressor

Figure 2-3 depicts the twin-diaphragm eccentric-drive compressor fabricated as a prototype. The unit was designed to produce a flow of 4.5-cfm at 1.25-psia inlet pressure (1 lb/hr) based on an assumed volumetric efficiency of 83 percent. Each compression chamber was 5.0 in. in diameter by 0.38 in. in stroke. Design speed was 700 rpm.

Several problems were encountered during development testing of the compressor. During initial runs it was noted that the unit required much more power than anticipated and that the obtained volumetric efficiency was extremely low. Investigation of the low flow led to rework of the unit to increase stroke and to the fabrication of new diaphragms. Also, Fluoraloy bushing, used as a main bearing on the eccentric shaft, was replaced with an oil-filled bronze bushing. The resulting improvement was significant; Figure 2-4 shows performance of the unit. As noted, new design flow was attained at roughly twice the design speed, showing that actual volumetric efficiency was 42 percent.

Evaluation of the diaphragm compressor in the breadboard system was hampered by the problems noted above; a short run was conducted and difficulties were encountered with urine carry-over. This was assumed to have been caused by the effect of pulsating flow on separation performance in the separator; however, subsequent investigation shows that blockage of a demistor screen in the separator, causing localized high-velocity flow in the separator, was probably responsible.

Vane Compressor

The Gast vane compressor was extensively reworked by the addition of carbon-face-type shaft seals, and was tested with various vane/housing-finish combinations in an extensive development effort. Figure 2-5 summarizes the steps taken and the performance obtained. The final configuration is shown on Figure 2-6. Two basic problems were encountered with the vane compressor: seal leakage and vane wear and performance. From pressure decay tests, seal leakage (both seals) is estimated to have varied from as low as 1.5 cu ft/hr to as great as 5.6 cu ft/hr at inlet pressure conditions. Exact cause of this variation has not been definitely pinned down. Variations in seal pressure loading did not vary the leakage appreciably, although it did increase power loss. The seals generally used G39-grade carbon running against cast iron. Plating of the cast iron was varied, as it was for the housing. In the final configuration, "Tuftride" surface finish was used due to its improved wear and friction characteristics. The probable cause of this variable seal performance was surface finish and/or flatness of the static face.

DIAPHRAGM COMPRESSOR.

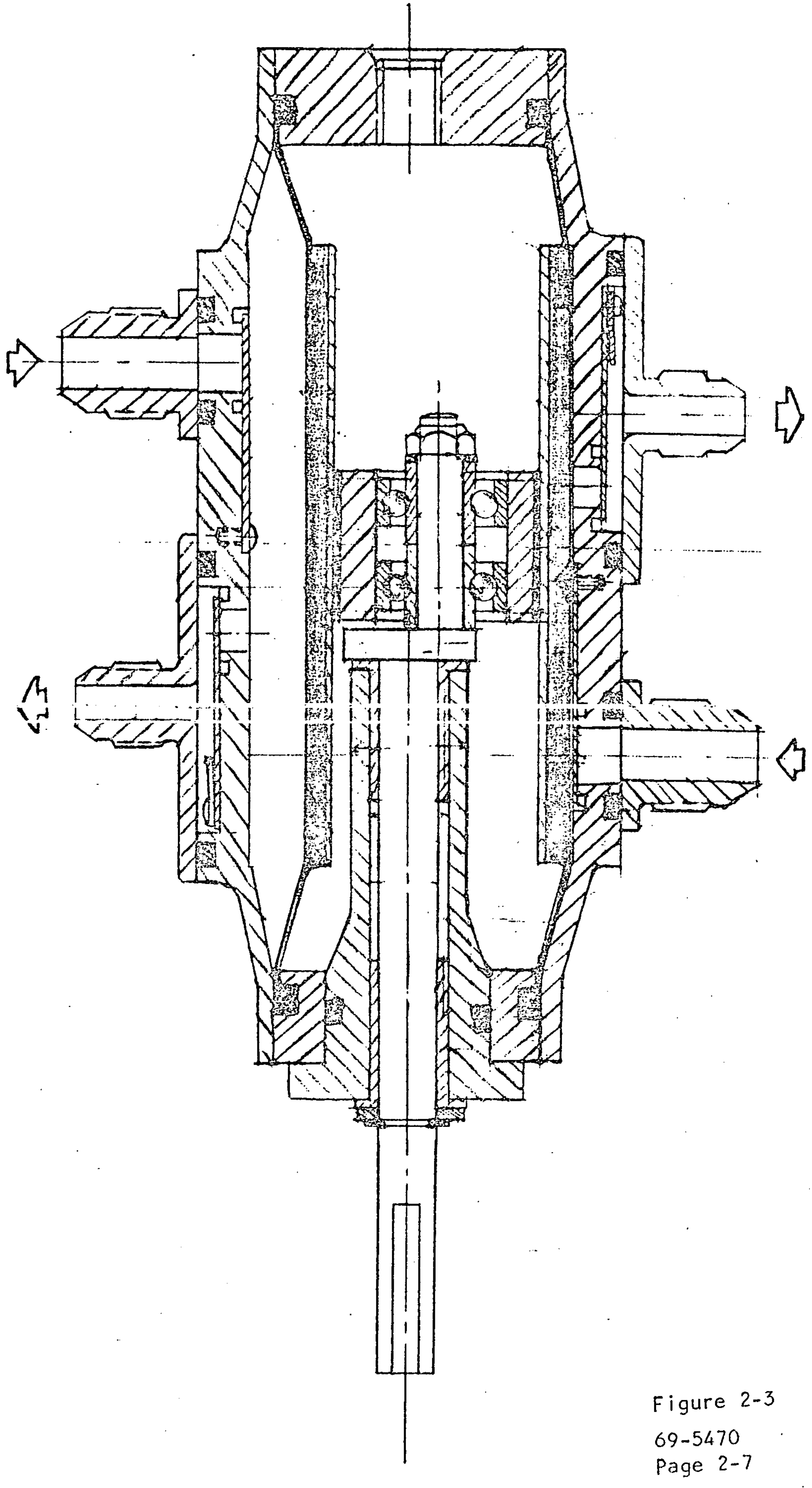

Figure 2-3

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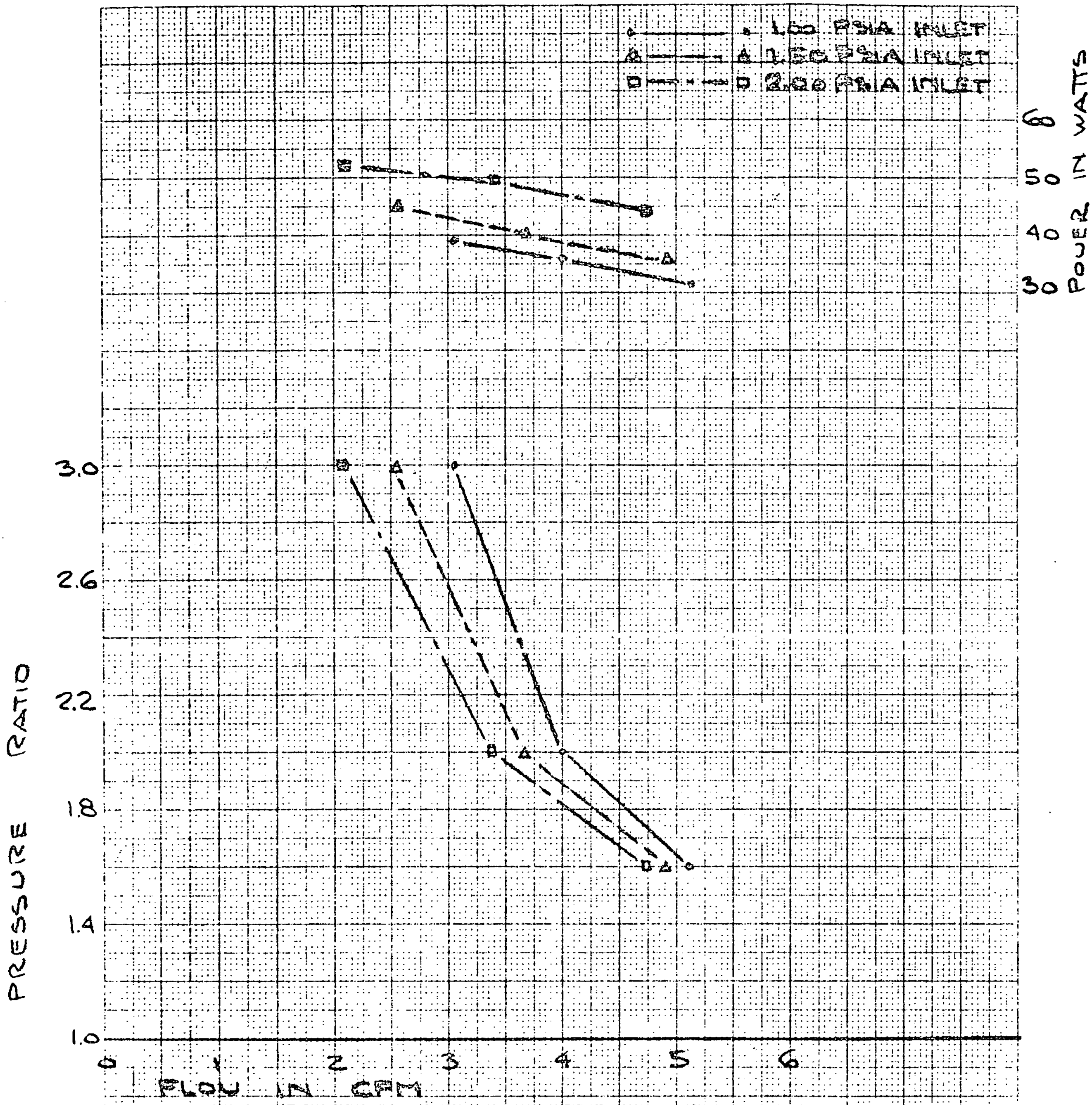

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PERFORMANCE DIAPHRAM COMPRESSOR @ 1400 RPM AND 1.00 PSIA INLET PRESSURE

Figure 2-4

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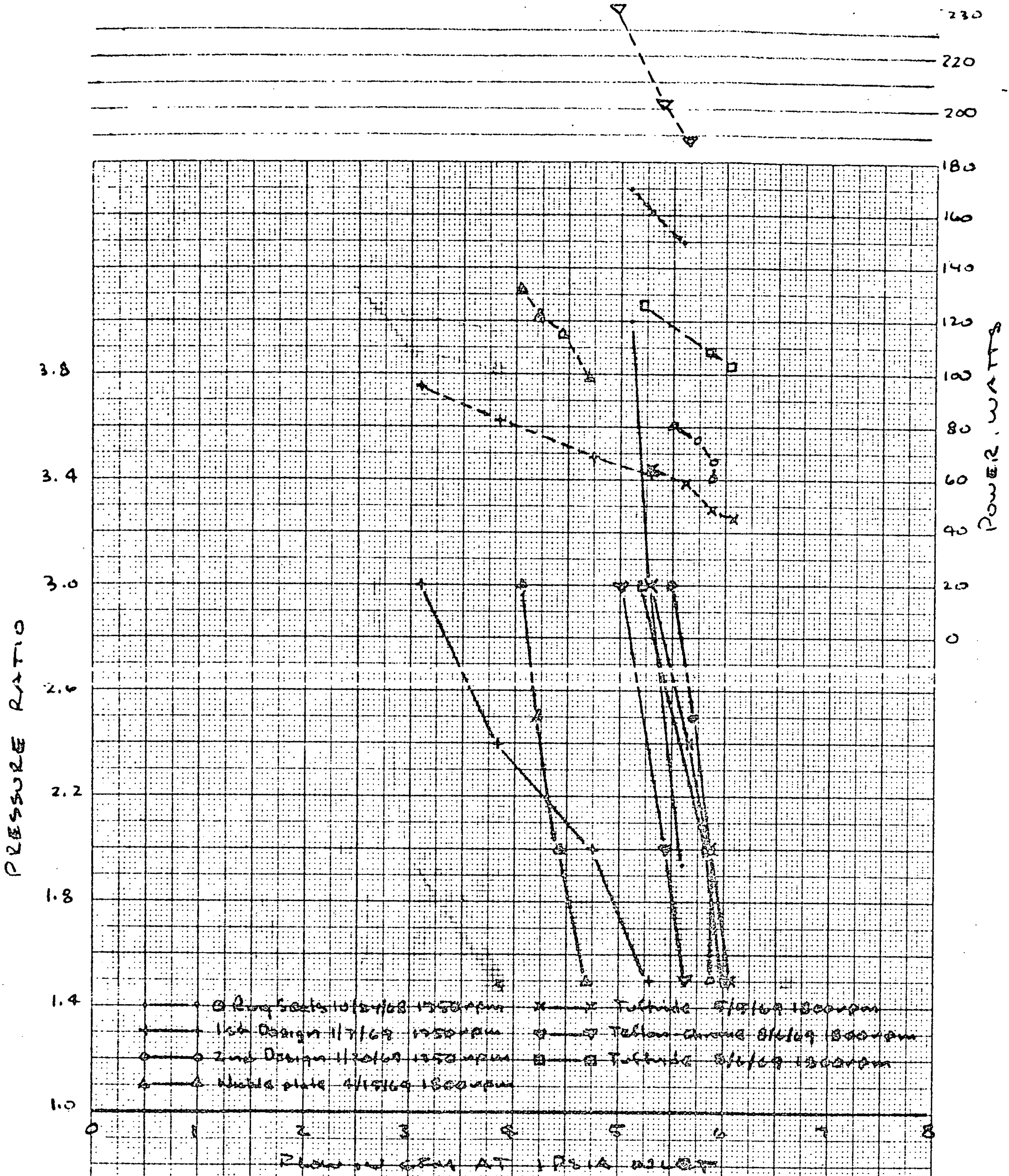

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PROGRESS OF VANE COMPRESSOR PERFORMANCE

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Figure 2-5

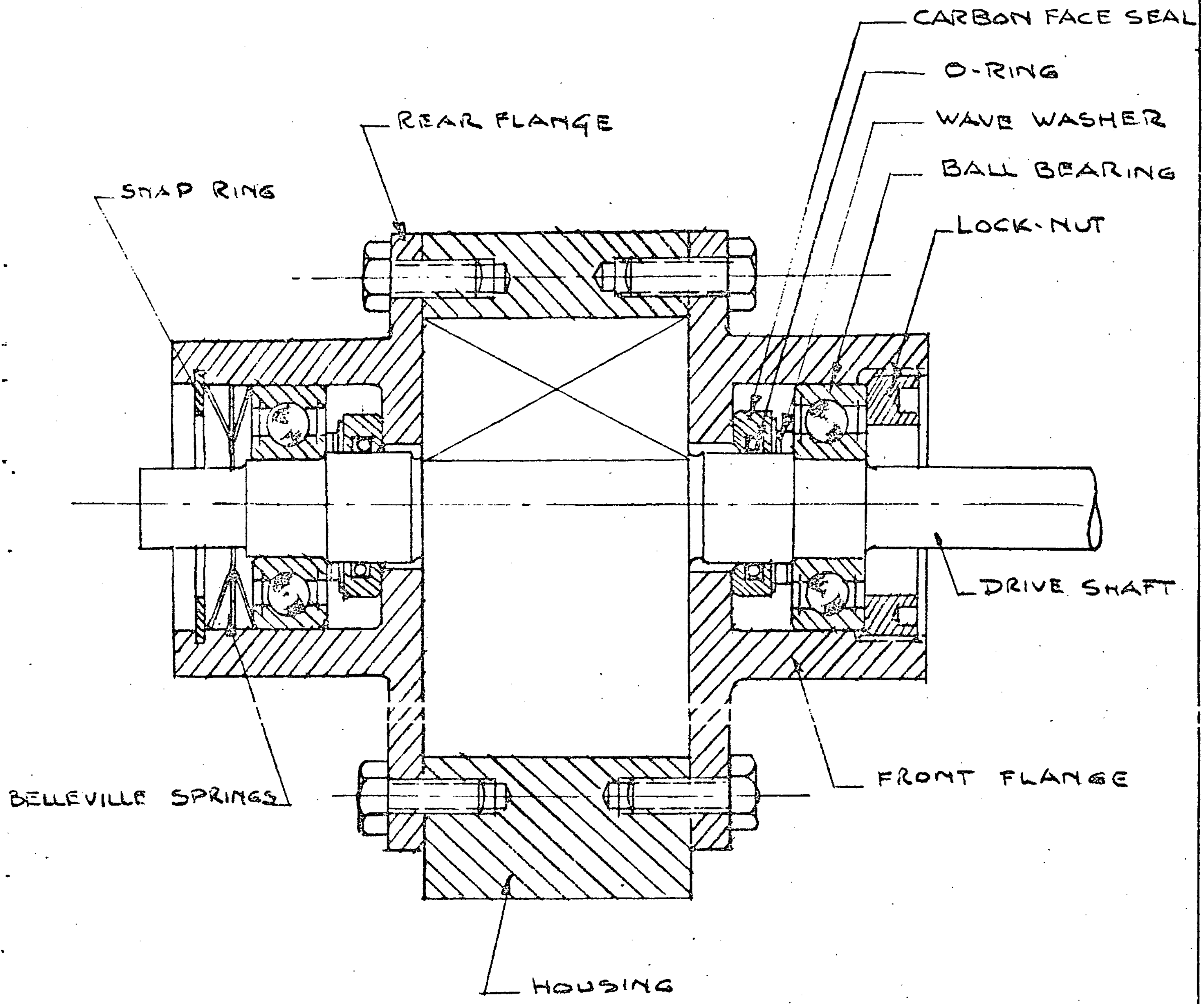

Figure 2-6

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Title

— VANE COMPRESSOR —

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Vane material selection and matching housing surface treatment became a fundemental and overriding problem. Initially, the standard Gast carbon-vane/plain cast iron combination was used and produced good results, although definite vane wear was noted. Since corrosion could be expected from the water vapor environment, an 0.0002-in. flash copper plate was applied to the housing. Excessive wear of this plating was observed and a search was initiated for an improved plating. A 0.0002-in. soft chrome was tested; its corrosion resistance was considered marginal due to porosity. A 0.001-in. electroless nickle coating was then tried; it gave excellent corrosion resistance, but extremely high vane wear caused ultimate drastic failure of the carbon vanes during the first extensive operation of the complete system. The Gast Company recommended the Tuftride process, which is essentially a flame hardening treatment. This finish appeared to have satisfactory corrosion resistance and excellent vane wear characteristics, and was ultimately utilized for the final system test.

