PERFORMANCE EVALUATION OF A PROPANE-FIRED
HOUSEHOLD-TYPE ABSORPTION REFRIGERATOR

Manufactured by
Excel Refrigeration Corporation
Fort Lauderdale, Florida

Report to
U. S. Army Natick, Massachusetts
Natick, Massachusetts

NATIONAL BUREAU OF STANDARDS REPORT
10 390

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
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PERFORMANCE EVALUATION OF A PROPANE-FIRED
HOUSEHOLD-TYPE ABSORPTION REFRIGERATOR

Manufactured by
Excel Refrigeration Corporation
Fort Lauderdale, Florida

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Report to
U. S. Army Natick Laboratories
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U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
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1.0 Introduction

The Excel refrigerator was received at the National Bureau of Standards Laboratories on July 5, 1968 and tests were subsequently conducted at the request of the U. S. Army Natick Laboratories. The initial request was to determine the maximum ambient temperature at which the refrigerator could function effectively. This and other information was developed in the course of this investigation.

This report presents the results of a laboratory investigation of a propane-fired absorption refrigerator manufactured by the Excel Refrigeration Corporation, Fort Lauderdale, Florida.

The purpose of this investigation was to determine quantitatively several performance characteristics of this refrigerator. The major characteristics were (in the order that they were studied):

a. The fuel line pressure that allowed the refrigerator to operate at its maximum cooling capacity in an ambient temperature of 90 °F at 50% relative humidity.

b. Determination of maximum ambient temperatures in which this refrigerator would operate effectively.

c. Maximum ambient temperature at which this refrigerator established a primary failure mode.

d. Minimum thermostat setting that allowed the refrigerator to operate effectively in an ambient temperature that approached the primary failure mode temperature.
e. Determination of whether this refrigerator could satisfy the temperature criteria established in the American Standard Test Procedures for Household Electric Refrigerators (Mechanically Operated) (B38.2-1961), i.e.,

<table>
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<th>Ambient Temperature (°F)</th>
<th>Avg. General Food Compartment Temp. (°F)</th>
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f. Maximum tilt angle at which the refrigerator would operate satisfactorily.

In addition to the above purpose a second objective was to provide results for use in establishing an American Standard Test Procedures for Household Absorption Refrigerators.

The refrigerator was not dismantled and parts were not disassembled during the course of this investigation. The unit was in operating condition at the conclusion of the study. The refrigerator specification name plate allowed energy sources of both propane and butane. Only propane was used in this study.

Conclusions concerning quantitative performance characteristics were arrived at by computations and analysis of experimental data as presented in detailed graphic and tabular form given in the appendices.

The data listings and plots were completed using the Environmental Engineering Section's Data Acquisition System and the National Bureau of Standards' Univac 1108 computer.
2.0 Description of Test Specimen

The Excel refrigerator was manufactured by the Excel Refrigeration Corporation, 5320 Northwest 10th Terrace, Fort Lauderdale, Florida 33309.

The Excel refrigerator specification plate read:

Model No. X-L-600
Serial No. 6-337
Producer rated energy input, 1600 Btu/hr
Energy source, i) propane, ii) butane
Ammonia weight, less than two (2) pounds
Test pressure, less than 1500 psig

The outside physical dimensions were 26 1/2" wide, 23 1/2" deep and 43 1/2" high.

This refrigerator contained the following equipment inside:

(See Figure 1):

Three (3) food shelves
One crisper with cover
One freezer compartment with three (3) ice trays
One defrost tray
Two (2) door shelves (formed from the interior door liner)
The door seal was a gasket-magnet combination.

Figures 1, 2 and 3 show the front, back and freezer compartment of the Excel refrigerator, respectively. Figure 4 is a side view of Excel burner assembly.
3.0 Test Apparatus and Procedure

The test procedure necessary to accomplish each objective as indicated in the introduction required occasional modification of the testing apparatus. Consequently, discussion of each of the following test procedures includes a description of the addition or alteration of the testing equipment relative to that particular test.

All testing was conducted in one of the National Bureau of Standards environmental testing laboratories having a controllable ambient temperature range of 40 °F to 150 °F with simultaneous control of relative humidity.

Prior to actual testing, the refrigerator was placed in the laboratory test room. The back of the refrigerator was placed parallel to one of the laboratory walls, approximately six (6) inches from the wall. The refrigerator was then leveled in the manner prescribed in the manufacturers instruction manual that accompanied the refrigerator.

