Transient Tests of A/C System Performed on a Caravan 1994

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CONTENTS

TRANSIENT TESTS OF A/C SYSTEM PERFORMED ON A 1994 CARAVAN

Introduction

Tests intended to determine the variation of some parameters, mainly refrigerant mass flow and velocity, on the low side of the A/C system during start up conditions were performed in a '94 Caravan .

The tests were designed to capture the rapid changes in conditions at the evaporator outlet during air conditioning system start up. In particular we were interested in finding the range of refrigerant flow rates under transient operation to determine conditions at the plate evaporator that might produce acoustic resonance.

Instrumentation

Instrumentation of the suction-liquid line hose assembly was performed on the suction side. Six different measurements were made:

1) Differential pressure across a venturi.
2) Suction manometric pressure.
3) Suction temperature.
4) Acceleration on the suction line right next to the expansion valve (downstream).
5) Reference temperature
6) Clutch voltage

Pressure was measured by using two Validyne Engineering differential pressure transducers model (DP15); one using a diaphragm of –20 to 20 psid. This transducer was connected to the high and low pressure ports of a Gerand ¾" 440 Venturi flow meter. The other pressure transducer had a diaphragm, which gave it a range from –320 to 320 psid. This transducer was connected to the high pressure port of the Venturi flow meter on one side and open to the atmosphere on the other. The pressure transducers, according to the manufacturer, have a frequency response of up to 1 kHz, but it is more likely that this response will be limited by the acoustic resonance frequency of the lines connecting the transducers, therefore these lines were as short as possible (approx. 4").

Temperature was measured using a specially ordered high speed thermocouple, which according to the manufacturer (Nanmac Co.) has a response time of 20 ms. The reference temperature for this thermocouple was obtained using a twoterminal temperature transducer chip model AD590 from Analog Devices. This transducer was calibrated in the laboratory and was used for two purposes:

1) To provide a reference temperature for the above thermocouple since it was mounted in thermal contact with the connection of the thermocouple to copper instrument cables.

2) Measure the outdoor temperature (Auto Lab temperature where car was tested).

A PCB model 352B66 miniature accelerometer with a sensitivity of 100 mV/g was installed as described above. The accelerometer was mounted in this position to try to pick up any acoustic resonance or other type of noise generated in the plate evaporator through the suction line.

Voltage to the compressor clutch was measured after passing it through a voltage divider to reduce the signal sent to our data acquisition system. This signal was used as a way to determine when the compressor started to operate.

Finally all the sensors were connected to a high speed data acquisition system. The sample frequency used was 2 kHz. for temperatures, pressures and clutch voltage and 50 kHz. for acceleration.

The 2kHz. data channels were filtered with a low pass filter with a 667 Hz. band pass. The acceleration data filter bandwidth was 14 500 Hz. Photographs of the test apparatus are shown in appendix D.

Tests Description

After recovering the refrigerant from the system, the original suction-liquid line hose assembly was replaced by the instrumented version of the assembly and the system was charged to specifications (34-36 oz).

Tests Performed

Name:	Test Description:
Baseline 3	The air conditioning fan was set at maximum with the windows open so that the system would not cycle. After the system ran for a considerable time and attained "steady state" operation data was collected.
Test 3	The heater was turned on at the highest settings with the windows closed. After the van was very hot, re-circulation of the air was started with the idea of warming up the evaporator to empty it. Finally the A/C and instrumentation systems were started.
Test 4	Test 4 is identical to Test 3 with the exception that

	acceleration measurements were not taken. This was done to lengthen the time of data collection.
Test 5	Test 5 was performed using the same procedure described in test 3 but the difference was that the system charge was lowered 200g from the initial 1000g of charge in the system.
Test 6	The difference between test 6 and test 5 is the elimination of the acceleration channel to lengthen the time of data collection.

Results

Appendix A show the basic and calculated data for each test. Clutch voltage, acceleration, suction temperature, differential pressure across the venturi, suction pressure, and reference temperature were directly plotted from data. Mass flow, density and average velocity assuming the smallest circuit area equal to 6 1/2 plates.

Our examination of the data shows the following:

1) All measured data seems to be reasonable.

2) The evaporator of this vehicle did not whistle during this series of tests.

3) The acceleration measurements do not show any harmonic content in the expected acoustic resonance region. But it should be noted that the accelerometer could not be mounted in the plate evaporator and was therefore mounted in the suction line in an attempt to detect plate evaporator acoustics at this more accessible location.