Three vane materials were tried throughout the program: carbon impregnated Teflon or "Fluoraloy", "Vespel," a micarata-like hard plastic, and the standard Gast carbon. The results are summarized in the following paragraphs:

1. Fluoraloy Vanes: The Fluoraloy vanes were operated with an early, chrome-plated, housing. This combination gave consistent service, wear was minimal, but power quite high due to vane friction. This high friction resulted in heat generation in the vanes which, coupled with the low heat conduction and high coefficient of expansion, resulted in substantial vane dimensional instability. This was evidenced by considerable variation in performance. Typically, good flow performance was attained with closely fitted blades, but high power resulted due to vane friction, If the vanes were fitted with a generous end-gap vane, power losses were considerably reduced but flow suffered. The data for this configuration, shown on Figure 2-5, was the best compromise attained for this unit; flow was satisfactory but power was high. The unit was operated for a number of hours both in the test system and on the bench, and consistently performed as shown on Figure 2-5.

2. Vespel Vanes: The Vespel vane was totally unsatisfactory; power was so high that full compressor speed could not be attained and flow was a fraction of normal.

3. Carbon Vane: The carbon vanes always evidenced the best power consumption, but wear of the vanes, particularly at the centrifugally loaded blade tip, was a consistent problem. The early carbon-electroless nickle combination resulted in high wear, causing the low flow shown on Figure 2-6 and eventual failure, as noted above. The Tuftride housing finish reduced this wear considerably; initial operation (5/5/69) was the best vane compressor performance measured. In operation in the system, the small amount of wear produced carbon powder, which combined with water droplets in the gas stream to form a sticky paste. The paste eventually built up on the vanes to cause a random sticking of the vane in the rotor slot. This sticking was evidenced by a periodic loud noise, caused by the vanes suddenly being freed by centrifugal force and slamming against the housing. This noisy operation was noted late in the system test program. At the end of this test, one of the vanes was found to have been fractured in three pieces; compressor flow and power had obviously suffered. Build-up of the carbon material had also occurred on the inner face of the housing, causing a rough, high-friction, surface which had affected operation. At the end of the system test program when the compressor was opened, the broken vane and carbon build-up had reduced clearances to such an extent that, upon reassembly, the rotor could not be turned. Therefore, it was necessary to clean a major portion of this accumulation from the housing before post-test calibration of the compressor could be obtained. The 8/6/69 data on Figure 2-5 shows the results of this calibration: power has increased over that measured on 5/5/69 due to a greater seal load and higher vane losses caused by some of the build-up.

Development Status of the Compressor

Results of the development and systems testing of the two compressor types show that the vane unit has a fundemental weakness; to obtain satisfactory performance, a housing finish/vane combination must be found with extremely low friction and, at the same time, low wear. The carbon vane does have a low friction characteristic but its wear characteristics cause problems. Unless a better combination can be found, the Fluoraloy vane appears to be the only acceptable one, and its power is excessive. In comparison, the diaphragm unit, while still requiring mechanical development and diaphragm life investigation, does offer reasonable performance. Table 2-2 summarizes the performance of these two types as they now stand. Of interest is the obvious fact that mechanical and friction losses are a major contributor in the performance of each machine.

Further analysis of other compressor types, to provide a valid comparison of the performance obtained with the vane and diaphragm types, should be conducted.

TABLE 2-2

COMPRESSOR PERFORMANCE SUMMARY

Compressor Type	Diaphragm[1]	Teflon-Vane[2]	Carbon-Vane[1] (Before Test)	Carbon-Vane[2] (After Test)
Working Fluid	Air	Air	Air	Air
Inlet Pressure, psia	1.0	1.0	1.0	1.0
Discharge Pressure, psia	2.0	2.0	2.0	2.0
Flow, cfm	4.0	5.4	5.8	5.8
Flow, lb/hr	1.2	1.65	1.77	1.77
Adiabatic Power, watts	10	13.5	14.5	14.5
Adiabatic Efficiency, percent	75	29	76	69
Actual Compression Power, watts	13	47	19	21
Compressor Speed, rpm	1400	1800	1800	1800
Vane Friction Losses, watts	---	86	10	29.5
Diaphragm Losses, watts	15	---	---	---
Bearing Losses, watts	8	24	15	24
Seal Losses, watts	---	45	5	34.5
Total Shaft Power, watts	36	202	49	109
Shaft Power, watts/lb flow	30	122	36	61.5

[1] Test performance, estimated distribution of losses

[2] Test performance, test data on losses

SECTION 3

SEPARATOR DEVELOPMENT

INTRODUCTION

Initial system design studies established the desirability of combining the brine circulating pump with the rotating, artificial, g-field portion of the phase separator. To accomplish this, two fundamental approaches were considered: a rotating paddle type which is essentially a centrifugal pump; and a rotating bowl type with a pitot-type pump. Analysis of the two devices predicted that the paddle design would require greater power because of the energy lost in fluid drag on the large internal wetted surface. The pitot type, conversely, would be more complicated to fabricate since all internal fluid connections must be confined to a small area at the top of the rotating drum. The preliminary configurations of each type is shown in Figures 3-1 and 3-2, which depict test models built to confirm analytical predictions.

Initial Investigation

Pumping Performance

Testing of the two model designs confirmed that the paddle wheel design would require higher power. Baseline performance for the brine circulating pump was set at 160 lb/hr flow rate at 8.7 psi differential pressure. For this pumping requirement, the paddle wheel separator was found to require over 100 watts of shaft power. This prediction was based on the model test and correlating analysis which showed that power was proportional to fluid drag on the inside wetted surface of the housing. The model test program for the pitot separator was also analytically correlated to full-scale performance. Pumping head was found to be essentially flat due to the relatively small pressure drop in the pitot itself and, thus, nearly equal to kinetic head at the pitot tip. Power requirement was found to be primarily a function of pitot drag in the fluid. The expressions developed for head and power were as follows:

Head $$Hp = \frac{(1-K)^2 \rho (R_p)^2 \omega^2}{2g} \qquad \text{lb/ft}^2$$

Power $$P = \frac{C_D D \rho \omega^2}{8g} \left(R_p^4 - R_L^4\right), \qquad \text{ft lb/sec}$$

where K = slip coefficient, $0 < K < 1$

R_p = pitot radius from centerline of rotation, ft

R_L = fluid level in drum from centerline of rotation, ft

($R_p - R_L$ = depth of pitot immersion)

C_D = pitot drag coefficient

D = pitot diameter, ft

ω = drum rotational speed, radians/sec

ρ = fluid density lb/ft^3

To check these expressions, a full-scale model of the proposed pitot separator was fabricated and tested. Figure 3-3 compares test results with predicted results.

Separation Performance

Experimental and analytical investigation of the separator as a device to provide and maintain control of the boiling urine/water vapor interface consisted of visual observation of fluid behavior in the rotating g-field of the model units, as well as analytical prediction of droplet performance after leaving the fluid surface. In general, it was found that separator speeds necessary for pumping provided more than adequate fluid control; as little as 1000 rpm was required to keep the fluid in a drum unit against the side walls of the drum with the axis of the unit horizontal.

Expressions for the behavior of small fluid droplets entrained in the vapor stream after leaving the fluid surface were developed and utilized to predict the ability of the separator to prevent these potential contaminants from leaving the separator. Figure 3-4 shows the results of one such analysis; these curves plot the distance traveled by droplets of 2-μ diameter and 20-μ diameter leaving the fluid surface at a given initial velocity normal to the fluid surface. At the distance shown, the droplet will be decelerated to zero and begin to fall back to the surface under the influence of the centrifugal g-field provided by the rotational velocity ω. From this and other analyses, a 2-in. inner-surface radius and 4-in. long disengagement area were established as being desirable to the separator designed for a speed of 1600 to 1800 rpm. (ω = 167 to 188 rad/sec).

Prototype Separator

Utilizing the data and analysis outlined above, the prototype unit shown on Figure 3-5 was fabricated. Pumping performance, measured after approximately 250 hr of operation during system test, is shown on Figure 3-6. This performance was correlated with the expressions presented earlier in this section; the results are shown on Table 3-1.

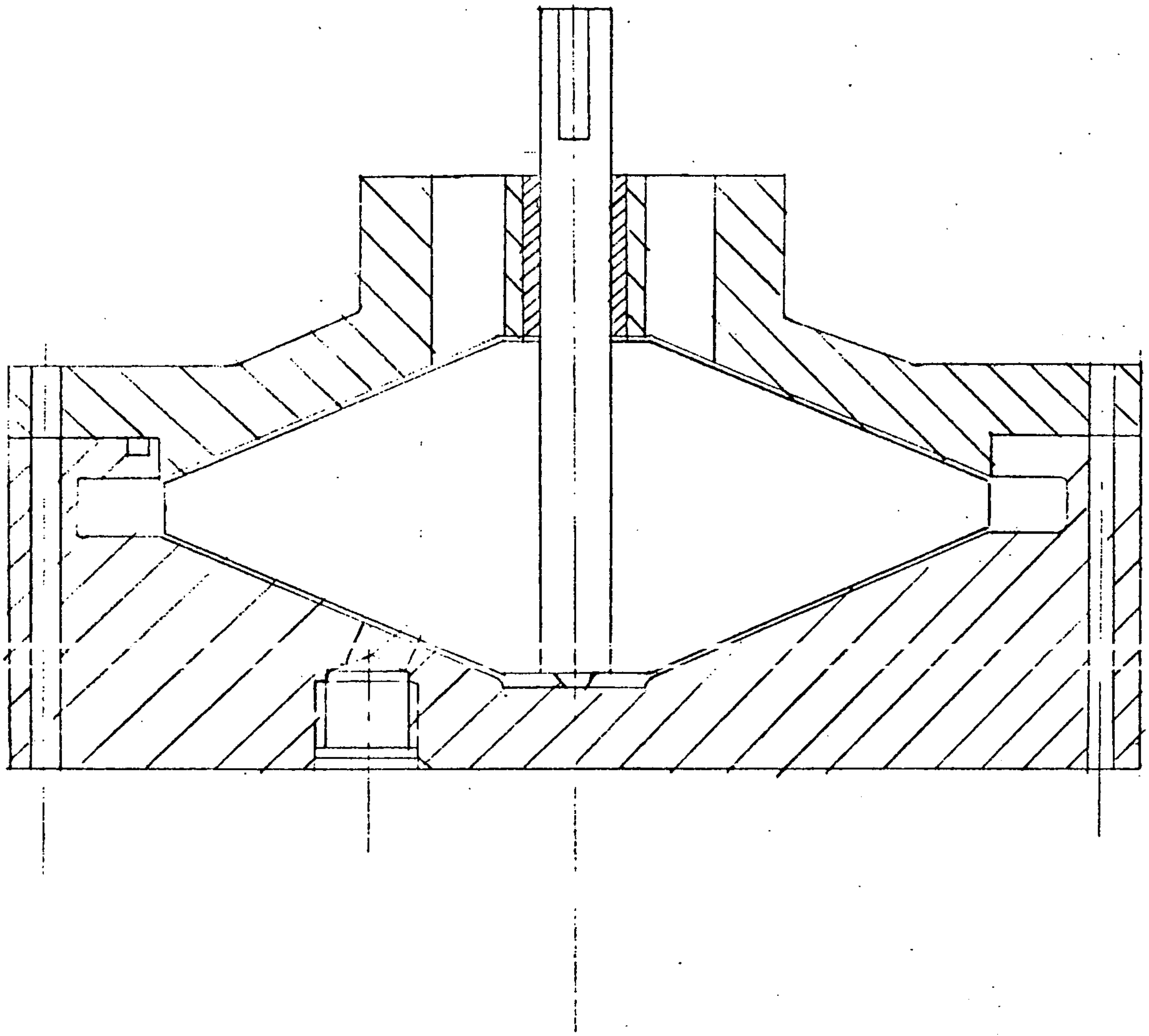

Figure 3-1

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Title
— VAPOR SEPARATOR —

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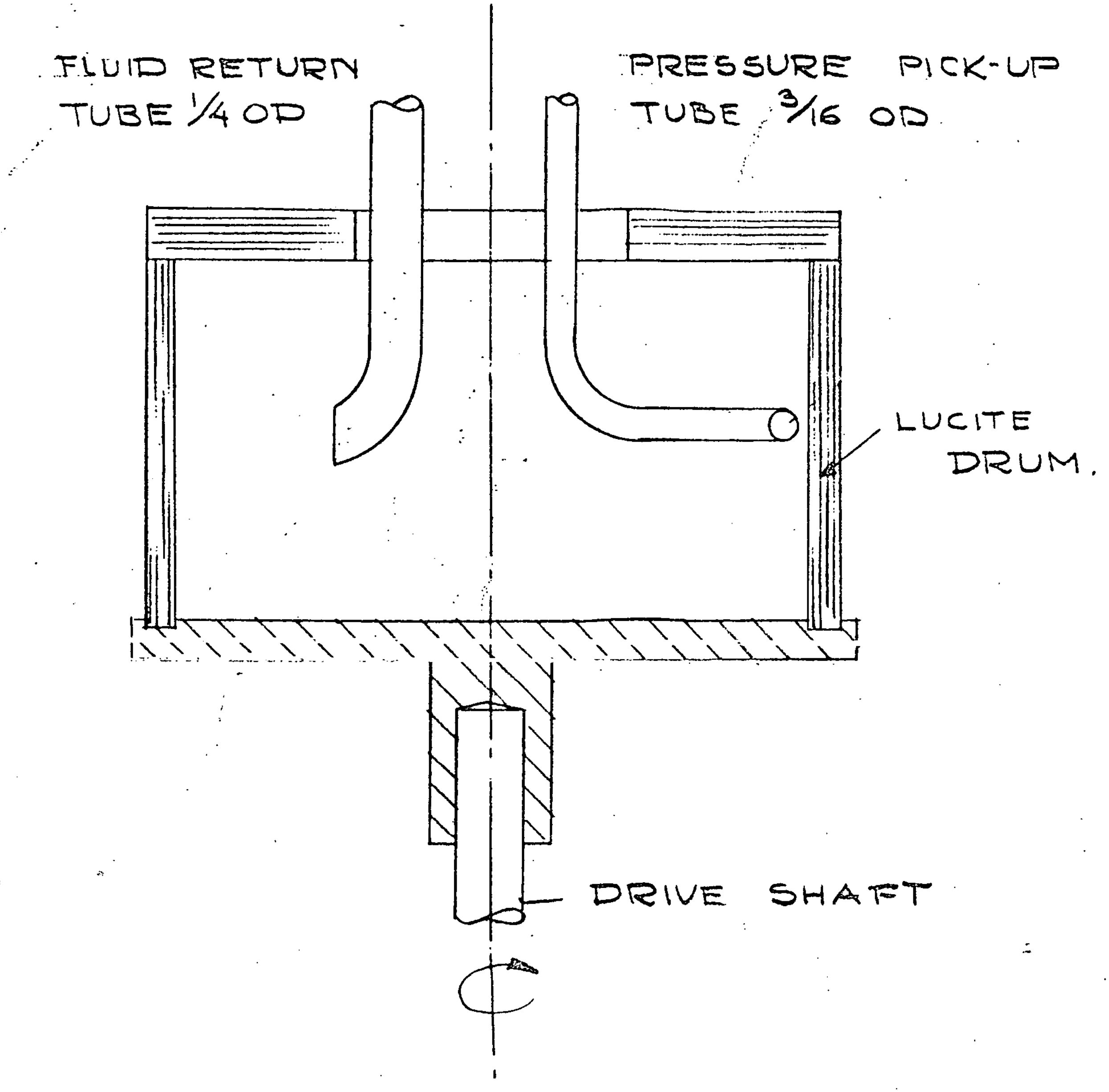

Figure 3-2

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Title

CENTRIFUGE SEPARATOR

APP.