3.1 Fuel Line Pressure Test

The first test was conducted to determine the fuel line pressure that would allow the refrigerator to operate at its optimum cooling capacity in an ambient temperature of 90 °F and 50% R.H. The laboratory test room conditions were maintained at 90 °F and 50% R.H. Four fuel line pressures were investigated, a) eight (8) inches W.G., b) eleven (11) inches W.G., c) thirteen (13) inches W.G. and d) fifteen (15) inches W.G.
Fig 1. Interior - Excel refrigerator
Fig 2. Absorber, condenser, heater box, and associated apparatus of Excel absorption cooling system
Fig 3. Freezer compartment - Excel refrigerator
Fig 4. Burner assembly - Excel refrigerator
A water manometer was used to measure the fuel line pressure. A propane pressure regulator was used to control the fuel line pressures. A portable propane tank was used to supply fuel to operate the refrigerator. The fuel consumption rate was determined by daily weighings of the gas tank. The difference between the weight of the tank one day and the preceding day, divided by the number of hours elapsed between readings, yielded the average fuel consumption rate in pounds per hour.

Thermocouples were placed in the following locations: a) one in the air of the freezer compartment, b) a two-in-one averaging thermocouple in the air of the general food compartment, c) a two-in-one averaging thermocouple outside of the refrigerator to measure the average ambient air temperature, and d) one in an ice bath for reference. Midway through this test a thermocouple was installed at the outlet of the general food compartment evaporator coil and a thermocouple was placed in the middle of an ice cube in an ice tray in the freezer compartment. Thermocouples were read using a self-balancing electronic potentiometer that displayed the temperatures on chart paper in degrees Fahrenheit. The thermostat sensor normally attached to the general food compartment evaporator coil was removed from its receptor and exposed to the laboratory ambient air. This was done to assure that the thermostat would call for maximum cooling of the refrigerator throughout the test. Figure 5 shows the general food compartment evaporator coil and the thermostat sensor in its receptor.
Fig 5. General food compartment evaporator coil and thermostat sensor in receptor - Excel refrigerator
3.2 Elevated Ambient Temperature Test

The maximum ambient temperature in which this refrigerator could operate effectively was determined in the following manner. The ambient temperature was initially maintained at 90 °F. The fuel line pressure was kept at the optimum level determined in the previous test (this pressure was not altered for the remainder of the testing). If the refrigerator could operate effectively in a 90 °F ambient, the ambient was increased 10 °F. If the refrigerator could operate at this temperature the ambient would again be increased 10 °F. This procedure was repeated until the refrigerator ceased to function effectively. The refrigerator was allowed to operate at each ambient temperature for a minimum of one week. This minimum time period was sufficient to permit the refrigerator to achieve a thermal steady state. The results of this test thus allowed a closer look at the operating characteristics of the refrigerator resulting from near-failure-point ambient temperature operation. The transition temperature between effective and ineffective operation was determined by slowly increasing the ambient temperature from 100 °F until a portion of the refrigerator cooling system showed ineffective operation. This type of ineffective operation was defined as primary failure mode operation. Two additional thermocouples were installed for this test. The new thermocouple locations were at the inlet point and at the midpoint of the general food compartment evaporator coil.
3.3 Thermostat Tests

3.3.1

The thermostat test was conducted in two parts. The first test was to determine which setting allowed the refrigerator to operate effectively in an ambient temperature that approached the primary failure mode temperature. Prior to this test the thermostat sensor was reinstalled in its receptor. Also, the thermostat control knob range was calibrated such that there was five equal increments between the minimum (defrost) and maximum cooling positions. The ambient temperature was then adjusted to about 105 °F (this was near the primary failure mode temperature). The thermostat was then set at each of the six settings, and the resulting behavior characteristics were observed.

3.3.2

The second part of the thermostat test was to determine whether the refrigerator could satisfy the temperature criteria suggested in the American Standard Test Procedures for Household Electric Refrigerators (Mechanically Operated) (B38.2-1961). For this test the ambient temperature was maintained, successively, at 70 °F, 90 °F, and 110 °F. At each of these ambient temperatures, the thermostat was adjusted to its warmest position (not defrosting), position #1, the coldest position (#5), and two intermediate positions (#2 and #3.5).
3.4 Tilt Test

The last test was to investigate the ability of the refrigerator to operate while inclined in a pitch or a yaw position. The refrigerator was tilted in one degree increments with each position held for 24 hours or until positive failure due to tilt occurred. Preliminary tests showed that failure would be apparent within about five hours from the time of each tilting. All refrigerator temperatures rapidly approached ambient temperature when failure was produced by tilting.