4) If we assume that the evaporator circuiting included a pass with 6 1/2 plates, calculated peak velocities are in the neighborhood of refrigerant velocities which produced whistling in plates tested at the University of Illinois.

Appendix B shows graphs of suction and saturated temperatures of the different tests performed. Suction temperatures are measured directly as presented in appendix A. The saturated temperatures were estimated using suction pressures and a R134a curve fit shown at the end of appendix C. The curve fit was obtained with the use of the package Engineering Equation Solver (EES). As can be seen in these graphs for test 3 and test 4 there is a region in which the two graphs coincide after the clutch engages at approximately 15 to 25 seconds for the test 3 graph and at 40 to 57 seconds for test 4 graphs. The graphs indicate that during this time two phase refrigerant circulates through our instruments and therefore the calculated velocities are not expected to be correct. For the baseline 3 test as well as tests 5 and 6 it seems that we always experienced superheated vapor flow.

Appendix C shows the set of equations used to calculate mass flow and density. Density calculations are valid only for superheated refrigerant. Density is needed to estimate mass flow and with mass flow, the velocity can be estimated once the cross sectional area of the 6 ½ refrigerant channels of the first circuit for the plate evaporator are determined.

Conclusion

This data represents the first attempt at performing high speed data acquisition to detect transient behavior in the field. We believe that the new testing methods produce valid results. While no whistling was observed in these tests (This vehicle never whistles), it appears that observed refrigerant velocities are in the range of velocities which produce whistling in the laboratory. If after further analysis there is a need to test the same or other systems, more tests could be performed relatively simply.