APP. 10-7-68

CH.

DR.

PA-95442

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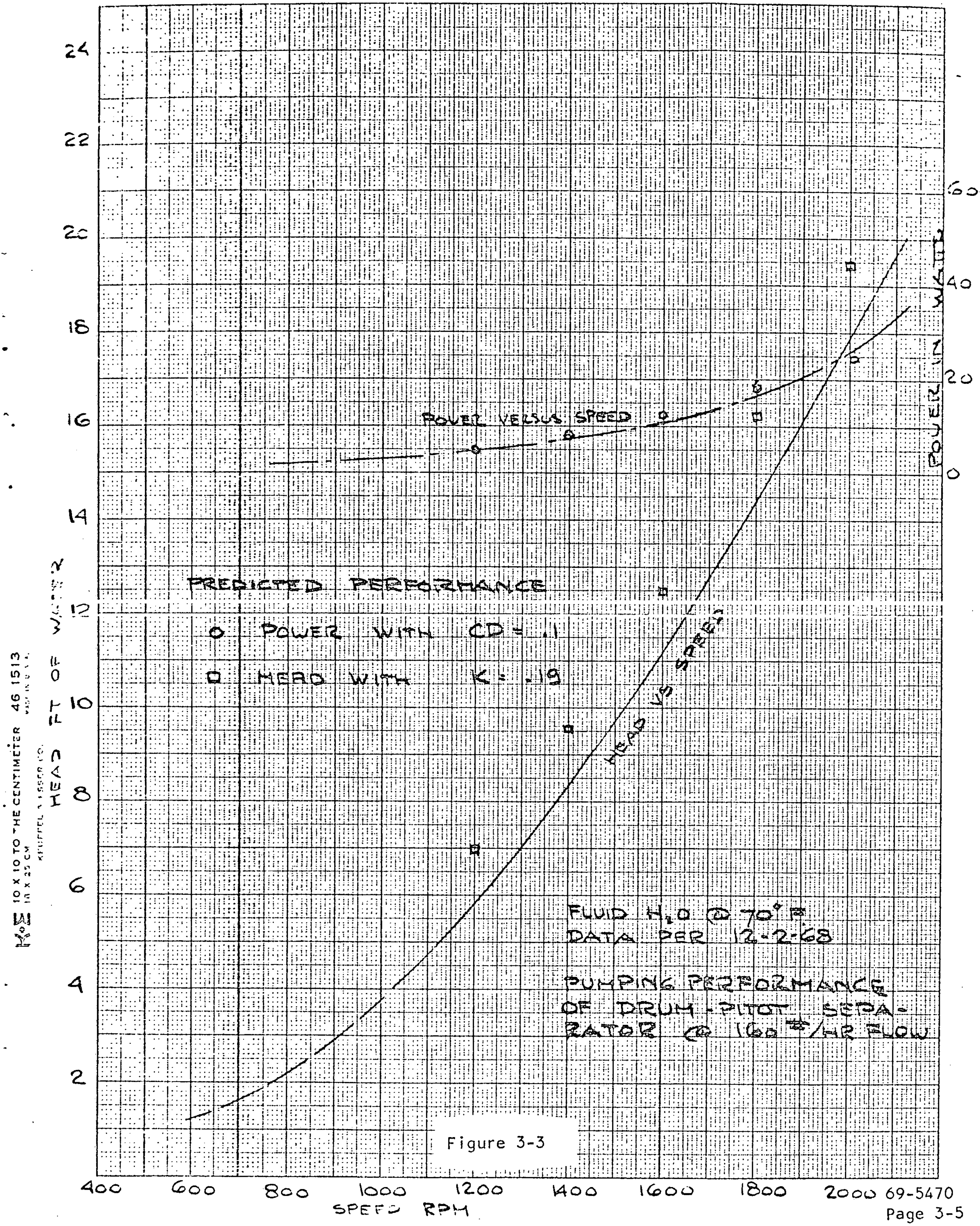
HEAD FT OF WATER
24
22
20
18
16
14
12
10
8
6
4
2
400
600
800
1000
1200
1400
1600
1800
2000
SPEED RPM
POWER IN WATTS
60
40
20
0
POWER VERSUS SPEED
HEAD VS SPEED
PREDICTED PERFORMANCE
○ POWER WITH CD = .1
□ HEAD WITH K = .19
FLUID H2O @ 70° F.
DATA PER 12-2-68
PUMPING PERFORMANCE
OF DRUM-PITOT SEPARATOR @ 160 #/HR FLOW
10 X 10 TO THE CENTIMETER 46 1513
10 X 25 CM
KEUFFEL & ESSER CO.
MADE IN U.S.A.

Figure 3-3

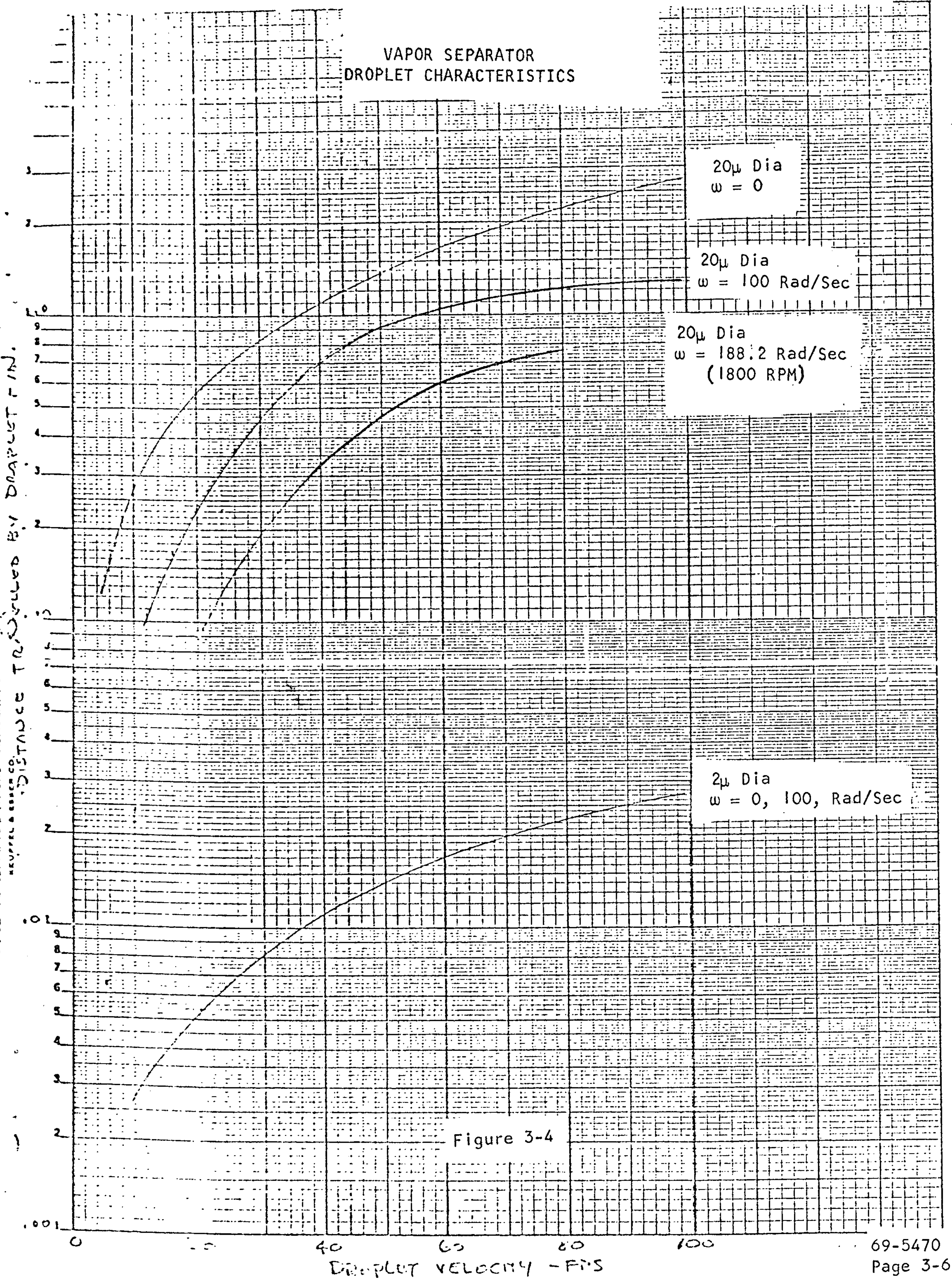
VAPOR SEPARATOR
DROPLET CHARACTERISTICS
20μ Dia
ω = 0
20μ Dia
ω = 100 Rad/Sec
20μ Dia
ω = 188.2 Rad/Sec
(1800 RPM)
2μ Dia
ω = 0, 100, Rad/Sec
DISTANCE TRAVELLED BY DROPLET ~ IN.
DROPLET VELOCITY - FPS
0
20
40
60
80
100
.001
.01
.1
1.0
KEUFFEL & ESSER CO.

Figure 3-4

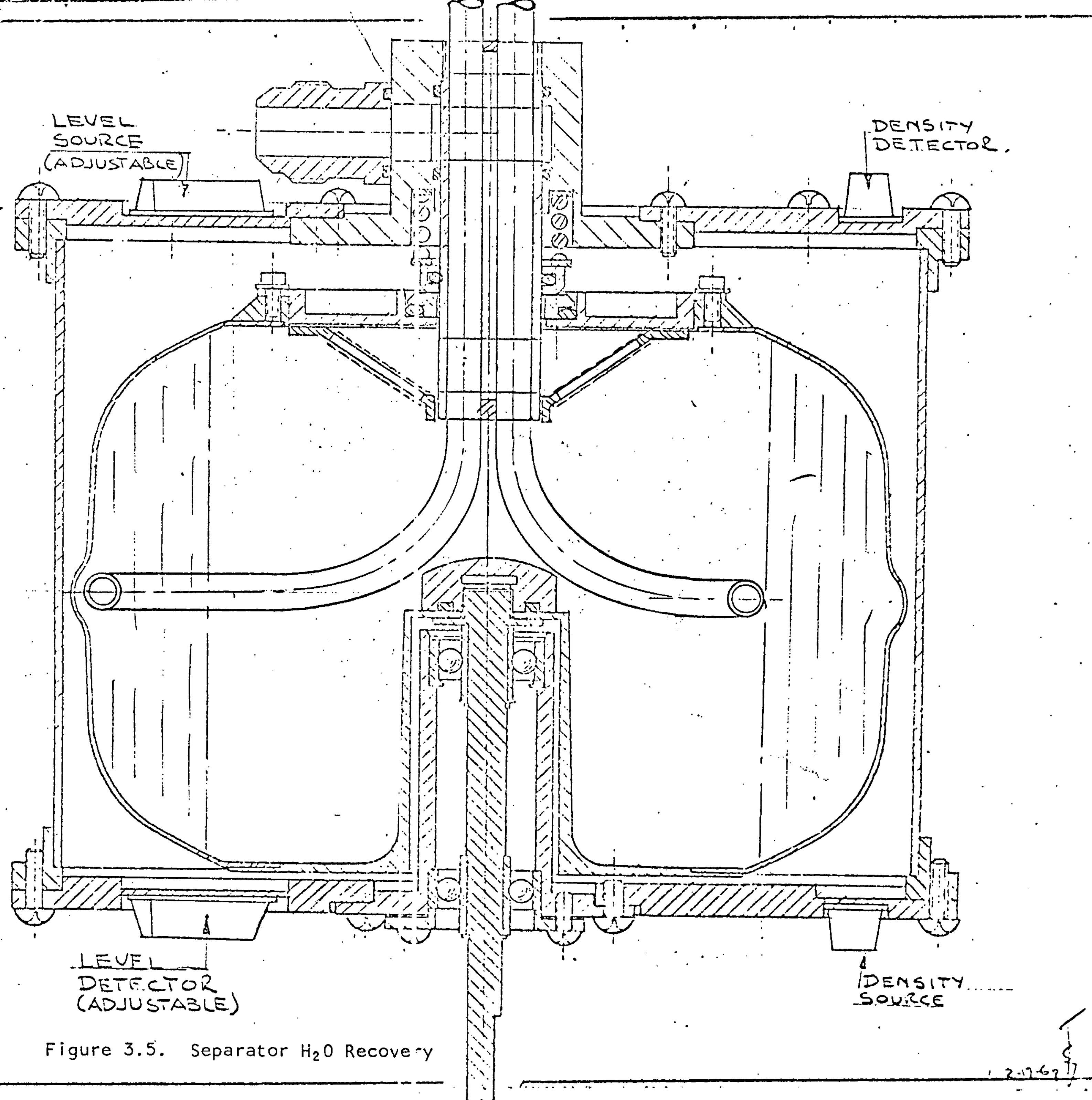

Figure 3.5. Separator H_2O Recovery

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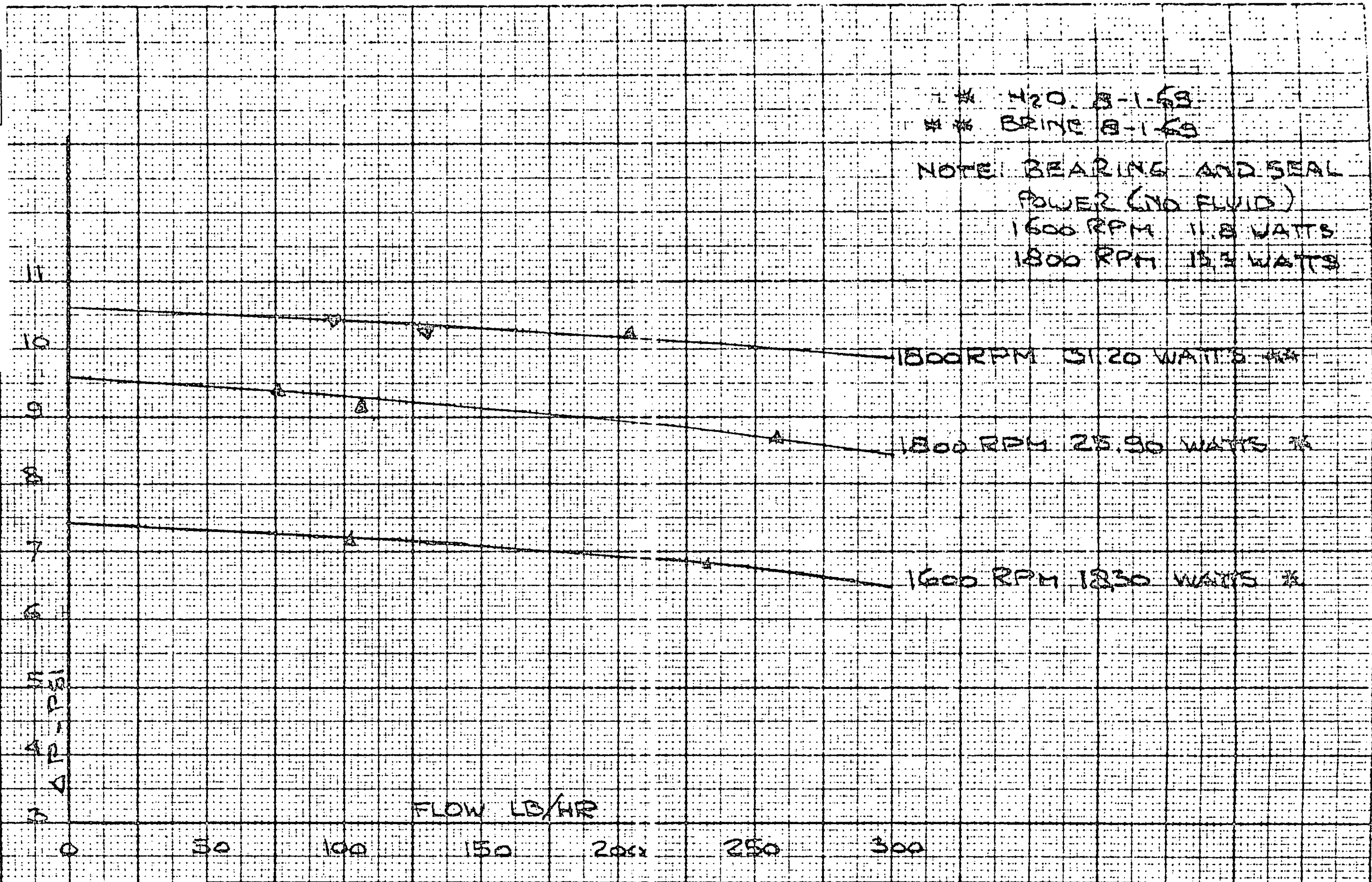

CALCULATED BY	PHASE SEPARATOR CALIBRATION (ΔP VS. LB/HR)	Figure 3-6
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TABLE 3-1

CORRELATION OF SEPARATOR PERFORMANCE

Fluid	Speed	Slip Factor, K	Coefficient C_D
H_2O	1600	0.10 to 0.13	0.094
H_2O	1800	0.11 to 0.15	0.12
44 - Percent Brine	1600	0.11 to 0.14	0.145
44 - Percent Brine	1800	0.15 to 0.17	0.15

Development Status of the Separator

Mechanically and hydraulically, the separator appears to be an excellent design. Refinements in bearing and seal arrangement may be desirable to improve life and reduce power consumption, but basically the overall configuration requires little change. Detailed evaluation of entrainment does appear desirable. Test experience indicates that contaminant carry-over does occur occasionally; particularly foam carry-over after long periods of operation at sea level pressure. Foaming appears to be the result of extensive aeration of the brine and resulting frothing when the pressure in the separator is suddenly decreased from 14.7 to 1-psia. This situation should not be typical of normal operation, but an ability to tolerate some foaming appears to be desirable. An early screen-type demistor plugged completely, indicating that foaming, or possible some entrainment, had reached the demistor area and then remained trapped on the screen surface where it was dried to a solid. A revised design utilizes wire spokes, eliminating the fine mesh which retains contaminants. In operation, this design did not plug, although some residue was observed adhering to the spokes and surrounding structure.

