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Heat Pump Operating Data

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HEAT PUMP OPERATING DATA

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ABSTRACT

The Copeland Corporation is field testing its new CR compressor in 29 residential heat pump systems installed in the West Central Ohio area. Six of these systems are instrumented with a microprocessor based field data recorder which provides detailed data on the operating conditions under which the compressor operates. Considerable information has been obtained on system operation during cooling and heating under different ambient conditions. The instrumentation techniques are valuable for use in other system evaluations.

INTRODUCTION

Reliability is a prime concern in the development of any new compressor. Copeland has, therefore, implemented a significant program of laboratory life testing under normal and accelerated conditions to qualify new compressors for production (1).

This program is supplemented by field use testing when appropriate. In the case of the CR compressor, twenty-nine residential heat pump systems have been in use in the West Central Ohio area since May, 1977, to help verify this compressor's performance and reliability.

One of the major problems in field tests is that the conditions are uncontrolled and it is difficult to collect and correlate detailed, useful data. The decision to cluster the field test in an area where the units can be readily monitored helped to overcome some of the problems. Since the area experiences severe and variable weather conditions, this installation plan is valid.

The difficulty of collecting data was approached through the development of a new microprocessor based field data recorder. This recorder automatically controls the system and stores operating data on digital cassette tapes. Details of this field data recorder and some of the findings are covered in this paper.

DATA COLLECTION TECHNIQUES

The primary goal of the field data collection system is to generate a detailed history of the conditions under which the compressor must operate. This information is of use in the design of heat pump compressors and will aid in tracking causes in the event of failure. The information also provides a means for verifying and improving the laboratory life tests. To achieve this goal, a technique was required that would measure and record pressures, temperatures and time. Additionally, the system was expected to require little or no regular maintenance, be simple enough to operate so that it could be operated by field trial participant home owners and require attention no more often than once per week. Two basic approaches to this problem were evaluated.

The first approach was the use of conventional recording devices, such as strip or circular chart temperature and pressure recorders. These recorders could be installed in the homes so that each week the participant could replace the charts and return the recorded data to Copeland for analysis. This approach had undesirable features. Circular charts rotating at one revolution per week do not provide adequate resolution. Consider a condition of 10-minute duration, such as a defrost cycle, recorded on a 12" diameter circular chart. At one revolution per week, the segment containing this information would be .04" wide at full scale. Even on 24-hour charts, full scale would only be .26" wide. The data under these conditions would be superimposed on itself and unresolvable.

A strip chart recorder can solve this problem by using more chart paper. If a standard 120' roll of chart paper were used to represent one week of data, then the 10-minute event would be displayed on 1.4" of chart. This resolution is satisfactory; however, if three recorders are required for each of the six instrumented systems, then 2160' of chart would have to be manually analyzed each week. This approach was judged to be too cumbersome.

The second alternative was to utilize electronic techniques developed for a laboratory data collection system. Transducers convert the required parameters to electrical signals which are measured and controlled by a microprocessor. The only additional function required was a convenient means to store the measured data. A digital tape cassette recorder was chosen for this function because of its small size and the simplicity of changing tapes. With this approach, large amounts of data could be accurately measured and stored in a form that facilitates reading and analyzing by a computer. Additionally, the system was small (resembling a small suitcase) and could be operated by the home owner.

Figure 1 is a detailed block diagram of the data collection system. Signal transducers shown at the bottom of the figure sense temperatures and pressures. It is worth mentioning that there are a large number of different transducers available to measure different parameters, such as current, voltage, watts, resistance, and humidity. Nearly all of these transducers can be acquired with standard output signals compatible with this type recording system. The primary measurements required here are temperature and pressure, and copper constantan thermocouples and solid state strain gage type pressure transducers were used. These pressure transducers do exhibit an inconvenient offset voltage that varies slightly with temperature. This type, however, is much less expensive than others and maintains satisfactory accuracy for this application.