Appendix A: Graphs of Tests

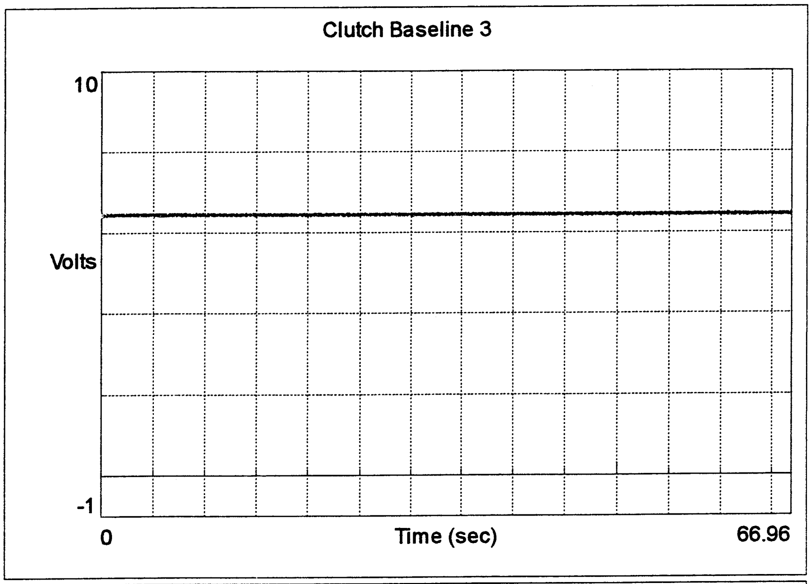
Baseline 3

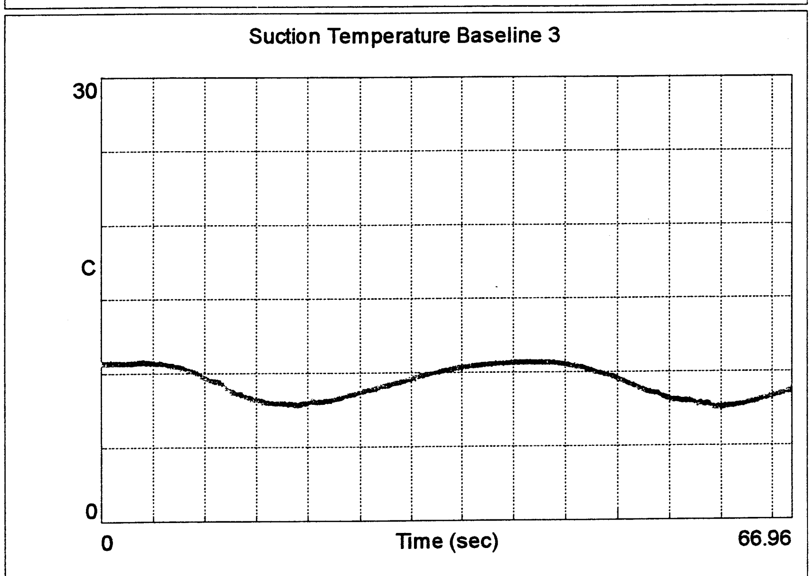
Test 3

Test 4

Test 5

Test 6


Clutch Baseline 3
10
Volts
-1
0
Time (sec)
66.96


Suction Temperature Baseline 3
30
C
0
0
Time (sec)
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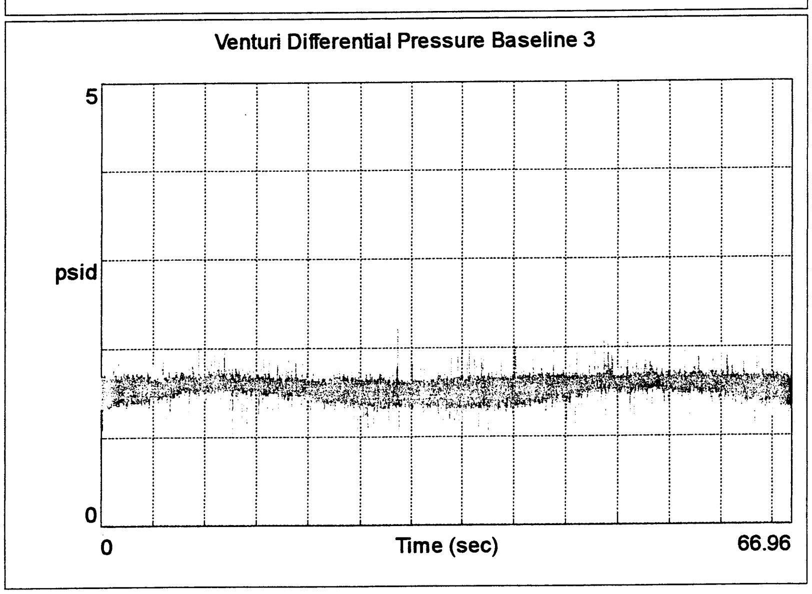
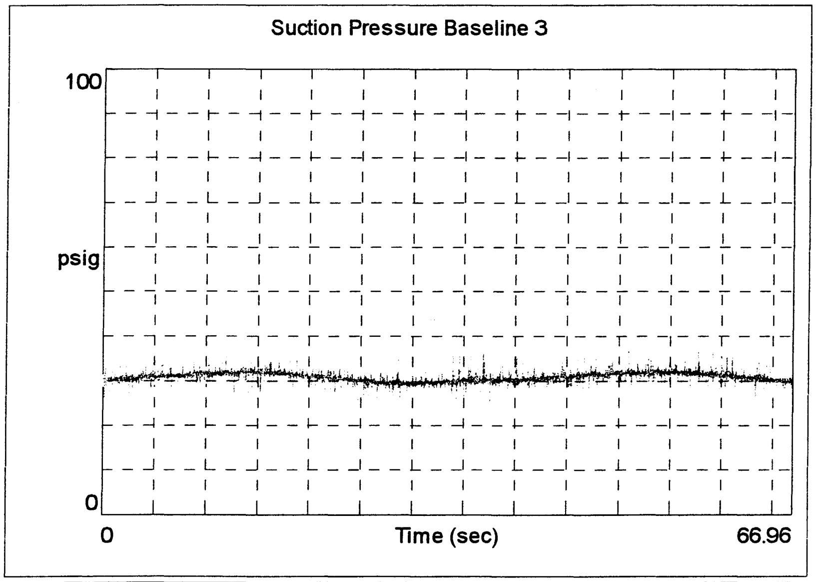

