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Laboratory Evaluation of the Steady-State and Part Load Performance of Absorption Type Heating and Cooling Equipment

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Building Equipment Division
Washington, DC 20234

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

An absorption water chiller and an absorption heat pump were extensively tested under steady-state and cyclic operating conditions. The tests were performed on two different units, one for a cooling only and one for a heating only application, and the results are reported in two separate parts.

In addition to the "black box tests" of the units, the causes for the degradation during part load operation were investigated in more detail using the absorption chiller. Migration of the fluids during the off periods were found to be a major contribution to the degradation.

Furthermore, the influence of various heating water temperatures and flow rates and the sensitivity of the charge on steady-state performance was more closely investigated employing the absorption heat pump.

Key Words: Absorption heat pump; absorption water chiller; causes of degradation; part load performance; steady-state performance

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TABLE OF CONTENTS

	Page
Abstract	iii
Acknowledgements	iv
List of Figures (Parts I and II)	vi
List of Tables (Parts I and II)	vii
PART I - TESTING OF THE ABSORPTION WATER CHILLER	
Introduction	1
Experimental Set-Up	1
Testing Procedure and Evaluation	3
Results and Discussion	5
Steady-State Performance	5
Part Load Performance in the Original Operating Mode	5
Part Load Performance with the Valves in Operation and Without Insulation Applied	7
Part Load Performance with Insulation and the Valves in Operation	9
Part Load Performance at High Cycle Rates	11
Seasonal Performance	11
Conclusions	12
References	12
Appendix	15
PART II - TESTING OF THE ABSORPTION HEAT PUMP	
Introduction	33
Experimental Set-Up	33
Heat Pump Description	33
Test Facility	35
Instrumentation	35
Steady-State Test Procedure	36
Cyclic Tests	36
Results and Discussions	37
Steady-State Test Results	37
Cyclic Test Results	40
Charge Sensitivity	40
Further Tests	44
Conclusions	44
References	45
Appendix	47

LIST OF FIGURES

Part I

Figure 1. Scheme of the absorption water chiller under investigation . . . 2

Figure 2. Steady-State capacity of the absorption water chiller versus outdoor air temperature 6

Figure 3. Part load factor versus cooling load factor for different cycle rates and operating modes of the absorption chiller . . . 8

Figure 4. Comparison of typical behavior of high- and low-side pressures during a cycle with and without valves in operation; spindown was enabled in the latter case 10

Part II

Figure 1. Schematic of the absorption heat pump 34

Figure 2. Coefficient of performance and heating capacity for the absorption heat pump as a function of ambient temperatures . . . 38

Figure 3. Effect of varying inlet load water temperatures on COP for three ambient temperatures 39

Figure 4. Cyclic performance of the heat pump 41

Figure 5. Capacity and evaporator inlet and outlet temperatures as a function of time for a typical cyclic test 42

Figure 6. COP as a function of ambient temperature and refrigerant charge 43

LIST OF TABLES

Part I

Table 1. Cyclic Test Results 14

Table 2. Calculated Seasonal Performance Results 14

Table 3. Thermocouple Locations, Absorption Chiller 16

Part II

Table 1. System Pressures and Concentrations and Evaporator Conditions as a Function of Refrigerant Charge and Ambient Temperature 46

Table 2. Channel Numbers and Thermocouple Locations 48

PART I

TESTING OF THE ABSORPTION WATER CHILLER

INTRODUCTION

An experimental investigation designed to determine the part-load performance of an ammonia-water absorption water chiller is described. The steady-state and cyclic performance of the chiller were measured under controlled conditions in an environmental chamber. Two valves were installed in the chiller to separate high- and low-pressure regions during off times, and insulation was applied to the chiller components. By these measures, losses due to cyclic operation were reduced by over 50%, resulting in a 6% to 7% increase in the calculated seasonal performance factor for typical northern and southern climates in the United States. The use of the valves eliminated the need of the "spindown" period, thereby reducing the consumption of parasitic electrical energy.

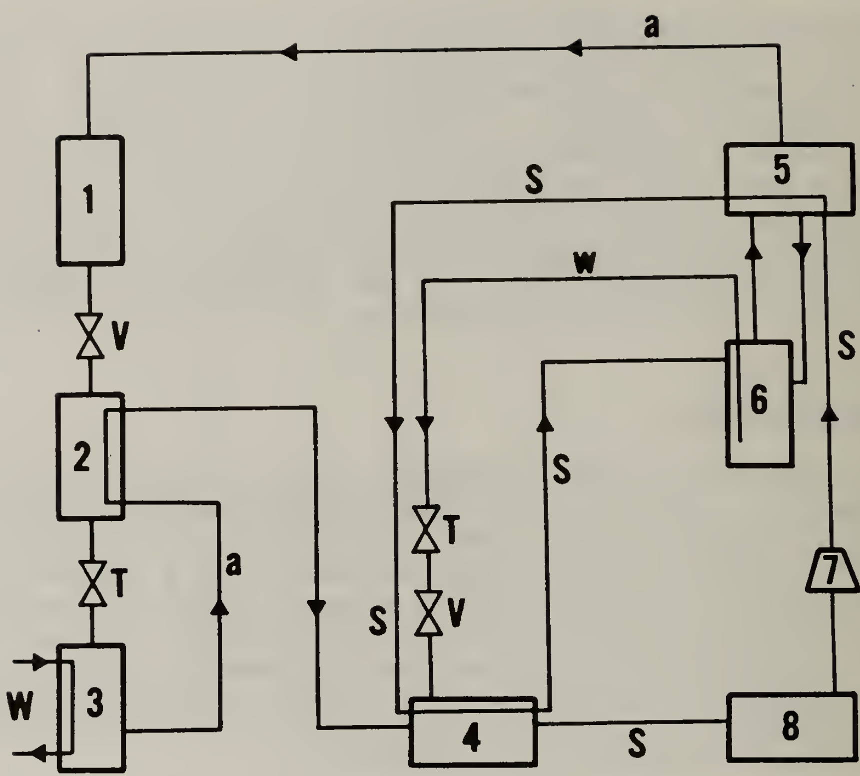
EXPERIMENTAL SETUP

An air-cooled ammonia-water absorption chiller was used in the experimental investigation. The chiller was rated by the manufacturer as capable of cooling 0.45 l/s (7.2 gpm) of water from 12.8°C (55°F) to 7.2°C (45°F) at 35°C (95°F) outdoor dry-bulb temperature; this corresponds to a nominal capacity of 10,550 W (36,000 Btu/hr). The unit is fired by natural gas and requires an energy input of 23,150 W (79,000 Btu/hr) to the combustor. It was designed for residential service, with all of the absorption system components included in one modular package. Also included is a pump for circulating chilled water through the evaporator. The electrical energy required to run the blower and the chilled water and solution pumps is 1050 W.

The chiller was installed in an environmental chamber at the National Bureau of Standards in which the operating conditions (i.e., the air and inlet water temperatures) could be controlled. Air was circulated within the chamber to ensure a uniform air temperature. During cyclic tests, the air temperature was maintained within ±1°C (± 1.8°F) of the set point, while fluctuations during steady-state tests were less than 0.3°C (0.5°F). The test facility was designed to allow a once-through passage of chilled water through the evaporator at a constant inlet temperature of 12.8°C (55°F).

A schematic diagram showing the major components of the absorption chiller appears in Fig. 1. Thermocouples were installed at the inlet and outlet of every component, which provided meaningful temperature measurements at these locations when the solution pump was in operation. The thermocouples were connected to a data acquisition system, which recorded the temperatures at these locations at one-minute intervals.

The capacity of the chiller was obtained by measuring the flow rate and temperature change of the water flowing through the evaporator. A turbine meter was installed in the inlet stream and calibrated in situ at the design



1 CONDENSER
2 REFRIGERANT HEAT EXCHANGER
3 EVAPORATOR
4 SOLUTION COOLED ABSORBER

5 RECTIFIER
6 GENERATOR
7 SOLUTION PUMP
8 AIR COOLED ABSORBER

S STRONG SOLUTION
w WEAK SOLUTION
a AMMONIA VAPOR
W CHILLED WATER

V VALVES BUILT IN TO SEPARATE HIGH AND LOW PRESSURE REGIONS

T RESTRICTORS

Figure 1. Scheme of the absorption water chiller under investigation.

flow rate. An electronic counter was connected to the turbine meter to allow recording of the instantaneous and average flow during a test. The chilled water flow rate and inlet temperature were maintained constant at 0.45 l/s and 12.8°C (55°F) in all tests. Thermocouples were installed in the chilled water inlet and outlet streams close to the unit and were connected to the data acquisition system. In addition, two thermopiles were installed between the two streams and connected to a strip-chart recorder to provide a continuous record of the temperature difference. The estimated precision of the capacity measurement is within 1%.

The volumetric flow rate, temperature, and pressure of the natural gas were measured in each test. The higher heating value of the natural gas was determined in a calorimeter in operation at the National Bureau of Standards. The energy consumption of the combustor heating the generator was determined with an estimated precision of 2%.

Pressure gauges were mounted on the generator and absorber of the unit to measure the high- and low-side pressures. These pressures were recorded at the beginning and end of the burner on-time and spindown periods. In addition, for some cyclic tests, the pressures were recorded at short time intervals during the entire cycle. Both pressure gauges were calibrated on a deadweight gauge-tester prior to the tests.

Before most of the tests were conducted, two remote-activated ball valves were installed. Their positions within the unit are indicated in Fig. 1. In order to install the valves, it was necessary to remove ammonia and to replace it again after the work was completed. The ammonia charge was adjusted to maximize the steady-state capacity at the standard rating point (35°C [95°F] outdoor air temperature, 12.7°C [55°F] chilled water return temperature). This capacity was within 1% of that obtained before the valves were installed.

After testing the influence of the valves, the following parts of the absorption chiller were insulated with glass wool: the solution-cooled absorber, the receiver located before the solution pump, and the rectifier and that part of the generator that is not in direct contact with the burner. In addition, the panel between the components listed above and the condensing unit was insulated. To prevent further heat losses from the generator by convection, the exhaust for the flue gases was closed during off-times. The effect of the insulation on the steady-state performance was checked, and no change in the capacity was detectable.

TESTING PROCEDURE AND EVALUATION

All tests were conducted with a chilled water flow rate of 0.45 l/s (7.2 gpm) and a chilled water inlet temperature of 12.8°C (55°F). Prior to each steady-state test, steady conditions were first established in the environmental chamber and then data were taken and averaged over a 30-minute period. The steady-state capacity, $\dot{Q}_{ss}$, was determined by the relationship

$$\dot{Q}_{ss} = \dot{m} C_p \Delta T_{ss} \qquad (1)$$

where $\dot{m}$ is the mass flow rate of chilled water, C_p is the specific heat of water, and ΔT_{ss} is the steady-state temperature difference between the inlet and outlet chilled water streams. $\dot{Q}_{ss}$ is the instantaneous capacity which is equal to the average capacity in steady-state operation

The steady-state coefficient of performance (COP_{ss}) is defined here as the ratio of the capacity to the sum of the rate of gas energy input to the combustors and the steady-state electrical power input to the blower and pumps, $\dot{E}_{ss}$.

$$COP_{ss} = \frac{\dot{Q}_{ss}}{\dot{E}_{ss}} \tag{2}$$

This definition of COP weights the rate of gas energy input and power consumption equally. Since other equally appropriate definitions of COP exist, the experimental results in Tab. 1 contain the ratio of the electrical power to the rate of gas energy inputs.

For the cyclic tests, steady conditions were first established in the environmental chamber. After a warm-up period, the unit was cycled on and off for the amount of time appropriate for each test for three cycles. The averaged data from the last two cycles were used in the following calculation.

The total cooling during a cycle, Q_{cyc}, was determined by

$$Q_{cyc} = \dot{m}C_p \int_{t_1}^{t_2} \Delta T \, dt \tag{3}$$

where ΔT is the instantaneous temperature difference between the inlet and outlet chilled water streams and t_1 and t_2 are the times that the chilled water pump was turned on and off, respectively.

The pump operating time coincided with the burner on-time when the spindown period was disabled. Otherwise, the pump operating time was about 4.5 minutes longer than the burner on-time. (In the following discussion, the term "on-time" always means burner on-time, although the capacity was evaluated for the entire period in which the chilled water circulation pump was in operation.) The total gas and electrical energy input to the unit over the interval t_1 to t_2, E_{cyc}, was measured and used to calculate the coefficient of performance for cyclic operation.

$$COP_{cyc} = \frac{Q_{cyc}}{E_{cyc}} \tag{4}$$

The cyclic test data are presented in Tab. 1 in terms of a cooling-load factor and a part-load factor, similar to the factors used to describe the cyclic performance of vapor compression machines.[5] The cooling load factor, CLF, is defined

$$CLF = \frac{Q_{cyc}}{\dot{Q}_{ss}\, T_{cyc}} \quad (5)$$

where Q_{cyc} is the integral cyclic capacity over one cycle, $\dot{Q}_{ss}$ is the steady-state capacity rate at the same air temperature as for the cyclic test, and T_{cyc} is the cycle period which is the sum of the burner on- and off-times.

Defined in another (equivalent) way, CLF is the ratio of the cooling that is supplied at a particular outdoor air temperature to the steady-state capacity of the machine at that temperature. It is a dimensionless measure of the degree of part-load operation. Values near unity indicate that the machine must operate nearly continuously to meet the load; values near zero occur when the machine is off for most of the time.

The part-load factor, PLF, is defined

$$PLF = \frac{COP_{cyc}}{COP_{ss}} \quad (6)$$

The part-load factor is less than or equal to unity; it is a dimensionless measure of the performance penalty for cyclic operation.

RESULTS AND DISCUSSION

STEADY-STATE PERFORMANCE

Steady-state tests were conducted at air temperatures of 21.7°C (71°F), 26.7°C (80°F), 35.0°C (95°F), and 38.0°C (100.4°F). The test results appear in lines 1, 2, 3, and 4 of Tab. 1. A plot of the measured capacity versus air temperature is shown in Fig. 2. The capacity is strongly dependent on the air temperature, especially for temperatures higher than about 30°C (86°F). Increasing temperatures decreased the capacity significantly.

PART-LOAD PERFORMANCE IN THE ORIGINAL OPERATING MODE

Cycle rates were chosen for most of the tests according to the thermostat characteristics supplied by the manufacturer. (Thermostat cycle rates are not constant but rather a parabolic function of burner on-time.[3] The maximum recommended cycle rate for this absorption chiller is about 1.5 cycles per hour (CPH), which occurs at 50% on-time. At 20% and 80% on-time, the cycle rate with the recommended thermostat is 1.0 CPH.)

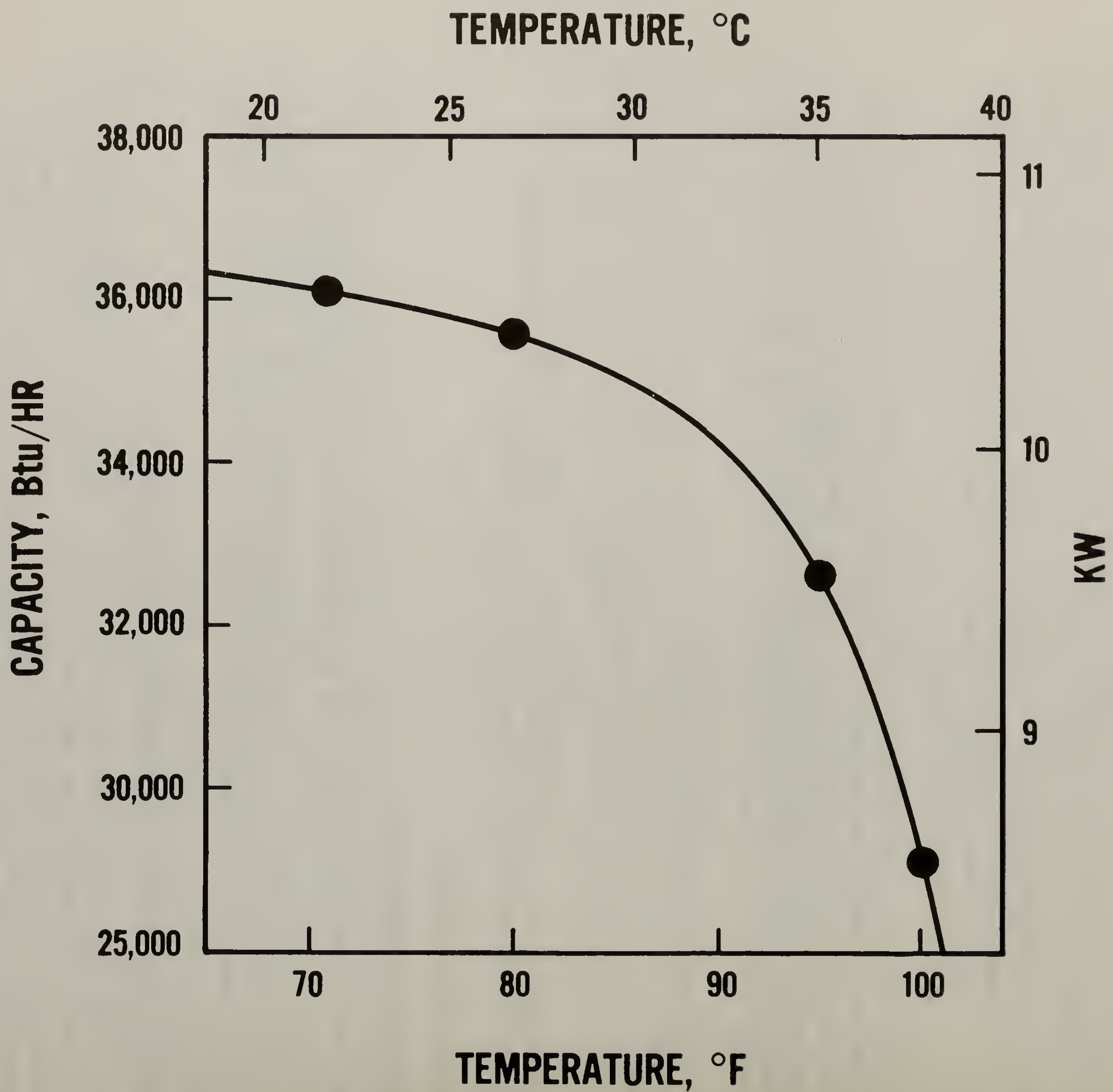


Figure 2. Steady-state capacity of the absorption water chiller vs. outdoor air temperature.

The tests listed in lines 5, 6, 7, 8, and 14 of Tab. 1 were conducted to measure the part-load performance of the absorption chiller in its original operating mode (i.e., without additional insulation, without the valves in operation, and with the spindown period enabled). The tests shown in lines 5 and 8 were conducted under the same conditions but at the beginning and in between the other tests, respectively, to check the reproducibility of the experimental data, which was found to be satisfactory. During a cooling season, an absorption chiller is operated at a variety of cycle rates and outdoor air temperatures. Tests were conducted to determine how changes in the outdoor temperature affect the part-load factor (PLF) at a given cycle rate. The results in lines 5, 6, and 7 of Tab. 1 show that both the part-load factor and the cooling load factor (CLF) decrease with increasing outdoor air temperature. The deviation in PLF between 21.6°C (71°F) and 35°C (95°F) is about 7%, while the change in CLF is about 9% In an installation in which the chiller is appropriately sized, part-load operation is more likely to occur at temperatures below the design condition. Therefore, all of the remaining cyclic tests were conducted at 26.6°C (80°F) as a representative condition.

The circles in Fig. 3 show the experimental values of PLF plotted versus CLF for the absorption chiller in its original operating mode over a range of part-load operating conditions. The size of the symbols in Fig. 3 is indicative of the uncertainty in the measured values. For comparison, the part-load performance of vapor compression systems (at a maximum cycle rate of 3 CPH), as assumed in Ref 4, is indicated by line a in Fig. 3. The performance of the absorption system is not considerably lower than that of vapor compression systems when it is operated at the recommended cycle rate, which is about one-half the cycle rate for vapor compression systems.

PART-LOAD PERFORMANCE WITH THE VALVES IN OPERATION AND WITHOUT INSULATION APPLIED

In this section, the part-load performance of the chiller in its original operating mode (lines 5, 6, 7, 8, and 14 of Tab. 1) is compared with its performance when the valves are closed during the burner off-time and open during the burner on-time (lines 10 and 16). The spindown period was disabled when the valves were operated. Tests were also conducted in which the valves were closed after the spindown period was completed. However, these tests resulted in slightly lower part-load factors than those with disabled spindown, and they required significantly more electrical energy. Apparently, the operation of the valves eliminates the need of the spindown period.

Comparing the temperature changes within the unit during the on-time, it was obvious that the average temperatures during the cycle are closer to their steady-state values when the valves are operated than when they are not. Further, when the valves were operated, there was no time delay for the temperature rise of the fluid leaving the solution-cooled absorber. This time-delay, which was 1.5 minutes in the original operating mode, indicates that the liquid absorbent solution traveled during the off-time from the generator to the solution-cooled absorber and needed to be pumped back to the generator. A similar time-delay was observed for the capacity in the original operating mode. Again, it took approximately 1.5 minutes after turning on the unit

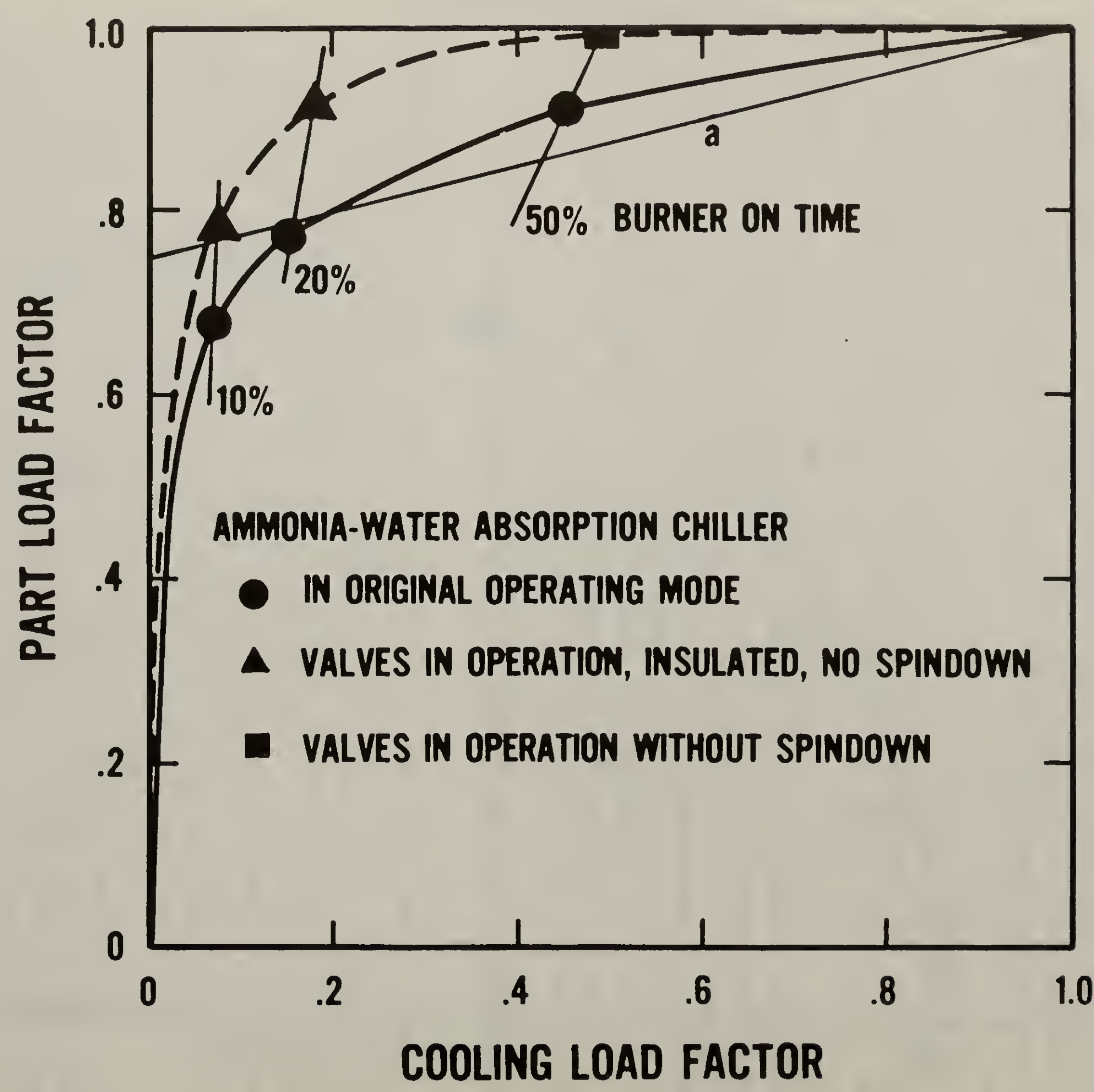


Figure 3. Part load factor vs. cooling-load factor for different cycle rates and operating modes of the absorption chiller.

until it started to cool down the incoming water. This time-delay was not present when the valves were operated.