The transducer signals are sequentially selected for measurement in the multiplexer. Once selected, the signal amplified to an appropriate level and converted to an 8 bit binary number by the A/D converter. The clock is read and recorded once for each complete set of 15 data channels. The

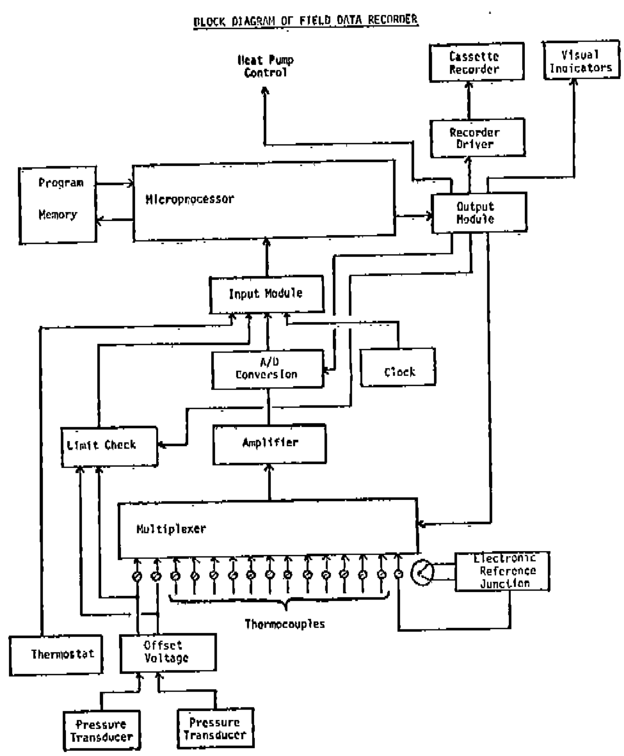


Figure 1

microprocessor sends the data to the recorder driver section where it is stored until 80 words have been received. At this time, the recorder driver sends 64 words to the recorder where they are recorded in block form. A limit section continually checks to see that the discharge pressure is below a preset limit and that the suction pressure is greater than a preset limit. Additionally, a signal from the thermostat is monitored to tell when heat pump system is required. When it is, the processor turns on a switch starting the heat pump system. The processor also drives visual indicators signifying that the heat pump is running, that a high or low limit is exceeded or that data is being written onto the tape.

All the above described operations are controlled by the microprocessor, such as selecting a channel, converting analog signals to binary numbers, and limit checking. The microprocessor accomplishes these functions by executing the instructions contained in the program memory. The programming capability and electronic speed and accuracy of this system are very advantageous. This can be better understood by describing the operation. The data recorder has been programmed to record data at different rates and times for various conditions. For example, when the heat pump system is operating, a complete set of data is taken every 30 seconds. During non-operating periods, data is only recorded every 30 minutes. The suction and discharge pressures are continuously monitored and should they exceed preset limits, data is recorded as long as the limit is exceeded. Data is also recorded immediately before and after the start and stop of each operating cycle. This is accomplished by having the data recorder monitor the thermostat and control the heat pump. When the thermostat calls for system operation, the data recorder takes a set of data, turns on the heat pump, immediately takes another set of data, and then takes data on 30 second intervals. When the thermostat is satisfied, the data recorder takes a set of data, turns the unit off, takes another set of data, then reverts to taking data on 30 minute intervals.

The data is recorded on a 300' digital cassette tape which has a capacity of 2,214,000 binary bits of information. The parameters comprising a set of data represent 216 binary bits and, therefore, a single tape can hold 10,250 sets of data. Due to the various data collection rates, the length of time a tape will run is determined by the operating conditions. The following table gives times to fill a tape under different conditions.

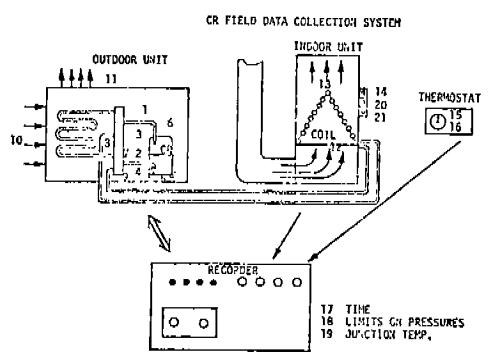
1.	Continuous Update (Every 7.5 seconds)	21 Hrs.
2.	Heat Pump Operating (Every 30 seconds)	85 Hrs.
3.	Heat Pump Not Operating (Every 30 minutes)	5,125 Hrs.