No evidence was seen of excessive solids accumulation in the drum after the system test program. A minor amount of residue remained in crevices in the bowl; but this can be considered negligible, indicating that the solids tend to remain in suspension in the brine and do not have a tendency to settle in the separator.

SECTION 4

BRINE HEATER-CONDENSER DEVELOPMENT

Heat Exchanger Design

Preliminary analysis established the basic design requirements of the brine heater/condenser as follows:

Brine Side:	Flow	157 lb/hr
	Concentration	50 percent solids
	Inlet Temperature	120°F
	Minimum Velocity	2 - 3 ft/sec
Steam Side:	Flow	1 lb/hr
	Inlet Temperature	445°F
	Pressure	2.5 psia
	Saturation Temperature	135°F

The heat exchanger unit, shown on Figure 4-1, was designed and fabricated to meet these requirements. The brine tubing assembly consisted of 13.5 ft of 7/32-in.-O.D. (0.219 in.), 0.016-in.-wall stainless tubing in a serpentine coil. At the design point flow of 157 lb/hr, the brine velocity was 3 ft/sec--adequate to prevent deposits of brine solids. Total heat transfer area, based on steam-side surface, is 0.77 sq ft. The estimated steam-side heat transfer coefficient (h_s) was 700 Btu/hr (ft^2)(°F), based on considerable conservatism in allowance for non-condensables and condensate film build-up due to lack of gravity. Brine-side surface coefficient (h_s) was estimated to be 718 Btu/hr (ft^2)(°F), based on estimated fluid properties and turbulent flow correlations. Overall heat transfer rate was thus calculated to be 310 Btu/hr (ft^2)(°F). Additional conservatism resulted when active surface area was reduced to 0.47 sq.ft, giving a UA of 146 Btu/hr°F.

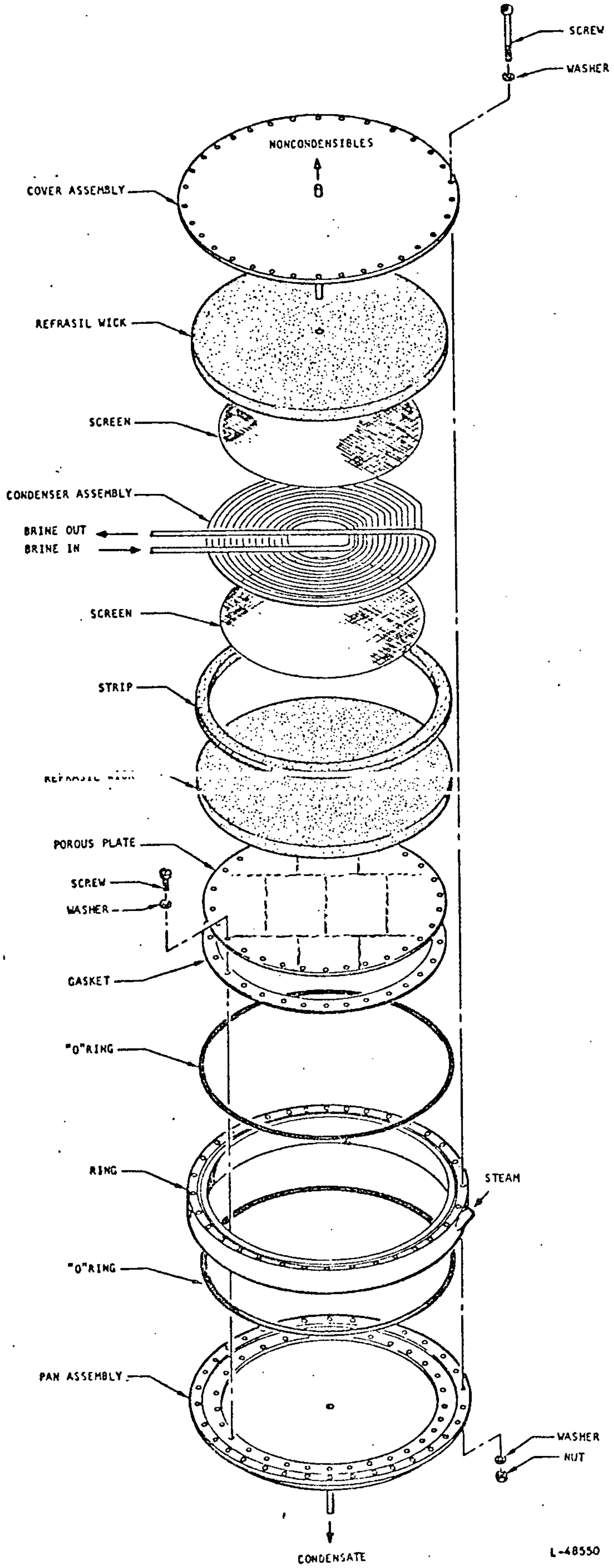

SCREW
WASHER
NONCONDENSIBLES
COVER ASSEMBLY
REFRASIL WICK
SCREEN
CONDENSER ASSEMBLY
BRINE OUT
BRINE IN
SCREEN
STRIP
REFRASIL WICK
POROUS PLATE
SCREW
WASHER
GASKET
"O"RING
RING
STEAM
"O"RING
PAN ASSEMBLY
WASHER
NUT
CONDENSATE
L-48550

Figure 4-1

Performance of Heat Exchanger

Accurate performance data on the heat exchanger was not obtained in the system test program due to heavy non-condensable flow caused by compressor seal leakage and difficulty in obtaining accurate brine flow and Δt measurements. Two typical sets of data on heat exchanger performance are noted below:

Test Date:		7/17/69	7/31/69
Brine Side:	Flow	220 lb/hr	200 lb/hr
	Concentration	20 percent	43 percent
	Inlet Temperature	111°F	105°F
	Outlet Temperature	115°F	109°F
	Heat Transfer Rate	758 Btu/hr	695 Btu/hr
	MTD	9 F	6 F
	UA, Based on Brine-Side Rate	40 Btu/hr°F	116 Btu/hr°F
Steam Side:	Flow	1.0 lb/hr	.7 lb/hr
	Inlet Temperature	136°F	116°F
	Pressure	2.34 psia	1.4 psia
	Saturation Temperature	132°F	113°F
	Heat Transfer Rate	1018 Btu/hr	710 Btu/hr
	UA, Based on Steam-Side Rate	113 Btu/hr°F	118 Btu/hr°F

From this data it can be seen that overall UA appears lower than originally anticipated; especially since actual UA predicted would have been about 300 if no conservatism was used. The energy balance for the 7/17 data is not good; brine conditions indicate a lower heat transfer rate than water condensed; this is typical of much of the test data, the result, it is assumed, of inaccuracies in brine flow and temperature data.

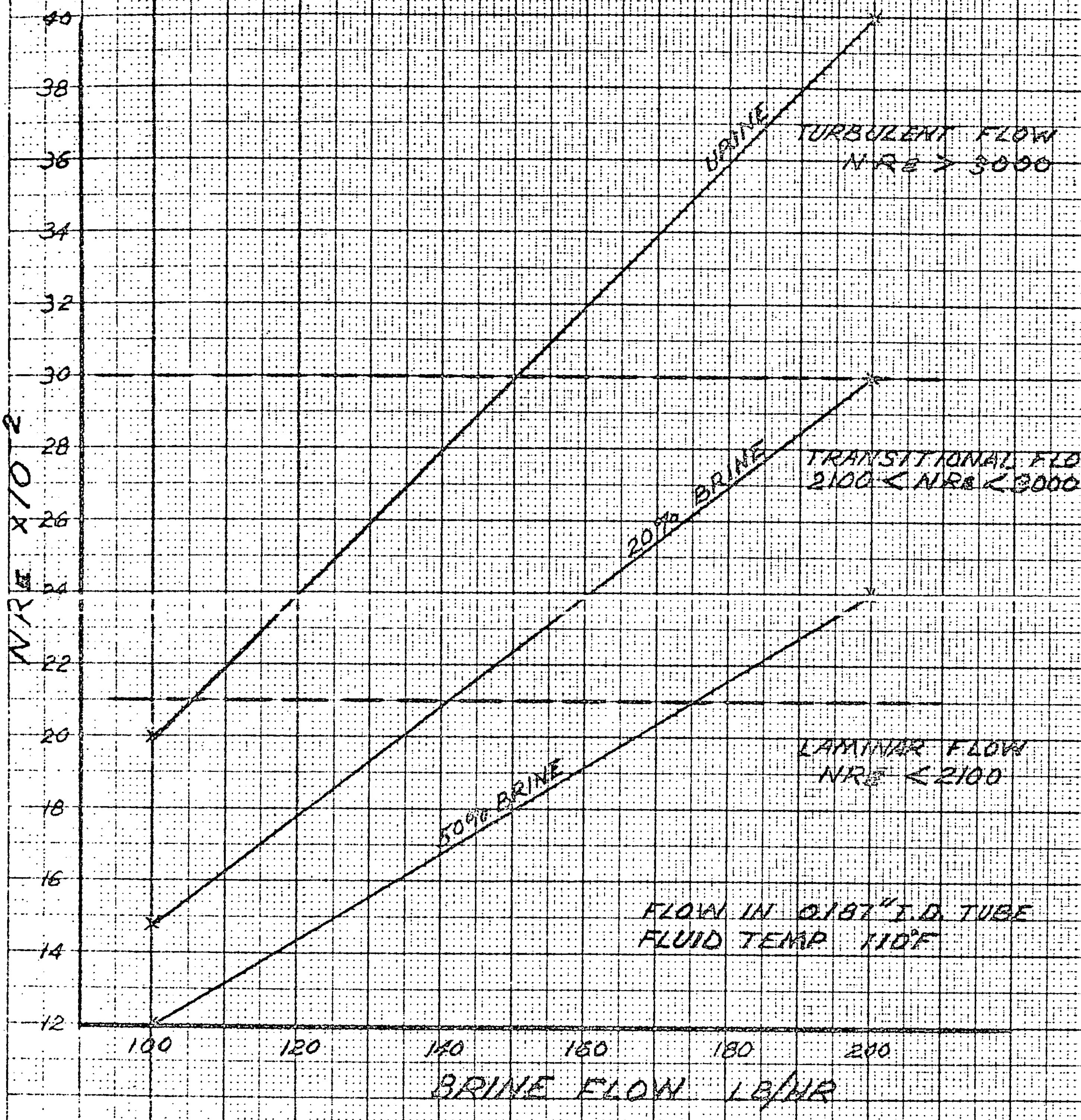
There is some evidence that at higher brine concentrations a definite fall-off in heat transfer performance was responsible for lower production rates. The system test data (see Section 6) shows this fall-off in rate; since steam conditions at the inlet to the compressor were held relatively constant, a fall-off in production with an increase in brine concentration can only be attributed to condensing capacity limitation.

To investigate this phenomenon, an analysis of the heat exchanger was conducted. Figures 4-2 and 4-3 summarize this work and show the effect of brine flow rate and concentration on heat transfer. At low flow rates and high solids concentration, the flow in the heat exchanger is in the laminar or transition transition region and thus effects a drastic reduction in the brine side coefficient. This could explain the production drop-off observed; in all probability brine-side coefficients did not reach the extremely low values shown for laminar flow, but coefficients of 100 to 200 Btu/hr $(ft^2)(^0F)$ could be possible and, with brine side controlling, could explain the performance attained.

Another problem encountered with the heat exchanger was plugging of the brine passages. The tendency toward laminar flow could explain the random nature of this plugging; at high concentrations, a form of spiral instability could be initiated. As flow drops into the laminar region, a large boundry layer is formed which can lead to solids adhering to the tube walls. This, coupled with an increase in viscosity caused by a reduction in bulk temperature as heat transfer falls, can result in more flow reduction with consequent build up until the tube is completely blocked. The flat head characteristics of the brine separator/pump do not provide a compensating increase in pressure to overcome this tendency to plug.

Development Status of Brine Heater-Condenser

As discussed above, the brine side of the heat exchanger may require design changes. Solution of the heat transfer limitation may require additional surface area or higher fluid velocities or both. Higher brine flow rates, to attain higher velocity, should also tend to inhibit plugging.



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REYNOLDS NUMBER VS FLOW RATE
IN BRINE HEATER CONDENSER
BRINE SIDE

Figure 4-2

AIRESEARCH MANUFACTURING COMPANY
DIVISION OF THE GARRETT CORPORATION
LOS ANGELES, CALIFORNIA

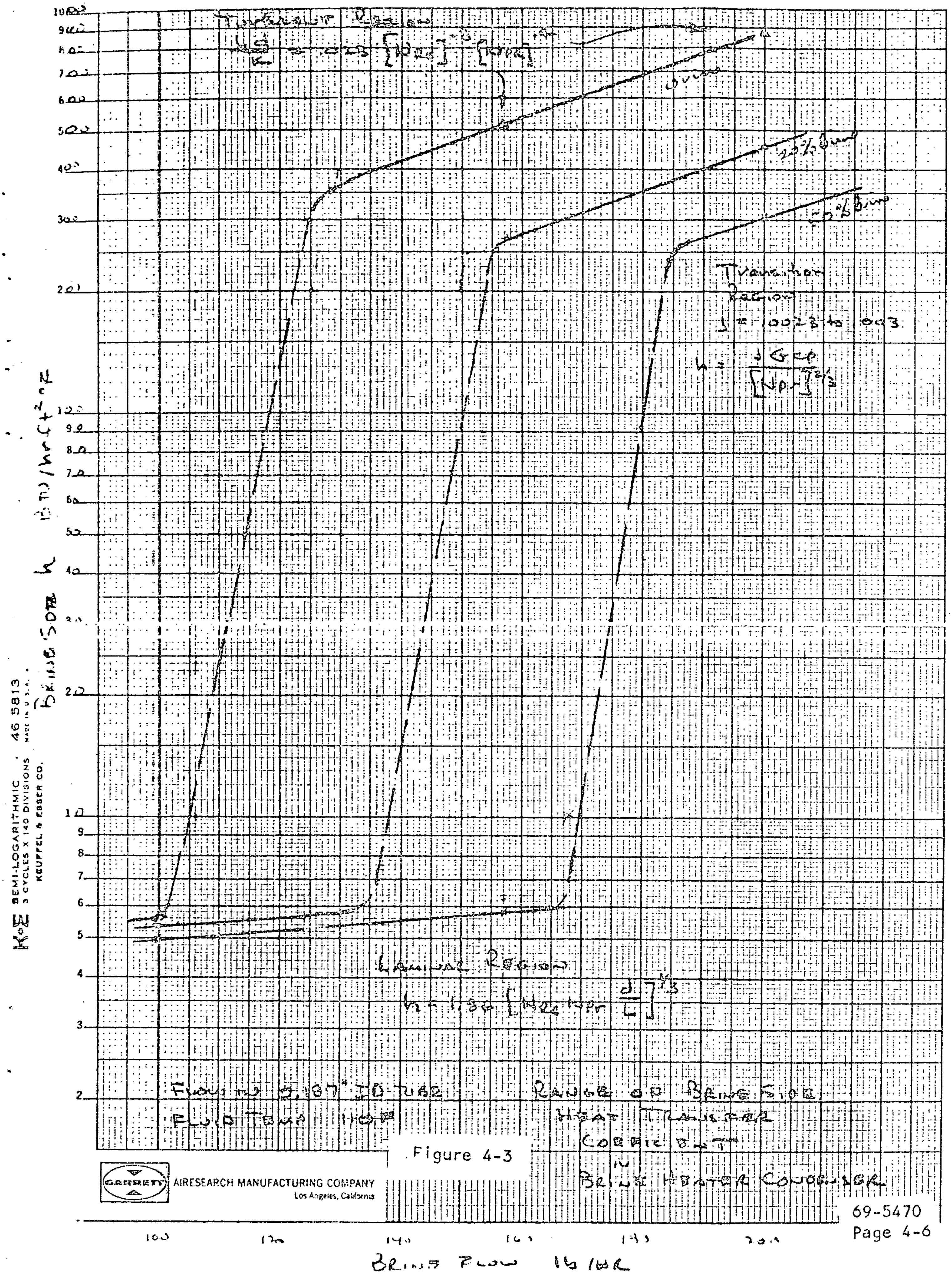
Turbulent Region
hD/k = .023 [NRe]^.8 [NPr]
0% Brine
20% Brine
25% Brine
Transition Region
j = .0023 to .003
h = j G cp / [Npr]^2/3
Laminar Region
h = 1.86 [NRe Npr d/L]^1/3
Flowing in 0.187" ID Tube
Fluid Temp 110°F
Range of Brine Side Heat Transfer Coeffic'nt in Brine Heater Condenser
Brine Side h Btu/hr ft² °F
Brine Flow lb/hr
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
100
120
140
160
180
200
K&E SEMI-LOGARITHMIC 46 5813
3 CYCLES X 140 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Figure 4-3