The valves also affect the behavior of the pressures as illustrated in Fig. 4. During the off-time, the high- and low-side pressures converge to the same pressure, and then they both drop at the same rate in the original operating mode. The low-side pressure remains unchanged during the off-time when the valves are operated, while the high-side pressure drops significantly in the beginning of the off-time but then stabilizes at a relatively high value. During the on-time, the high-side pressure achieves higher values (closer to the steady-state values) when the valves are operated, while the low-side pressure remains stable at its steady-state value. The peaks shown by the high- and low-side pressures after turning off the unit were observed in all cases in which spindown was disabled including those cases in which the valves were not operated. They are due to time-delays in heat and mass fluxes in generator and absorber, respectively. During cyclic operation at high outdoor air temperatures, these peaks could cause the pressure relief valve to open. The peaks could be significantly reduced by a short spindown period, e.g., thirty seconds.

The above described behavior was qualitatively observed for all cycle rates. It indicates that, during the on-time, these variables return toward their steady-state values from higher initial values, resulting in an increased COP and PLF. The increase in performance is significant. For example, at 1.0 CPH and 20% on-time, the PLF increases by more than 13% (lines 5 and 10 of Tab. 1). In this case, the valve operation reduces the degradation in performance as a result of cyclic operation to almost half its original value.

Less electrical energy is used when the spindown period is disabled. The difference in electrical use increases as the on-time decreases. For 1.0 CPH and 20% on-time, the power consumption is reduced by 30%; this can be evaluated by comparison of the electricity to gas input ratio in Tab. 1 lines 8 and 10.

PART-LOAD PERFORMANCE WITH INSULATION AND THE VALVES IN OPERATION

The chiller was insulated as described earlier in an effort to further improve its part-load performance. The insulation produced no detectable change in the steady-state performance. With the insulation in place, the chiller was operated with the spindown period disabled and the valves in operation (Tests 11, 13, 17, 18, Tab. 1). The effect of the insulation could be seen by examining the temperatures at various points within the unit. With the insulation in place, the temperatures were generally higher when the unit was turned on. For example, the temperature of the weak solution leaving the generator was 75°C (167°F) at the beginning of the on-time in the case of the insulated unit and 47°C (117°F) when the unit was not insulated; the valves were operated in both cases. (For comparison, the steady-state value is 115°C [239°F]). The behavior of the pressures was, within experimental error, not affected by the insulation. Qualitatively, these effects were observed for all cycle rates.

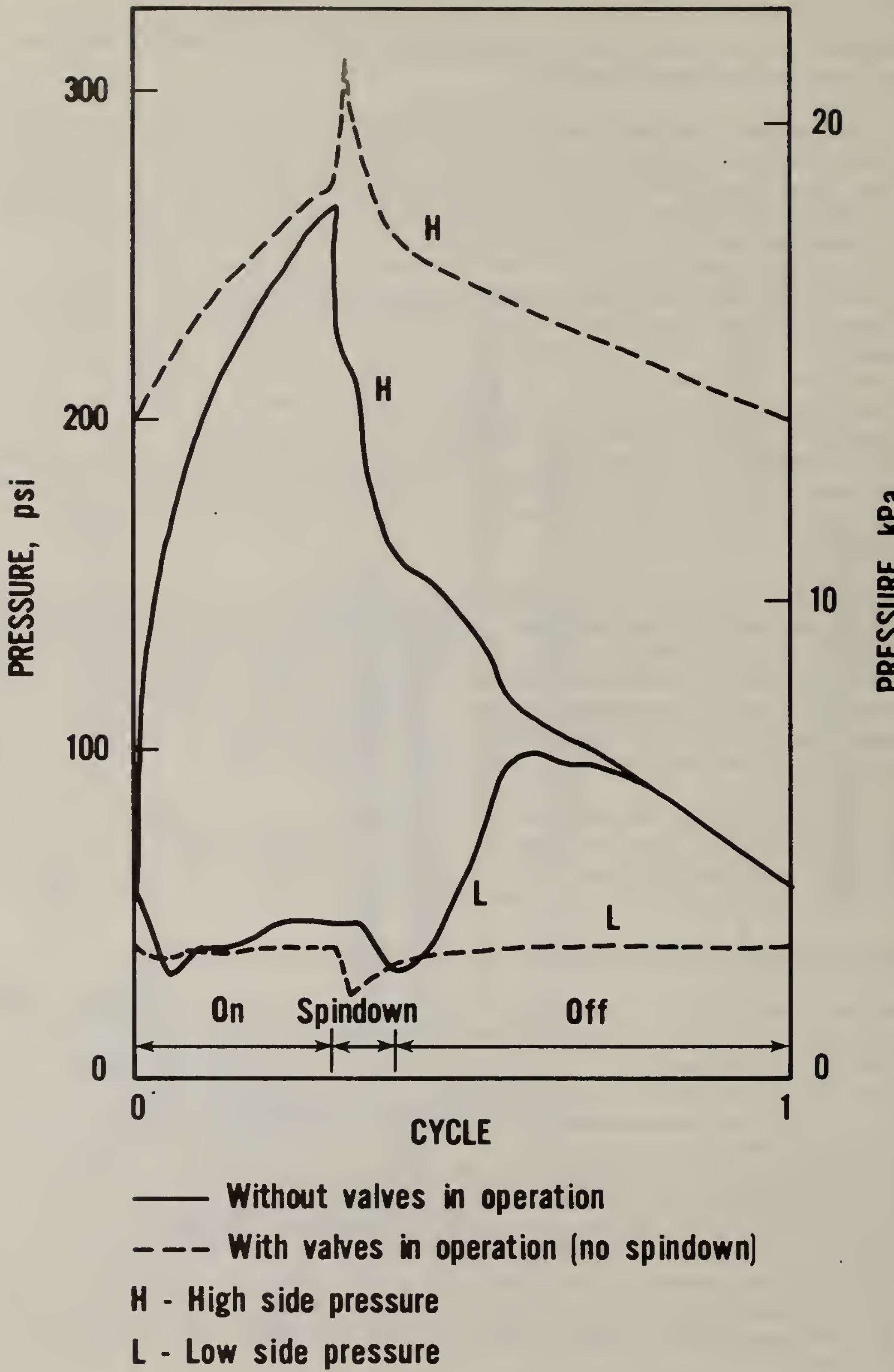


Figure 4. Comparison of typical behavior of high- and low-side pressures during a cycle with and without valves in operation; on the latter case, spindown was enabled.

Insulating the chiller components improved the part-load performance of the chiller. The triangles in Fig. 3 show values of PLF plotted versus CLF for the insulated unit with the valves in operation and the spindown period disabled (Tests 11, 13, Tab. 1). The square symbol in Fig. 3 represents a test that was conducted without insulation (line 16, Tab. 1). However, since the PLF for this test was 0.994, a further increase in PLF due to insulation is not expected; the test result indicated by the square in Fig. 3 thus represents both the uninsulated and insulated results with the valves in operation. The PLF at 20% on-time and 1.0 CPH is 15% higher than that for the unit in its original operating mode. The insulation itself achieves an increase in PLF of 3% compared to operation of the valves alone, which is a much smaller contribution than that attributed to the operation of the valves alone (Tests 10, 11, Tab. 1).

PART-LOAD PERFORMANCE AT HIGH CYCLE RATES

The maximum cycle rate recommended for the absorption chiller (1.5 CPH at 50% on-time) is about half of that commonly employed for vapor compression systems. Lower cycle rates result in larger temperature fluctuations in the air-conditioned space and, presumably, lower occupant comfort. To see if this disadvantage of the absorption chiller could be relaxed, the unit was tested with the insulation in place and with the valves in operation at 2.0 CPH, 20% on-time and 3.0 CPH, 50% on-time. The results are shown in lines 17 and 18 of Tab. 1. The performance is almost as good as for the lower cycle rates, which are displayed in lines 11 and 16. The maximum deviation in PLF is 2%. These results demonstrate that, with the insulation and valves, the absorption unit may be operated at cycle rates typical for vapor compression systems while still showing a considerably higher performance than vapor compression systems, as indicated by line a in Fig. 3.

In order to show the influence the cycle rate on the absorption chiller performance in its original operating mode, the chiller was tested at 3.0 CPH, 50% on-time. The test results appear in line 19 of Tab. 1. The PLF is 7% lower at the higher cycle rate than at the recommended cycle rate (line 14).

Higher cycle rates with spindown enabled result in a larger percentage of electrical energy input. A 37% reduction in electrical energy consumption is achieved at 3.0 CPH, 50% on-time, by eliminating the spindown period (Tab. 1 lines 18 and 19).

SEASONAL PERFORMANCE

The performance data obtained in this investigation were used to calculate the seasonal performance factor, SPF, of the absorption chiller. The seasonal performance factor is defined as the ratio of the total cooling load supplied to the total fuel and electrical energy consumed by the chiller during the cooling season. In the results given below, the fuel and electrical energy were equally weighted. To fairly compare absorption chillers with vapor compression machines, however, the electrical energy consumption should be divided by the efficiency of its generation for both systems.

The calculations were made for residential applications according to the modified bin-temperature method given in Ref 5. The modified bin-temperature calculation procedure uses the information in Fig. 3 to estimate the part-load performance of the chiller in each temperature bin and thereby provides an estimate of the seasonal performance including the effects of cyclic operation. The calculations were done for a generalized northern and southern climate;[5] the results are shown in Tab. 2.

Column 1 in Tab. 2 shows the values of SPF that would be achieved if the unit were to operate under all circumstances with the steady-state COP for any given air temperature. This is an upper limit for the SPF. Column 2 in Tab. 2 displays the SPF obtained by the unit in its original operating mode, while column 3 shows the SPF achieved by the unit with insulation in place, the valves in operation, and the spindown period disabled. Compared with the original operating mode, the insulation and valves increase the SPF by 7.0% in the southern climate and by 6.4% in the northern climate. Expressed in another way, these figures indicate that the losses due to part-load operation can be reduced by approximately 50% by the insulation and valves.

CONCLUSIONS

The results show that migration of the working fluids during the off-time is a major factor contributing to the degradation of the absorption chiller performance during cyclic operation. This migration can be reduced by the installation of automatic valves that separate the low- and high-pressure regions during the off-periods. The use of the valves eliminates the need for the spindown period and results in a significant reduction of electrical energy consumption during cyclic operation. Insulating the chiller components in this way also increased the part load performance but not to the same extent as the valves. A 6% to 7% increase in the calculated seasonal performance factor results from the use of the valves and insulation.

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TABLE 1
Cyclic Test Results

No.	Air Temp. °C(°F)	Cycle Rate CPH	Burner On/off Time [min]	Burner On Time percent	Electric to Gas Input Ratio 10^2	Valves Applied	Insulation Applied	Spindown Enabled	PLF	CLF
1	21.7 (71)	Steady State Test			4.69	N.A.	no	N.A.	1.0	1.0
2	26.7 (80)	"	"	"	4.64	N.A.	no	N.A.	1.0	1.0
3	35.0 (95)	"	"	"	4.73	N.A.	no	N.A.	1.0	1.0
4	37.8 (100)	"	"	"	4.80	N.A.	no	N.A.	1.0	1.0
5	26.7 (80)	1	12/48	20	6.27	no	no	yes	0.771	0.153
6	21.7 (71)	1	12/48	20	6.10	no	no	yes	0.788	0.164
7	35.0 (95)	1	12/48	20	6.56	no	no	yes	0.735	0.149
8	26.7 (80)	1	12/48	20	6.26	no	no	yes	0.769	0.152
9	26.7 (80)	1	12/48	20	6.21	yes	no	yes	0.870	0.171
10	26.7 (80)	1	12/48	20	4.78	yes	no	no	0.882	0.172
11	26.7 (80)	1	12/48	20	4.86	yes	yes	no	0.918	0.180
12	26.7 (80)	0.6	10/90	10	6.52	no	yes	yes	0.679	0.068
13	26.7 (80)	0.6	10/90	10	4.75	yes	yes	no	0.783	0.076
14	26.7 (80)	1.5	20/20	50	5.68	no	no	yes	0.912	0.451
15	26.7 (80)	1.5	20/20	50	5.67	yes	no	yes	0.979	0.489
16	26.7 (80)	1.5	20/20	50	4.72	yes	no	no	0.994	0.491
17	26.7 (80)	2	6/24	20	4.87	yes	yes	no	0.898	0.175
18	26.7 (80)	3	10/10	50	4.86	yes	yes	no	0.996	0.483
19	26.7 (80)	3	10/10	50	6.65	no	no	yes	0.849	0.429

TABLE 2
Calculated Seasonal Performance Results

	Maximum Achievable SPF	Absorption Chiller in Original Operation Mode	Modified Absorption Chiller
Southern Climate	0.434	0.387	0.413
Northern Climate	0.436	0.386	0.405

APPENDIX

Experimental Data in Detail

In the following, the original experimental data will be presented for all the tests performed. Table 3 gives all thermocouple locations. In Table 4, all steady-state test data are presented. The cyclic test data follow.

Table 3. Thermocouple Locations, Absorption Chiller

Channel No.	Location
0	Icebath
1	Pump in
2	Pump Out
3	Solution into Generator
4	Solution out of Generator
5	Solution into Absorber Heat Exchanger
6	Unit Plenum Air DB
7	Ammonia into Condenser
8	Ammonia out of Condenser
9	Ammonia into Evaporator
10	Ammonia out of Evaporator
11	Ammonia into Absorber
12	Liquid Ammonia into Refr. Heat Ex.
13	Liquid Ammonia out of Refr. Heat Ex.
14	Generator Top
15	Middle
16	Bottom
17	Solution cooled Absorber Top
18	Bottom
19	Air cooled Absorber Bottom
20	Middle
21	Top
22	Condenser Top
23	Middle
24	Bottom
25	Evaporator Top
26	Middle
27	Bottom
28	Air Inlet
29	Air off Condenser Coils
30	Stack Gases
31	Water Inlet
32	Water Outlet
33	Water Bypass
34	Ambient Air DB
35	Ambient Air WB
36	Temperature Difference Water Inlet/Outlet (16 Junction Thermopile, Reading in mV)
37	Evaporator Water Discharge Line
38	Evaporator Water Bottom
39	Middle
40	Top
41	Evaporator Water Inlet Line
42	Solution out of Absorber
43	Solution out of Absorber Coils
44	Absorbent into Absorber
45	Refrigerant into Refr. Heat Ex.
46	Gas Supply Temperature
47	Icebath

NUMBER OF TEST	1	2	3	4	
Time (min)	30	30	30	30	
Gas Meter (ft^3)	38.2	38.25	37.6	37.6	
Gas Pressure (in H_2O)	5.2	5.2	5.2	5.2	
Bar. Pressure (in Hg)	29.5	29.6	29.7	29.6	
Water Flow Rate (Hz)	324	326	325	326	water flowrate in Hz x 2.247^{-10} = water flowrate in gal/min.
Pressures Low/High (psig)	36/245	42/260	57/310	59/325	
Power to Unit (kWh)	524	526	528	534	
Power to pumps only (kWh)	219	222	233	239	
Oxygen %	--	9.0	8.5	8.9	
CO_2 Sample %	--	50	50	49.0	
CO_2 Span %	—	99	100	99	
CO_2 Zero %	--	40.5	42	41	
Composition of Weak Solution $\frac{\text{lb }(NH_3)}{\text{lb }(NH_3 + H_2O)}$	0.53	.053	.087	.085	
Outdoor Temperature °F	71	80	95	100	

STEADY-STATE TEST DATA

No. 5	A	B	Cyclic Test C	12/48 min on/off time 20% on time	80°F outdoor temperature
Burner on time (min)	12	12	12		
Gas meter (ft^3)	15.35	15.30	15.2		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in hg)	29.1	29.1	29.1		
Water flow rate (Hz)	323	323	323		
Power (cycle) kWh	275	277	276		
Pressure: Low/high side (psig)	112	112	112		
at start of burner on time:	71/75	67/175	50/56		
at end of burner on time:	45/259	45/256	45/260		
at end of spin down:	36/153	33/150	33/145		
Capacity (Btu/hr)	5479	5482	5459		
Gas input (Btu/hr)	15352	15340	15238		
Electricity (Btu/hr)	941	945	942		
COP_{cyc}	.337	.337	.337		
PLF/CLF	.77/.15	.77/.15	.77/.15		
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 6	A	B	Cyclic Test C	12/48 min on/off time 20% on time	70°F Outdoor temperature
Burner on time (min)	12	12	12		
Gas meter (ft^3)	16.0	15.4	15.4		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.1	29.1	29.1		
Water flow rate (Hz)	320	323	323		
Power (cycle) kWh	285	276	271		
Pressure: Low/high side (psig)	114	113	115		
at start of burner on time:	42/47	58/65	60/67		
at end of burner on time:	36/235	37/242	-/-		
at end of spin down:	23/130	-/-	-/-		
Capacity (Btu/hr)	6018	5845	5805		
Gas input (Btu/hr)	15957	15358	15373		
Electricity (Btu/h)	972	941	926		
COP_{cyc}	.356	.359	.356		
PLF/CLF	.785/.167	.792/.162	.786/.161		
Steady State COP	.453				
Capacity (Btu/hr)	36122				

CYCLIC TEST DATA

No. 7	A	B	C	12/48 min on/off time 20% on time	95°F Outdoor temperature
Burner on time (min)	12	12	12		
Gas rate (ft^3)	15.01	14.99	15.04		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in hg)	29.6	29.6	29.6		
Water flow rate (Hz)	325	323	324		
Power (cycle) kWh	289	292	287		
Power pumps only kWh	118	118	116		
Pressures: burner on	84/90	68/110	85/92		
burner off	58/305	58/307	58/304		
unit off	45/179	39/190	40/195		
Capacity (Btu/hr)	4921	4793	4730		
Gas input (Btu/h)	15009	15009	15049		
Electricity (Btu/h)	986	996	979		
COP_{cyc}	.308	.299	.295		
PLF/CLF	.753/.151	.732/.147	.721/.145		
Steady State COP	.409				
Capacity	32600				

CYCLIC TEST DATA

No. 8	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	12	12	12		
Gas meter (ft^3)	15.05	15.7	15.4		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.6	29.6	325		
Water flow rate (Hz)	325	324	325		
Power unit (kWh)	272	282	289		
Power pumps only (kWh)	110	115	116		
Pressure (psi) burner on	36/120	53/60	77/85		
burner off	47/267	46/262	47/270		
unit off	42/155	32/150	35/150		
Capacity (Btu/hr)	5266	5607	5609		
Gas input (Btu/h)	14959	15655	15307		
Electricity (Btu/h)	928	962	986		
COP_{cyc}	.331	.337	.344		
PLF/CLF	.754/.148	.768/.158	.784/.158		
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 9	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	12	12	12		
Gas meter (ft^3)	15.6	15.5	15.4		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.1	29.1	29.1		
Water flow rate (Hz)	323	323	323		
Power unit (kWh)	286	281	277		
Power pumps only (kWh)	114	114	112		
Pressure (psi) burner on	18/141	25/145	18/137		
burner off	45/259	45/260	44/264		
unit off	32/155	33/148	32/150		
Capacity (Btu/hr)	6270	6329	6297		
Gas input (Btu/h)	15589	15539	15439		
Electricity (Btu/h)	975	959	945		
COP_{cyc}	.379	.384	.384		
PLF/CLF	.87/.384	.87/.380	.87/.382		
Steady State COP					
Capacity	35500				

CYCLIC TEST DATA

No. 10	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	12	12	12		
Gas meter (ft^3)	15.2	15.2	15.2		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.7	2-.7	29.7		
Water flow rate (Hz)	320	322	320		
Power unit (kWh)	211	213	212		
Power Pumps only (kWh)	89	89	88		
Pressure (psi) burner on	35/168	37/157	38/160		
burner off	45/270	42/262	45/262		
unit off	-/-	-/-	-/-		
Capacity (Btu/hr)	6240	6087	6150		
Gas input (Btu/h)	15238	15238	15231		
Electricity (Btu/h)	720	727	723		
COP_{cyc}	.391	.381	.385		
PLF/CLF	.88/.17	.88/.17	.11/.17		
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 11	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	12	12	12		
Gas meter (ft^3)	15.2	15.1	15.2		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.7	29.7	29.7		
Water flow rate (Hz)	322	327	328		
Power unit (kWh)	213	214	217		
Power Pumps only (kWh)	90	89	92		
Pressure (psi) burner on	38/162	37/160	38/160		
burner off	43/265	45/265	46/273		
unit off	-/-	-/-	-/-		
Capacity (Btu/hr)	6403	6328	6431		
Gas input (Btu/h)	15193	15059	15159		
Electricity (Btu/h)	727	730	740		
COP_{cyc}	.403	.401	.405		
PLF/CLF	.918/.180	.913/.178	.922/.181		
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 12	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	10	10	10		
Gas meter (ft^3)	12.75	12.76			
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.6	29.0	29.0		
Water flow rate (Hz)	326	325	326		
Power unit (kWh)	244	249	242		
Power Pumps only (kWh)	98	98	96		
Pressure (psi) burner on	68/75	67/75	69/75		
burner off	45/258	44/252	46/250		
unit off	35/150	32/153	33/155		
Capacity (Btu/hr)			4019		
Gas input (Btu/h)	CHART DRIVE OUT OF ORDER		12678		
Electricity (Btu/h)			826		
COP_{cyc}			.298		
PLF/CLF			.679/.068		
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 13	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	10	10	10		
Gas meter (ft^3)	12.58	12.6	12.5		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.7	29.7	29.7		
Water flow rate (Hz)	324	321	324		
Power unit (kWh)	177	175	177		
Power pumps only (kWh)	74	72	74		
Pressure (psi) burner on	36/137	36/140	35/140		
burner off	44/258	45/265	36/142		
unit off	41/301	41/304	-/-		
Capacity (Btu/hr)	4616	4540	4510		
Gas input (Btu/h)	12617	12638	12537		
Electricity (Btu/h)	604	597	604		
COP_{cyc}	.349	.343	.343		
PLF/CLF	.745/.078	.781/.277	.782/.076		
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 14	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	20	20	20		
Gas meter (ft^3)	25.65	25.4	25.7		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.35	29.35	29.35		
Water flow rate (H_z)	323	325	323		
Power (cycle) kWh 417 174	17/17 45/265 -/-	426 174 86/94 48/275 35/150	422 173 90/100 47/270 34/155		
Capacity (Btu/hr)	10673	10702	10855		
Gas input (Btu/h)	25452	25204	25502		
Electricity (Btu/h)	1422	1453	1439		
COP_{cyc}	.397	.401	.403		
PLF/CLF	.904/.45	.915/.45	.918/.46		
Steady State COP Capacity	.439 35500				