Under normal operating conditions, a tape lasts about one week.

The number of measurements that can be stored on a tape is a function of the number of binary bits used to represent a measured quantity. Our data recorder uses 8 bit binary numbers. This fact determines the resolution accuracy of the system. Eight binary bits can resolve one part in 256 or about .4% of the measurement span. The temperature measurement span is 512°F or from -56°F to 456°F. This gives a temperature resolution of 2°F which is a good match to the accuracy specifications for the CuCa thermocouple wire used. The suction and discharge pressure spans were 0 to 300 PSIA and 0 to 1,000 PSIA respectively. This gives a resolution of approximately 1 PSIA and 4 PSIA for the suction and discharge pressures respectively.

Figure 2 shows pictorially the manner in which the data recorder interfaces to the heat pump system and the parameters that are measured. Air temperatures in and out of the indoor and outdoor coils are multiple thermocouples connected in parallel and located in different areas of the air flow to provide an average value and avoid possible errors due to air stratification. Items 20 and 21 are a start/stop cycle counter and running time clock These devices were installed on all 29 systems and are not related to the data recorder. Measurement 19 deserves further discussion.

Use of thermocouple voltage from the copper constantan wire to measure temperature requires that the temperature of the junction (reference junction) of the constantan wire to the typically copper terminal of the measureing device be known. Quite often this is accomplished by placing this junction in an ice bath. Electronic reference junctions are also available; however, they only provide temperature compensation for a single thermocouple and are somewhat expensive. The data recorder allows these junctions to float with the ambient temperature. The junction temperature is measured with a thermocouple which uses electronic junction compensation. Later when the data is



1 SUCTION PRESSURE
2 DISCHARGE PRESSURE
3 RETURN GAS TEMP.
4 DISCHARGE GAS TEMP.
5 BOTTOM SHELL TEMP.
6 TOP SHELL TEMP.
7 DISCHARGE GAS TEMP. @RV
8 GAS TEMP. TO OUTDOOR COIL
9 GAS TEMP. TO INDOOR COIL
10 INLET AIR TEMP.
11 OUTLET AIR TEMP.
12 RETURN AIR TEMP.
13 AIR OFF COIL TEMP.
14 MONITOR STATUS
15 WALL THERMOSTAT TEMP
16 THERMOSTAT STATUS

ALSO

20 NO. OF CYCLES
21 RUNNING TIME

Figure 2

decoded, all thermocouple voltages are adjusted based on the reference junction measurement #19.

Once the data is measured and stored on the cassette tapes, the next problem is to effectively analyze the data and report the results. To accomplish this task, the capabilities of an IBM 370 computer were utilized. A problem is that this machine is used primarily for administrative tasks and there was no convenient method to enter data. This is probably a typical problem for many engineers desiring to use the company computer to analyze engineering data. This problem was solved by a cassette tape reader which transfers the data from the cassette tapes to an IBM compatible 9 track tape which can be directly loaded on the 370 tape drives. The power of the larger computer can now analyze the data, write reports, and efficiently store the data for later analysis.

An interesting aspect of the computer data interpretation is the method used to handle the nonlinear thermocouple voltage. Note that the data recorder measures a thermocouple voltage which is a nonlinear function of the junction temperature. Linearization is accomplished by storing temperature values in computer memory locations. The address of each location is selected to correspond to the appropriate measured voltage. Retrieval then is accomplished by retrieving the temperature that is stored at the memory location identified by the voltage measurement.

Figure 3 shows a printout of the data discussed above. Although the coding isn't given, the type of reading can be easily deduced. The fourth column from the right shows that the high limit for discharge pressure (320 psig) was exceeded at 2.45.57 (approximately 2:45 A.M.). This occurred during a defrost cycle as could be deduced from the discharge pressure and air temperature off of the coils. Most of the time shown on this sheet, the thermostat was calling for heat (second column from right coded CNTL showing ON) and the data recorder was on the operating time mode (first column from right coded COND showing TI). At 2.21.55, however, the recorder went into the change mode (CH) as the thermostat was satisfied; and at 2.45.57, the recorder went into continuous limit (LI) mode as the limit was exceeded.