SECTION 5

SYSTEM CONTROLS

INTRODUCTION

During the supporting development phase, two basic control functions required major emphasis: the feed of waste water to the system and the discharge or dump of waste solids as a brine. Analysis of the basic cycle arrangement indicated that waste feed should be controlled by monitoring the level in the separator, allowing the fluid level in the spinning portion of the separator to rise and fall slightly as waste water is added and water is evaporated from the separator. This level movement could, in turn, be sensed and controlled through feed of waste water to the brine loop. Waste solids removal is accomplished as follows: At or near 50-percent solids the concentrated brine is dumped upon command from a density controller which tracks brine solids content and triggers a dump valve, allowing brine to be discharged to a waste tank. The resulting decrease in level in the separator signals the addition of waste water by the level control. The injection of relatively low solids urine/wash water then reduces the brine density. The dump control ceases to discharge brine until the concentration again reaches 50 percent.

A review of possible means for sensing brine level in the separator and density in the brine loop indicated that a most attractive concept was the use of a nuclear sensing system which senses the variation in attenuation of gamma radiation by a variable fluid-vapor interface and/or a variation in fluid density. A contract was negotiated with the General Nucleonics Division of the Tyco Corporation, Claremont, California, for the development and fabrication of a control system based upon this principal.

Level Control Systems

The separator level controller uses low energy gamma transmission. A small shielded gamma source (Americium 241) is mounted on one side of the separator housing and a GM tube detector is mounted directly across from it on the other side as shown in Figure 3-5. The gamma energy is low enough (approximately the same as a dental x-ray machine) that the number of gamma ray photons detected changes by approximately 80 percent as the brine level varies over the 0.7 inches between the low and high level. The resultant steep count rate/level curve permits operation within the required accuracy using only a small source and detector.

Figure 5-1 is a block diagram of the Nucleonic level controller operation. The count rate into the detector decreases rapidly as the liquid level increases in the separator. The signal pulses from the gammas impinging on the detector pass first into the amplifier-discriminator circuit where all pulses over a low noise level are given a uniform pulse shape and a low output impedance for the integrator circuit. In the integrator circuit the pulse train is converted to a dc voltage proportional to pulse rate. This dc voltage is compared to a reference voltage in the level comparator circuits. The reference voltages are preadjusted to permit signals from the comparators for the proper brine level fill turn-on and cut-off.

Figure 5-2 is a plot of the level control system count rate versus separator level. The high- and low-level control points were placed at 700 cc and 500 cc, respectively. Two modes of waste feed valve operation could be utilized: a pulsed mode where the valve was pulsed open for 1/20 second every 10 seconds between the high- and low-level settings of the controller; and a on-off mode where the valve was on below the 500 cc level and off above it. The latter mode of operation was utilized primarily during system test activity as a simple method of keeping fluid in the separator at the lowest level to maintain the best separator performance.

Density Control System

Concentration is sensed by measuring the density, using the gamma ray absorption technique. This technique uses a gamma ray source on one side of the liquid being measured and gamma ray detectors on the other side. The greater the concentration, or density, the greater the attenuation of the gamma rays; therefore, a smaller amount of gamma ray radiation reaches the detector. The gamma signal from the detectors is converted to control the dump valve, which in turn controls the solids concentration. Absorption is directly proportional to the density of the liquid. The realtionship between transmitted radiation and material density is determined by the radiation absorption law.

$$I = I_0 \exp(-\mu \rho d)$$

where,

I_0 is the intensity of the incident radiation

I is the intensity of the radiation transmitted through a material layer of the thickness d and the density ρ

ρd is the mass per unit area of the material

μ is the mass absorption coefficient of the material

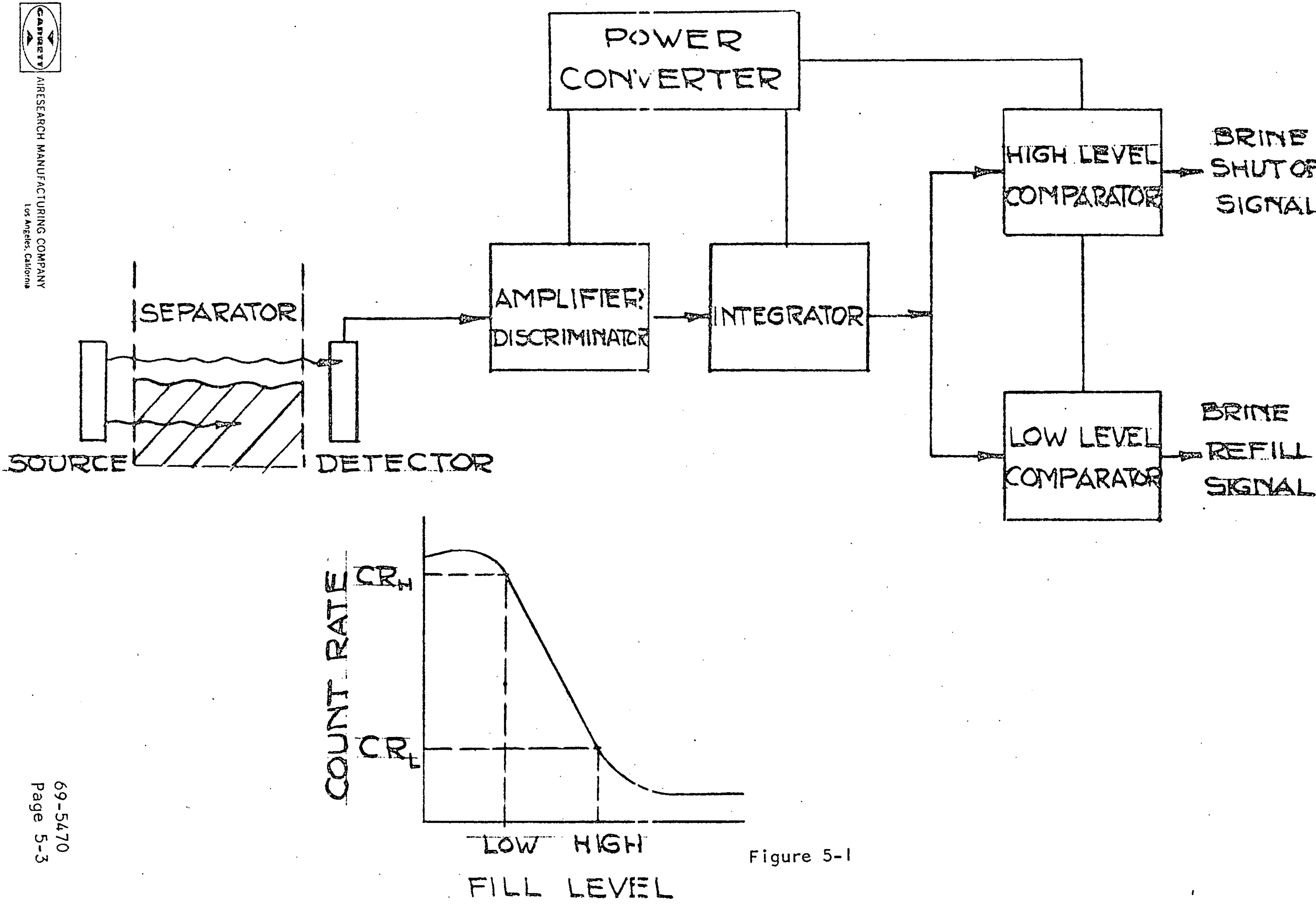
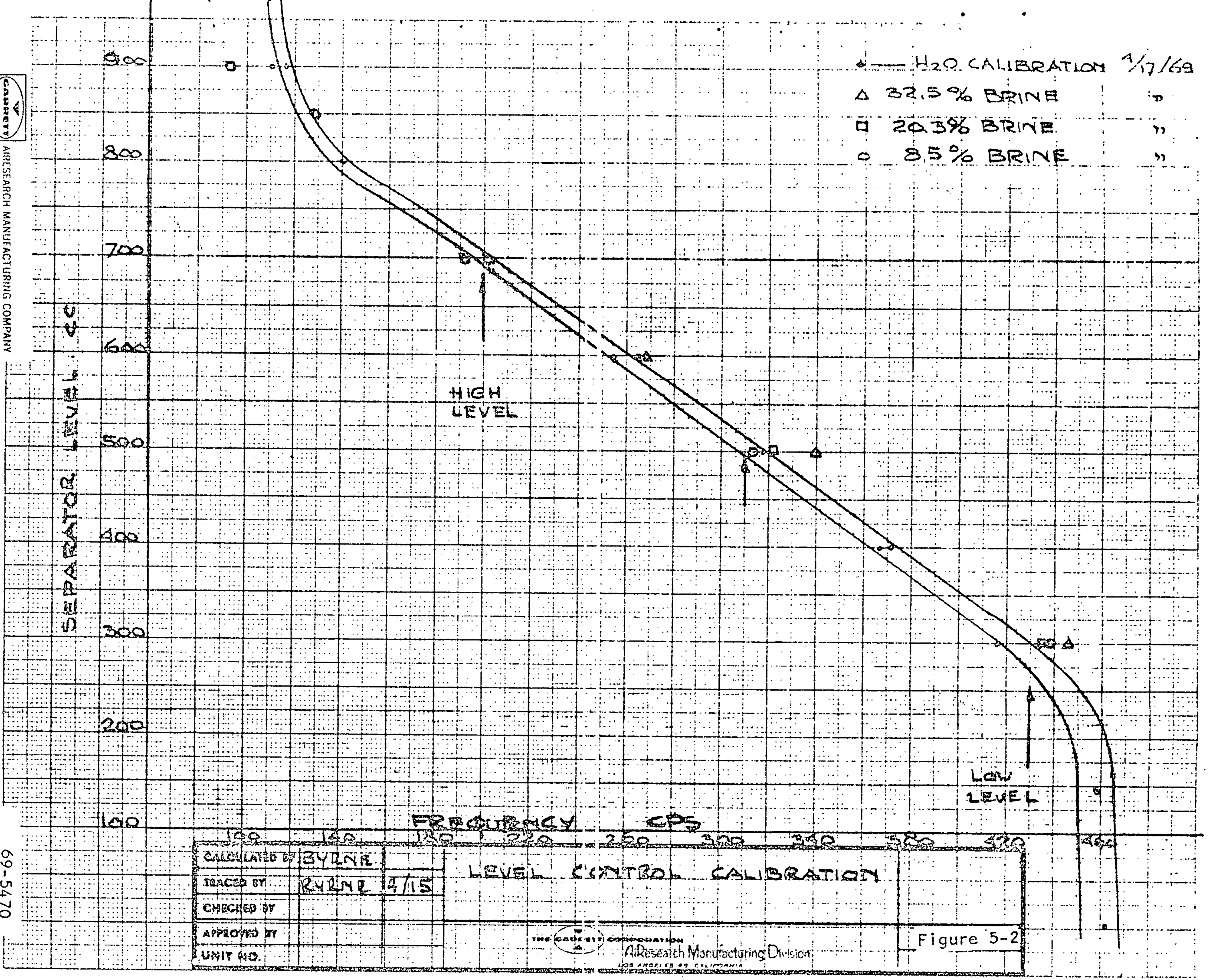

POWER CONVERTER
SEPARATOR
SOURCE
DETECTOR
AMPLIFIER/ DISCRIMINATOR
INTEGRATOR
HIGH LEVEL COMPARATOR
LOW LEVEL COMPARATOR
BRINE SHUTOF SIGNAL
BRINE REFILL SIGNAL
COUNT RATE
CR_H
CR_L
LOW
HIGH
FILL LEVEL