No. 15	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	20	20	UNSTEADY WATER TEMPERATURE		
Gas meter (ft^3)	25.35	25.65			
Gas pressure (in H_2O)	5.2	5.2			
Barometer (in Hg)	29.35	29.35			
Water flow rate (Hz)	323	323			
Power unit (kWh)	422	418			
Power pumps only (kWh)	171	173			
Pressure (psi) burner on	30/150	30/150			
burner off	47/270	47/273			
unit off	-/⊔	33/155			
Capacity (Btu/hr)	11350	11617			
Gas input (Btu/h)	25154	25452			
Electricity (Btu/h)	1439	1426			
COP_{cyc}	.427	.432			
PLF/CLF	.972/.48	.985/.49			
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 16	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	20	20			
Gas meter (ft^3)	25.3	25.45			
Gas pressure (in H_2O)	5.2	5.2			
Barometer (in Hg)	29.35	29.35			
Water flow rate (Hz)	322	325			
Power unit (kWh)	348	353			
Power pumps only (kWh)	149	149			
Pressure (psi) burner on	38/210	30/205			
burner off	46/258	47/270			
unit off	-/-	-/-			
Capacity (Btu/hr)	11451	11552			
Gas input (Btu/h)	25105	25253			
Electricity (Btu/h)	1187	1204			
COP_{cyc}	.436	.437			
PLF/CLF	.992/.48	.995/.49			
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 17	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	6	6	6		
Gas meter (ft^3)	7.5	7.5	7.25		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.5	29.5	29.5		
Water flow rate (Hz)	325	326	327		
Power unit (kWh)	105	109	109		
Power pump only (kWh)	45	45	45		
Pressure (psi) burner on	37/200	42/170	43/190		
burner off	49/260	49/265	50/260		
unit off	-/-	-/-	-/-		
Capacity (Btu/hr)	3181	3095	3099		
Gas input (Btu/h)	7479	7479	7579		
Electricity (Btu/h)	358	372	372		
COP_{cyc}	.406	.394	.390		
PLF/CLF	.925/.179	.898/.174	.888/.175		
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 18	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	10	10			
Gas meter (ft^3)	13.0	12.5			
Gas pressure (in H_2O)	5.2	5.2			
Barometer (in Hg)	29.7	29.7			
Water flow rate (Hz)	325	323			
Power unit (kWh)	179	178			
Power pumps only (kWh)	72	78			
Pressure (psi) burner on	80/125	45/245			
burner off	46/265	49/278			
unit off	43/305	46/320			
Capacity (Btu/hr)	5708	5736			
Gas input (Btu/h)	12487	12437			
Electricity (Btu/h)	610	610			
COP_{cyc}	.436	.440			
PLF/CLF	.993/.482	1.0/.485			
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

No. 19	A	B	Cyclic Test C	12/48 on/off time 20 % on time	80°F Outdoor temperature
Burner on time (min)	10	10	10		
Gas meter (ft^3)	12.75	12.75	12.7		
Gas pressure (in H_2O)	5.2	5.2	5.2		
Barometer (in Hg)	29.4	29.4	29.4		
Water flow rate (Hz)	324	326	325		
Power unit (kWh)	250	251	247		
Power pumps only (kWh)	107	100	101		
Pressure (psi) burner on	77/122	65/116	77/127		
burner off	45/256	45/256	47/262		
unit off	31/137	32/150	35/149		
Capacity (Btu/hr)	5060	5182	5041		
Gas input (Btu/h)	12788	12788	2738		
Electricity (Btu/h)	853	856	843		
COP_{cyc}	.371	.380	.371		
PLF/CLF	.845/.428	.865/.430	.846/.426		
Steady State COP	.439				
Capacity	35500				

CYCLIC TEST DATA

PART II

TESTING OF THE ABSORPTION HEAT PUMP

INTRODUCTION

A gas-fired air-to-water heating only absorption heat pump using ammonia and water as the working fluid has been investigated. This machine is a prototype unit developed by an American investigator under Government sponsorship and was tested in an environmental chamber. The steady state COP (based on total energy input) and capacity ranged from 0.81 and 14.3 kW at an ambient temperature of -21°C to 1.14 and 15.9 kW at 16°C with an inlet water temperature of 41°C. The sensitivity of the steady-state performance to inlet water temperature was also investigated. The performance was significantly decreased by cycling; for example, at a cycling rate of two cycles per hour and 20 percent burner on time the COP was 0.53 of the steady-state value.

In the second set of steady-state tests samples of the strong and weak absorbent were taken, heat flows across the components of the absorption cycle were measured and the sensitivity to varying refrierant charges was investigated. The performance of the heat pump was found to be sensitive to the charge of ammonia with the optimum charge a function of ambient temperature.

EXPERIMENTAL SET UP

HEAT PUMP DESCRIPTION

The unit tested in this study was an air-to-water absorption heat pump using ammonia and water as refrigerant and absorbent. It is fired by natural gas and is designed for heating-only operation in a residential application. The complete absorption cycle, burner, controls, etc. are contained in a single package which will be located outdoors; only the heating coil and load water circulating pump would be located inside.

The heat pump utilizes an ammonia-water absorption cycle with the addition of flue gas heat exchanger as shown in Fig. 1. In the generator, direct firing by natural gas supplies the heat necessary to boil refrigerant vapor out of the weak absorbent returning from the absorber. Cooling water flows in parallel to the absorber and condenser. The rectifier employs a "triple heat exchanger" which preheats the weak absorbent flowing into the generator by both cooling the exiting strong absorbent and partially condensing the exiting vapor, thus purifying the refrigerant vapor.

In the falling-film type absorber, solution absorbs refrigerant vapor as it drips over tubes while load water inside the tubes removes the heat of absorption.

The evaporator is a finned coil which extracts heat from ambient air, vaporizing liquid refrigerant supplied by the condenser.

Defrosting of the evaporator coil is accomplished by routing refrigerant vapor from the rectifier through the solenoid-operated defrost valve directly to the evaporator. A defrost is initiated when the difference between the ambient and evaporator outlet temperatures exceeds a given value which depends on ambient temperature. For the purposes of these tests the temperatures were monitored and the defrost cycle was initiated manually.

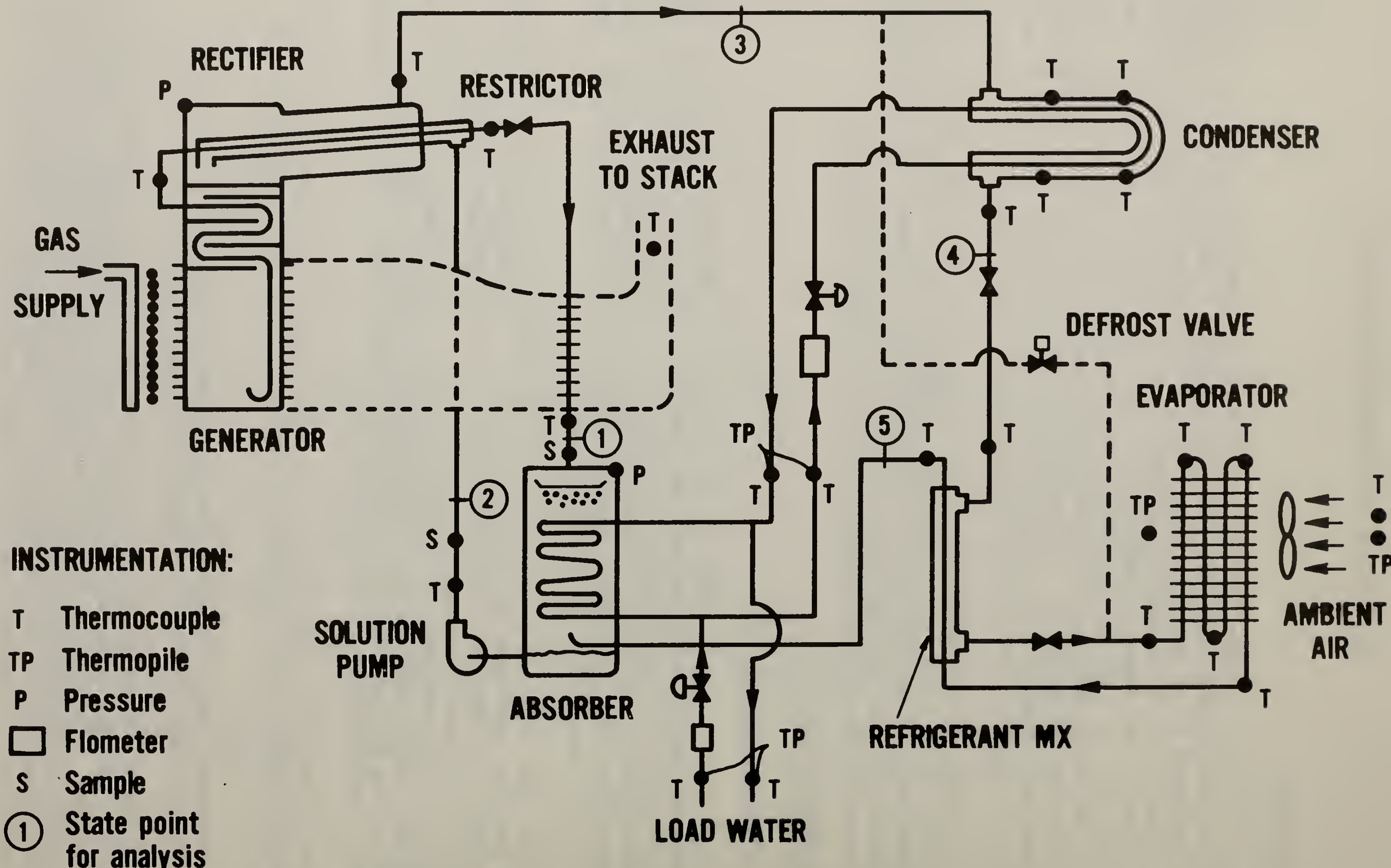


Figure 1. Scheme of the absorption heat pump

TEST FACILITY

The heat pump was tested in an environmental chamber with controlled dew point and dry bulb temperatures. The chamber had sufficient volume such that air was internally circulated to insure a uniform temperature distribution. Ambient air temperature was maintained within ± 0.3°C during steady state tests and ± 1°C during cyclic tests.

Load water circulates in a closed loop between the heat pump and indoor heating coil which would normally be located in a supply air duct. In the test facility, this was modified to a once-through flow arrangement with a constant (± 0.2°C) water temperature supplied to the unit. This arrangement eliminated any transient effects of an indoor coil during cyclic operation and provided better control of the water temperature.

INSTRUMENTATION

The mass flow rate of the load water, $\dot{M}_{load}$, was measured with a turbine flow meter. The temperature rise of the water was measured with a 16 junction copper-constantan thermopile installed in thermowells. Literature values were used for the specific heat capacity, C_p of water.

The gas input to the heat pump was measured with a dry volume flow test meter. The volume of gas used by the machine over a given time was corrected to standard conditions and multiplied by the higher heating value of the gas, which was determined on the NBS site daily, to obtain the energy supplied. The electrical energy needed to power the solution pump, fan and controls was measured with a watt-hour meter.

A turbine flowmeter and thermopile were installed in the condenser water loop so that the heats of condensation and absorption could be separated. A thermopile was installed across the air side of the evaporator to measure the temperature change of the air. This ΔT was multiplied by a measured correction factor to account for the temperature distribution over the evaporator coil. The volume rate of the air flow was determined by traversing a vane anemometer across the face of the evaporator coil were used to calculate the heat supplied to the evaporator. Finally, samples of the strong and weak absorbent were taken for determining the mixture composition.

In addition to these data, the temperatures at various points in the cycle (as indicated in Fig. 1) were measured with thermocouples attached to the outside of the tubes. The pressure in the generator and absorber were recorded. The heat input to generator and the gas heat exchanger was determined by an analysis of the combustion products in the exhaust. The heat lost through the exhaust stack was calculated from the temperature of the flue gas (measured by a six junction averaging thermocouple) and its CO_2 content determined by an infrared analyzer.

The output of the thermocouples, thermopiles and pressure transducers were scanned by a datalogger and stored by a microcomputer. The gas and electric consumption and turbine flowmeter readings were recorded manually.

STEADY-STATE TEST PROCEDURE

The steady-state tests followed the procedures outlined in (1) where applicable. The entire test set up was operated until steady conditions were obtained. A test lasting for 30 minutes was then started. The datalogger recorded data every two minutes; the gas, electric and flow meters were recorded at the beginning and end of the test, and samples of the weak and strong absorbent were taken and analyzed. Average values for all measurements were then used for analysis.

The primary indices used for the performance of a heat pump were COP and capacity. The heating capacity of the unit was determined by:

$$\dot{Q}_{load} = \dot{M}_{load} C_p \Delta T \tag{1}$$

The coefficient of performance was defined as:

$$COP = \frac{\dot{Q}_{load}}{\dot{Q}_{gas} + \dot{E}_{elec}} \tag{2}$$

CYCLIC TESTS

In the cyclic tests, which also followed the procedures of (1), part load operation was simulated by manually cycling the unit on and off. The chamber and water supply were allowed to reach the desired conditions and then the heat pump was turned on and allowed to reach steady-state. The unit was then turned off for the predetermined time and cycled on and off for two or three complete cycles until reproducable behaviors were observed. The next cycle was then used for the determination of cyclic performance. During the "off" portion of the cycle the load water system continued to operate, but the water was diverted past the heat pump.

Cycling rates of 1.5 and 3 cycles per hour at 50% burner on time were tested. At 20% on time, the rates were decreased to 1 and 2 CPH following the characteristic parabolic thermostat behavior as discussed in (2). The on time refers to that fraction of a complete cycle where the burner is operating. The machine continued to operate for a 3.5-4 minute "spindown" period after the burner shut off to recover residual heating capacity in the unit.

The total heat provided by the heat pump during a cycle was given by:

$$Q_{load,cyc} = \dot{M}_{load} C_p \int_{t_o}^{t_2} \Delta T \, dt \tag{3}$$

where the temperature difference of the water entering and exiting the unit, ΔT, was integrated between t_o, the time at which the unit was turned on and t_2, the time the machine was shut off (i.e., after "spindown"). This was determined by integrating the output of the load water thermopile recorded on a strip chart recorder with a planimeter. The energy input to the machine during a cycle is the total gas input from t_o to t_1, the time that the burner was operating and the electrical input measured for the entire cycle length τ. The cyclic coefficient of performance was then calculated by:

$$COP_{cyc} = \frac{Q_{load,cyc}}{\int_{t_o}^{t_1} \dot{Q}_{gas}\, dt + \int_{0}^{\tau} \dot{E}_{elec}\, dt} \tag{4}$$

The cyclic performance can also be expressed as a fraction of the steady-state performance. The heating load factor, Γ_h, represents the fractional capacity in cyclic operation:

$$\Gamma_h = \frac{Q_{load,cyc}(T)}{\dot{Q}_{load,ss}(T) \cdot \tau} \tag{5}$$

where $\dot{Q}_{load,ss}$ is the steady-state capacity and τ is the time for a complete cycle. The COP penalty in cyclic operation is given by the part load factor:

$$PLF = \frac{COP_{cyc}(T)}{COP_{ss}(T)} \tag{6}$$

where COP_{ss} is the steady-state coefficient of performance, determined for the same ambient temperature as COP_{cyc}.

RESULTS AND DISCUSSIONS

STEADY-STATE TEST RESULTS

The steady-state performance of the heat pump was tested over a range of ambient and inlet load water temperatures. The coefficient of performance and the capacity variations with ambient temperature are shown in Fig. 2 for a load water temperature of 41°C and flow rate of 0.38 ℓ/sec (which are the manufacturer's design conditions). The COP and capacity curves have similar shapes because the energy inputs were almost independent of the ambient temperature. The gas input varied from 13.4 to 14.3 kW and the electric input from 0.55 to 0.65 kW as the ambient temperature decreased.

The performance levels off at both high and low ambient temperatures. Below about 0°C, a two-phase mixture of liquid and vapor refrigerant exits the evaporator (as indicated by a constant temperature profile throughout the evaporator). At the extreme case of -21°C, the COP is slightly lower than the combustion efficiency of 0.84, any heat extracted from ambient is thus offset by heat losses from the unit. Above about 5°C, the performance is relatively insensitive to ambient temperature.

The effect of varying inlet load water temperature on COP is shown in Fig. 3. At an ambient temperatures of -21 and -9°C, the COP decreases as inlet water temperature increases. At an ambient temperature of 9°C, performance does not depend on water temperature over the range investigated. This and the fact that the performance levels off at high ambient temperatures indicates that the generator is the component limiting the performance at high ambient temperatures.

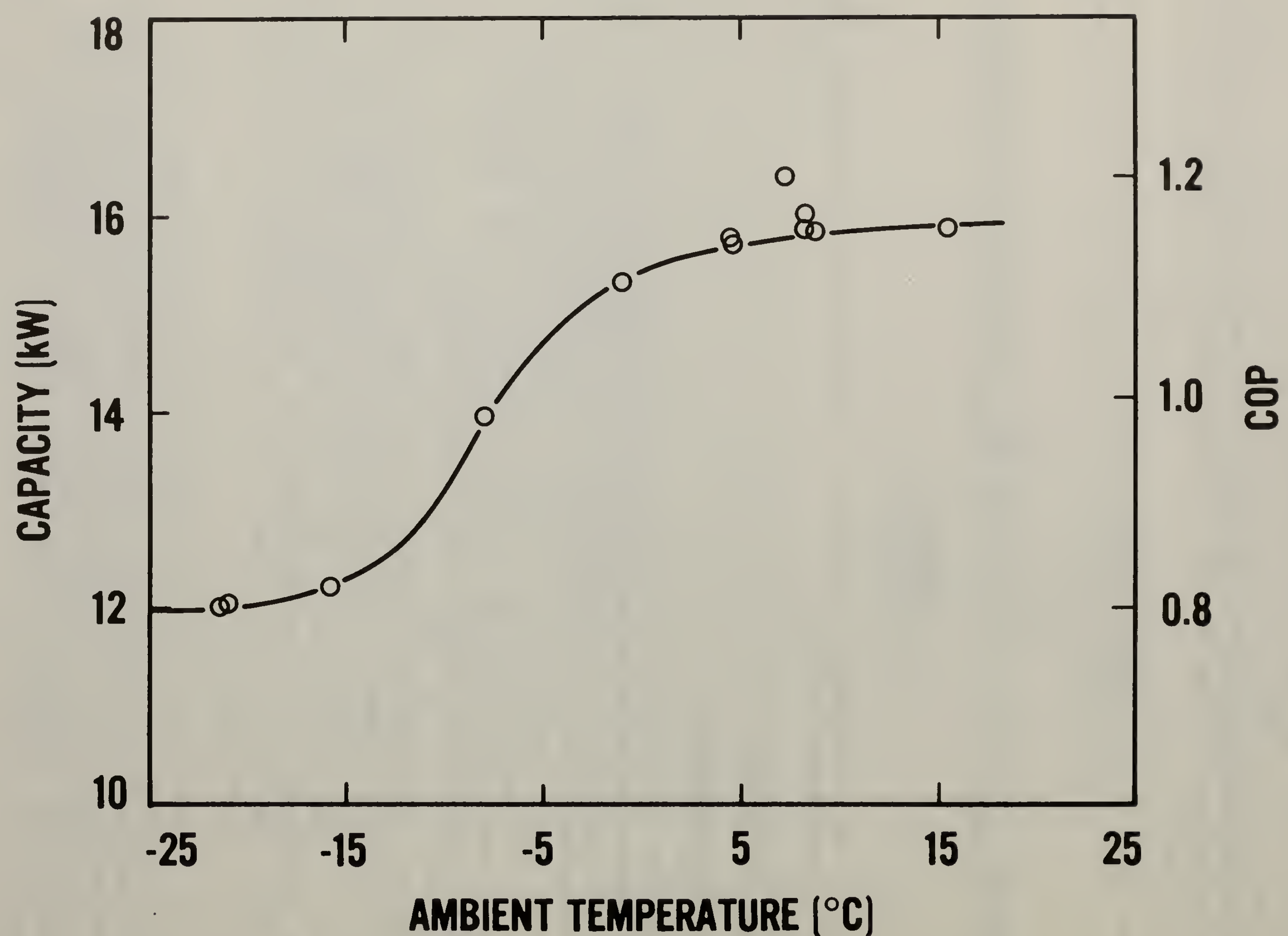


Figure 2. Coefficient of performance and heating capacity for the absorption heat pump as a function of ambient temperature.

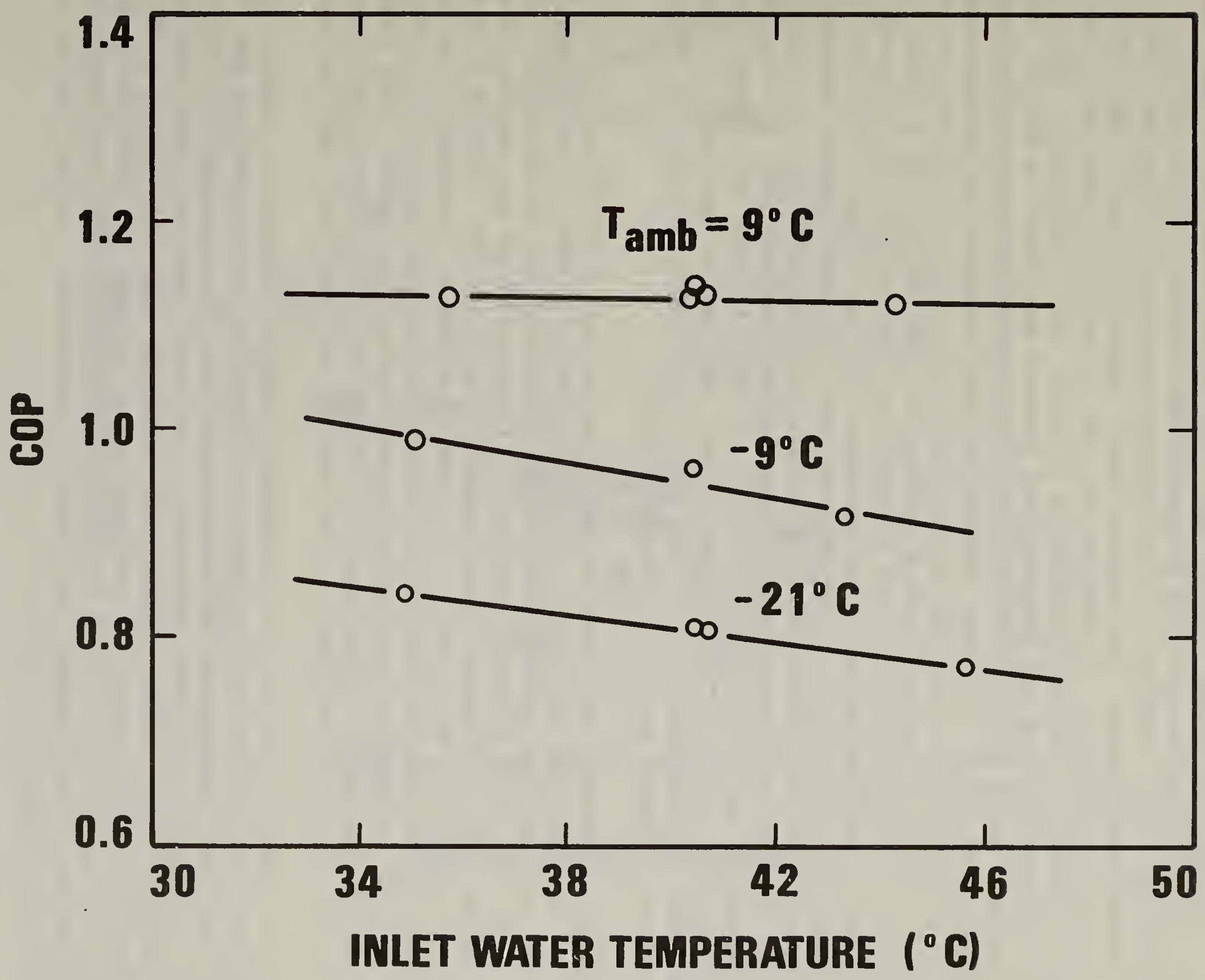


Figure 3. Effect of varying inlet load water temperature on COP for three ambient temperatures.