Note that at 2.48.02, the system high pressure switch setting was exceeded and the compressor was shut off. At 2.53.03, the system monitor (third column from right, MON) locked out the compressor.

TYPICAL OPERATING DATA

Defrost Cycle

Figure 4 provides an indication of the excellent resolution obtained from the field data recorder. This is a full defrost cycle on a time-initiated coil-temperature terminated heat pump system at an outdoor ambient of about 40°F. The defrost cycle started two minutes after the system started in the heat pump mode and lasted about three and a half minutes.

REPORT DP22J — HEAT PUMP TEST ANALYSIS—HEAT PUMP MODE — ALL POINTS FOR UNIT 1 — DATE 03/16/78 — OBSERVATION INTERVAL 02/20/78 00.00.00 TO 03/16/78 00.00.00 — PAGE 44

UNIT	DATE	TIME	SUCT PRES	DISC PRES	R-G TEMP	D-G TEMP	B-S TEMP	T-S TEMP	D-RV TEMP	RV-O TEMP	RV-I TEMP	01-A TEMP	OO-A TEMP	W-T TEMP	R-A TEMP	IC-A TEMP	R-J TEMP	LOW LIM	HI LIM	MON CNTL	COND
1	02/22/78	02.11.15	33	180	6	174	113	15	184	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.11.46	33	180	6	174	113	15	184	6	159	20	15	76	74	89	78			ON	TI
1	02/22/78	02.12.17	33	184	6	176	113	15	184	8	161	20	15	76	74	89	78			ON	TI
1	02/22/78	02.12.48	33	184	6	176	113	15	184	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.13.19	33	184	6	174	113	15	182	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.13.50	33	184	6	174	113	15	184	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.14.21	33	180	6	174	113	15	184	6	159	20	15	74	74	89	78			ON	TI
1	02/22/78	02.14.52	33	180	6	174	113	15	184	6	159	20	15	74	74	89	78			ON	TI
1	02/22/78	02.15.23	34	184	6	174	113	15	184	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.15.54	33	184	6	176	113	15	184	8	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.16.25	33	184	6	174	113	15	184	6	161	20	15	76	74	89	78			ON	TI
1	02/22/78	02.16.56	34	184	6	176	113	15	184	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.17.27	34	184	6	176	113	15	184	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.18.29	34	184	6	176	113	15	184	8	161	20	15	76	74	89	78			ON	TI
1	02/22/78	02.19.00	33	184	6	176	113	15	184	8	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.19.31	34	184	6	176	113	15	184	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.20.02	33	184	6	174	113	15	184	8	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.20.33	33	184	6	174	113	15	184	6	161	20	15	74	74	89	78			ON	TI
1	02/22/78	02.21.04	34	184	6	176	113	15	184	8	161	20	15	76	74	89	78			ON	TI
1	02/22/78	02.21.35	33	184	6	176	113	15	184	6	161	20	15	76	74	89	78			ON	TI
1	02/22/78	02.21.55	34	184	6	176	113	15	184	6	161	20	15	74	74	94	78			ON	CH