Figure 5-1



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TRACED BY	BYRNE	4/15	
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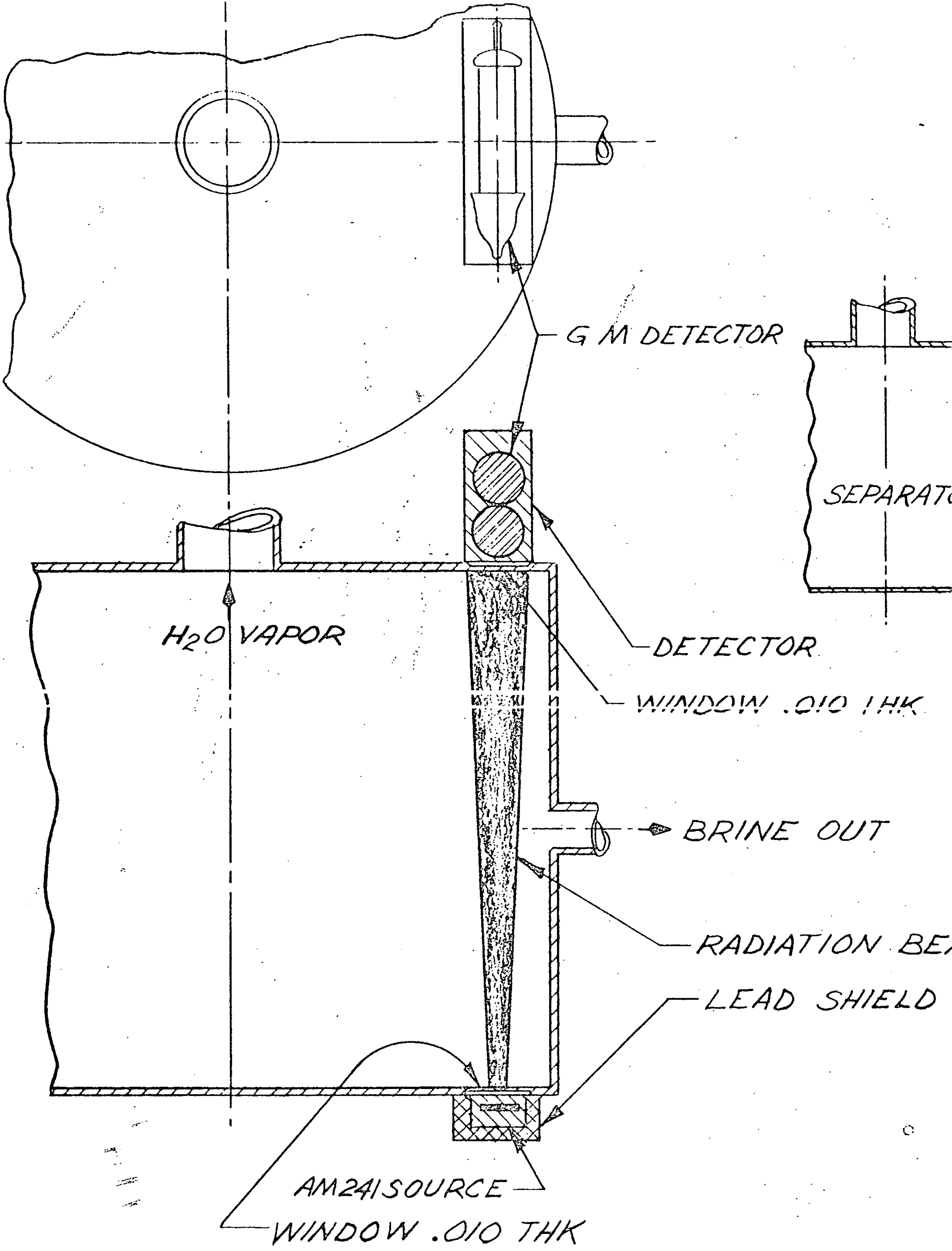
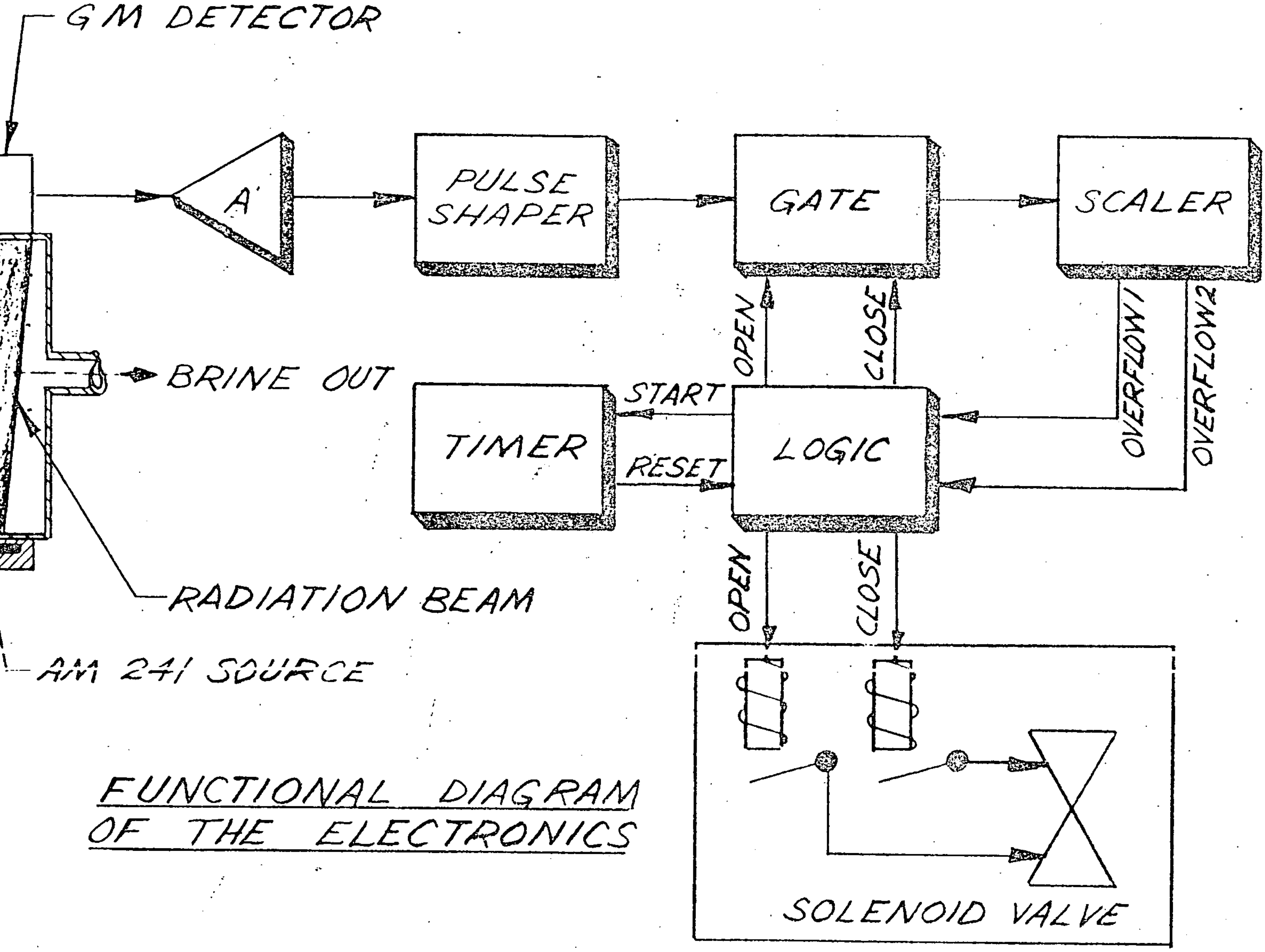
APPROVED BY			Figure 5-2
UNIT NO.			

THE GARRETT CORPORATION
AiResearch Manufacturing Division
LOS ANGELES 45 CALIFORNIA



SEPARATOR CONFIGURATION



FUNCTIONAL DIAGRAM OF THE ELECTRONICS

Figure 5-3

GENERAL NUCLEONICS CORP.

CONCENTRATION CONTROLLE
SCHEMATIC-DIAGRAM

SIZE	CODE IDENT NO	DRAWING NO.
B	24494	SK100152

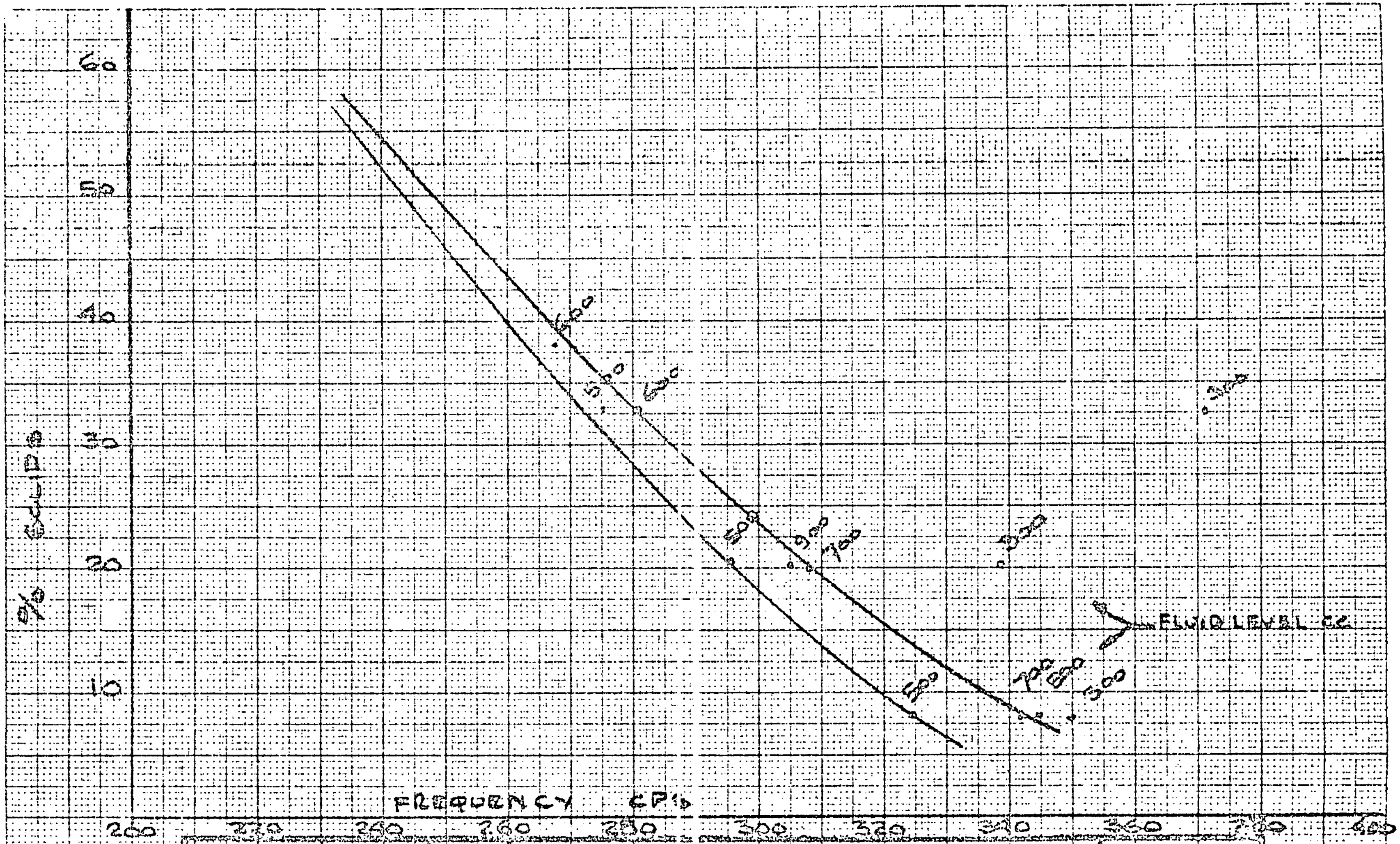
Each gamma photon interacting with the detector results in a pulse-out for each gamma photon reaching the detector. The gamma photon rate results in a corresponding electronic pulse rate out of the detector. The required counting rate is given by the required accuracy in the available measuring time. The design goal accuracy was ±2 percent of solid concentration. This is equivalent to a change in density of approximately 0.4 percent. For example, a solid concentration of 50 ±2 percent corresponds to a brine density of 1.245 ±0.005 g/cc, which is a relative density change of 0.4 percent. The maximum rate of change of solids concentration is approximately 0.5 percent per minute, corresponding to 0.1 percent in density per minute. Within a measuring time of 30 seconds, a change in concentration will be only 0.05 percent, which is an acceptable error.

Figure 5-3 shows the electronic circuitry used in the controller. The pulses from the detector are amplified and shaped and then fed through a pulse gate into a binary scaler consisting of 14 IC flip-flop units. The gate is opened by the logic for the measuring time of 30 seconds, which is determined by a digital timer. The measurements are taken in a recycle mode, each starting immediately after the end of the previous one. After each measurement is finished, the logic determines if a certain number of counts, corresponding to a solid concentration in the separator of 55 ±2 percent, is reached (defined by the first (lower) overflow signal). If the correct number has been reached, the logic generates an output pulse which opens the solenoid valve. If the second (higher) overflow signal, corresponding to a concentration of 50 ±2 percent, is reached, the logic closes the solenoid valve.

Figure 5-4 is a calibration of the density controller, depicting the band of pulses counted in the 30-second-gate period versus solids concentration in the brine. The variation shown is a function of liquid level in the separator, which will vary the attenuation of the gamma particles.

Radioisotope Source

The radioisotope source Americuim 241 has the advantage that the specific dose rate constant for 60 KeV gamma radiation is the lowest of all radiation energies existing in nature; i.e., 0.035 mr/mc-hr in one meter. Therefore, an unshielded 60 mc source would lead to a dose rate of approximately 2.1 mr/hr in 1 meter distance, or about 22 mc/hr in one foot. The source is additionally shielded on the sides and on the bottom. 1/16 in. of lead is sufficient to reduce the direct radiation by a factor of almost 1000. The unshielded part of the beam shining into the separator is almost completely stopped inside the separator so that no additional shielding on the other side is necessary. With this shielding, no unusual precautions are required.



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APPROVED BY		
UNIT NO.		

DENSITY CONTROL CALIBRATION

AiResearch Manufacturing Division
LOS ANGELES CALIFORNIA

Figure 5-4

SECTION 6

SYSTEM TEST PROGRAM

To evaluate the performance of the components when integrated into a system, and to gain experience and data on the performance of the cycle, a breadboard system was assembled for test. The breadboard system is shown schematically on Figure 6-1 and pictorialy on Figure 6-2. The system test program was to be conducted in three parts:

Part 1: A preliminary shakedown run with water

Part 2: A ten-day run with urine, operating 16 hours per day

Part 3: A five-day run with a simulated wash water

An initial attempt to conduct the test program resulted in a series of component problems; particularly a compressor failure. After 5 days of operation with urine the test program was terminated.

After further development testing of the compressor and rework of some system features, a 10-day run with urine was conducted. The test program was terminated at this time, and because the major objectives of the program had been met.

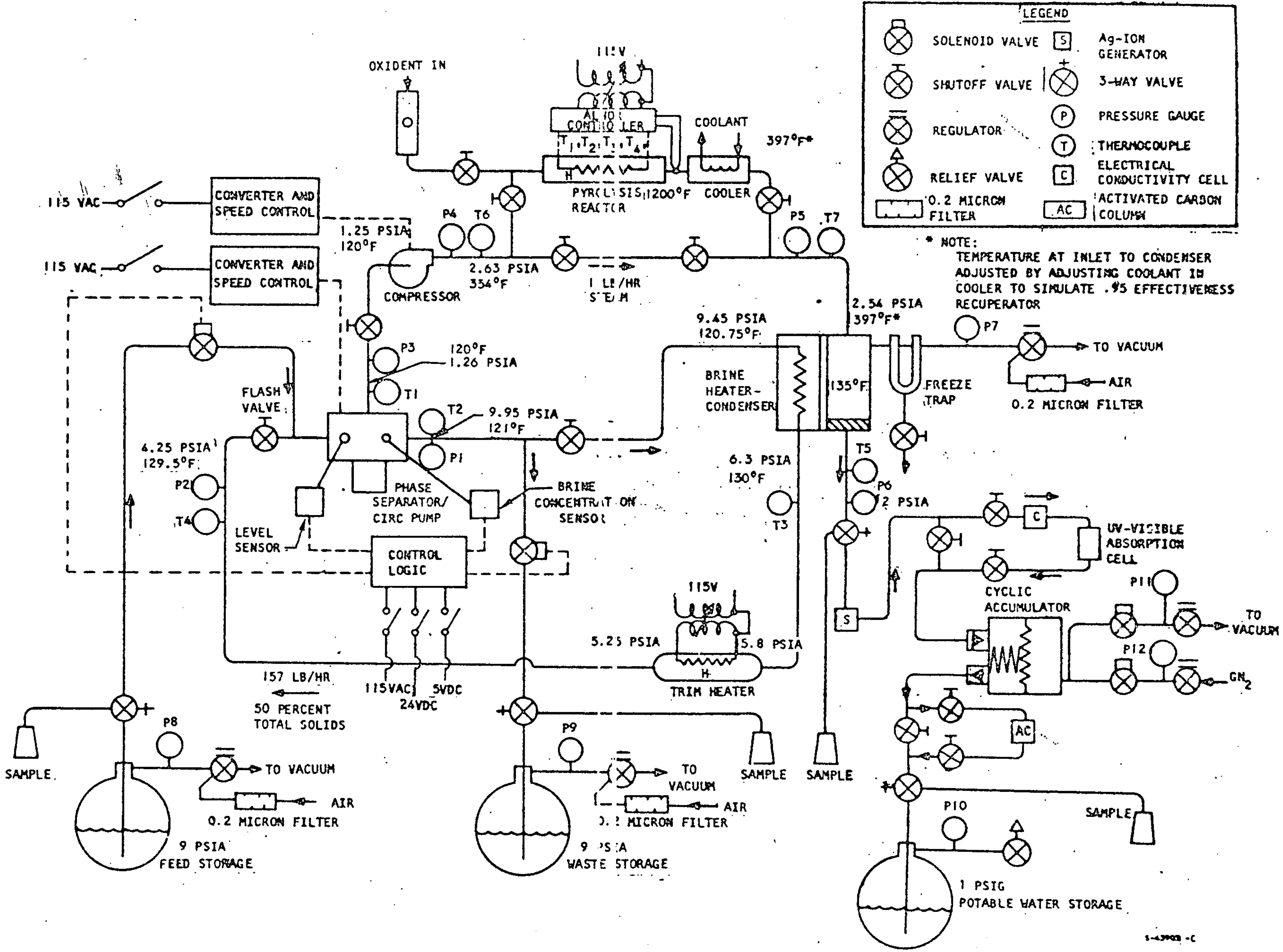
Initial System Test

On April 22, 1969, the system was sterilized with a 12-percent ethylene oxide vapor for 15 hours. The system was then flushed with filtered distilled water and prepared for test. Rinse samples showed evidence of bacteria, later identified as being in the filtered flush water.

On April 23, 1969, the system was re-sterilized with a mixture of alcohol and water, held overnight, drained, and prepared for operation.

On April 24, 1969, the system was charged with 700 cc of fresh urine, the feed tank filled with a mixture of 10.5 lb urine and 6.0 lb distilled water, and operation started. The system was operated for approximately 8 hours, and produced 5600 cc (12.3 lb) of product water. Toward the end of the run, unusual noises were noticed in the compressor. Table 6-1 presents representative performance information, and Table 6-2 shows chemical analysis of the water produced.

On April 25, 1969, the system was operated for approximately 4 hours and produced an additional 1250 cc of product water. Production rate during this run appeared to have decreased to approximately 0.6 lb/hr and periodic noisy operation was noted. The compressor was opened and inspection showed no visible damage or deterioration.