In another series of tests, the load water flow rate was varied 6 percent above and 16 percent below the nominal value of 0.38 ℓ/sec at 8 and -8°C ambients with no significant effect on COP or capacity.

CYCLIC TEST RESULTS

Since in normal operation, a heat pump will cycle on and off to meet varying loads, the cylic performance is of particular interest. Tests were performed at an 8°C ambient and the design load water conditions. Two cycling rates were investigated: the typical vapor compression heat pump cycle rate of 3 cycles per hour at 50 percent on time (3) and half this rate (1 1/2 cph), which is commonly used for absorption chillers (4). The results expressed in terms of the part load and heating load factors are shown in Fig. 4. With decreasing heating load factor the part load factor decreases very rapidly, especially for short on times; indicating that a substantial performance penalty is associated with the cyclic operation. As can be seen from the symbols in Fig. 4, the performance penalty is less severe for a lower cycle rate ("•" in Fig. 4) than for the higher rate ("O" in Fig. 4). Although the lower cycle rate yields better performance it is not clear whether it is practical because longer off-periods may result in less comfort control in a heating application. The cyclic performance of the heat pump is dependent not only on the cycle rates but also on the ambient temperature. All cyclic tests were conducted at 8°C except one at 20% on time, 1 cycle per 3 hours, which was also conducted at -8°C ("◇" in Fig. 4). As can be seen in Fig. 4 by comparison of the symbols, •, ◇, at 20% on time that a decrease in ambient temperature reduces the cyclic performance.

The capacity versus time behavior for a cyclic test with 10 minutes on, 10 minutes off is shown in Fig. 5. This response is typical. The capacity appears to rise very quickly when the machine turns on; however, this is when the warm load water which was sitting in the unit flows out across the exit thermopile. The refrigerant side capacity soon dominated causing a drop in water side capacity which starts to rise after about 3 minutes. (The cause of the small "bump" in the curve at 4 minutes was not determined but is very reproducible and appears in varying degrees in all the tests.) The unit had not yet reached steady-state when the burner shut off. During the "spin-down" period the capacity continued to rise briefly and then fell off sharply.

While the machine was off, the difference in the high and low side pressures caused hot solution to migrate from the generator to the absorber and from there into the evaporator. The refrigerant from the condenser also migrates into the evaporator. These migrations resulted in a significant heat loss to ambient air. Also, since the absorber is filled with solution, a reduced area for heat and mass transfer is available when the unit cycled back on; consequentially, absorption starts gradually while the solution pump pumps the solution out of the absorber back into the generator. During this period the capacity is severely limited.

CHARGE SENSITIVITY

The heat pump was tested with varying charges of ammonia. The optimum charge was found to be a function of ambient temperature (Fig. 6). The overall effect of reduced charge is to give a more constant COP over the range of ambient temperatures investigated. The original charge was adjusted for

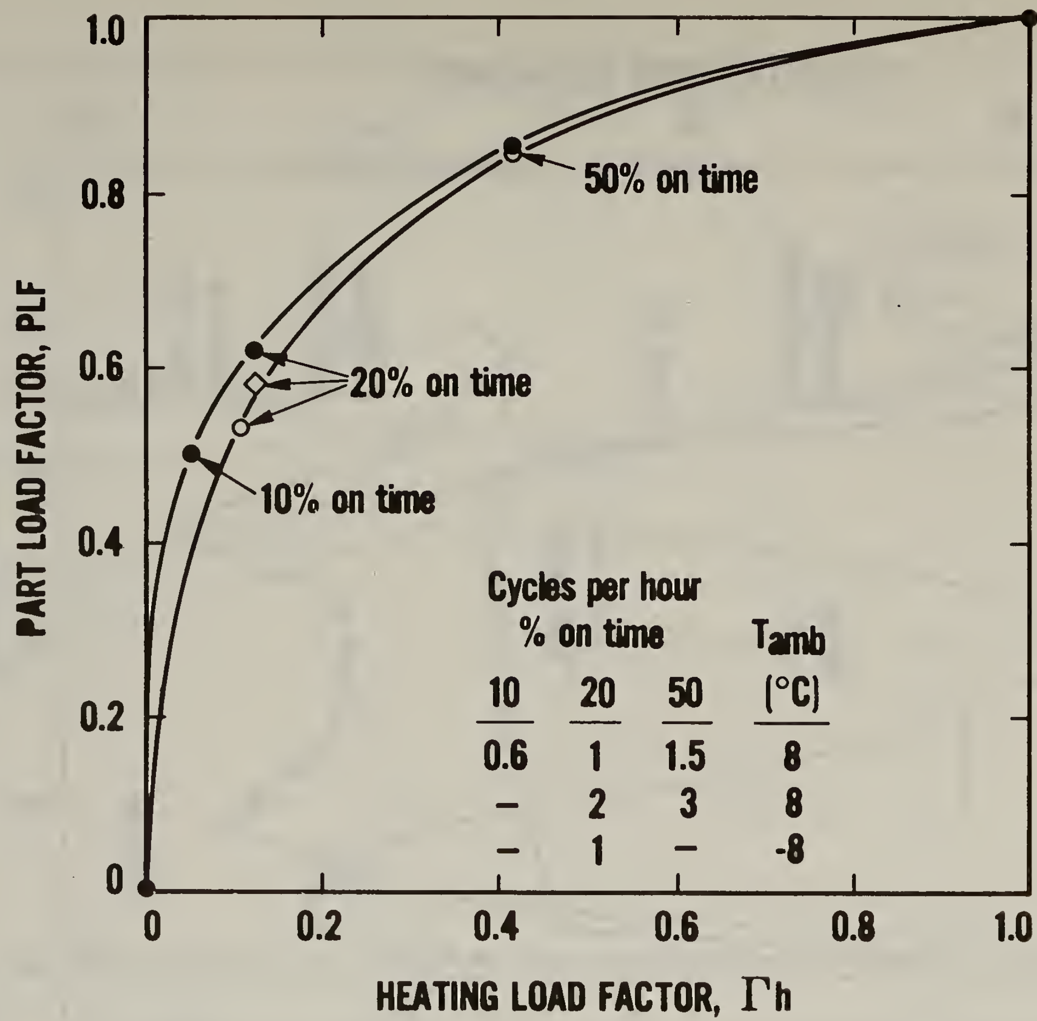


Figure 4. Cyclic performance of the heat pump.

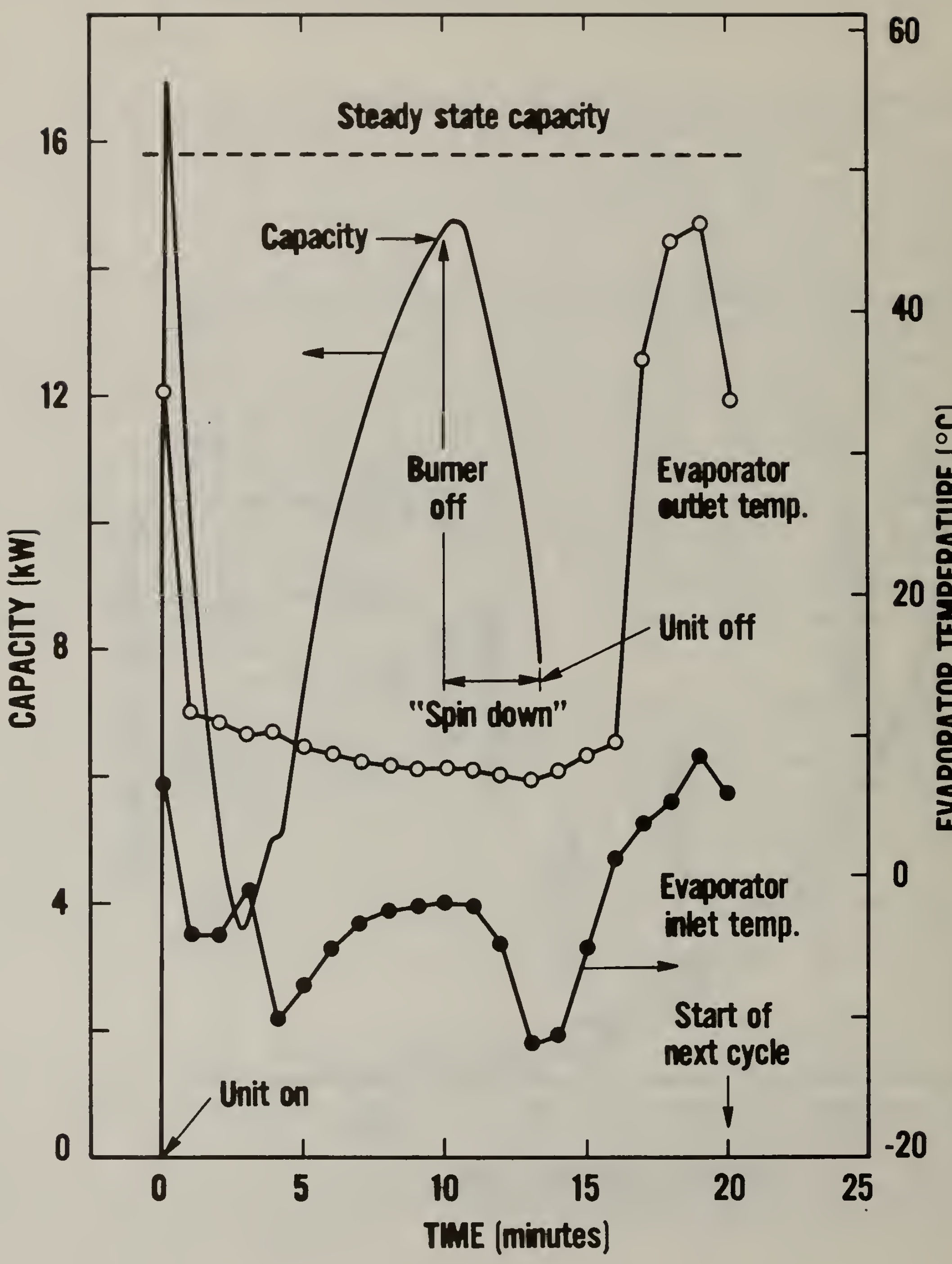


Figure 5. Capacity and evaporator inlet and outlet temperatures as a function of time for a typical cyclic test.

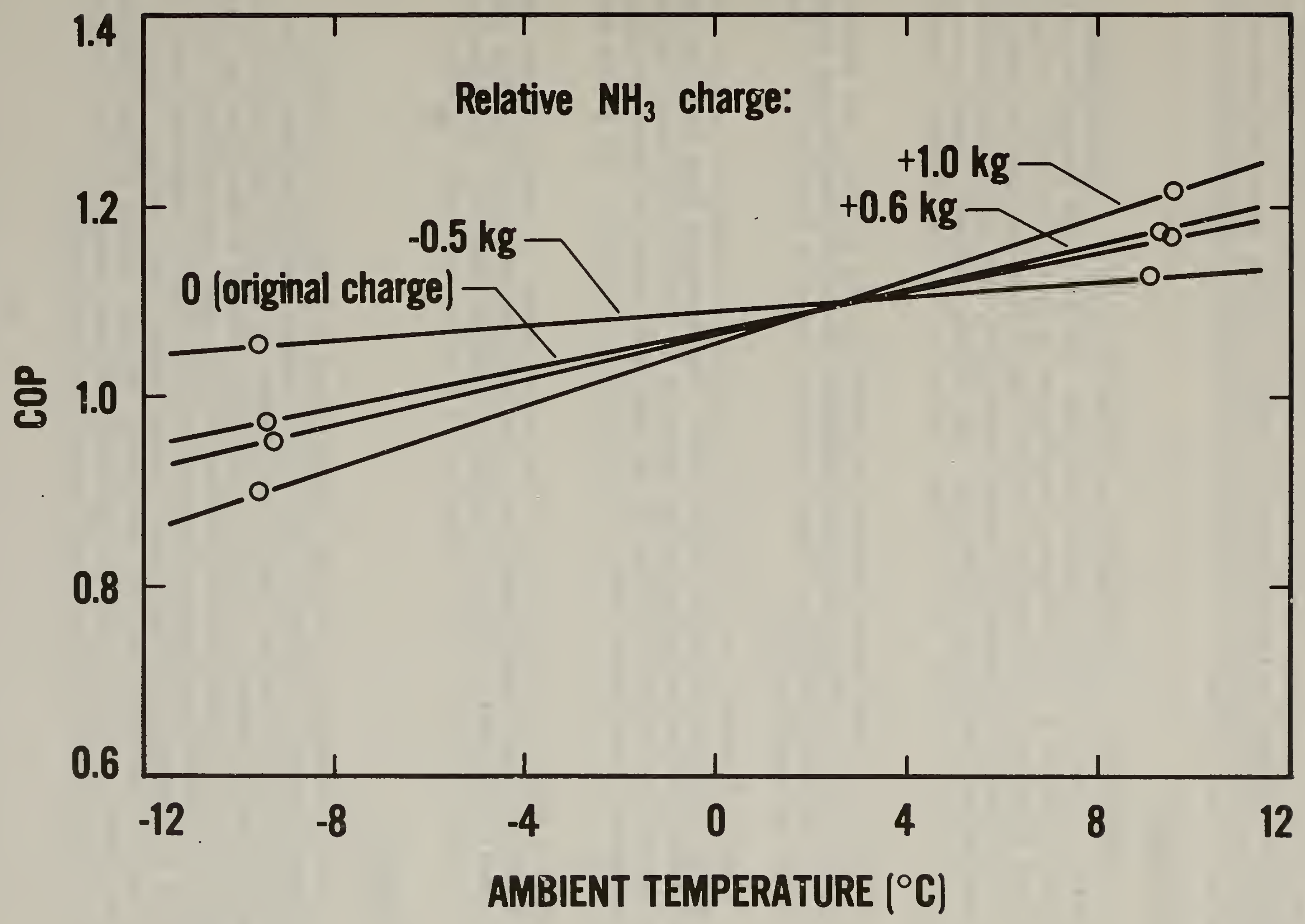


Figure 6. COP as a function of ambient temperature and refrigerant charge.

optimum performance of 2°C. The highest and lowest charges investigated were adjusted for optimum performance of about 9°C and -9°C, respectively.

The refrigerant charge has a significant effect on the evaporator pressure and temperature, thus controlling heat transfer from ambient due to the amount of refrigerant present in the evaporator. Table 1 shows values for pressure, temperature and compositions of the solution and their dependence of ambient temperature and charge.

FURTHER TESTS

a) The effects of frost accumulation on the evaporator coil were investigated according to the procedures outlined in (1). The unit was brought to steady-state operation at a 1.5°C ambient temperature with -1°C dewpoint temperature. A defrost cycle was initiated and upon its completion the frost accumulation test was begun. The evaporator accumulated frost very slowly and operated for 8.4 hours before requiring defrosting. The average COP and capacity over the test were 0.96 of steady state dry coil values at the same ambient temperature.

b) The split of load water between the condenser and absorber was investigated at -8 and 8°C ambient with the condenser flowrate being varied from 33% to 67% of the total flowrate. Over the entire range of conditions the change in COP was no more than 2%.

c) A turbine flowmeter was installed in the cycle to measure the flow rate of the strong absorbent (absorber inlet) line. The measured flow rate was compared against the value which can be obtained by calculation using the heat of condensation and the compositions of the weak and strong solution assuming that saturated refrigerant vapor is leaving the rectifier. The values agree within 4%.

In order to check the consistency of the measurements an energy balance was calculated for each steady-state test. The heat delivered by the heat pump was typically 8% smaller than the amount of energy supplied. The error in the overall energy balance is due to neglecting heat losses to the ambient.

CONCLUSIONS

The prototype absorption heat pump tested shows a significant performance degradation in cyclic operation; this would suggest modifications to the absorption cycle to improve cyclic performance or possibly some type of heat storage system to reduce the need for cycling. Except at very low ambient temperatures the steady-state performance of the heat pump would be superior to that of a natural gas furnace, however any meaningful comparison must be based on a seasonal efficiency which takes cycling into account. Finally, the performance is sensitive to the refrigerant charge. Unlike a vapor compression heat pump, however, there is no single optimum charge for this absorption machine; rather, the optimum charge varies with temperature.

REFERENCES

1. W. H. Parken, et al., "Method of Testing, Rating and Estimating the Heating Seasonal Performance of Heat Pumps," National Bureau of Standards, Washington, D.C., NBSIR 80-2002, April 1980.

2. "Low-Voltage Room Thermostats," NEMA Standards Publication no. DC3-1978, National Electrical Manufacturers Association, New York, 1972.

3. Lorne Nelson, Honeywell, Inc., Minneapolis, MN, private communication.

4. Richard Merrick, Arkla Industries, Inc., Evansville, IN, private communication.

Table 1. System Pressures and Concentrations and Evaporator Conditions as a Function of Refrigerant Charge and Ambient Temperature

Relative NH_3 charge* (kg)	Ambient Temp. (°C)	Pressure (MP_a)		NH_3 conc.		Evap. Temp. (°C)		$\dot{Q}_{evap}$ (kW)
		gen	abs	strong	weak	inlet	outlet	
+1.0	-9.1	2.15	0.27	0.169	.363	-10.8	-10.9	.93
+0.6	-8.4	2.14	0.26	0.149	.342	-11.2	-11.3	2.17
0	-8.7	2.10	0.25	0.134	.320	-12.1	-12.1	2.83
-0.5	-8.9	2.10	0.21	0.096	.280	-13.7	-12.5	5.48
+1.0	8.8	2.22	0.44	0.200	.393	2.4	3.4	6.49
+0.6	8.0	2.22	0.41	0.186	.381	0.8	8.0	7.00
0	8.6	2.20	0.38	0.173	.369	- 0.4	8.8	6.63
-0.5	7.5	2.15	0.27	0.129	.316	- 7.5	6.8	7.11

*Ammonia charge of heat pump relative to original charge of unit

APPENDIX

In Table 2 a listing of channel numbers and thermocouple locations is given. All other test data refer to these channel numbers.

Following Table 2 all test data are presented, first those for the steady-state tests and second, those of the cyclic tests.

Table 2. Channel Numbers and Thermocouple Locations

Channel No.	Original Units	Location
0	°F	Icebath
1	°F	Solution Pump Outlet, Weak Absorbent
2	°F	Flue Gas HX, Outlet, Strong Absorbent
3	°F	Condenser Inlet, Ref. Vapor
4	°F	Refrigerant Heat Exchanger Inlet (Condenser Side)
5	°F	Refrigerant Heat Exchanger Outlet (Condenser Side)
6	°F	Evaporator Outlet, Refrigerant HX Inlet
7	°F	Refrigerant Heat Exchanger Outlet (Evaporator Side)
8	°F	Triple Heat Exchanger Inlet, Weak Absorbent
9	°F	Absorber Inlet, Strong Absorbent
10	°F	Load Water Outlet
11	°F	Load Water Out of Absorber
12	°F	Rectifier Shell
13	°F	3% of way through Evaporator
14	°F	Generator Outlet/Triple HX Inlet (Strong Absorber)
15	°F	82% of Way through Condenser
16	°F	62% of Way through Condenser
17	°F	41% of Way through Condenser
18	°F	20% of way through Condenser
19	°F	Condenser Outlet
20	°F	Load Water into Mixing Barrel
25	°F	Load Water out of Condenser (in thermocouplewell)
26	°F	Load Water Inlet (in thermowell)
27	mV	Condenser Load Water Thermopile (10 Junc Cu-Co)
28	°F	Air Into Evaporator (averaging T.C.)
29	mV	Evaporator Air Thermopile (4 Junc Cu-Co)
30	°F	Stack Gas Exhaust (Chromel-Alumel T.C.)
31	°F	Load Water Inlet (in thermocouplewell)
32	°F	Load Water Outlet (in thermocouplewell)
33	°F	Bypass Water (not used when unit is operating)
34	°F	Dry Bulb Near Evaporator Inlet
35	°F	Wet Bulb Near Evaporator Inlet
36	mV	Load Water Thermopile (16 junc. Cu-Co)
37	°F	Rectifier Outlet, Refrigerant Vapor
38	°F	33% of Way Through Evaporator
39	°F	67% of Way Through Evaporator
40	°F	19% of Way Through Evaporator
41	°F	48% of Way through Evaporator
42	°F	85% of Way Through Evaporator

46	°F	Natural Gas Supply at Meter
47	V	Pressure Transducer Supply Voltage
48	mV	Absorber Pressure
49	mV	Generator Pressure

NOTES: In data sheets that follow, temperatures have been converted to °C, thermopile readings to temperature difference in °C, and pressures to MPa.

Unless noted, all thermocouples are copper-constantan and installed on outside of pipe.