To determine the tilt angle two large protractors, accurate to \( \pm 0.5^\circ \), were drawn on construction paper. These protractors were trued vertically with a plumb bob and secured to the front and side of the refrigerator. The refrigerator was tilted by lifting one of its base edges at a time with a hydraulic jack. The angle the refrigerator had been tilted was measured using the protractor and a plumb bob.

4.0 Results and Discussion of Results

4.1 Fuel Line Pressure Test

The optimum fuel line pressure tests results are summarized in Table 1. The results of this test were used to determine the fuel line pressure that was used in all the subsequent tests.
Three main factors were used to select an optimum fuel line pressure. Considered were the general food compartment temperature, the frozen food compartment temperature, and the corresponding fuel consumption rate. The fuel line pressure that delivered continuously stable optimum refrigerator operation with the lowest fuel consumption rate was considered to be the optimum.

During the eight (8) inch W.G. fuel line pressure test, the refrigerator showed signs of unstable operation. The temperature in the freezer compartment and the general food compartment rose almost continuously during this test. Consequently, the eight inch W.G. fuel line pressure possibility was rejected.

The three remaining fuel line pressures, eleven, thirteen, and fifteen inches W.G., fulfilled the continuous stable refrigerator operation criterion. Consequently, the lowest fuel consumption rate determined the choice of these fuel line pressures. This fuel line pressure was eleven (11) inches W.G. Graph 1 shows the linear relationship between the fuel consumption rate and fuel line pressure. Detailed data and plots of fuel consumption rates and temperatures versus test time in calendar days are given in Appendix.
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<td>22.35</td>
<td>11.09</td>
<td>2.62</td>
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<td>90.7</td>
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</table>

* Thermocouples to monitor these temperatures had not been installed at the time of the 8 in. W.G. fuel line pressure test.
Graph 1

FUEL CONSUMPTION RATE (lb./hr.) vs FUEL LINE PRESSURE (in. W.G.)

Graph 1
4.2 Elevated Ambient Temperature Tests

The primary purpose of the maximum ambient temperature test was to determine the lowest elevated temperature increment in which the refrigerator would fail to operate effectively.

The ambient temperature was increased from 90 °F to an average of 102.6 °F, and then to an average of 109.7 °F. It was held in excess of a week at each of these average ambient temperatures. It was then adjusted to an average of 118.2 °F for three days. It was apparent during this short test period that the refrigerator could not operate effectively at this elevated ambient temperature. The ambient temperature was then reduced to 112 °F where it was held for ten days. The ambient temperature was then reduced to an average of 88.2 °F. The results of these tests are given in Table 2.

While at 102.6 °F ambient temperature, the refrigerator operated satisfactorily. Once the refrigerator established steady state conditions, which took approximately 24 hours, there was very little fluctuation of its temperatures for the duration of the test.

The refrigerator behaved somewhat differently, however, in an average ambient temperature of 109.7 °F. All the internal temperatures except the evaporator coil temperature rose continually during this test. In a later test, it was discovered that this upward trend of refrigerator temperatures would occur when the ambient temperature went above the primary failure mode temperature. However, this behaviour did not become evident until the average ambient temperature was increased to 118.2 °F.
### Table 2  Elevated Ambient Temperature Tests Results

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<td>118.2</td>
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<td>88.2</td>
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<td>6.62</td>
<td>V</td>
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</tbody>
</table>
In only three days of operation at this average ambient temperature of 118.2 °F, the freezer, ice tray, and evaporator coil temperature of both refrigerators climbed above 32 °F. Refrigeration at this high ambient temperature was totally unsatisfactory.

In an attempt to regain effective refrigerator operation, the average ambient temperature was lowered to 112.6 °F. This ambient temperature was maintained for ten days. During this time, the refrigerator temperatures did not drop, but rose even higher than they were during the 118.2 °F ambient temperature test. This behavior implied that there was a definite ambient temperature, above which, refrigerator operation would always be ineffective. To regain effective operation and thermal equilibrium, the ambient temperature had to be dropped below the primary failure mode temperature.