1	02/22/78	02.22.33	36	152	8	174	113	15	178	13	157	20	15	74	74	94	78				CH
1	02/22/78	02.43.24	52	35	39	41	78	58	30	30	30	32	23	74	67	71	76				CH
1	02/22/78	02.43.32	47	67	30	62	78	55	65	37	37	32	23	74	69	71	76			ON	CH
1	02/22/78	02.44.03	23	86	23	118	78	51	120	87	48	34	25	74	69	65	76			ON	TI
1	02/22/78	02.44.34	45	156	16	145	83	44	151	137	69	34	30	74	69	51	76			ON	TI
1	02/22/78	02.45.05	55	231	30	164	87	41	172	161	32	41	39	74	69	51	76			ON	TI
1	02/22/78	02.45.36	58	285	32	178	94	39	186	174	32	41	55	74	69	51	76			ON	TI
1	02/22/78	02.45.49	58	313	32	182	96	39	192	182	34	41	65	74	69	51	76			ON	LI
1	02/22/78	02.45.57	60	320	32	186	96	39	196	186	34	41	67	74	69	53	76	ON		ON	LI
1	02/22/78	02.46.05	61	332	34	188	96	39	198	190	34	41	69	74	69	53	76	ON		ON	LI
1	02/22/78	02.46.13	61	340	34	192	98	39	202	194	37	41	71	74	71	53	76	ON		ON	TI
1	02/22/78	02.46.22	61	352	34	194	100	39	204	196	37	44	71	74	69	53	76	ON		ON	LI
1	02/22/78	02.46.30	62	360	34	198	100	41	208	200	37	41	74	74	69	53	76	ON		ON	LI
1	02/22/78	02.46.38	63	367	37	200	102	41	210	202	39	41	74	74	71	53	76	ON		ON	LI
1	02/22/78	02.46.47	63	379	37	202	102	41	211	206	37	41	69	74	69	53	76	ON		ON	TI
1	02/22/78	02.47.03	64	402	37	208	105	41	217	208	37	46	65	74	71	55	76	ON		ON	LI
1	02/22/78	02.47.12	64	410	39	210	107	41	219	210	39	44	74	74	69	55	76	ON		ON	LI
1	02/22/78	02.47.20	65	414	39	211	107	41	219	211	39	46	76	74	71	55	76	ON		ON	TI
1	02/22/78	02.47.28	67	414	39	211	109	44	221	213	39	44	85	74	71	55	76	ON		ON	LI
1	02/22/78	02.47.37	67	414	39	213	111	44	223	215	39	44	89	74	71	55	76	ON		ON	LI
1	02/22/78	02.47.45	67	418	39	213	111	44	223	215	39	44	89	74	71	55	76	ON		ON	LI
1	02/22/78	02.47.53	67	426	39	215	113	44	225	217	39	41	91	74	71	55	76	ON		ON	TI
1	02/22/78	02.48.02	65	414	41	215	113	44	223	215	48	41	89	74	69	60	76	ON		ON	LI
1	02/22/78	02.48.24	132	117	78	184	113	74	192	147	113	44	78	74	69	71	76			ON	TI
1	02/22/78	02.48.55	119	106	78	164	109	74	168	128	111	44	65	74	71	71	76			ON	TI
1	02/22/78	02.49.26	113	102	78	149	107	76	135	120	105	48	44	74	71	69	76			ON	TI
1	02/22/78	02.49.57	110	102	76	137	107	78	118	111	96	46	37	74	71	69	76			ON	TI
1	02/22/78	02.50.28	103	98	76	126	105	78	107	102	89	44	37	74	71	69	76			ON	TI
1	02/22/78	02.50.59	98	94	74	118	105	78	96	98	85	41	34	74	71	69	76			ON	TI
1	02/22/78	02.51.30	95	94	74	109	102	78	89	91	80	41	34	74	71	69	76			ON	TI
1	02/22/78	02.52.01	90	90	71	100	102	80	83	87	76	39	32	74	71	69	76			ON	TI
1	02/22/78	02.52.32	88	82	71	94	102	78	78	83	74	39	34	74	69	69	76			ON	TI
1	02/22/78	02.53.03	85	78	65	89	100	78	76	78	71	41	32	74	69	69	76		ON	ON	TI
1	02/22/78	02.53.34	83	74	69	85	100	78	71	76	69	39	32	74	69	69	76		ON	ON	TI