STEADY STATE TEST NO: AB1701
DATE: 11/ 3/82

TEST CONDITIONS:
AMBIENT--DRY BULB: -8.6 C DEW PT: -17.8 C
COOLING WATER--TEMP: 40.5 C TOT FLOW: .366 L/SEC
COND FLOW: .139 L/SEC
AMMONIA CHARGE: .0 KG

ENERGY INPUTS:
GAS: 13.71 KW ELECTRIC--TOTAL: .579 KW
FAN: .214 KW
QGEN: 11.56 KW COMB EFF: .843
QEVAP: 3.27 KW

ENERGY OUTPUTS:
QLOAD: 14.18 KW
QCOND: 5.64 KW QABS: 8.54 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD L.O.C.* = .65 KW = 4.6 %

COP: .993 COP-GAS: 1.035

SAMPLE CONCENTRATIONS:
STRONG ABS: .135 WEAK ABS: .320
.137 .313

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.03	26	40.2	C	.08
1	42.4	C	.13	27	9.92	CD	.03
2	58.9	C	.16	28	-8.6	C	.10
3	75.4	C	.12	29	-2.11	CD	.04
4	15.1	C	.23	30	69.1	C	.24
5	-12.2	C	.08	31	40.5	C	.08
6	-12.3	C	.07	32	49.9	C	.08
7	-11.7	C	.43	33	38.6	C	.07
8	41.8	C	.16	34	-9.0	C	.14
9	74.8	C	.08	35	-8.6	C	.11
10	49.4	C	.07	36	9.48	CD	.04
11	49.6	C	.08	37	75.7	C	.16
12	115.3	C	.20	38	-12.1	C	.09
13	-12.3	C	.08	39	-12.2	C	.07
14	127.1	C	.18	40	-12.1	C	.08
15	52.0	C	.06	41	-12.1	C	.07
16	52.8	C	.06	42	-12.1	C	.06
17	54.4	C	.07	46	22.0	C	.03
18	58.1	C	.10	47	10.126	V	.000
19	48.5	C	.12	48	.243	MPA	.002
20	40.1	C	.16	49	2.137	MPA	.003
25	49.8	C	.08				

*Lack of closure

STEADY STATE TEST NO: AB1702
DATE: 11/ 3/82

TEST CONDITIONS:
AMBIENT---DRY BULB: -9.2 C DEW PT: -17.8 C
COOLING WATER---TEMP: 35.5 C TOT FLOW: .366 L/SEC
COND FLOW: .139 L/SEC
AMMONIA CHARGE: .0 KG

ENERGY INPUTS:
GAS: 13.80 KW ELECTRIC---TOTAL: .561 KW
FAN: .214 KW
QGEN: 11.64 KW COMB EFF: .843
QEVAP: 4.00 KW

ENERGY OUTPUTS:
QLOAD: 14.70 KW
QCOND: 5.76 KW QABS: 8.94 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD L.O.C. = .94 KW = 6.4 %

COP: 1.023 COP--GAS: 1.065

SAMPLE CONCENTRATIONS:
STRONG ABS: .133 WEAK ABS: .320
.133 .339

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.03	26	35.1	C	.06
1	38.2	C	.10	27	10.24	CD	.02
2	53.8	C	.06	28	-9.2	C	.09
3	69.0	C	.08	29	-2.57	CD	.06
4	15.2	C	.16	30	66.9	C	.09
5	-13.4	C	.06	31	35.5	C	.05
6	-13.5	C	.08	32	45.2	C	.05
7	-13.2	C	.36	33	33.5	C	.05
8	37.6	C	.08	34	-9.2	C	.11
9	70.4	C	.05	35	-8.8	C	.11
10	44.7	C	.05	36	9.93	CD	.03
11	44.9	C	.05	37	69.2	C	.07
12	107.0	C	.09	38	-13.3	C	.08
13	-13.5	C	.06	39	-13.3	C	.07
14	119.3	C	.10	40	-13.2	C	.06
15	47.6	C	.03	41	-13.3	C	.07
16	48.3	C	.03	42	-13.3	C	.06
17	49.5	C	.05	46	22.1	C	.03
18	52.6	C	.06	47	10.126	V	.000
19	42.1	C	.07	48	.228	MPA	.001
20	34.9	C	.10	49	1.911	MPA	.001
25	45.1	C	.06				

STEADY STATE TEST NO: AB1703
DATE: 11/16/82

TEST CONDITIONS:
AMBIENT--DRY BULB: -8.7 C DEW PT: -16.1 C
COOLING WATER--TEMP: 40.7 C TOT FLOW: .337 L/SEC
COND FLOW: .167 L/SEC
AMMONIA CHARGE: .0 KG

ENERGY INPUTS:
GAS: 14.02 KW ELECTRIC--TOTAL: .577 KW
FAN: .220 KW
QGEN: 11.80 KW COMB EFF: .842
QEVAP: 2.83 KW

ENERGY OUTPUTS:
QLOAD: 14.15 KW
QCOND: 5.77 KW QABS: 8.37 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD L.O.C. = .49 KW = 3.5 %

COP: .969 COP-GAS: 1.009

SAMPLE CONCENTRATIONS:
STRONG ABS: .135 WEAK ABS: .323
.132 .316

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.02	26	40.4	C	.12
1	42.1	C	.11	27	8.47	CD	.02
2	58.6	C	.15	28	-8.7	C	.09
3	75.7	C	.14	29	-1.79	CD	.03
4	17.2	C	.10	30	73.6	C	.27
5	-12.0	C	.03	31	40.7	C	.12
6	-12.1	C	.05	32	50.9	C	.11
7	-11.9	C	.14	33	26.4	C	.05
8	41.1	C	.13	34	-8.9	C	.14
9	74.7	C	.09	35	-8.7	C	.09
10	50.4	C	.13	36	10.25	CD	.02
11	51.5	C	.13	37	74.3	C	.16
12	116.4	C	.21	38	-11.9	C	.07
13	-12.1	C	.04	39	-12.0	C	.06
14	127.9	C	.18	40	-11.8	C	.07
15	51.3	C	.13	41	-11.9	C	.06
16	52.1	C	.12	42	-11.9	C	.07
17	53.6	C	.13	46	20.8	C	.06
18	57.1	C	.15	47	10.125	V	.000
19	47.5	C	.14	48	.246	MPA	.011
20	39.7	C	.14	49	2.101	MPA	.006
25	48.7	C	.11				

STEADY STATE TEST

NO: AB1704
DATE: 11/16/82

TEST CONDITIONS:
AMBIENT---DRY BULB: -8.9 C DEW PT: -16.1 C
COOLING WATER---TEMP: 40.8 C TOT FLOW: .339 L/SEC
COND FLOW: .113 L/SEC
AMMONIA CHARGE: .0 KG

ENERGY INPUTS:
GAS: 14.01 KW ELECTRIC---TOTAL: .579 KW
FAN: .220 KW
QGEN: 11.77 KW COMB EFF: .840
QEVAP: 2.98 KW

ENERGY OUTPUTS:
QLOAD: 14.17 KW
QCOND: 5.43 KW QABS: 8.74 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD L.O.C. = .57 KW = 4.1 %

COP: .971 COP-GAS: 1.011

SAMPLE CONCENTRATIONS:
STRONG ABS: .137 WEAK ABS: .325
.137 .318

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.3	C	.03	26	40.5	C	.06
1	42.1	C	.09	27	11.76	CD	.03
2	60.4	C	.12	28	-8.9	C	.10
3	77.9	C	.13	29	-1.88	CD	.05
4	16.2	C	.16	30	74.4	C	.07
5	-12.3	C	.06	31	40.8	C	.07
6	-12.4	C	.08	32	51.0	C	.08
7	-12.0	C	.18	33	26.3	C	.09
8	41.2	C	.08	34	-9.0	C	.14
9	75.9	C	.10	35	-8.9	C	.07
10	50.6	C	.08	36	10.21	CD	.02
11	50.5	C	.07	37	76.5	C	.09
12	119.5	C	.10	38	-12.2	C	.08
13	-12.4	C	.07	39	-12.2	C	.09
14	131.8	C	.09	40	-12.2	C	.09
15	54.0	C	.06	41	-12.2	C	.08
16	54.9	C	.07	42	-12.2	C	.09
17	56.5	C	.09	46	20.6	C	.03
18	60.6	C	.07	47	10.125	V	.000
19	51.4	C	.06	48	.242	MPA	.001
20	40.0	C	.07	49	2.245	MPA	.004
25	52.1	C	.08				

STEADY STATE TEST NO: AB1705
DATE: 11/18/82

TEST CONDITIONS:
AMBIENT--DRY BULB: -8.4 C DEW PT: -16.1 C
COOLING WATER--TEMP: 40.6 C TOT FLOW: .324 L/SEC
COND FLOW: .159 L/SEC
AMMONIA CHARGE: .6 KG

ENERGY INPUTS:
GAS: 13.97 KW ELECTRIC--TOTAL: .583 KW
FAN: .218 KW
QGEN: 11.81 KW COMB EFF: .845
QEVAP: 2.17 KW

ENERGY OUTPUTS:
QLOAD: 13.81 KW
QCOND: 5.85 KW QABS: 7.96 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD L.O.C. = .17 KW = 1.3 %

COP: .948 COP-GAS: .988

SAMPLE CONCENTRATIONS:
STRONG ABS: .149 WEAK ABS: .345
.149 .329

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.03	26	40.3	C	.05
1	41.3	C	.06	27	9.03	CD	.02
2	57.6	C	.07	28	-8.4	C	.07
3	73.5	C	.09	29	-1.38	CD	.05
4	18.6	C	.16	30	73.4	C	.10
5	-11.2	C	.04	31	40.6	C	.04
6	-11.3	C	.05	32	51.0	C	.05
7	-11.3	C	.08	33	39.1	C	.04
8	40.3	C	.05	34	-8.8	C	.18
9	73.5	C	.06	35	-8.6	C	.09
10	50.5	C	.05	36	10.42	CD	.03
11	51.3	C	.06	37	71.5	C	.06
12	110.5	C	.13	38	-11.1	C	.03
13	-11.2	C	.03	39	-11.1	C	.01
14	122.2	C	.11	40	-11.0	C	.05
15	52.1	C	.06	41	-11.1	C	.06
16	52.9	C	.07	42	-11.1	C	.03
17	54.1	C	.06	46	21.3	C	.02
18	57.2	C	.07	47	10.125	V	.000
19	47.8	C	.08	48	.257	MPA	.001
20	39.9	C	.06	49	2.143	MPA	.003
25	49.1	C	.06				

STEADY STATE TEST

NO: AB1706
DATE: 11/24/82

TEST CONDITIONS:
AMBIENT--DRY BULB: -9.1 C   DEW PT: -17.8 C
COOLING WATER--TEMP: 40.7 C   TOT FLOW: .336 L/SEC
COND FLOW: .171 L/SEC
AMMONIA CHARGE: 1.0 KG

ENERGY INPUTS:
GAS: 13.93 KW   ELECTRIC--TOTAL: .581 KW
FAN: .216 KW
QGEN: 11.74 KW   COMB EFF: .843
QEVAP: .93 KW

ENERGY OUTPUTS:
QLOAD: 12.99 KW
QCOND: 5.97 KW   QABS: 7.02 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD   L.O.C. = -.31 KW = -2.4 %

COP: .895   COP-GAS: .932

SAMPLE CONCENTRATIONS:
STRONG ABS: .169   WEAK ABS: .365
.169   .360

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.1	C	.00	26	40.4	C	.06
1	39.3	C	.12	27	8.56	CD	.03
2	55.9	C	.09	28	-9.1	C	.09
3	69.4	C	.06	29	-.60	CD	.04
4	19.7	C	.16	30	70.7	C	.08
5	-10.8	C	.08	31	40.7	C	.05
6	-10.9	C	.11	32	50.1	C	.06
7	-11.0	C	.18	33	38.3	C	.04
8	38.4	C	.11	34	-9.1	C	.17
9	71.3	C	.06	35	-9.0	C	.09
10	49.6	C	.07	36	9.45	CD	.03
11	50.3	C	.07	37	67.7	C	.07
12	105.3	C	.09	38	-10.7	C	.07
13	-10.8	C	.07	39	-10.7	C	.09
14	117.5	C	.10	40	-10.6	C	.11
15	52.1	C	.06	41	-10.6	C	.09
16	52.8	C	.07	42	-10.6	C	.09
17	53.8	C	.06	46	20.7	C	.04
18	56.3	C	.06	47	10.125	V	.001
19	47.0	C	.06	48	.266	MPA	.003
20	39.9	C	.07	49	2.148	MPA	.005
25	48.7	C	.06				

STEADY STATE TEST NO: AB1707
DATE: 11/30/82

TEST CONDITIONS:
AMBIENT--DRY BULB: -8.9 C DEW PT: -17.8 C
COOLING WATER--TEMP: 41.0 C TOT FLOW: .328 L/SEC
COND FLOW: .164 L/SEC
AMMONIA CHARGE: -.4 KG

ENERGY INPUTS:
GAS: 13.95 KW ELECTRIC--TOTAL: .567 KW
FAN: .216 KW
QGEN: 11.68 KW COMB EFF: .837
QEVAP: 5.04 KW

ENERGY OUTPUTS:
QLOAD: 15.25 KW
QCOND: 5.66 KW QABS: 9.59 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD L.O.C. = 1.46 KW = 9.6 %

COP: 1.050 COP-GAS: 1.093

SAMPLE CONCENTRATIONS:
STRONG ABS: .096 WEAK ABS: .283
.096 .277

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.03	26	40.9	C	.03
1	48.5	C	.06	27	8.44	CD	.01
2	65.6	C	.04	28	-8.9	C	.07
3	88.3	C	.05	29	-2.98	CD	.08
4	15.7	C	.41	30	78.2	C	.05
5	-12.1	C	.15	31	41.0	C	.03
6	-12.5	C	.17	32	52.3	C	.04
7	15.1	C	.41	33	38.7	C	.03
8	47.6	C	.06	34	-9.1	C	.14
9	81.9	C	.03	35	-9.2	C	.21
10	51.6	C	.04	36	11.34	CD	.02
11	53.0	C	.04	37	86.5	C	.05
12	129.9	C	.07	38	-13.7	C	.09
13	-13.7	C	.07	39	-13.6	C	.14
14	140.0	C	.09	40	-13.7	C	.10
15	51.6	C	.03	41	-13.7	C	.06
16	52.4	C	.03	42	-13.2	C	.12
17	54.9	C	.02	46	21.9	C	.03
18	61.0	C	.09	47	10.125	V	.000
19	49.3	C	.03	48	.210	MPA	.002
20	40.1	C	.04	49	2.097	MPA	.002
25	49.2	C	.03				

STEADY STATE TEST

NO: AB4701
DATE: 10/28/82

TEST CONDITIONS:
AMBIENT---DRY BULB: 8.3 C   DEW PT: 5.1 C
COOLING WATER--TEMP: 40.5 C   TOT FLOW: .352 L/SEC
COND FLOW: .124 L/SEC
AMMONIA CHARGE: .0 KG

ENERGY INPUTS:
GAS: 13.45 KW   ELECTRIC---TOTAL: .569 KW
FAN: .200 KW
QGEN: 11.46 KW   COND EFF: .852
QEVAP: 6.56 KW

ENERGY OUTPUTS:
QLOAD: 16.57 KW
QCOND: 5.94 KW   QABS: 10.63 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD   L.O.C. = 1.45 KW = 8.8 %

COP: 1.182   COP-GAS: 1.232

SAMPLE CONCENTRATIONS:
STRONG ABS: .181   WEAK ABS: .366
.177   .368

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.02	26	40.3	C	.09
1	46.0	C	.10	27	11.70	CD	.03
2	60.0	C	.11	28	8.3	C	.28
3	73.1	C	.11	29	-4.16	CD	.08
4	33.1	C	.08	30	80.7	C	.22
5	21.0	C	.24	31	40.5	C	.10
6	6.7	C	.06	32	51.9	C	.07
7	34.3	C	.04	33	39.7	C	.09
8	45.3	C	.09	34	8.3	C	.30
9	75.3	C	.09	35	5.1	C	.09
10	51.5	C	.08	36	11.50	CD	.04
11	51.7	C	.07	37	73.3	C	.11
12	107.9	C	.14	38	-2.1	C	.05
13	-2.3	C	.06	39	7.4	C	.08
14	119.1	C	.12	41	-1.7	C	.11
15	54.0	C	.08	42	7.7	C	.06
16	54.7	C	.09	46	21.4	C	.06
17	55.8	C	.09	47	10.125	V	.000
18	58.8	C	.10	48	.354	MPA	.001
19	47.8	C	.17	49	2.253	MPA	.004
25	51.8	C	.07				

STEADY STATE TEST

NO: AK4702
DATE: 11/ 1/82

TEST CONDITIONS:

AMBIENT---DRY BULB:	8.4 C	DEW PT:	4.4 C
COOLING WATER---TEMP:	34.9 C	TOT FLOW:	.375 L/SEC
		COND FLOW:	.140 L/SEC
AMMONIA CHARGE:	.0 KG		

ENERGY INPUTS:

GAS:	13.48 KW	ELECTRIC---TOTAL:	.545 KW
		FAN:	.198 KW
QGEN:	11.43 KW	COMB EFF:	.848
QEVAP:	6.74 KW		

ENERGY OUTPUTS:

QLOAD:	16.42 KW		
QCOND:	5.98 KW	QABS:	10.43 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD   L.O.C. = 1.75 KW = 10.7 %

COP: 1.171   COP-GAS: 1.218

SAMPLE CONCENTRATIONS:

STRONG ABS:	.170	WEAK ABS:	.373
	.172		.369

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.00	26	34.8	C	.05
1	40.7	C	.04	27	10.60	CD	.01
2	54.2	C	.03	28	8.4	C	.20
3	66.7	C	.03	29	-4.30	CD	.06
4	30.4	C	.05	30	77.7	C	.11
5	16.8	C	.07	31	34.9	C	.05
6	6.8	C	.05	32	45.6	C	.04
7	31.4	C	.04	33	33.2	C	.04
8	40.2	C	.03	34	8.4	C	.23
9	70.4	C	.04	35	4.4	C	.07
10	45.2	C	.05	36	10.80	CD	.01
11	45.5	C	.05	37	66.7	C	.04
12	100.5	C	.07	38	-4.5	C	.09
13	-4.9	C	.06	39	8.3	C	.04
14	111.7	C	.07	41	5.2	C	.11
15	48.6	C	.04	42	7.9	C	.05
16	49.2	C	.03	46	22.2	C	.03
17	50.0	C	.05	47	10.125	V	.000
18	52.5	C	.05	48	.309	MPA	.001
19	39.4	C	.07	49	1.970	MPA	.003
25	45.2	C	.04				

STEADY STATE TEST

NO: AB4703
DATE: 11/15/82

TEST CONDITIONS:

AMBIENT---DRY BULB: 8.6 C DEW PT: 5.4 C
COOLING WATER---TEMP: 40.8 C TOT FLOW: .334 L/SEC
COND FLOW: .169 L/SEC
AMMONIA CHARGE: .0 KG
WEAK ABSORBENT FLOW: 0.0182 ℓ/sec

ENERGY INPUTS:

GAS: 13.54 KW
ELECTRIC---TOTAL: .549 KW
FAN: .200 KW
QGEN: 11.47 KW
COND EFF: .847
QEVAP: 6.63 KW

ENERGY OUTPUTS:

QLOAD: 16.40 KW
QCOND: 6.11 KW
QABS: 10.28 KW

ENERGY BALANCE:

QGEN + QEVAP ? QLOAD L.O.C. = 1.70 KW = 10.4 %

COP: 1.164 COP-GAS: 1.211

SAMPLE CONCENTRATIONS:

STRONG ABS: .173 WEAK ABS: .369
.173 .368

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.00	26	40.6	C	.05
1	47.6	C	.06	27	8.85	CD	.02
2	60.2	C	.06	28	8.6	C	.08
3	73.8	C	.07	29	-4.20	CD	.07
4	35.3	C	.07	30	80.7	C	.06
5	20.7	C	.19	31	40.8	C	.06
6	8.8	C	.07	32	52.7	C	.06
7	34.5	C	.07	33	31.0	C	.04
8	46.8	C	.05	34	9.1	C	.20
9	75.9	C	.05	35	5.4	C	.06
10	52.3	C	.07	36	11.96	CD	.02
11	53.9	C	.04	37	72.2	C	.10
12	107.5	C	.10	38	-.3	C	.06
13	-.4	C	.06	39	8.6	C	.09
14	117.9	C	.08	40	-.4	C	.07
15	53.0	C	.07	41	.0	C	.10
16	53.7	C	.06	42	9.6	C	.04
17	54.8	C	.07	46	21.0	C	.05
18	57.7	C	.10	47	10.118	V	.001
19	45.7	C	.04	48	.381	MPA	.001
20	39.7	C	.06	49	2.197	MPA	.003
25	49.4	C	.06				

STEADY STATE TEST

NO: AB4704
DATE: 11/17/82

TEST CONDITIONS:

AMBIENT---DRY BULB: 8.3 C DEW PT: 3.8 C
COOLING WATER--TEMP: 40.6 C TOT FLOW: .282 L/SEC
COND FLOW: .188 L/SEC
AMMONIA CHARGE: .0 KG

ENERGY INPUTS:

GAS: 13.60 KW ELECTRIC---TOTAL: .547 KW
FAN: .199 KW
QGEN: 11.49 KW COMB EFF: .845
QEVAP: 6.69 KW

ENERGY OUTPUTS:

QLOAD: 16.37 KW
QCOND: 6.27 KW QABS: 10.10 KW

ENERGY BALANCE:

QGEN + QEVAP ? QLOAD L.O.C. = 1.82 KW = 11.1 %

COP: 1.157 COP-GAS: 1.203

SAMPLE CONCENTRATIONS:

STRONG ABS: .162 WEAK ABS: .359
.161 .362

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.03	26	40.5	C	.04
1	51.6	C	.09	27	8.18	CD	.02
2	62.7	C	.07	28	8.3	C	.07
3	77.7	C	.03	29	-4.23	CD	.08
4	32.6	C	.15	30	82.2	C	.05
5	15.5	C	1.05	31	40.6	C	.04
6	6.5	C	.39	32	54.7	C	.03
7	32.0	C	.13	33	31.9	C	.03
8	50.6	C	.08	34	8.8	C	.12
9	78.8	C	.05	35	3.8	C	.03
10	54.0	C	.07	36	14.12	CD	.02
11	58.9	C	.05	37	75.7	C	.04
12	110.0	C	.06	38	1.8	C	.06
13	1.7	C	.07	39	1.8	C	.07
14	120.1	C	.06	40	1.7	C	.09
15	52.4	C	.04	41	1.7	C	.08
16	53.2	C	.03	42	2.8	C	.20
17	54.4	C	.05	46	20.8	C	.05
18	57.7	C	.06	47	10.112	V	.004
19	45.4	C	.07	48	.422	MPA	.001
20	39.7	C	.11	49	2.169	MPA	.002
25	48.5	C	.05				

STEADY STATE TEST NO: AB4705
DATE: 11/17/82

TEST CONDITIONS:
AMBIENT---DRY BULB: 8.1 C DEW PT: 3.7 C
COOLING WATER--TEMP: 35.4 C TOT FLOW: .340 L/SEC
COND FLOW: .169 L/SEC
AMMONIA CHARGE: .0 KG

ENERGY INPUTS:
GAS: 13.62 KW ELECTRIC---TOTAL: .532 KW
FAN: .200 KW
QGEN: 11.55 KW COMB EFF: .848
QEVAP: 6.84 KW

ENERGY OUTPUTS:
QLOAD: 16.53 KW
QCOND: 6.16 KW QABS: 10.37 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD L.O.C. = 1.86 KW = 11.2 %

COP: 1.168 COP-GAS: 1.214

SAMPLE CONCENTRATIONS:
STRONG ABS: .173 WEAK ABS: .378
.172 .374

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.03	26	35.2	C	.06
1	42.7	C	.05	27	9.00	CD	.02
2	55.1	C	.04	28	8.1	C	.11
3	68.7	C	.03	29	-4.32	CD	.09
4	32.8	C	.03	30	79.2	C	.10
5	16.8	C	.10	31	35.4	C	.04
6	8.4	C	.06	32	47.2	C	.03
7	31.9	C	.03	33	27.4	C	.08
8	41.9	C	.05	34	8.8	C	.15
9	71.7	C	.04	35	3.7	C	.06
10	47.0	C	.06	36	11.98	CD	.02
11	48.3	C	.06	37	66.5	C	.03
12	99.9	C	.06	38	-2.4	C	.03
13	-2.5	C	.06	39	9.3	C	.06
14	111.2	C	.06	40	-2.5	C	.06
15	48.6	C	.03	41	1.2	C	.36
16	49.3	C	.05	42	9.1	C	.07
17	50.1	C	.04	46	20.8	C	.05
18	52.7	C	.05	47	10.124	V	.000
19	38.7	C	.07	48	.346	MPA	.001
20	34.5	C	.09	49	1.977	MPA	.001
25	44.1	C	.04				

STEADY STATE TEST

NO: AB4706
DATE: 11/18/82

TEST CONDITIONS:
AMBIENT--DRY BULB: 8.0 C   DEW PT: 5.0 C
COOLING WATER--TEMP: 40.7 C   TOT FLOW: .341 L/SEC
COND FLOW: .172 L/SEC
AMMONIA CHARGE: .6 KG