* NOTE:
TEMPERATURE AT INLET TO CONDENSER ADJUSTED BY ADJUSTING COOLANT IN COOLER TO SIMULATE .95 EFFECTIVENESS RECUPERATOR

Figure 6-1. Breadboard Demonstration Process Schedule

ITEM NO	FUNCTION	MANUFACTURER AND MODEL
1.	FEED STORAGE VESSEL	12 LITER FLASK
2.	BRINE STORAGE SAMPLE VESSEL	2 LITER FLASK
3.	BRINE STORAGE PRESSURE GAUGE	FA-160, 0-15 PSIA
4.	BRINE STORAGE PRESSURE REGULATOR	CONOFLOW, H-20VT-XXXX
5.	BRINE STORAGE - SAMPLE SELECTOR VALVE	HOKE, 1/4 INCH 3-WAY BALL, 7165G4S
6.	BRINE STORAGE FILTER	BARNSTEAD VENTGARD, 03111
7.	PHASE SEPARATOR RECIRCULATION PUMP MOTOR	BODINE ELECTRIC, NSH-34
8.	PHASE SEPARATOR RECIRCULATION PUMP CLUTCH	HURST CHAIN, Z1790
9.	PHASE SEPARATOR RECIRCULATION PUMP TORQUE SENSOR	LEBOW ASSOCIATES, 1102S
10	PHASE SEPARATOR RECIRCULATION PUMP	AIRESEARCH PA-77378
11.	FEED STORAGE VESSEL AND WASTE STORAGE VESSEL VACUUM PUMP	DUO SEAL MODEL 1405
12	FEED SOLENOID VALVE	VALCOR SIC50HT34-90
13.	WASTE STORAGE VESSEL	2 LITER FLASK
14.	WASTE STORAGE SAMPLE VESSEL	1 LITER FLASK
15.	WASTE STORAGE PRESSURE GAUGE	WALLACE & TIERNAN FA-233
16.	WASTE STORAGE PRESSURE REGULATOR	CONOFLOW, H-20VT-XXXX
17.	WASTE STORAGE - SAMPLE SELECTOR VALVE	HOKE, 1/4 INCH 3-WAY BALL, 7165G4S
18.	WASTE SOLENOID VALVE	VALCOR SIC50HT34-90
19.	VAPOR COMPRESSOR MOTOR	BODINE ELECTRIC, NASH-34
20.	VAPOR COMPRESSOR UNIVERSAL	BOSTON FC 12-3/8
21.	VAPOR COMPRESSOR TORQUE SENSOR	LEBOW ASSOCIATES, 1102
22.	VAPOR COMPRESSOR	AIRESEARCH PA-77084
23.	PHASE SEPARATOR RECIRCULATION PUMP VAPOR SHUTOFF VALVE	HOKE, 3/8 INCH BALL, 7222F6S
24.	FLASH VALVE	HOKE, 2315F4Y/280-25
25.	PHASE SEPARATOR RECIRCULATION PUMP VAPOR PRESSURE GAUGE	BARTON, 0-4 PSIA
26.	PHASE SEPARATOR RECIRCULATION PUMP VAPOR THERMOCOUPLE	S. S. SHEATH CuC
27.	PHASE SEPARATOR RECIRCULATION PUMP BRINE OUTLET THERMOCOUPLE	S. S. SHEATH CuC
28.	PHASE SEPARATOR RECIRCULATION PUMP BRINE OUTLET PRESSURE GAUGE	U. S. GAUGE, COMPOUND 30 INCH VACUUM-30 PSIG
29.	BRINE RECIRCULATION LOOP SHUTOFF VALVE	HOKE, 1/4 INCH BALL VALVE, 7122G4Y
30.	DELETED	
31.	DELETED	
32.	BRINE HEATER CONDENSER	AIRESEARCH PA 97015
33.	BRINE TRIM HEATER	AIRESEARCH
34.	BRINE FLASH VALVE UPSTREAM THERMOCOUPLE	S. S. SHEATH CuC
35.	BRINE FLASH VALVE UPSTREAM PRESSURE GAUGE	U. S. GAUGE, COMPOUND 30 INCH VACUUM-30 PSIG
36.	COMPRESSOR STEAM OUTLET THERMOCOUPLE	S. S. SHEATH CuC
37.	COMPRESSOR STEAM OUTLET PRESSURE GAUGE	WALLACE & TIERNAN FA-233
38.	CATALYST BED STEAM BYPASS SHUTOFF VALVE, 1	HOKE, 3/8 INCH VALVE 7222F6S
39.	CATALYST BED STEAM SHUTOFF VALVE	HOKE, 3/8 INCH VALVE 7222F6S
40.	OXIDENT GAS FLOW METER	WALLACE TIERNAN 3 INCH PURGE METER
41.	OXIDENT GAS METERING VALVE	HOKE, 1335G4Y
42.	FURNACE	MARSHALL FURNACE 2200°F
43.	REACTOR TUBE	AIRESEARCH
44-47.	REACTOR THERMOCOUPLES	S. S. SHEATH CA
48.	REACTOR STEAM OUTLET THERMOCOUPLE (TO ALNOR CONTROLLER)	S. S. SHEATH CA
49.	STEAM COOLER	AIRESEARCH
50.	STEAM COOLER SHUTOFF VALVE	HOKE, 3/8 INCH BALL VALVE, 7222F6S
51.	INLET CONDENSER STEAM PRESSURE GAUGE	WALLACE & TIERNAN FA-233
52.	INLET CONDENSER STEAM TEMPERATURE THERMOCOUPLES	S. S. SHEATH CuC
53.	CONDENSATE PRESSURE GAUGE	WALLACE & TIERNAN FA-233
54.	CONDENSATE TEMPERATURE THERMOCOUPLE	S. S. SHEATH CuC
55.	CONDENSATE SAMPLE VALVE (1)	HOKE 1/4 INCH BALL VALVE 7122G4Y
56.	U-V BYPASS VALVE (1)	HOKE 1/4 INCH BALL VALVE 7122G4Y
57.	SILVER ION GENERATOR	AIRESEARCH 133448
58.	U-V BYPASS VALVE (2)	HOKE 1/4 INCH BALL VALVE 7122G4Y
59.	CONDENSATE SPECIFIC CONDUCTANCE CELL	BECKMAN INSTRUMENTS, 001
60.	CONDENSATE SAMPLE VESSEL)(1)	1 LITER FLASK
61.	CONDENSATE CYCLIC ACCUMULATOR	AIRESEARCH, 811500-3
62.	FREEZE TRAP	AIRESEARCH
63.	NONCONDENSIBLE VAPOR VENT PRESSURE GAUGE	WALLACE & TIERNAN FA-233
64.	NONCONDENSIBLE VAPOR VENT PRESSURE REGULATOR	CONOFLOW, H-20VT-XXXX
65.	NONCONDENSIBLE VAPOR VENT AND POTABLE WATER STORAGE AIR FILTER	BARNSTEAD VENTGARD, 03111
66.	POTABLE WATER STORAGE - SAMPLE SELECTOR VALVE	HOKE, 1/4 INCH 3-WAY BALL 7165G4S
67.	POTABLE WATER STORAGE VESSEL	12 LITER FLASK
68.	POTABLE WATER STORAGE SAMPLE VESSEL 2)	2 LITER FLASK
69.	POTABLE WATER STORAGE PRESSURE GAUGE	WALLACE & TIERNAN FA-233
70.	VACUUM SHUTOFF VALVE	DRAGON, 810
71.	REFRIGERANT RECIRCULATION PUMP	EASTERN INDUSTRIES E-1
72.	REFRIGERATOR	FREON/ WATER-GLYCOL
73.	CYCLIC ACCUMULATOR AND NONCONDENSIBLE VENT VACUUM PUMP	DUO SEAL 1405
74.	CYCLIC ACCUMULATOR VACUUM SOLENOID	ECKEL VALVE, AF 77C-2210
75.	CYCLIC ACCUMULATOR GN_2 SOLENOID	ECKEL VALVE, AF 77C-2210
76.	POTABLE WATER VESSEL RELIEF VALVE	AIRESEARCH
77.	CONDENSATE SHUTOFF VALVE (1)	HOKE 1/4 INCH BALL VALVE 7122G4Y
78.	CATALYST BED STEAM BYPASS SHUTOFF VALVE 2	HOKE 3/8 INCH VALVE 7222F6S
79.	ACTIVATED CARBON COLUMN	AIRESEARCH
80.	WASTE STORAGE AIR FILTER	BARNSTEAD VENTGARD 03111
81.	CARBON BYPASS VALVE (1)	HOKE 1/4 INCH BALL VALVE 7122G4Y
82.	CARBON BYPASS VALVE (2)	HOKE 1/4 INCH BALL VALVE 7122G4Y
83.	CONDENSATE SHUTOFF VALVE (2)	HOKE 1/4 INCH BALL VALVE 7122G4Y

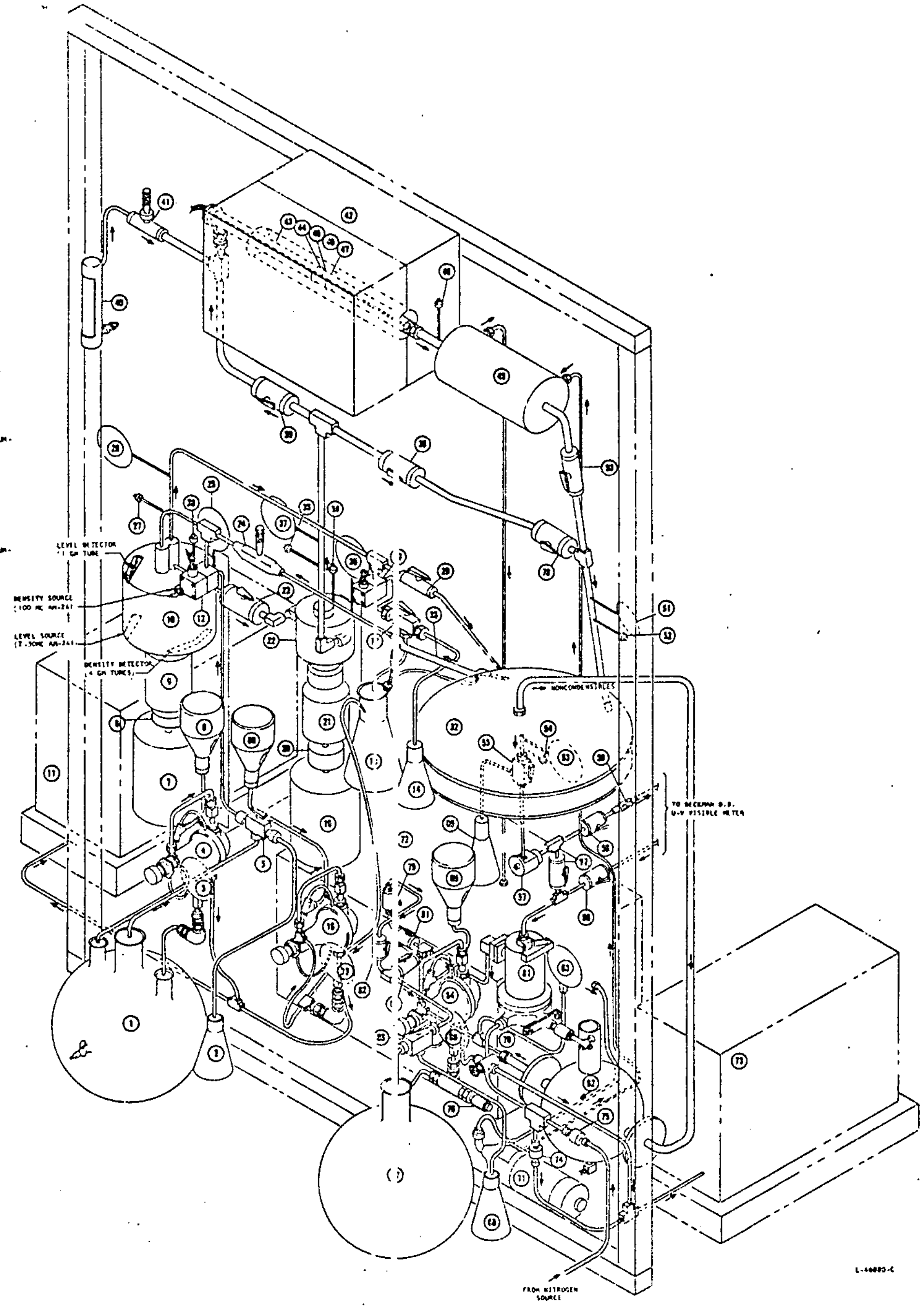


Figure 6-2. Flash Evaporation Vapor Compressor Pilot Plant Layout

TABLE 6-1

SYSTEM PERFORMANCE

Date and Time	April 24, 1969 at 1730

Brineloop

Separator Pressure Out, P_1, psia	12.8
Flash Valve Pressure, P_2, psia	5.4
Separator Temp Out, T_2, F	112
Heater/Condensor Temp Out, T_2, F	---
Elect Heater Temp Out, T_4, F	117
Density, Percent Solids	Approx 6
Elect Heater Power, watts	33.0

Separator

Steam Pressure Out, P_3, psia	1.23
Steam Temp Out, T_2, F	106
RPM	1836
Power, watts	43.1
Brine Level, cc	680

Compressor

Outlet Pressure, P_4, psia	1.75
Outlet Temp, T_6, F	200
RPM	1827
Power, watts	113

Condensor

Steam Inlet Pressure, P_5, psia	1.85
Steam Inlet Temp, T_7, F	130
Condensate Outlet Pressure, P_6, psia	1.47
Condensate Outlet Temp, T_5, F	111
Noncondensible Vent Pressure, P_7, psia	1.8
Condensate Conductivity, Micro mhos/cm	40.0
Condensate Production Rate, lb/hr	Approx 1.2
Condensate pH	4.5

TABLE 6-2

CHEMICAL ANALYSIS OF PRODUCT WATER

CONSTITUENTS	AEROSPACE STDS. (1967)	TEST SAMPLE (24 April 1969)
Emission Spectroscopy, mg/l		
Ag	0.5	<0.0001
Al		0.003
As	0.5	<0.003
B	5.0	0.012
Ba	2.0	0.002
Ca		0.30
Cd	0.05	<0.001
Co		<0.001
Cr	0.05 Hexavalent, Cr^{+6}	<0.001
Cu	3.0	0.001
Fe	1.0	<0.001
Ga		<0.001
K		<1.0
Mg		0.15
Mn	0.1	0.002
Mo		<0.003
Na		0.20
Ni		0.15
Pb	0.2	<0.001
Si		33 (est.)
Sn		<0.001
Sr		0.002
Ti		<0.001
Tl		<0.001
V		<0.001
Zn	0.15	0.002

TABLE 6-2 (continued)

CHEMICAL ANALYSIS OF PRODUCT WATER

CONSTITUENTS	AEROSPACE STDS. (1967)	TEST SAMPLE (24 April 1969)
Specific Ion Electrodes, mg/l		
Cupric	3.0	<0.01
Cyanide		<0.1
Fluoride	2.0	0.6
Nitrate	100	0.015
Dow Kits, mg/l		
Urea Nitrogen		3.8
Uric Acid		3.8
Hellige, mg/l		
Sulfate	250	2.5
Turbidity, SiO_2	10, Jackson Units	5.5
Aminco Titrator, mg/l		
Chloride	450	9
Total Solids, mg/l	1,000	210
Surface Tension, dynes/cm		63.0
pH	5.0-10.0	4.5
Electrical Conductivity, μ mhos/cm	1700	37
Ammonia Nitrogen, mg/l		<5

On April 28, 1969, the system was operated for approximately 11 hours. Production varied from 1 lb/hr to zero. A total of 1700 cc of water was produced. During this operation the compressor seemed to progressively lose capacity and produce a random noise. Finally, after a long period of noisy and erratic operation, the compressor siezed.

On April 29, 1969, the compressor was removed and disassembled. The carbon vanes were found to be badly broken; a jagged piece was jammed into the inlet port, causing a locked rotor.

On April 30, 1969, the backup diaphragm compressor was installed and operation attempted. Considerable difficulty ensued. Foam and urine had evidently gone into the compressor and passed through the compressor into the condensor until the product water took on a definite yellowish hue. The diaphragm compressor was removed and a second vane unit installed. Operation of this unit was unsuccessful, so all operation of the system was terminated until investigation of the compressor problem could be made.