Figure 3

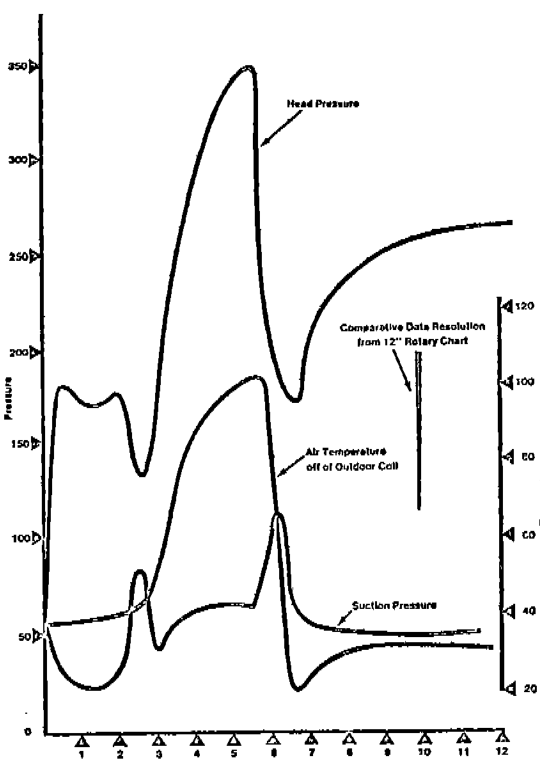


Figure 4

It can be seen that the head pressure in this case reached 350 psi. Even higher pressures have been observed at times in other systems as, in fact, was shown in Figure 3. The air temperature off of the coil (outdoor fan off) went above 100°F, providing an indication of heat loss. This can be significant; in general, the systems ran full ten minute defrost cycles at temperatures below 10°F. Defrost cycles have also been observed at temperatures of 60°F.

The capability of this field data recorder is illustrated on Figure 1 by comparing the segment of a 12" rotary chart. The rotary chart would have had all of this information compacted into that small segment.

Suction and Discharge Pressures as Function of Time

Figure 5 shows the suction and discharge pressures as a function of time for a particular system at three ambient temperatures. The curves terminate at the conclusion of the heating cycle, so it can be seen that the systems actually spend a significant part of their on time reaching equilibrium. At 23°F, the unit ran 12 minutes but did not reach equilibrium until about six minutes passed. At 67°F, the unit never did reach equilibrium. Operating analyses based on equilibrium operation can, therefore, be significantly in error.

Pressures as a Function of Ambient

Figures 6 and 7 show the discharge pressures and suction pressures of the six instrumented systems as functions of the outdoor temperature. The average of the systems is shown together with the high and low values. From a compressor standpoint, there is concern about the compression ratio. The variation in systems is significant. At a 60°F ambient, discharge pressures range from about 270 psig to 320 psig. Variables include the relationship of the sizes of the system and house, ducting, air flow, system charge, and line lengths. In fact, each system has been found to have its own characteristics depending on the particular house and installation.

The reason for the turn-up in pressure at ambients below 0°F is not understood. It may have something to do with flooding, used to control compressor temperatures at low refrigerant flow conditions.

<u>Other Observations</u>

The data taken thus far has indicated the need to take the ambient temperature into consideration. The ambient temperature is rarely stable for any length of time and the relationship of operating time and final pressure is a function of whether the ambient temperature is rising or falling. A heat pump in a home with good solar heat input may not run much during the day, but may experience long cycles in the evening. Data on cyclic rate as a function of ambient temperature can, therefore, be misleading since a rate of change dynamic model would be required to define this operational value.

The cyclic timers used on the systems show a total at this point of 110,000 cycles and some 46,000 operating hours primarily on heat pump operation. (Note that not all systems ran all winter.) This average ratio of 2.4 starts per operating hour is