ENERGY INPUTS:
GAS: 13.62 KW   ELECTRIC--TOTAL: .551 KW
FAN: .198 KW
QGEN: 11.54 KW   COMB EFF: .847
QEVAP: 7.00 KW

ENERGY OUTPUTS:
QLOAD: 16.54 KW
QCOND: 6.23 KW   QABS: 10.31 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD   L.O.C. = 1.99 KW = 12.0 %

COP: 1.167   COP-GAS: 1.214

SAMPLE CONCENTRATIONS:
STRONG ABS: .184   WEAK ABS: .381
.187   .380

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.03	26	40.6	C	.08
1	47.7	C	.09	27	8.87	CD	.02
2	60.0	C	.10	28	8.0	C	.08
3	73.5	C	.06	29	-4.41	CD	.08
4	35.1	C	.11	30	80.6	C	.06
5	19.5	C	.67	31	40.7	C	.08
6	8.0	C	.10	32	52.5	C	.07
7	34.4	C	.10	33	35.3	C	.06
8	46.8	C	.09	34	8.6	C	.22
9	75.6	C	.06	35	5.0	C	.06
10	52.3	C	.09	36	11.85	CD	.03
11	53.7	C	.06	37	71.5	C	.08
12	105.1	C	.11	38	.9	C	.08
13	.8	C	.09	39	1.0	C	.13
14	115.6	C	.09	40	.9	C	.08
15	53.3	C	.07	41	.8	C	.08
16	54.0	C	.06	42	5.2	C	1.00
17	55.0	C	.07	46	21.1	C	.04
18	57.7	C	.07	47	10.124	V	.000
19	45.6	C	.13	48	.406	MPA	.002
20	39.8	C	.15	49	2.220	MPA	.003
25	49.3	C	.07				

STEADY STATE TEST   NO: AB4707
DATE: 11/23/82

TEST CONDITIONS:
AMBIENT---DRY BULB: 8.8 C   DEW PT: 4.1 C
COOLING WATER---TEMP: 40.6 C   TOT FLOW: .341 L/SEC
COND FLOW: .169 L/SEC
AMMONIA CHARGE: 1.0 KG

ENERGY INPUTS:
GAS: 13.51 KW   ELECTRIC---TOTAL: .549 KW
FAN: .194 KW
QGEN: 11.44 KW   COMB EFF: .847
QEVAP: 6.49 KW

ENERGY OUTPUTS:
QLOAD: 16.98 KW
QCOND: 6.23 KW   QABS: 10.75 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD   L.O.C. = .95 KW = 5.6 %

COP: 1.208   COP-GAS: 1.257

SAMPLE CONCENTRATIONS:
STRONG ABS: .200   WEAK ABS: .388
.174   .398

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.2	C	.02	26	40.5	C	.07
1	47.7	C	.07	27	9.06	CD	.02
2	59.5	C	.07	28	8.8	C	.08
3	72.0	C	.06	29	-4.12	CD	.06
4	29.4	C	.31	30	79.9	C	.07
5	3.6	C	.14	31	40.6	C	.05
6	3.4	C	.23	32	52.7	C	.05
7	28.6	C	.29	33	39.2	C	.06
8	46.9	C	.05	34	8.8	C	.20
9	75.0	C	.04	35	4.0	C	.04
10	52.4	C	.05	36	12.17	CD	.02
11	53.8	C	.05	37	70.3	C	.08
12	102.3	C	.11	38	2.5	C	.06
13	2.4	C	.07	39	2.4	C	.08
14	112.7	C	.11	40	2.5	C	.04
15	53.4	C	.04	41	2.5	C	.05
16	54.0	C	.04	42	2.8	C	.06
17	54.9	C	.06	46	21.3	C	.06
18	57.5	C	.05	47	10.124	V	.000
19	46.3	C	.10	48	.441	MPA	.001
20	40.9	C	.12	49	2.222	MPA	.002
25	49.3	C	.07				

STEADY STATE TEST NO: AH4700
DATE: 11/30/82

TEST CONDITIONS:
AMBIENT--DRY BULB: 7.4 C DEW PT: 3.0 C
COOLING WATER--TEMP: 40.7 C TOT FLOW: .330 L/SEC
COND FLOW: .166 L/SEC
AMMONIA CHARGE: -.4 KG

ENERGY INPUTS:
GAS: 13.58 KW ELECTRIC--TOTAL: .532 KW
FAN: .196 KW
QGEN: 11.46 KW COMB EFF: .044
QEVAP: 7.07 KW

ENERGY OUTPUTS:
QLOAD: 15.86 KW
QCOND: 5.87 KW QABS: 9.99 KW

ENERGY BALANCE:
QGEN + QEVAP ? QLOAD L.O.C. = 2.67 KW = 16.8 %

COP: 1.124 COP-GAS: 1.168

SAMPLE CONCENTRATIONS:
STRONG ABS: .129 WEAK ABS: .321
.128 .312

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	.1	C	.03	26	40.7	C	.19
1	49.7	C	.16	27	0.67	CD	.03
2	63.8	C	.17	28	7.4	C	.28
3	81.9	C	.18	29	-4.43	CD	.07
4	33.1	C	.09	30	83.2	C	.10
5	21.3	C	.22	31	40.7	C	.19
6	6.8	C	.09	32	52.4	C	.17
7	32.4	C	.09	33	39.1	C	.17
8	48.9	C	.15	34	7.5	C	.17
9	79.8	C	.15	35	3.8	C	.08
10	51.9	C	.17	36	11.73	CD	.04
11	53.3	C	.16	37	79.9	C	.19
12	119.7	C	.23	38	2.4	C	.18
13	-7.5	C	.08	39	8.0	C	.08
14	129.9	C	.24	40	-7.1	C	.08
15	52.2	C	.16	41	6.0	C	.08
16	52.9	C	.16	42	7.7	C	.08
17	54.7	C	.16	46	21.1	C	.08
18	58.9	C	.21	47	10.123	V	.000
19	47.9	C	.23	48	.270	MPA	.001
20	39.9	C	.35	49	2.146	MPA	.008
25	49.2	C	.17				

STEADY STATE TEST NO: AB4709

DATE: 1/ 4/83

TEST CONDITIONS:

AMBIENT--DRY BULB: 8.7 C DEW PT: -1.1 C

COOLING WATER--TEMP: 40.4 C TOT FLOW: .333 L/SEC

COND FLOW: .164 L/SEC

AMMONIA CHARGE: -.2 KG

ENERGY INPUTS:

GAS: 13.81 KW ELECTRIC--TOTAL: .540 KW

FAN: .200 KW

QGEN: 11.68 KW COMB EFF: .846

QEVAP: 6.69 KW

ENERGY OUTPUTS:

QLOAD: 16.77 KW

QCOND: 5.85 KW QABS: 10.92 KW

ENERGY BALANCE:

QGEN + QEVAP ? QLOAD L.O.C. = 1.60 KW = 9.6 %

COP: 1.169 COP-GAS: 1.214

SAMPLE CONCENTRATIONS:

STRONG ABS: .154 WEAK ABS: .361

.152 .358

AVERAGE AND STANDARD DEVIATION OF RECORDED CHANNELS

CH	AVG		STD DEV	CH	AVG		STD DEV
0	21.4	C	.03	26	40.4	C	.16
1	48.9	C	.14	27	8.76	CD	.04
2	62.7	C	.18	28	8.7	C	.72
3	79.2	C	.18	29	-4.30	CD	.37
4	34.4	C	.19	30	84.0	C	.15
5	21.9	C	.31	31	40.4	C	.15
6	9.1	C	.60	32	52.7	C	.17
7	33.7	C	.17	33	27.9	C	.08
8	49.1	C	.15	34	8.7	C	.74
9	78.4	C	.13	35	9.1	C	.64
10	52.1	C	.15	36	12.27	CD	.05
11	53.7	C	.15	37	80.1	C	.19
12	117.0	C	.21	38	.8	C	1.53
13	-4.4	C	.21	39	10.0	C	.56
14	127.8	C	.24	40	-4.1	C	.21
15	52.4	C	.12	41	8.6	C	.75
16	53.2	C	.12	42	9.8	C	.68
17	54.9	C	.13	46	21.1	C	.04
18	58.5	C	.19	47	10.111	V	.001
19	47.2	C	.23	48	.314	MPA	.003
20	39.1	C	.24	49	2.166	MPA	.007
25	49.0	C	.14				

CYCLIC TEST

NO.: C17-1

DATE: 8-18-82

CYCLE TIMES: 12 / 48 ON/OFF

AMBIENT DRY BULB: -8.5 C

16.7 °F

WET BULB: -11.7 C

-or-

DEW POINT: 11.0 °F

WATER TEMP: 40.8 C

105.5°F

WATER FLOW: 0.377 kg/sec

6.03 gal/min

INTEGRATED CAPACITY 6.111 MJ

5792 BTU

GAS INPUT: 10.30 MJ

9759 BTU

ELECTRIC INPUT: 0.587 MJ

557 BTU

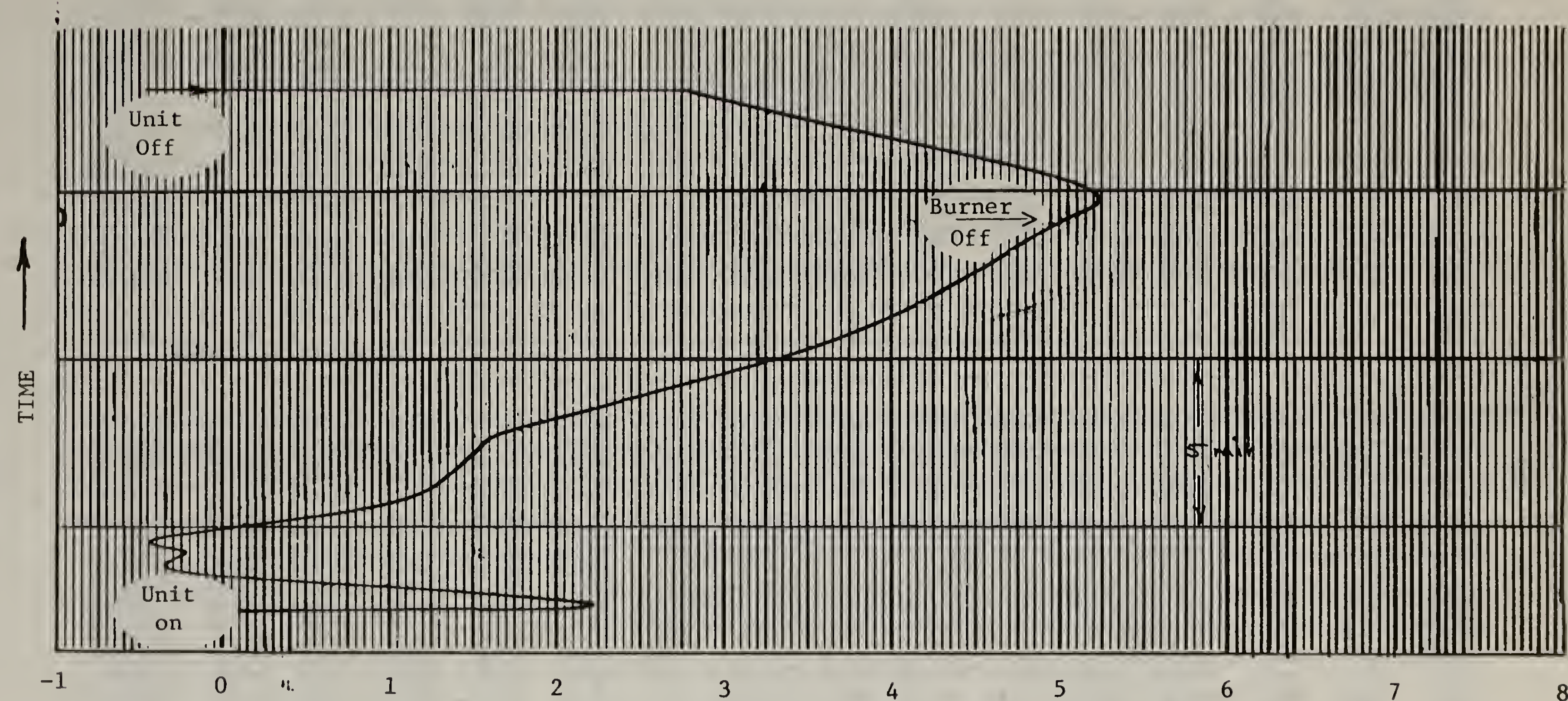
COP: 0.561

PLF = 0.582

HLF = 0.123

(Date are average of last 2 cycles)

Test No. C17-1



(Outlet - Inlet Water Temp. Thermopile)

Temperature Rise of Water Flowing Through
Unit As A Function of Time
For the Last Cycle

DATA FOR LAST CYCLE - Test No. C17-1

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
	F	F	F	F	F	F	F	F	F	F	F	F	MV	MV	MV
13:29:00	102.30	159.80	51.20	55.90	83.50	151.60	181.50	21.20	142.70	16.70	22.10	98.30	-6.71	2.89	2.59
13:30:00	97.50	159.00	49.90	54.20	85.30	151.70	180.50	20.70	155.60	16.70	23.30	99.00	1.43	2.98	3.26
13:31:00	62.10	99.60	47.80	22.30	27.20	159.10	160.00	15.60	168.50	16.90	19.10	104.40	-.06	2.80	4.87
13:32:00	70.70	72.20	43.20	26.50	38.90	152.30	127.20	14.80	150.80	16.40	17.80	105.30	-.43	2.31	5.13
13:33:00	85.40	79.70	38.00	20.10	30.90	129.10	127.40	11.30	154.10	17.80	17.20	105.60	.88	2.08	7.96
13:34:00	94.70	92.70	21.10	14.70	26.30	119.80	133.90	6.50	167.50	16.40	16.30	105.70	1.36	1.78	11.28
13:35:00	100.80	104.60	21.10	11.70	38.80	125.20	147.20	4.80	188.90	17.70	16.20	105.70	1.59	1.48	14.59
13:36:00	103.70	115.10	38.90	14.90	36.10	134.10	166.60	.70	208.50	17.30	17.00	105.80	2.25	1.38	16.32
13:37:00	106.00	122.10	42.70	18.30	51.10	142.50	190.00	1.20	225.70	16.00	14.90	105.70	2.96	1.56	16.84
13:38:00	108.80	127.20	49.00	19.20	65.90	149.10	209.20	7.10	239.00	16.10	13.60	105.70	3.61	1.87	16.91
13:39:00	108.60	131.80	35.30	20.70	59.30	154.20	220.50	10,90	245.60	17.80	15.30	105.60	4.09	2.06	17.16
13:40:00	107.50	135.40	31.70	18.70	60.30	157.90	228.10	11.20	247.60	15.80	14.30	105.50	4.45	2.07	17.46
13:41:00	107.60	137.10	37.70	16.20	65.30	162.00	232.10	11.20	248.30	16.00	13.40	105.50	4.78	2.09	17.66
13:42:00	108.30	137.60	24.70	12.50	65.80	164.20	234.10	12.60	249.80	17.80	14.90	105.40	5.17	2.13	17.44
13:43:00	109.00	134.70	15.60	12.10	51.30	160.50	231.80	12.20	245.50	16.30	14.40	105.30	4.93	2.10	15.47
13:44:00	108.90	129.50	12.10	10.40	28.00	153.20	225.50	10.10	239.50	16.30	13.30	105.30	4.05	2.05	14.32
13:45:00	108.20	128.00	12.40	11.70	22.10	145.60	218.80	10.62	234.70	17.60	14.30	105.30	3.15	2.08	13.59
13:46:00	107.90	134.10	29.80	12.70	27.70	139.80	218.30	8.80	232.60	16.90	14.20	105.20	2.55	1.99	13.29

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
	C	C	C	C	C	C	C	C	C	C	C	C	MV	MV	MV
13:29:00	39.06	71.00	10.67	13.28	28.61	66.44	83.06	-6.00	61.50	-8.50	-5.50	36.83	-6.71	2.89	2.59
13:30:00	36.39	70.56	9.94	12.33	29.61	66.50	82.50	-6.28	68.67	-8.50	-4.83	37.22	1.43	2.98	3.26
13:31:00	16.72	37.56	8.78	-5.39	-2.67	70.61	71.11	-9.11	75.83	-8.39	-7.17	40.22	-.06	2.80	4.87
13:32:00	21.50	22.33	6.22	-3.06	3.83	66.83	52.89	-9.56	66.00	-8.67	-7.89	40.72	-.43	2.31	5.13
13:33:00	29.67	26.50	3.33	-6.61	-.61	53.94	53.00	-11.50	67.83	-7.89	-8.22	40.89	.88	2.08	7.96
13:34:00	34.83	33.72	-6.06	-9.61	-3.17	48.78	56.61	-14.17	75.28	-8.67	-8.72	40.94	1.36	1.78	11.28
13:35:00	38.22	40.33	-6.06	-11.28	1.00	51.78	64.00	-15.11	87.17	-7.94	-8.78	40.94	1.59	1.48	14.59
13:36:00	39.83	46.17	3.83	-9.50	2.28	56.72	74.78	-17.39	98.06	-8.17	-8.33	41.00	2.25	1.38	16.32
13:37:00	41.11	50.06	5.94	-7.61	10.61	61.39	87.78	-17.11	107.61	-8.89	-9.50	40.94	2.96	1.56	16.84
13:38:00	42.67	52.89	9.44	-7.11	18.83	65.06	98.44	-13.83	115.00	-8.83	-10.22	40.94	3.61	1.87	16.91
13:39:00	42.56	55.44	1.83	-6.28	15.17	67.89	104.72	-11.72	118.67	-7.89	-9.28	40.89	4.09	2.06	17.16
13:40:00	41.94	57.44	-.17	-7.39	15.72	69.94	108.94	-11.56	119.78	-9.00	-9.83	40.83	4.45	2.07	17.46
13:41:00	42.00	58.39	3.17	-8.78	18.50	72.22	111.17	-11.56	120.17	-8.89	-10.33	40.83	4.78	2.09	17.66
13:42:00	42.39	58.67	-4.06	-10.83	18.78	73.44	112.28	-10.78	121.00	-7.89	-9.50	40.78	5.17	2.13	17.44
13:43:00	42.78	57.06	-9.11	-11.06	10.72	71.39	111.00	-11.00	118.61	-8.72	-9.78	40.72	4.93	2.10	15.47
13:44:00	42.72	54.17	-11.06	-12.00	-2.22	67.33	107.50	-12.17	115.28	-8.72	-10.39	40.72	4.05	2.05	14.32
13:45:00	42.33	52.22	-10.89	-11.28	-5.50	63.11	103.78	-11.89	112.61	-8.00	-9.72	40.72	3.15	2.08	13.59
13:46:00	42.17	56.72	-1.22	-10.72	-2.39	59.89	103.50	-12.89	111.44	-8.39	-9.89	40.67	2.55	1.99	13.29

Unit On: 13:29:59
Burner Off: 13:41:59
Unit Off: 13:45:43

CYCLIC TEST

NO.: C47-1

DATE: 8-5-82

CYCLE TIMES: 6 / 24 ON/OFF

AMBIENT DRY BULB: 7.9 C

46.2 °F

WET BULB: 6.3 C

-or-

DEW POINT: 43.3 °F

WATER TEMP: 46.6 C

105.1 °F

WATER FLOW: 0.367 kg/sec

5.88 gal/min

INTEGRATED CAPACITY 3.178 MJ

3012 BTU

GAS INPUT: 4.972 MJ

4712 BTU

ELECTRIC INPUT: 0.316 MJ

300 BTU

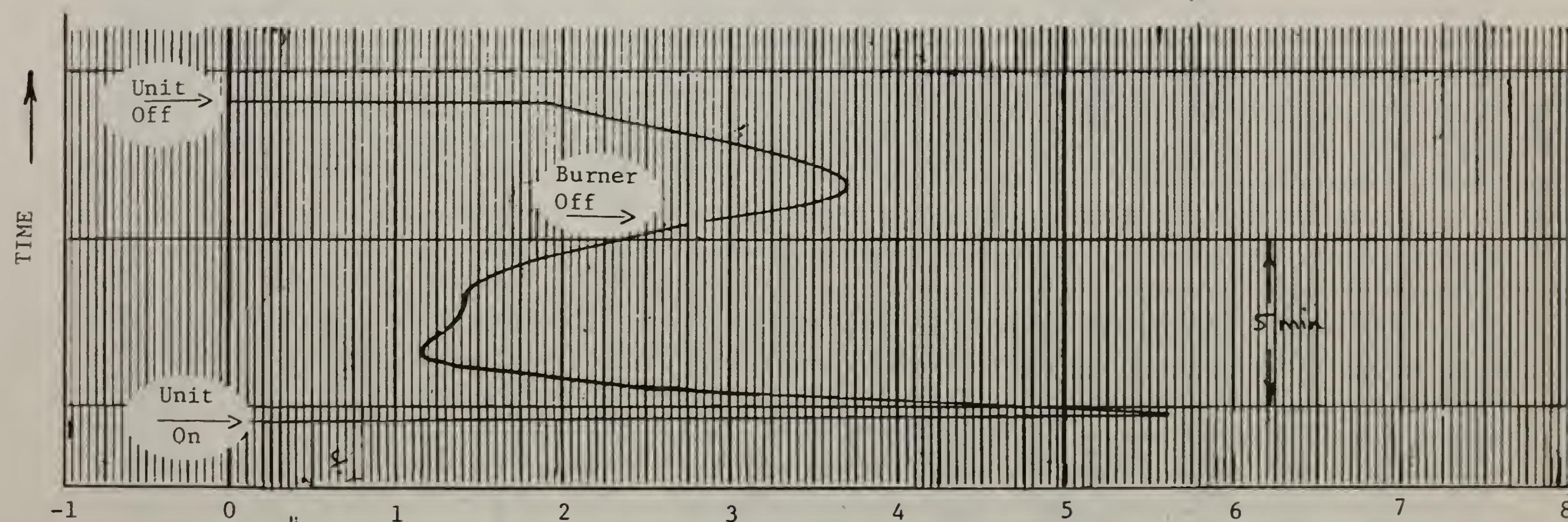
COP: 0.601

PLF = 0.529

HLF = 0.104

(Data are average of last two cycles)

Test No. C47-1



Channel 36 (mV)

(Outlet - Inlet Water Temp. Thermopile)

Temperature Rise of Water Flowing Through
Unit as a Function of Time
For the Last Cycle

DATA FOR LAST CYCLE - Test No. C47-1

CHANNEL NO. AND UNITS: TIME	1 F	2 F	5 F	6 F	7 F	9 F	12 F	13 F	14 F	28 F	29 F	31 F	36 MV	48 MV	49 MV
11:39:00	110.70	182.60	88.10	91.70	107.60	173.70	193.70	35.40	180.80	47.20	55.10	105.40	-2.27	3.71	5.89
11:40:00	110.50	169.80	86.20	68.10	102.80	176.00	189.80	46.00	187.50	48.60	53.50	105.30	4.67	4.44	6.82
11:41:00	104.60	115.80	76.70	62.20	58.90	163.00	160.90	31.70	179.80	47.40	49.80	105.40	1.72	3.00	7.77
11:42:00	106.20	107.70	65.70	45.70	69.10	147.70	147.70	27.70	173.70	46.20	47.10	105.40	1.24	2.27	9.57
11:43:00	104.90	112.70	50.50	42.40	73.60	135.30	159.10	30.50	188.50	46.00	46.50	105.30	1.42	1.33	13.11
11:44:00	106.30	115.50	59.10	43.00	72.90	133.50	169.80	13.10	204.50	46.10	46.80	105.30	1.66	1.49	15.24
11:45:00	109.40	122.70	71.70	45.40	69.90	137.50	187.20	6.40	219.20	45.90	46.30	105.20	2.43	1.82	16.43
11:46:00	110.30	130.00	68.20	50.10	79.10	148.20	205.80	18.40	234.80	45.50	44.10	105.30	3.47	2.48	15.76
11:47:00	109.30	128.10	74.70	46.10	77.10	149.10	212.30	18.30	232.90	45.00	42.90	105.20	3.39	2.39	14.34
11:48:00	108.70	125.60	76.50	44.60	77.10	144.10	209.20	11.00	226.10	45.10	44.00	105.10	2.83	2.00	13.90
11:49:00	108.10	123.10	78.20	44.90	78.50	130.70	203.50	5.60	221.30	43.50	43.50	105.10	1.90	1.87	13.23