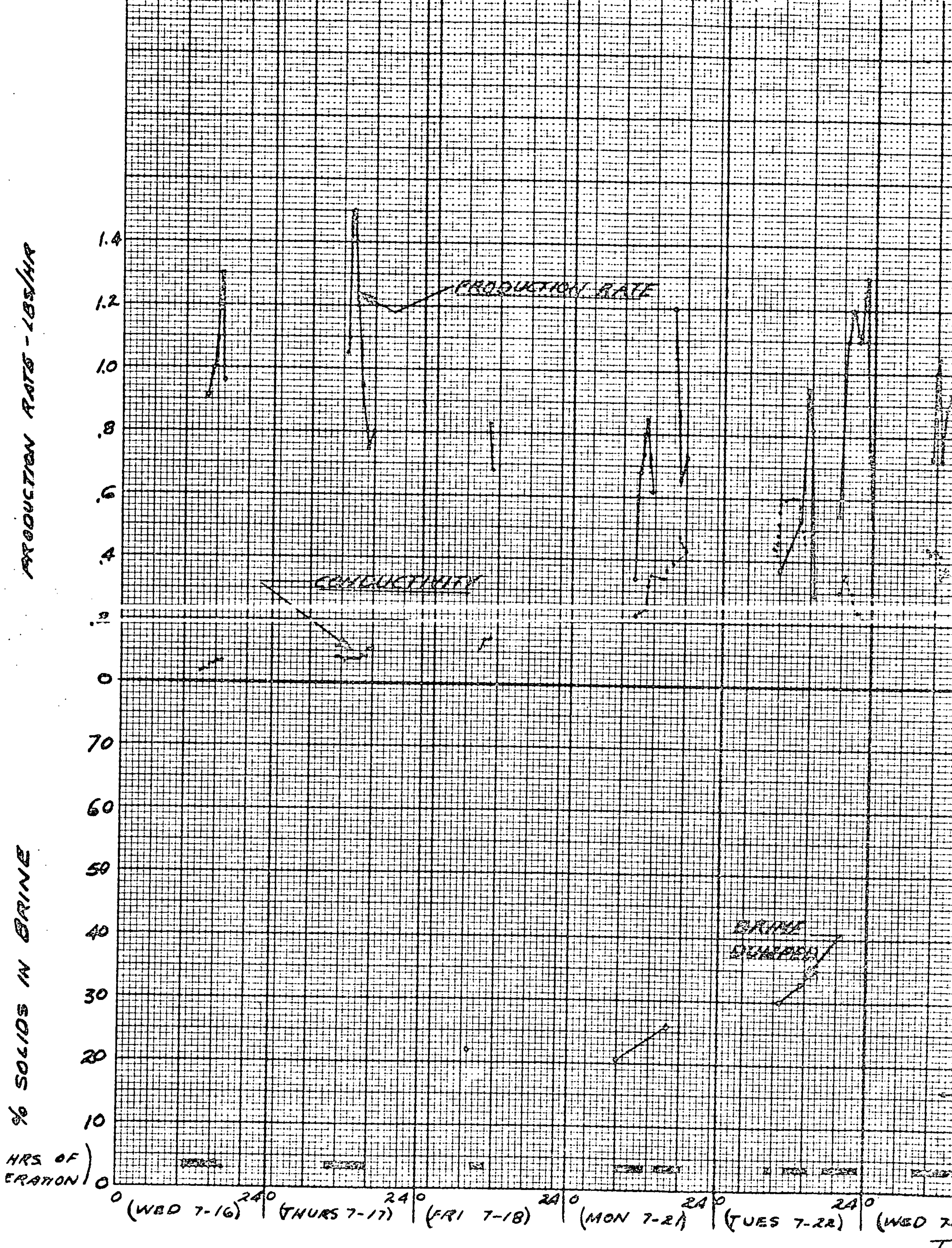
Second System Test

Results of the initial system test indicated that while the basic cycle and control system was operating quite well and a good quality water could be produced, component problems, particularly the compressor, caused progressively poorer performance and ultimately resulted in termination of the test. Further investigation of the vane compressor failure resulted in two improved compressor configurations which gave promise of good performance: a unit using Teflon blades and a unit with Tuftride housing coating and carbon vanes. Other modifications to the system included incorporation of a more powerful compressor drive system with a capacity to 180 watts and a revised separator demister design. In addition, the condenser was disassembled and cleaned and new wicks were installed. The system was then operated for a total of 104.5 hours over a two week period. 88.3 lb of water was produced from 93.1 lb of urine/wash water mixture for a 94.5-percent recovery efficiency. Figure 6-3 presents a graphic summary of the operation, showing hours operated, urine concentration history, production rate, and conductivity of the water produced. Detailed system performance data is presented on Table 6-3 and results of chemical and physical analysis of water produced are given on Tables 6-4 and 6-5.

Preliminary Checkout Runs - July 11 to July 18, 1969

The system was operated with water for a total of 17 hours over three days to check component and system operation. Production rate varied from 0.75 to 1 lb/hr and operation appeared trouble free. The Tuftride/carbon compressor was used.

Fi


PRODUCTION RATE - LBS/HR
1.4
1.2
1.0
.8
.6
.4
.2
0
PRODUCTION RATE
CONDUCTIVITY
% SOLIDS IN BRINE
70
60
50
40
30
20
10
BRINE DUMPED
HRS OF OPERATION
0
0 (WED 7-16) 24
0 (THURS 7-17) 24
0 (FRI 7-18) 24
0 (MON 7-21) 24
0 (TUES 7-22) 24
0 (WED 7-

6-3

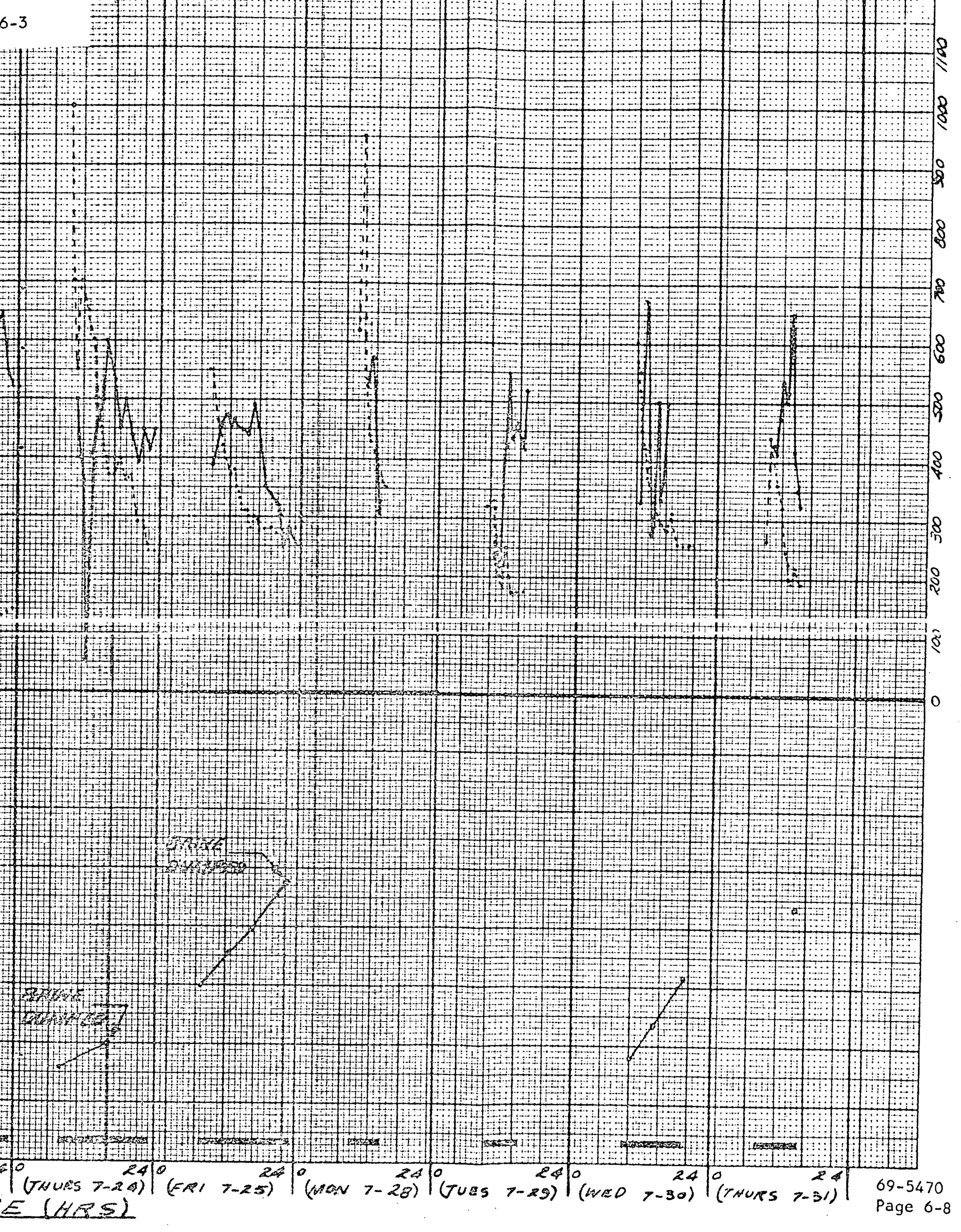

1100
1000
900
800
700
600
500
400
300
200
100
0
BRAKE CHANGED
BRAKE CHANGED
0 (THURS 7-24) 24
0 (FRI 7-25) 24
0 (MON 7-28) 24
0 (TUES 7-29) 24
0 (WED 7-30) 24
0 (THURS 7-31) 24
E (HRS)

TABLE 6-3

SYSTEM PERFORMANCE

Date and Time	7-21 1200	7-23 1200	7-25 1200	7-29 1200	7-31 1200
Brine Loop					
Separator Pressure Out, P_1, Min.	11.3	10.3	11.8	8.6	11.8
Flash Valve Pressure P_2, Min.	2.95	2.21	2.21	2.46	2.95
Separator Temp Out T_2, F	104	102	106	105.5	108
Heater/Condenser Temp Out T_3, F	106	112	112	109	115
Elec Heater Temp Out T_4, F	110	124	121	118	120
Density, $^0/_0$ Solids	24	15	35	17	45
Elect Heater Power, Watts	45	60	80	82	65
Separator					
Steam Pressure Out. P_3, psia	1.04	0.95	0.95	1.02	.96
Steam Temp Out, T_1, F	99	96	96	99	100
RPM	1763	1816	1788	1407	1810
Power, Watts	36	36.2	38.4	26.6	36.2
Brine Level, cc	520	530	510	505	570
Compressor					
Outlet Pressure, P_4, psia	2.45	2.6	2.47	4.85	1.65
Outlet Temp, T_6, F	144	154	131	156	155
RPM	2024	1896	1941	2065	2078
Power, Watts	121	119	134	166	115

TABLE 6-3 (continued)

SYSTEM PERFORMANCE

Date and Time	7-21 1200	7-23 1200	7-25 1200	7-29 1200	7-31 1200
Condenser					
Steam Inlet Pressure, P_5, Min.	2.19	1.09	1.98	1.8	1.57
Steam Inlet Temp, T_7, F	130	128	127	149	121
Condensate Outlet Pressure, P_6, psia	1.99	1.76	1.72	1.49	1.33
Condensate Outlet Temp, T_5, F	109	119	115	111	111
Noncondensible Vent Pressure, P_7, psia	0.4	0.4	0.45	1.18	---
Condensate Conductivity, μ mhos/cm	165	185	350	175	225
Condensate Production Rate, lb/hr	.72	.92	.90	1.1	1.0
Condensate pH	11.9	9.5	9.6	9.4	9.3

TABLE C-

PHYSICAL AND CHEMICAL ANA

Date	7-17	7-21	7-23	7-23
Post Treatment	EMS Charcoal (1)	Barnaby Cheney PC Charcoal(2)	Barnaby Cheney PC Charcoal(3)	None
Pre Treatment	None	None	None	None
pH	10.5	11.0	9.6	9.2
Conductance, μ mho/cm	290	1220	240	195
Color	None	None	None	None
Odor	Faint	Ammonia	Faint	Stron
Turbidity	None	None	None	Slight H
Foam	None	None	None	60 Se
Surface Tension dynes/cm^2	72	71.4	61.8	57.5
Urea Nitrogen mg/l	0	9	22	22
Uric Acid mg/l	0	6.3	9	12
Phenol mg/l	.067	.075	.073	.700
Ammonia Nitrogen mg/l	2	70	60	45
Chloride mg/l	<1	4	<1	<1
COD mg/l	0	18	24	30

(1) Sample was taken after appr
(2) Sample was first liter proc
(3) Sample was taken after appr
(4) Sample was first liter proc
(5) Sample was taken after appr
(6) Sample was second liter pro

IS OF PRODUCT

7-23	7-25	7-29	7-30	7-30	Aerospace Stds. (1967)
Barnaby Cheney 308 Charcoal(4)	Barnaby Cheney 308 Charcoal(5)	Pyrolysis	None	Witco 718 (6)	
None	None	None	CRO_3 & N_2SO_4	CRO_3 & N_2SO_4	
9.4	9.4	9.4	9.5	9.3	5-10
160	460	230	560	440	1700
None	None	None	Yellow	None	15 Platinum Cobalt Units
None	Definite Urine	Slight Urine	Strong Urine	Very Faint	None
None	None	None	Slight Haze	None	10 Jackson Units
None	None	10 Sec	Over 60 Sec	None	15 Sec. Max
72	71.5	71.0	65.5	71.5	---
20	30	6	30	12	---
9	33	22	34	20	---
.060	.014	.060	.012	.014	---
9	120	63	175	82	---
2	7	6	27	9	450
11.6	30	24	107	7	100

mately 6 lb of H_2O had been processed
ed by charcoal
mately 18 lbs of H_2O had been processed
ed by charcoal
mately 25 lbs of H_2O had been processed
sed by charcoal

TABLE 6-5

SPECTROGRAPHIC ANALYSIS OF PRODUCT WATER

All Values mg/l

Date	7-21	7-25	7-29	Aerospace Stds. (1967)
Post Treatment	PC Charcoal	308 Charcoal	Pyrolysis	
Al	<0.01	0.02	0.01	---
B	<0.1	0.4	<0.1	5.0
Ba	0.2	<0.2	<0.2	2.0
Ca	210.0	2.0	0.5	---
Co	<0.01	<0.01	<0.01	---
Cr	<0.01	0.01	<0.01	0.05
Cu	0.006	0.01	0.05	3.0
Fe	0.007	0.017	50.04	1.0
K	55.0	<0.5	300.0	---
Mg	<0.5	0.8	<0.5	---
Mn	<0.01	<0.01	0.25	0.1
Mo	0.02	0.04	<0.02	---
Na	0.7	0.5	<0.5	---
Ni	0.005	0.005	<0.01	---
P	<0.5	<0.5	<0.5	---
Pb	<0.01	<0.01	<0.01	0.2
Si	<0.1	1.0	10.0	---
	0.7	0.1	<0.1	---
Ti	<0.01	0.01	<0.01	---
V	<0.01	0.01	<0.01	---
Zn	<0.01	<0.01	<0.01	0.15

The system was then charged with urine and tested for 13.5 hours over 3 days to check operation with urine. Druing this period, the Teflon bladed compressor was tested. Its power consumption was considerably higher with no appreciable difference in performance; therefore, it was removed and the Tuftride unit reinstalled. A total of 11.41 lb of urine/wash water mix was processed and 10.32 lb of water produced. Recovery efficiency was thus 90.5-percent. Typical product water pH was 8.9 to 10.5, conductivity was 18 to 72µ mhos/cm.

One-Week Simulated Operation - July 21 to July 25, 1969

The system was operated for a total of 63.5 hours in 5 days under essentially steady state conditions. During this period, a total of 57.06 lb of urine/wash water was processed with 54.59 lb of product water produced for a recovery efficiency of 95.5 percent. Average production rate was 0.86 lb/hr.

Post Test Operation - July 28 to July 31, 1969

Following the one-week simulated operation, a series of special runs was conducted to obtain data in specific desired areas. During this period, a total of 27.5 hours of operation was logged in 4 days. A total of 23.35 lb of water was produced at an average rate of 0.85 lb/hr.

Assessment of System Test Results

System Operation

As mentioned earlier in this report, four general problem areas were found during the system test activity:

(1) Compressor life and power consumption

(2) Compressor seal leakage

(3) Foaming in the separator causing contaminate carry-over

(4) Heat transfer limitation and tube plugging at high urine concentration

Each of these problems must be solved by further development and design improvement. On the positive side, system control operation was found to be satisfactory and general system performance was quite good.

Post Treatment

The quality of the product water varied considerably, depending on the post-treatment used. It was obvious that the type of charcoal used will have an effect on the life of a charcoal post-treatment bed. Of the 3 types tested, the Witco 718 appeared to be superior in removing odor--the most difficult task in post-treatment. Evaluation of pyrolysis was not carried far enough due to time limitations; the performance attained in a single short run on August 29, 1969, was not good--previous experience indicates it can be better.

Water Quality

A study of Tables 6-4 and 6-5 shows that water quality was generally satisfactory except for some difficulty in odor. COD's ran below maximum except when no post-treatment was used. Conductivity was below limits except after foam carry-over. pH of the product was consistently basic, indicating ammonia carry-over, which may also be responsible for the odor problem. Certain isolated elements were found in appreciable quantities, particularly Fe with pyrolysis, Si, K, and Cu. Detailed evaluation of the reasons for these rather high concentrations was not made; it is probable that controllable sources will be found in the system.