The last objective of the elevated temperature test was to determine the primary failure mode temperature. Sub-primary failure mode temperature refrigerator operation was established by maintaining an ambient temperature of approximately 90 °F for fourteen days. The ambient temperature was slowly increased until evidence of a primary failure mode was observed.

The results of this test are most easily interpreted when presented graphically. Graph 2 clearly illustrates the ambient temperature at which a component of the refrigerator began to function ineffectively. In the Excel, the evaporator coil exhibited the primary failure mode.
At rising ambient temperatures below 110 °F, the Excel internal temperatures stayed relatively constant with respect to each other. Between 110 °F and 111 °F, the midpoint temperature of the evaporator coil began to rise at a faster rate than any of the other temperatures. This temperature was 1 °F and 4 °F lower than the ice tray and freezer air temperatures, respectively, at 110 °F ambient temperature. At 111 °F ambient temperature, the midpoint of the evaporator coil was 3 °F higher than both the ice tray and freezer air temperatures. In this ambient temperature interval of 110 °F to 111 °F, the ice tray temperature rose from below freezing to 35 °F. Therefore, between 110 °F and 111 °F, the Excel refrigerator established a failure mode.

4.3 Thermostat Tests

4.3.1

The purpose of the first thermostat test was to determine the minimum thermostat setting that would allow the Excel refrigerator to operate effectively in an ambient temperature that approached the primary failure mode temperature. For this test, the ambient temperature was kept at about 105 °F.
The refrigerator performed satisfactorily with its thermostat in positions five and four. The ice tray temperature rose from 31 °F to 42.5 °F with its thermostat in position three. The other Excel temperatures did not change substantially. In position two, the Excel maintained the same temperatures that were observed at the end of position three test. Operating in position one, the Excel temperatures rose until they were in the temperature interval 35 °F to 57 °F. In the zero or defrost position, all the Excel temperatures rose to about 97 °F. Therefore, position 4 was the optimum operating thermostat setting with regard to effective operation and fuel consumption.

4.3.2

The second thermostat test determined how closely the refrigerator could satisfy the temperature criterion suggested in the American Standard Test Procedures for Household Electric Refrigerators (Mechanically Operated) (B38.2-1961). These temperatures and the results of this test are summarized in Table 3. To assist in interpretation of the data, Graph 3 shows the frozen food temperature (i.e., ice tray temperature) versus the average general food compartment temperature and Graph 4 shows the fuel consumption rate versus the average general food compartment temperature for each of the three ambient temperatures (i.e., 70 °F, 90 °F, and 110 °F).
Graph 3
AVG. GEN. FOOD COMPART TEMP ($^\circ$F) VS. FUEL CONSUMPTION RATE (lb./hr) EXCEL REFRIGERATOR

Numbers indicate thermo stat settings (1~warmest, 5~coldest)
<table>
<thead>
<tr>
<th>Ambient Temperature (°F)</th>
<th>General Food Compartment Temp. Deemed Acceptable by B.38.2 at Ambient Temperature (°F)</th>
<th>Lowest General Food Compartment Temp. (°F)</th>
<th>Frozen Food Temperature Corresponding to Lowest Gen. Food Compartment Temperature (°F)</th>
<th>Fuel Consumption Rate Corresponding to Lowest General Food Compartment Temp. (lb/hr) x 10^{-2}</th>
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<tbody>
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</table>
A typical cooling curve for the Excel refrigerator revealed the following. As the cooling load increased because of increasing ambient temperature, the general food compartment temperature initially fell and simultaneously the frozen food temperature rose. A minimum general food compartment temperature was ultimately reached, after which, this temperature began to climb. The frozen food temperature climbed continually as the cooling load increased. It is apparent from the plot of general food compartment temperatures versus the frozen food temperature that the Excel refrigerant circuits give preference, first, to the general food compartment, and second, to the freezer compartment.

The refrigerator had more than enough cooling capacity to satisfy the general food compartment temperatures suggested in B38.2 ASA Standard at each of the three ambient temperatures referenced in that standard (but not at one thermostat setting).