CHANNEL NO. AND UNITS: TIME	1 C	2 C	5 C	6 C	7 C	9 C	12 C	13 C	14 C	28 C	29 C	31 C	36 MV	48 MV	49 MV
11:39:00	43.72	83.67	31.17	33.17	42.00	78.72	89.83	15.00	82.67	8.44	12.83	40.78	-2.27	3.71	5.89
11:40:00	43.61	76.56	30.11	20.06	39.33	80.00	87.67	7.78	86.39	9.22	11.94	40.72	4.67	4.44	6.82
11:41:00	40.33	46.56	24.83	16.78	14.94	72.78	71.61	-.17	82.11	8.56	9.89	40.78	1.72	3.00	7.77
11:42:00	41.22	42.06	18.72	7.61	20.61	64.28	64.28	-2.39	78.72	7.89	8.39	40.78	1.24	2.27	9.57
11:43:00	40.50	44.83	10.28	5.78	23.11	57.39	70.61	-.83	86.94	7.78	8.06	40.72	1.42	1.33	13.11
11:44:00	41.28	46.39	15.06	6.11	22.72	56.39	76.56	-10.50	95.83	7.83	8.22	40.72	1.66	1.49	15.24
11:45:00	43.00	50.39	22.06	7.44	21.06	58.61	86.22	-14.22	104.00	7.72	7.94	40.67	2.43	1.82	16.43
11:46:00	43.50	54.44	20.11	10.06	26.17	64.56	96.56	-7.56	112.67	7.50	6.72	40.72	3.47	2.48	15.76
11:47:00	42.94	53.39	23.72	7.83	25.06	65.06	100.17	-7.61	111.61	7.22	8.06	40.67	3.39	2.39	14.34
11:48:00	42.61	52.00	24.72	7.00	25.06	62.28	98.44	-11.67	107.83	7.28	6.67	40.61	2.83	2.00	13.90
11:49:00	42.28	50.61	26.00	7.17	25.83	54.83	95.28	-14.78	105.17	7.50	7.50	40.61	1.90	1.87	13.23

Unit On: 11:39:39
Burner Off: 11:45:39
Unit Off: 11:49:15

CYCLIC TEST

NO.: C47-2

DATE: 8-5-82

CYCLE TIMES: 12 / 48 ON/OFF

AMBIENT DRY BULB: 7.6 C

45.6 °F

WET BULB: 6.0 C

-or-

DEW POINT: 42.8 °F

WATER TEMP: 40.8 C

105.4 °F

WATER FLOW: 0.369 kg/sec

5.90 gal/min

INTEGRATED CAPACITY 7.342 MJ

6959 BTU

GAS INPUT: 10.02 MJ

9495 BTU

ELECTRIC INPUT: 0.535 MJ

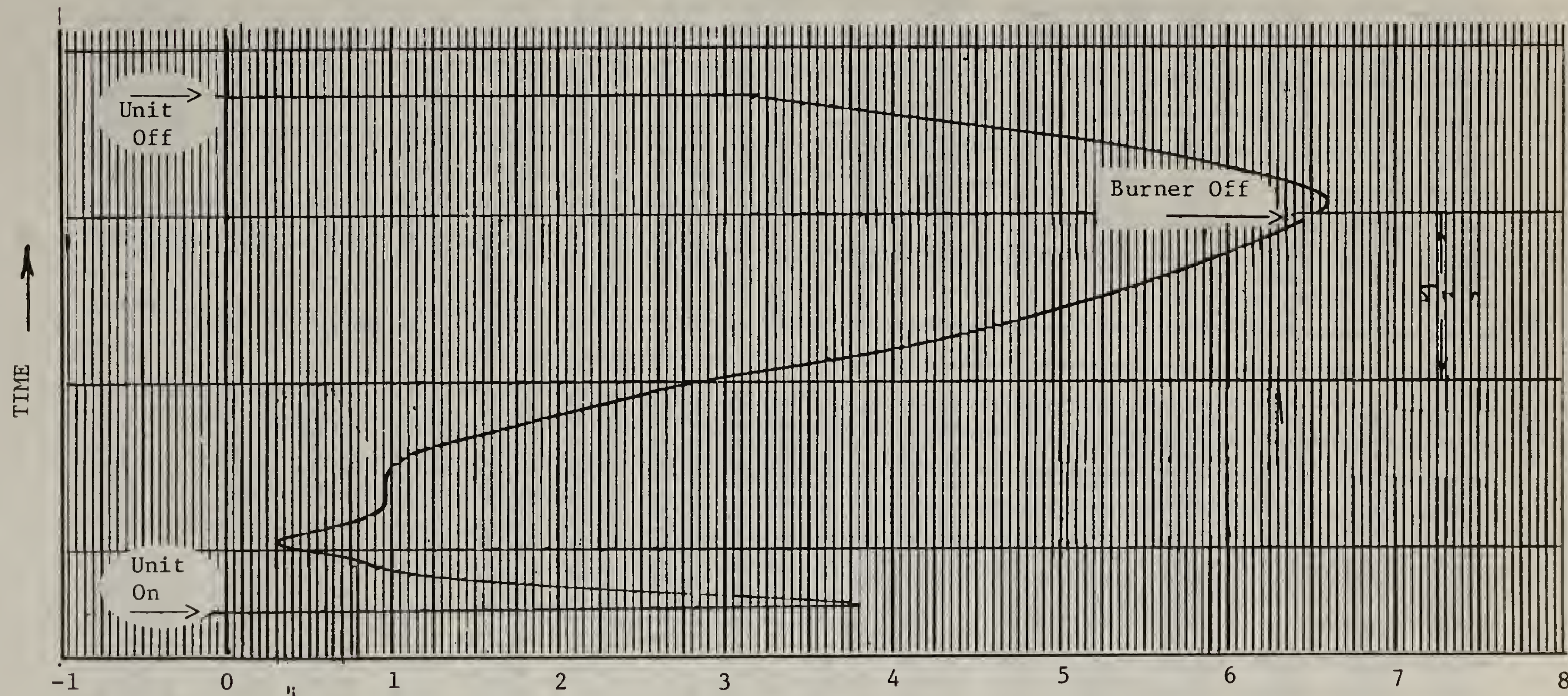
507 BTU

COP: 0.696

PLF = 0.619 HLF = 0.122

(Data are average of last two cycles)

Test No. C47-2



Channel 36 (mV)

(Outlet - Inlet Water Temp. Thermopile)

Temperature Rise of Water Flowing Through
Unit as a Function of Time
For the Last Cycle

DATA FOR LAST CYCLE - Test No. C47-2

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
CHANNEL NO. AND UNITS:	F	F	F	F	F	F	F	F	F	F	F	F	MV	MV	MV
15:05:00	116.00	160.40	72.60	70.10	101.00	156.30	175.50	43.70	148.90	46.90	55.50	105.60	-5.56	3.82	3.76
15:06:00	108.70	159.10	71.50	66.90	103.40	157.40	174.90	42.00	161.30	47.10	54.70	105.10	3.40	3.20	4.41
15:07:00	82.80	99.70	67.20	51.10	56.60	165.40	155.40	33.10	168.10	47.20	49.80	105.30	1.15	2.54	6.50
15:08:00	88.80	80.70	61.90	50.80	63.80	141.10	129.90	30.60	160.70	46.40	47.00	105.30	.30	2.06	6.80
15:09:00	98.20	96.40	56.60	44.80	70.70	124.80	134.10	34.00	169.30	46.00	46.30	105.30	.93	1.63	9.61
15:10:00	102.70	105.00	52.50	43.40	75.00	127.10	147.60	30.10	187.60	46.00	46.30	105.30	.97	1.43	12.78
15:11:00	105.30	112.90	62.20	43.90	74.90	129.60	164.70	16.10	208.10	45.80	46.50	105.30	1.35	1.40	15.02
15:12:00	107.90	119.50	72.80	46.50	71.80	134.80	182.90	7.70	224.00	45.70	46.40	105.40	2.16	1.67	16.10
15:13:00	107.60	126.40	67.60	51.50	75.70	145.90	203.80	15.50	236.70	45.50	45.00	105.40	3.07	2.32	16.65
15:14:00	106.40	127.50	52.90	48.30	66.10	153.10	214.10	22.00	241.10	45.10	42.90	105.40	4.20	2.68	17.05
15:15:00	108.20	130.20	51.10	46.30	69.70	154.70	215.00	24.80	237.70	44.70	41.10	105.40	4.98	2.84	17.57
15:16:00	110.20	132.30	54.80	45.50	75.90	157.60	215.20	26.70	236.00	44.40	39.60	105.40	5.61	2.94	17.92
15:17:00	111.60	133.70	60.70	45.10	82.20	159.90	215.60	27.80	235.70	45.10	39.00	105.40	6.13	2.96	18.23
15:18:00	113.00	134.70	63.90	45.10	87.10	161.50	216.10	28.10	235.90	44.40	38.40	105.40	6.55	2.94	18.04
15:19:00	114.10	132.80	67.50	44.60	87.70	157.80	213.30	27.90	229.30	44.00	37.90	105.40	6.21	2.94	16.11
15:20:00	113.50	129.90	79.40	43.70	83.40	151.50	209.10	23.00	224.10	44.00	38.90	105.40	5.20	2.51	14.95
15:21:00	111.10	127.70	79.50	43.40	81.30	145.60	205.40	11.20	220.40	44.80	41.90	105.40	3.71	1.90	14.19
15:22:00	110.20	138.80	81.70	44.10	81.60	137.00	206.90	7.80	220.60	45.90	43.10	105.30	2.58	1.96	14.17

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
CHANNEL NO. AND UNITS:	C	C	C	C	C	C	C	C	C	C	C	C	MV	MV	MV
15:05:00	46.67	71.33	22.56	21.17	38.33	69.06	79.72	6.50	64.94	8.28	13.06	40.89	-5.56	3.82	3.76
15:06:00	42.61	70.61	21.94	19.39	39.67	69.67	79.39	5.56	71.83	8.39	12.61	40.61	3.40	3.20	4.41
15:07:00	28.22	37.61	19.56	10.61	13.67	74.11	68.56	.61	75.61	8.44	9.89	40.72	1.15	2.54	6.50
15:08:00	31.56	27.06	16.61	10.44	17.67	60.61	54.39	-.78	71.50	8.00	8.33	40.72	.30	2.06	6.80
15:09:00	36.78	35.78	13.67	7.11	21.50	51.56	56.72	1.11	76.28	7.78	7.94	40.72	.93	1.63	9.61
15:10:00	39.28	40.56	11.39	6.33	23.89	52.83	64.22	-1.06	86.44	7.78	7.94	40.72	.97	1.43	12.78
15:11:00	40.72	44.94	16.78	6.61	23.83	54.22	73.72	-8.83	97.83	7.67	8.06	40.72	1.35	1.40	15.02
15:12:00	42.17	48.61	22.67	8.06	22.11	57.11	83.83	-13.50	106.67	7.61	8.00	40.78	2.16	1.67	16.10
15:13:00	42.00	52.44	19.78	10.83	24.28	63.28	95.44	-9.17	113.72	7.50	7.22	40.78	3.07	2.32	16.65
15:14:00	41.33	53.06	11.61	9.06	18.94	67.28	101.17	-5.56	116.17	7.28	6.06	40.78	4.20	2.68	17.05
15:15:00	42.33	54.56	10.61	7.94	20.94	68.17	101.67	-4.00	114.28	7.06	5.06	40.78	4.98	2.84	17.57
15:16:00	43.44	55.72	12.67	7.50	24.39	69.78	101.78	-2.94	113.33	6.89	4.22	40.78	5.61	2.94	17.92
15:17:00	44.22	56.50	15.94	7.28	27.89	71.06	102.00	-2.33	113.17	7.28	3.89	40.78	6.13	2.96	18.23
15:18:00	45.00	57.06	17.72	7.28	30.61	71.94	102.28	-2.17	113.28	6.89	3.56	40.78	6.55	2.94	18.04
15:19:00	45.61	56.00	19.72	7.00	30.94	69.89	100.72	-2.28	109.61	6.67	3.28	40.78	6.21	2.94	16.11
15:20:00	45.28	54.39	26.33	6.50	28.56	68.39	98.39	-5.00	106.72	6.67	3.83	40.78	5.20	2.51	14.95
15:21:00	43.94	53.17	26.39	6.33	27.39	63.11	96.33	-11.56	104.67	7.18	5.50	40.78	3.71	1.90	14.19
15:22:00	43.44	59.33	27.61	6.72	27.56	58.33	97.17	-13.44	104.78	7.72	6.17	40.72	2.58	1.96	14.17

Unit On: 15:05:57
Burner Off: 15:17:57
Unit Off: 15:21:37

CYCLIC TEST

NO.: C47-3

DATE: 8-6-82

CYCLE TIMES: 20 / 20 ON/OFF

AMBIENT DRY BULB:	7.7 C	WATER TEMP:	40.7 C
	45.9 °F		105.3 °F
WET BULB:	6.4 C	WATER FLOW:	0.367 kg/sec
-or- DEW POINT:	43.5 °F		5.88 gal/min

INTEGRATED CAPACITY 16.64 MJ

15739 BTU

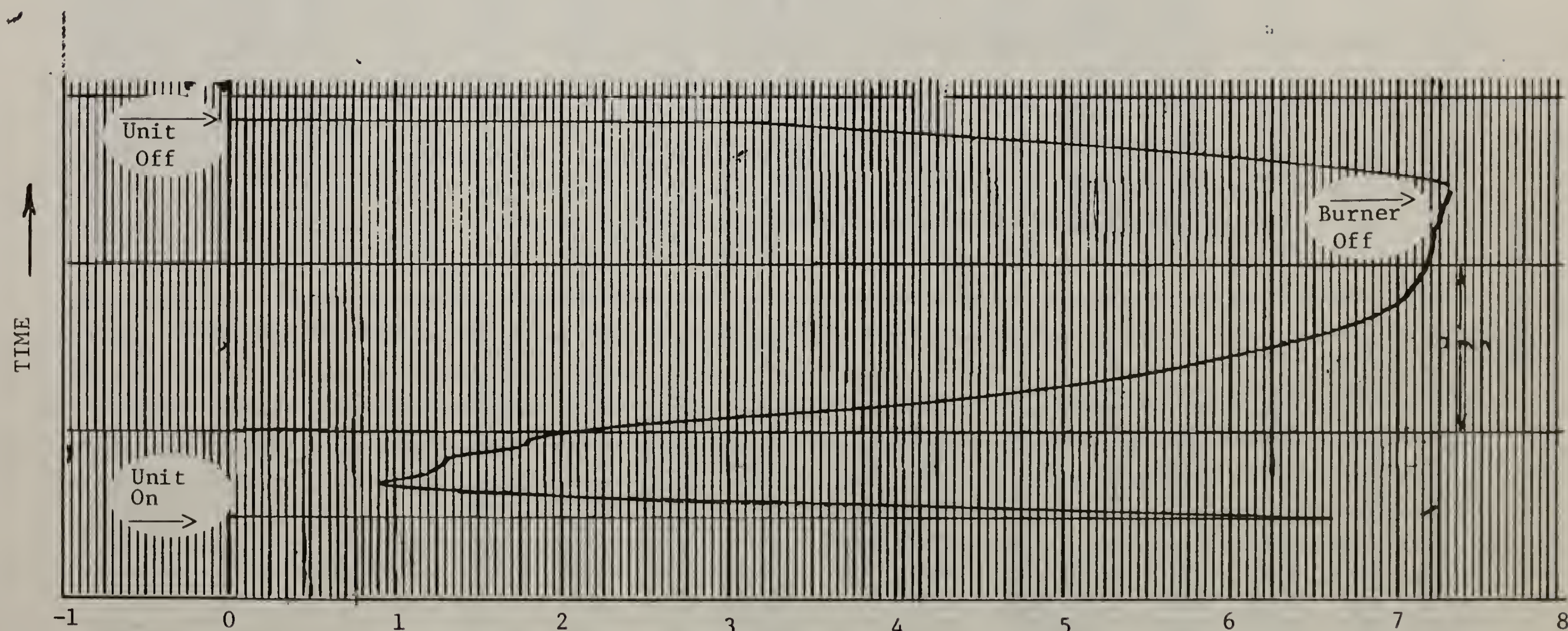
GAS INPUT:	16.52 MJ	ELECTRIC INPUT:	0.798 MJ
	15653 BTU		756 BTU

COP: 0.961

PLF = 0.854 HLF = 0.413

(Data are average of last two cycles)

Test No. C47-3



Channel 36 (mV)

(Outlet - Inlet Water Temp. Thermopile)

Temperature Rise of Water Flowing Through
Unit as a Function of Time
For the Last Cycle

DATA FOR LAST CYCLE - Test No. C47-3

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
CHANNEL NO. AND UNITS:	F	F	F	F	F	F	F	F	F	F	F	F	MV	MV	MV
11:29:00	113.50	187.00	104.40	124.10	136.00	184.10	200.50	53.00	201.60	48.40	58.10	109.30	-1.97	5.44	5.47
11:30:00	112.40	184.60	103.70	115.20	137.50	183.40	198.80	49.90	202.50	48.80	58.30	108.40	6.45	4.96	6.14
11:31:00	99.30	116.20	93.70	59.00	67.80	184.80	178.30	35.70	190.80	48.40	49.80	105.40	2.17	2.99	8.86
11:32:00	103.40	101.70	76.80	49.10	67.90	145.50	151.30	26.00	180.40	46.80	46.10	105.10	.99	2.11	9.60
11:33:00	104.40	110.60	64.30	47.50	75.60	133.10	161.50	33.30	191.10	46.30	45.70	105.00	1.30	1.56	13.43
11:34:00	104.40	117.00	66.20	47.20	74.10	132.50	173.70	12.00	208.80	46.00	45.50	104.90	1.72	1.56	14.77
11:35:00	108.00	116.60	76.20	47.00	73.30	135.20	181.10	7.10	219.30	45.80	45.10	104.90	2.09	1.76	15.95
11:36:00	108.80	126.40	76.00	49.90	81.30	145.10	202.10	14.20	230.80	45.50	43.90	104.90	3.15	2.28	16.72
11:37:00	108.80	129.90	70.00	48.00	79.60	153.00	214.00	21.60	238.70	45.00	42.00	104.90	4.32	2.68	17.05
11:38:00	109.90	131.50	61.90	46.90	77.90	156.40	217.50	26.20	239.80	44.80	40.70	104.90	5.08	2.95	17.40
11:39:00	110.60	133.00	63.10	45.80	79.10	158.70	217.70	27.10	238.20	44.60	40.00	104.90	5.67	2.95	17.78
11:40:00	111.80	134.30	65.00	45.60	83.60	160.50	217.10	27.70	236.70	44.90	39.60	104.90	6.11	2.96	18.11
11:41:00	112.80	135.10	66.70	45.70	87.60	161.90	217.20	28.10	236.40	45.10	39.50	104.90	6.50	2.96	18.34
11:42:00	113.50	135.80	67.20	45.70	90.20	162.90	217.40	28.30	236.90	45.10	39.10	104.90	6.80	2.95	18.52
11:43:00	114.30	136.40	67.50	45.60	91.20	163.70	218.30	28.30	237.80	45.20	38.90	105.00	6.99	2.95	18.60
11:44:00	115.00	136.60	67.80	45.70	91.90	164.30	219.10	28.50	238.70	45.20	38.90	105.00	7.08	2.96	18.64
11:45:00	115.30	137.40	68.00	45.80	92.20	164.60	219.80	28.70	239.30	45.30	38.90	104.90	7.15	2.97	18.69
11:46:00	115.40	137.70	67.00	45.90	92.70	165.30	220.60	28.80	239.80	45.50	38.90	104.90	7.19	2.97	18.69
11:47:00	115.70	137.90	67.60	45.90	92.70	165.40	221.20	29.10	240.20	45.50	38.90	104.90	7.21	2.98	18.71
11:48:00	115.50	138.50	67.30	46.00	92.90	165.80	221.80	29.00	240.40	45.50	39.00	104.90	7.24	3.00	18.76
11:49:00	115.80	138.40	67.10	46.20	93.00	166.10	221.80	29.60	240.50	46.10	39.40	104.90	7.27	3.01	18.77
11:50:00	115.90	138.40	67.10	46.50	93.10	166.30	221.80	29.50	240.50	45.80	39.10	104.90	7.29	3.00	18.38
11:51:00	115.70	135.60	67.70	46.20	91.60	161.60	218.20	29.30	232.60	45.50	38.90	104.90	6.70	3.01	16.28
11:52:00	115.00	131.80	80.30	45.40	85.80	154.40	212.60	25.40	226.00	45.40	39.80	104.90	5.58	2.68	15.00
11:53:00	111.70	129.20	80.20	44.50	82.40	148.30	207.90	13.30	221.30	46.30	43.00	104.90	4.03	1.99	14.27
11:54:00	110.20	131.30	81.30	45.50	81.90	141.40	207.70	8.20	220.50	47.30	45.00	104.90	2.69	1.97	14.11