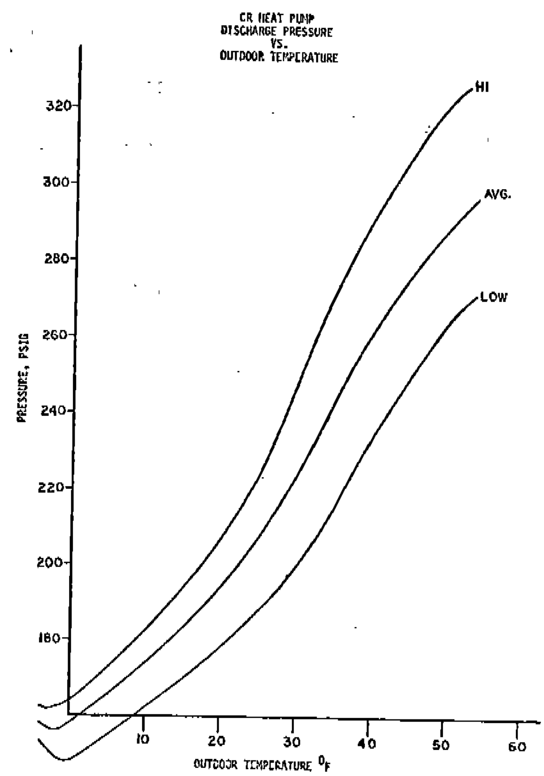


Figure 6

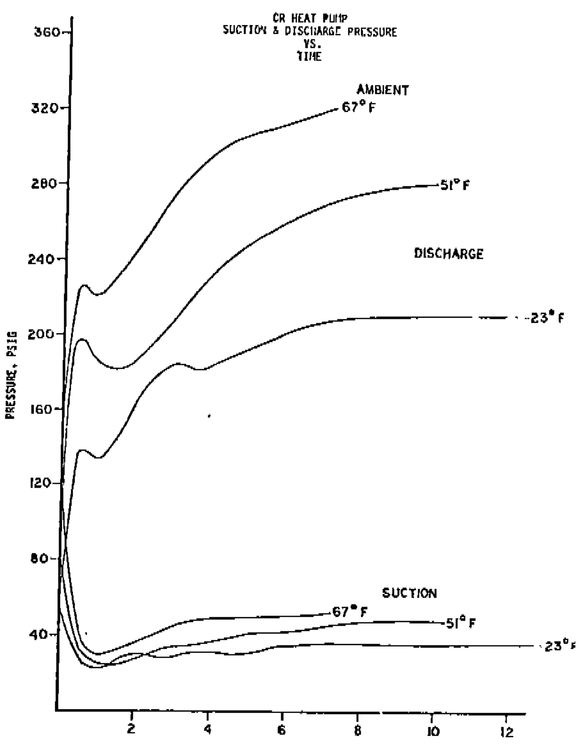


Figure 5

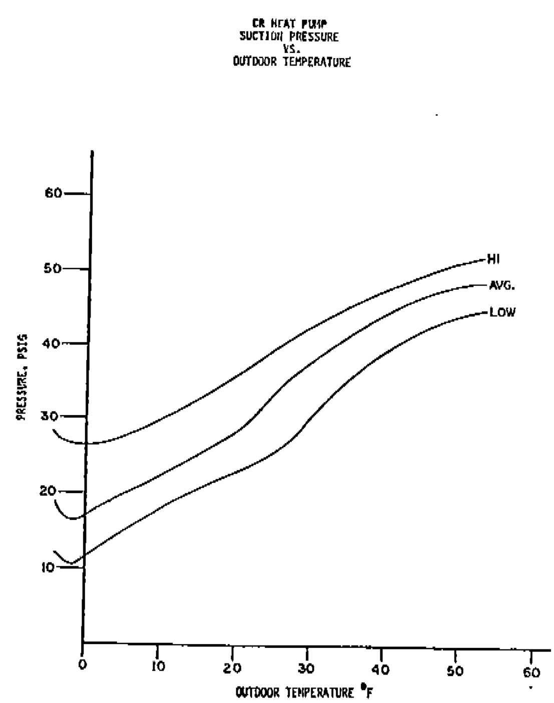


Figure 7

somewhat less than expected and will be factored into our laboratory test plans.

Another observation is the effort required to successfully manage a program of this kind. It requires a good deal of cooperation from customers, vendors and service personnel. The quantity of data obtainable also makes analysis a challenge.

CONCLUSION

The field test of this heat pump compressor model can be considered quite successful. Not only have no compressor failures been experienced over a very severe winter, but, we have gained considerable insight into the conditions experienced in operation. The field data recorder developed for this program works well and is suited for application to other systems.

REFERENCE

(1) F. E. Kalivoda and K. W. Yun, "Modeling Mechanical System Accelerated Life Tests", Proceedings 1976 Annual Reliability and Maintainability Symposium, pp 206-212, January 1976.