4.4 Tilt Test Results

The refrigerator was tilted in one degree increments, forward, backward, right, and left. The conditions of this test are shown in Table 4. The angle shown beside each direction of tilt in Table 4 is the maximum inclination prior to inducing failure.
<table>
<thead>
<tr>
<th>Direction of Tilt</th>
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5. Conclusions

The Excel refrigerator investigated in this study was found to operate most effectively and economically at a fuel line pressure of eleven inches of water. This result is in agreement with the recommendations of the refrigerator manufacturer.

The maximum ambient temperature in which this refrigerator functioned effectively was 110 °F. Above this ambient temperature, the refrigerator would display primary failure mode behavior.

The thermostat tests showed that a) the Excel refrigerator had more than enough cooling capacity to satisfy the general food compartment temperatures suggested in B38.2 ASA Standard 1961 at each of the three ambient temperatures referenced in that standard (but not at one thermostat setting), and b) in an ambient temperature of about 105 °F, (approaching the primary failure mode temperature) the Excel thermostat had to be kept in position four, or colder to produce effective operation.
The tilt test revealed that the operating ability of the refrigerator was extremely sensitive to the degree that it was inclined from the vertical. Depending on the direction of tilt, the Excel refrigerator could only tolerate tilts from 0 to 2°.

6. Acknowledgment

The authors appreciate the technical assistance of Mr. John Grimes. He helped assemble the testing apparatus and was responsible for the environmental control of the testing laboratory.
Appendix A  Temperature Data Listings

<table>
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**NOTE**—**ASTERISK DENOTES NO DATA**
Appendix B  Temperature Plots

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SYMBOL LEGEND

□ GENERAL FOOD COMPART TEMP
○ FREEZER EVAP COIL INLET TEMP
▲ AMBIENT TEMPERATURE
+ GEN EVAP COIL INLET TEMP
× GEN EVAP COIL MIDPOINT TEMP
◎ GEN EVAP COIL EXIT TEMP
↑ ICE TRAY TEMPERATURE
TEMPERATURE VS. TEST PERIOD
EXCEL REFRIGERATOR

TEMPERATURE F

CALENDAR DAYS

FRAME NUMBER 3
TEMPERATURE VS. TEST PERIOD
EXCEL REFRIGERATOR

CALIBER DAVS

TEMPERATURE F

-5 -45 -70 -95 -120

1 8 15 22 29 36
TEMPERATURE VS. TEST PERIOD
EXCEL REFRIGERATOR
TEMPERATURE VS. TEST PERIOD
EXCEL REFRIGERATOR

- Temperature vs. test period for Excel refrigerator.
- The data is plotted on a graph with temperature on the y-axis and calendar days on the x-axis.
TEMPERATURE VS. TEST PERIOD
EXCEL REFRIGERATOR

FRAME NUMBER 7
TEMPERATURE VS. TEST PERIOD
EXCEL REFRIGERATOR

TEMPERATURE F

FRAME NUMBER

15 CALENDAR DAYS

THERMOSTAT POSITION NUMBER

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Appendix C  Fuel Consumption Rate Data Listing

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**NOTE**—ASTERISK DENOTES NO DATA
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SYMBOL LEGEND

Ø EXCEL UNIT
FUEL CONSUMPTION RATE VS TEST PERIOD
EXCEL REFRIGERATOR

FUEL CONSUMPTION RATE LB/H

FUEL LINE PRESSURE IN W.G.

11"  13"  15"  8"

CALENDAR DAYS
FUEL CONSUMPTION RATE VS TEST PERIOD
EXCEL REFRIGERATOR

FUEL CONSUMPTION RATE LBM/HR

CALENDAR DAYS

FRAME NUMBER 11
FUEL CONSUMPTION RATE VS TEST PERIOD
EXCEL REFRIGERATOR

-0.100
-0.080
-0.060
-0.040
-0.020

0.020
0.040
0.060
0.080
0.100

0  8  15  22  29  36
CALENDAR DAYS

FRAME NUMBER 13
FUEL CONSUMPTION RATE VS TEST PERIOD
EXCEL REFRIGERATOR
FUEL CONSUMPTION RATE VS TEST PERIOD
EXCEL REFRIGERATOR

Fuel Consumption Rate (lb/hr) vs Calendar Days

- Fuel Consumption Rate on the Y-axis (0.020 to 0.100)
- Calendar Days on the X-axis (106 to 141)

Data points indicate variability in fuel consumption over the test period.