'17-3C

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
CHANNEL NO. AND UNITS:	C	C	C	C	C	C	C	C	C	C	C	C	MV	MV	MV
11:29:00	45.28	86.11	40.22	51.17	57.78	84.50	93.61	11.67	94.22	9.11	14.50	42.94	-1.97	5.44	5.47
11:30:00	44.67	84.78	39.83	46.22	58.61	84.11	92.67	9.94	94.72	9.33	14.61	42.44	6.45	4.96	6.14
11:31:00	37.39	46.78	34.28	15.00	19.89	84.89	81.28	2.06	88.22	9.11	9.89	40.78	2.17	2.99	8.86
11:32:00	39.67	38.72	24.89	9.50	19.94	63.06	66.28	-3.33	82.44	8.22	7.83	40.61	.99	2.11	9.60
11:33:00	40.22	43.67	17.94	8.61	24.22	56.17	71.94	.72	88.39	7.94	7.61	40.56	1.30	1.56	13.43
11:34:00	40.22	47.22	19.00	8.44	23.39	55.83	78.72	-11.11	98.22	7.78	7.50	40.50	1.72	1.56	14.77
11:35:00	42.22	47.00	24.56	8.33	22.94	57.33	82.83	-13.83	104.06	7.67	7.28	40.50	2.09	1.76	15.95
11:36:00	42.67	52.44	24.44	9.94	27.39	62.83	94.50	-9.89	110.44	7.50	6.61	40.50	3.15	2.28	16.72
11:37:00	42.67	54.39	21.11	8.89	26.44	67.22	101.11	-5.78	114.83	7.22	5.56	40.50	4.32	2.68	17.05
11:38:00	43.28	55.28	16.61	8.28	25.50	69.11	103.06	-3.22	115.44	7.11	4.83	40.50	5.08	2.95	17.40
11:39:00	43.67	56.11	17.28	7.67	26.17	70.39	103.17	-2.72	114.56	7.00	4.44	40.50	5.67	2.95	17.78
11:40:00	44.33	56.83	18.33	7.56	28.67	71.39	102.83	-2.39	113.72	7.17	4.22	40.50	6.11	2.96	18.11
11:41:00	44.89	57.28	19.28	7.61	30.89	72.17	102.89	-2.17	113.56	7.28	4.17	40.50	6.50	2.96	18.34
11:42:00	45.28	57.67	19.56	7.61	32.33	72.72	103.00	-2.06	113.83	7.28	3.94	40.50	6.80	2.95	18.52
11:43:00	45.72	58.00	19.72	7.56	32.89	73.17	103.50	-2.06	114.33	7.33	3.83	40.56	6.99	2.95	18.60
11:44:00	46.11	58.11	19.89	7.61	33.28	73.50	103.94	-1.94	114.83	7.33	3.83	40.56	7.08	2.96	18.64
11:45:00	46.28	58.56	20.00	7.67	33.44	73.67	104.33	-1.83	115.17	7.39	3.83	40.50	7.15	2.97	18.69
11:46:00	46.33	58.72	19.44	7.72	33.72	74.06	104.78	-1.78	115.44	7.50	3.83	40.50	7.19	2.97	18.69
11:47:00	46.50	58.83	19.78	7.72	33.72	74.11	105.11	-1.61	115.67	7.50	3.83	40.50	7.21	2.98	18.71
11:48:00	46.39	59.17	19.61	7.78	33.83	74.33	105.44	-1.67	115.78	7.50	3.89	40.50	7.24	3.00	18.76
11:49:00	46.56	59.11	19.50	7.89	33.89	74.50	105.44	-1.33	115.83	7.83	4.11	40.50	7.27	3.01	18.77
11:50:00	46.61	59.11	19.50	8.06	33.94	74.61	105.44	-1.39	115.83	7.67	3.94	40.50	7.29	3.00	18.38
11:51:00	46.50	57.56	19.83	7.89	33.11	72.00	103.44	-1.50	111.44	7.50	3.83	40.50	6.70	3.01	16.28
11:52:00	46.11	55.44	26.83	7.44	29.89	68.00	100.33	-3.67	107.78	7.44	4.33	40.50	5.58	2.68	15.00
11:53:00	44.28	54.00	26.78	6.94	28.00	64.61	97.72	-10.39	105.17	7.94	6.11	40.50	4.03	1.99	14.27
11:54:00	43.44	55.17	27.39	7.50	27.72	60.78	97.61	-13.22	104.72	8.50	7.22	40.50	2.69	1.97	14.11

Unit On: 11:29:56
Burner Off: 11:49:56
Unit Off: 11:53:49

CYCLIC TEST

NO.: C47-4

DATE: 8-6-82

CYCLE TIMES: 10 / 10 ON/OFF

AMBIENT DRY BULB: 7.9 C

46.2 °F

WET BULB: 6.6 C

-or-

DEW POINT: 43.8 °F

WATER TEMP: 40.4 C

104.8 °F

WATER FLOW: 0.366 kg/sec

5.85 gal/min

INTEGRATED CAPACITY 8.291 MJ

7858 BTU

GAS INPUT: 8.280 MJ

7848 BTU

ELECTRIC INPUT: 0.445 MJ

422 BTU

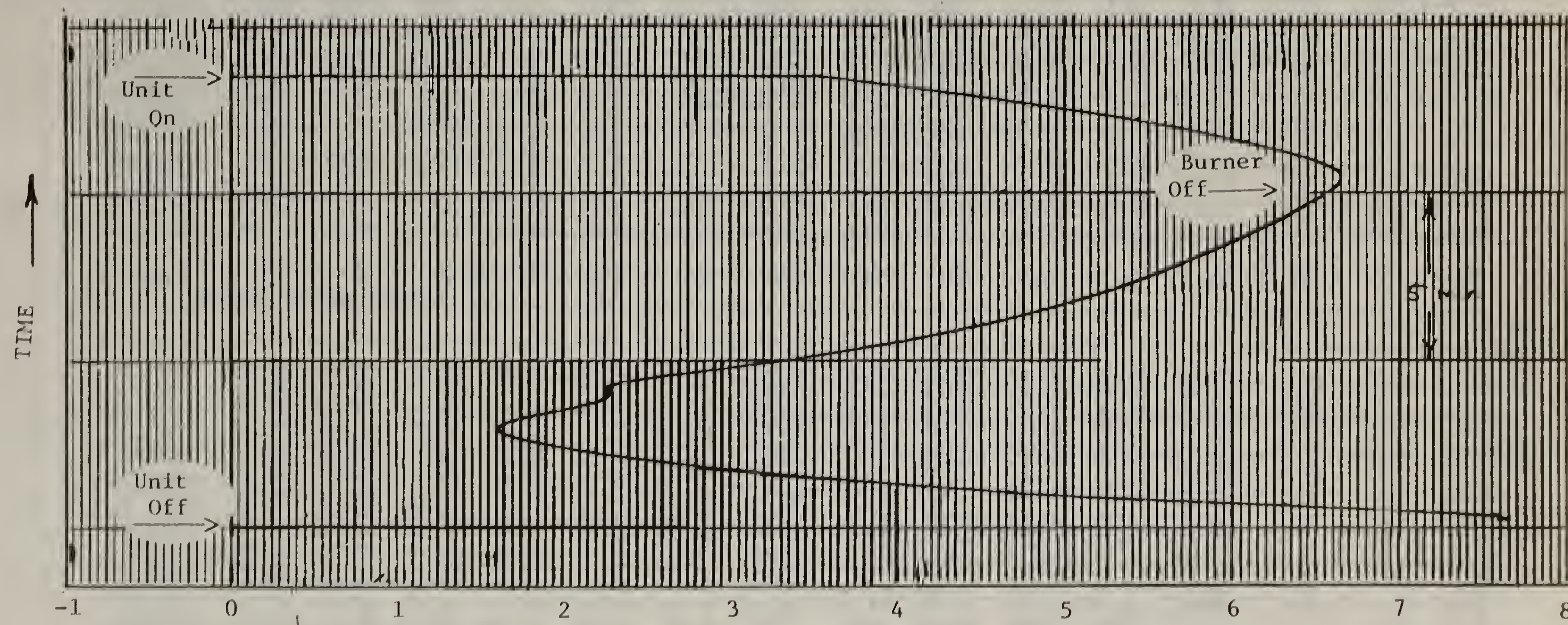
COP: 0.950

PLF = 0.845

HLF = 0.412

(Data are average of last two cycles)

Test No. C47-4



Channel 36 (mV)

(Outlet - Inlet Water Temp. Thermopile)

Temperature Rise of Water Flowing Through
Unit as a Function of Time
For the Last Cycle

DATA FOR LAST CYCLE - Test No. C47-4

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
CHANNEL NO. AND UNITS:	F	F	F	F	F	F	F	F	F	F	F	F	MV	MV	MV
13:04:00	111.40	212.00	101.60	114.60	120.60	175.10	217.30	47.20	225.30	48.20	48.80	103.70	2.74	5.00	11.12
13:05:00	114.60	207.40	103.90	92.60	115.90	175.30	215.20	43.50	220.50	48.60	51.80	103.90	7.59	3.57	11.49
13:06:00	114.90	124.60	73.50	52.60	77.10	138.70	188.20	24.40	211.50	47.10	44.40	104.70	3.76	2.47	12.05
13:07:00	109.70	116.50	71.20	51.10	77.00	134.20	171.90	24.20	203.40	46.80	46.50	104.90	1.94	1.89	13.25
13:08:00	108.20	123.70	71.20	50.00	75.50	133.70	187.30	30.10	214.10	46.60	46.50	104.90	1.92	1.56	15.70
13:09:00	109.00	119.80	79.30	50.00	78.90	143.30	191.20	13.60	222.40	46.20	45.90	105.00	2.44	2.19	16.38
13:10:00	110.00	129.50	80.00	48.40	84.30	148.60	207.50	17.30	232.30	45.80	44.20	104.90	3.80	2.45	17.01
13:11:00	110.50	131.80	76.90	47.40	86.70	155.10	215.50	22.70	238.20	45.30	42.20	104.90	4.75	2.74	17.36
13:12:00	111.60	133.60	76.60	46.50	88.40	158.20	218.50	25.80	239.20	44.90	40.80	105.00	5.41	2.87	17.66
13:13:00	112.50	135.00	72.00	46.00	88.30	160.60	219.20	27.20	238.80	44.90	40.10	104.90	5.90	2.97	17.99
13:14:00	113.00	135.80	70.40	45.70	88.70	162.30	219.30	28.20	238.20	45.50	39.90	104.90	6.32	2.99	18.24
13:15:00	113.60	136.30	69.50	45.80	90.20	163.00	218.90	28.40	237.30	45.10	39.40	104.90	6.63	2.99	17.86
13:16:00	114.20	133.40	72.00	45.60	89.00	158.70	215.00	28.30	229.40	44.90	39.20	104.90	6.20	2.97	15.97
13:17:00	113.00	130.20	80.70	44.80	84.20	151.80	209.80	23.10	223.60	45.30	40.60	104.90	5.15	2.54	14.84
13:19:00	110.50	159.30	83.60	45.40	82.80	141.90	211.90	10.60	222.80	47.10	44.40	104.90	2.85	2.19	14.41

47-4D

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
CHANNEL NO. AND UNITS:	C	C	C	C	C	C	C	C	C	C	C	C	MV	MV	MV
13:04:00	44.11	100.00	38.67	45.89	49.22	79.50	102.94	8.44	107.39	9.00	9.33	39.83	2.74	5.00	11.12
13:05:00	45.89	97.44	39.94	33.67	46.61	79.61	101.78	6.39	104.72	9.22	11.00	39.94	7.59	3.57	11.49
13:06:00	46.06	51.44	23.36	11.44	25.06	59.28	86.78	-4.22	99.72	8.39	8.00	40.39	3.76	2.47	12.05
13:07:00	43.17	46.94	21.78	10.61	25.00	56.78	77.72	-4.33	95.22	8.22	8.06	40.50	1.94	1.89	13.25
13:08:00	42.33	50.94	21.78	10.00	24.17	56.50	86.28	-1.06	101.17	8.11	8.06	40.50	1.92	1.56	15.70
13:09:00	42.78	48.78	26.28	10.00	26.06	61.83	88.44	-10.22	105.78	7.89	7.72	40.56	2.44	2.19	16.38
13:10:00	43.33	54.17	26.67	9.11	29.06	64.78	97.50	-7.89	111.28	7.67	6.78	40.50	3.80	2.45	17.01
13:11:00	43.61	55.44	24.94	8.56	30.39	68.39	101.94	-5.17	114.56	7.39	5.67	40.50	4.75	2.74	17.36
13:12:00	44.22	56.44	24.78	8.06	31.33	70.11	103.61	-3.44	115.11	7.17	4.89	40.56	5.41	2.87	17.66
13:13:00	44.72	57.22	22.22	7.78	31.28	71.44	104.00	-2.67	114.89	7.17	4.50	40.50	5.90	2.97	17.99
13:14:00	45.00	57.67	21.33	7.61	31.50	72.39	104.06	-2.11	114.56	7.50	4.39	40.50	6.32	2.99	18.24
13:15:00	45.33	57.94	20.83	7.67	32.33	72.78	103.83	-2.00	114.06	7.28	4.11	40.50	6.63	2.99	17.86
13:16:00	45.67	56.33	22.22	7.56	31.67	70.39	101.67	-2.06	109.67	7.17	4.00	40.50	6.20	2.97	15.97
13:17:00	45.00	54.56	27.06	7.11	29.00	66.56	98.78	-4.94	106.44	7.39	4.78	40.50	5.15	2.54	14.84
13:19:00	43.61	70.72	28.67	7.44	28.22	61.06	99.94	-11.89	106.00	8.39	6.89	40.50	2.85	2.19	14.41

Unit On: 13:14:51
Burner Off: 13:14:51
Unit Off: 13:18:19

CYCLIC TEST

NO.: C47-5

DATE: 8-16-82

CYCLE TIMES: 10 / 90 ON/OFF

AMBIENT DRY BULB: 8.3 C

46.9 °F

WET BULB: 6.6 C

-or-

DEW POINT: 43.9 °F

WATER TEMP: 40.2 C

104.4 °F

WATER FLOW: 0.362 kg/sec

5.79 gal/min

INTEGRATED CAPACITY 5.043 MJ

4780 BTU

GAS INPUT: 8.506 MJ

8062 BTU

ELECTRIC INPUT: 0.466 MJ

442 BTU

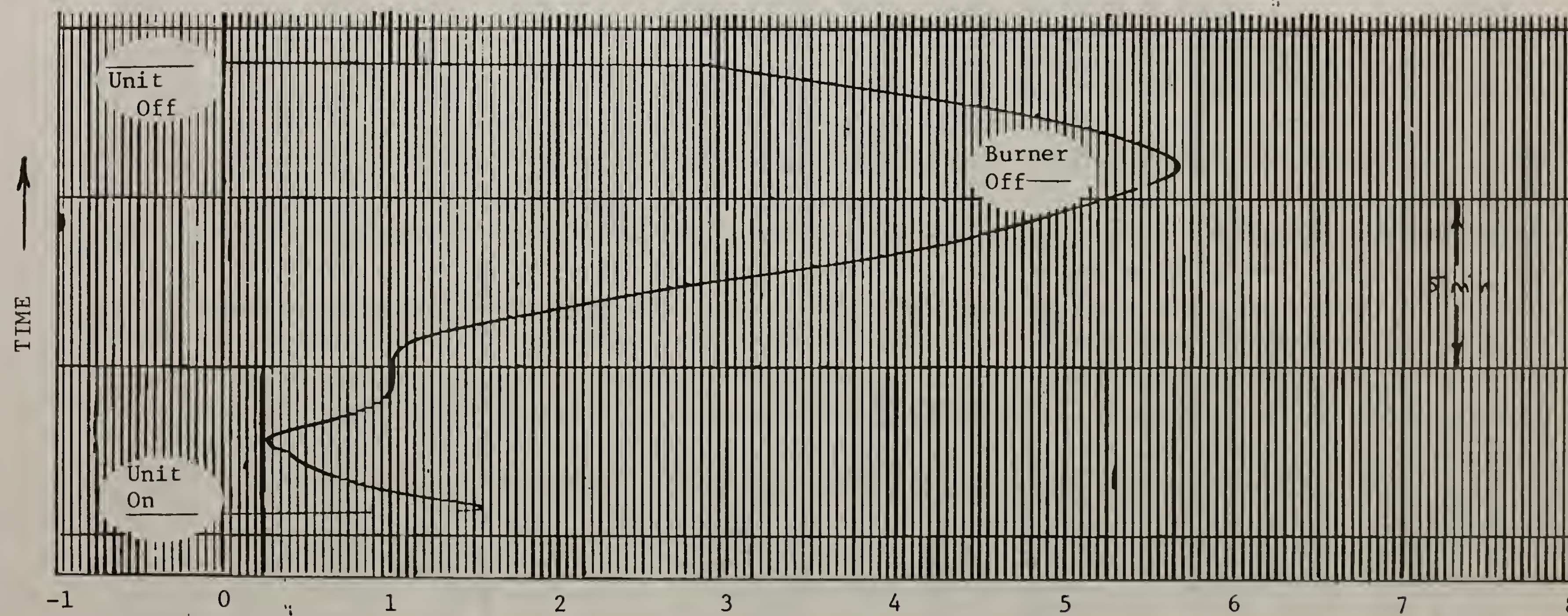
COP: 0.562

PLF = 0.500

HLF = 0.050

(Data are average of last two cycles)

Test No. C47-5



Channel 36 (mV)

(Outlet - Inlet Water Temp. Thermopile)

Temperature Rise of Water Flowing Through
Unit as a Function of Time
For the Last Cycle

DATA FOR LAST CYCLE - Test No. C47-5

CHANNEL NO. AND UNITS:

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
	F	F	F	F	F	F	F	F	F	F	F	F	MV	MV	MV
14:24:00	105.80	137.00	44.60	50.50	72.00	141.90	154.50	44.60	130.50	47.20	49.60	92.90	-6.35	4.58	4.47
14:25:00	101.40	136.90	44.40	50.40	71.30	141.50	154.00	43.90	132.90	47.10	50.10	94.50	.71	4.47	4.31
14:26:00	93.60	106.50	43.10	49.60	54.40	147.00	138.80	35.50	153.10	47.40	48.70	103.60	.72	3.50	5.04
14:27:00	74.90	82.90	44.30	57.20	65.80	143.50	124.00	26.50	149.50	47.00	48.40	105.00	.30	2.90	5.75
14:28:00	94.50	82.60	46.10	46.60	64.40	136.40	129.90	26.60	164.30	46.80	47.50	105.20	.81	2.22	8.24
14:29:00	99.50	97.60	46.80	41.10	67.70	123.30	139.60	31.00	179.20	46.50	46.90	105.30	1.02	1.66	11.39
14:30:00	102.60	107.60	50.70	41.50	71.40	128.70	153.10	31.80	196.10	46.40	47.00	105.30	1.10	1.46	14.50
14:31:00	105.70	116.40	66.80	43.80	66.10	135.40	170.90	9.40	212.20	46.20	46.80	105.30	1.94	1.53	16.08
14:32:00	107.10	122.30	63.10	51.00	73.50	142.70	191.70	13.70	227.20	46.00	45.20	105.30	3.04	2.25	16.66
14:33:00	107.30	126.80	64.00	49.30	74.40	150.00	207.60	20.70	237.10	48.20	45.50	105.30	4.21	2.59	17.05
14:34:00	109.00	129.90	65.70	47.90	79.30	154.00	213.40	24.00	238.50	46.70	43.60	105.30	4.95	2.81	17.44
14:35:00	110.70	132.20	66.30	48.40	81.70	157.40	215.70	27.20	238.00	47.00	42.70	105.30	5.55	2.96	17.51
14:36:00	111.30	131.00	70.70	46.70	83.20	155.30	213.30	27.00	229.50	46.70	41.60	105.30	5.46	2.94	15.85
14:37:00	110.90	127.70	78.30	46.60	81.30	149.50	208.20	20.70	223.10	47.90	43.90	105.30	4.65	2.41	14.80
14:38:00	109.50	126.00	79.50	46.20	80.70	143.40	204.20	9.00	219.40	46.30	45.10	105.30	3.30	1.85	14.11
14:39:00	108.90	142.50	82.40	46.70	82.00	136.90	207.00	7.70	220.50	46.70	45.50	105.30	2.39	1.96	14.17

47-5C

CHANNEL NO. AND UNITS:

TIME	1	2	5	6	7	9	12	13	14	28	29	31	36	48	49
	C	C	C	C	C	C	C	C	C	C	C	C	MV	MV	MV
14:24:00	41.00	58.33	7.00	10.28	22.22	61.06	68.06	7.00	54.72	8.44	9.78	33.83	-6.35	4.58	4.47
14:25:00	38.56	58.28	6.89	10.22	21.83	60.83	67.78	6.61	56.06	8.39	10.06	34.72	.71	4.47	4.31
14:26:00	34.22	41.39	6.17	9.78	12.44	63.89	59.33	1.94	67.28	8.56	9.28	39.78	.72	3.50	5.04
14:27:00	23.83	28.28	6.83	14.00	18.78	61.94	51.11	-3.06	65.28	8.33	9.11	40.56	.30	2.90	5.75
14:28:00	34.72	28.11	7.83	8.11	18.00	58.00	54.39	-3.00	73.50	8.22	8.61	40.67	.81	2.22	8.24
14:29:00	37.50	36.44	8.22	5.06	19.83	50.72	59.78	-.56	81.78	8.06	8.28	40.72	1.02	1.66	11.39
14:30:00	39.22	42.00	10.39	5.28	21.89	53.72	67.28	-.11	91.17	8.00	8.33	40.72	1.10	1.46	14.50
14:31:00	40.94	46.89	19.33	6.56	18.94	57.44	77.17	-12.56	100.11	7.89	8.22	40.72	1.94	1.53	16.08
14:32:00	41.72	50.17	17.28	10.56	23.06	61.50	88.72	-10.17	108.44	7.78	7.33	40.72	3.04	2.25	16.66
14:33:00	41.83	52.67	17.78	9.61	23.56	65.56	97.56	-6.28	115.94	9.00	7.50	40.72	4.21	2.59	17.05
14:34:00	42.78	54.39	18.72	8.83	26.28	67.78	100.78	-4.44	114.72	8.17	6.44	40.72	4.95	2.81	17.44
14:35:00	43.72	55.67	19.06	9.11	27.61	69.67	102.06	-2.67	114.44	8.33	5.94	40.78	5.55	2.96	17.51
14:36:00	44.06	55.00	21.50	8.17	28.44	68.50	100.72	-2.78	109.72	8.17	5.33	40.72	5.46	2.94	15.85
14:37:00	43.83	53.17	25.72	8.11	27.39	65.28	97.89	-6.28	106.17	8.83	6.61	40.72	4.65	2.41	14.80
14:38:00	43.06	52.22	26.39	7.89	27.06	61.89	95.67	-12.78	104.11	7.94	7.28	40.72	3.30	1.85	14.11
14:39:00	42.72	61.39	28.00	8.17	27.78	58.28	97.22	-13.50	104.72	8.17	7.50	40.72	2.39	1.96	14.17

Unit On: 14:25:00
Burner Off: 14:35:00
Unit Off: 14:38:32

FROST ACCUMULATION TEST

NO.: F35-5

DATE: 8-30-82

AMBIENT: DRY BULB: 1.7 C — WATER TEMP.: 40.6 C

35.1 °F — 105.0 °F

WET BULB: 0.4 C — WATER FLOW: 0.365 kg/sec

32.8 °F — 5.84 gal/min

ELAPSED TIME: 8.429 HRS.

(END OF DEFROST TO END OF DEFROST)*

ENERGY TO LOAD: 472.8 MJ — AVERAGE CAPACITY: 15569 W

448.1 MBTU — 53157 BTU/HR

GAS INPUT: 411.2 MJ — ELECTRIC INPUT: 16.98 MJ

389.8 MBTU — 16.09 MBTU

COP: 1.104 (AVG. OVER 8.43 HOURS) — COP_{gas}: 1.150

AVERAGE COP AND CAPACITY ARE APPROXIMATELY 96.1% OF STEADY-STATE WITH DRY COIL (AS DETERMINED DURING FIRST PORTION OF TEST WHEN COIL WAS ONLY SLIGHTLY FROSTED).

*Defrost was initiated when (ambient - evaporator outlet) temperature exceeded 25.5°F.

NBS-114A (REV. 2-80)

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5. AUTHOR(S)

Reinhard Radermacher, Mark McLinden, Sanford Klein, David Didion

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

In this investigation, an absorption water chiller and an absorption heat pump were extensively tested under steady-state and cyclic operating conditions. Since the tests were performed on two different units, one for a cooling only and one for a heating only application, the report is set up in two parts discussing the results of the testing of each unit separately.

In addition to the "black box tests" of the units, the causes for the degradation during part load operation were investigated in more detail using the absorption chiller and determining that migration of the fluids during the off periods are a major contribution to the degradation.

Furthermore, the influence of various heating water temperatures and flow rates and the sensitivity to the charge was more closely investigated employing the absorption heat pump.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Charge sensitivity; investigation of part load degradation; laboratory test of absorption heat pump; laboratory test of absorption water chiller; part load performance; seasonal performance; steady-state performance.

13. AVAILABILITY

[X] Unlimited

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