Venturi Differential Pressure Baseline 3
5
psid
0
0
Time (sec)
66.96



Suction Pressure Baseline 3
100
psig
0
0
Time (sec)
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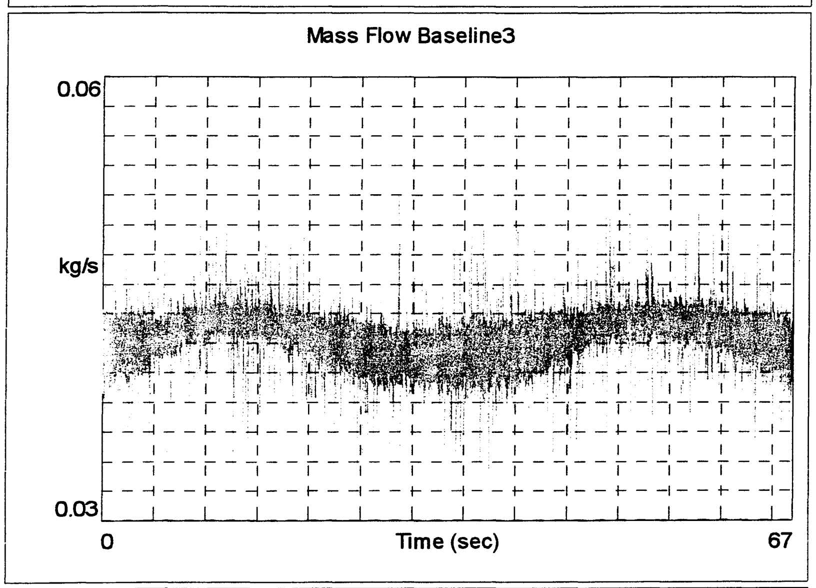


Mass Flow Baseline3
0.06
kg/s
0.03
0
Time (sec)
67

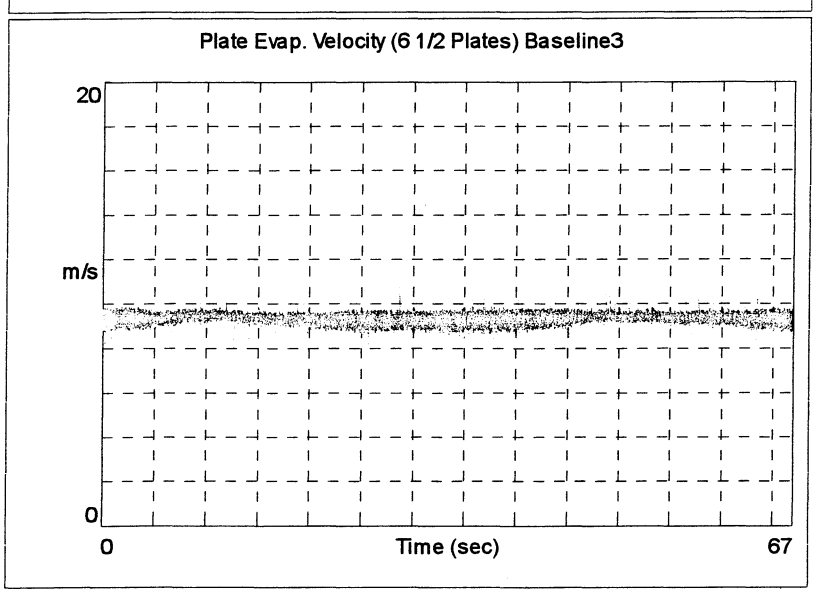
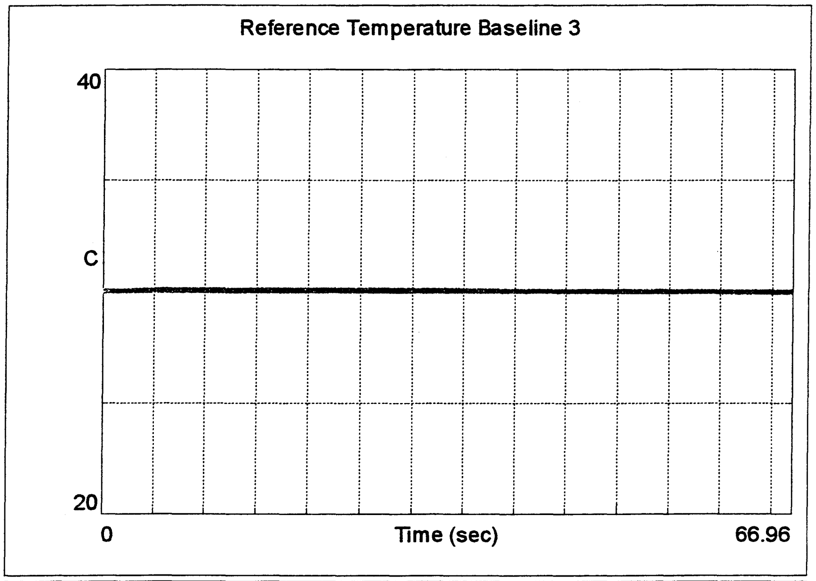
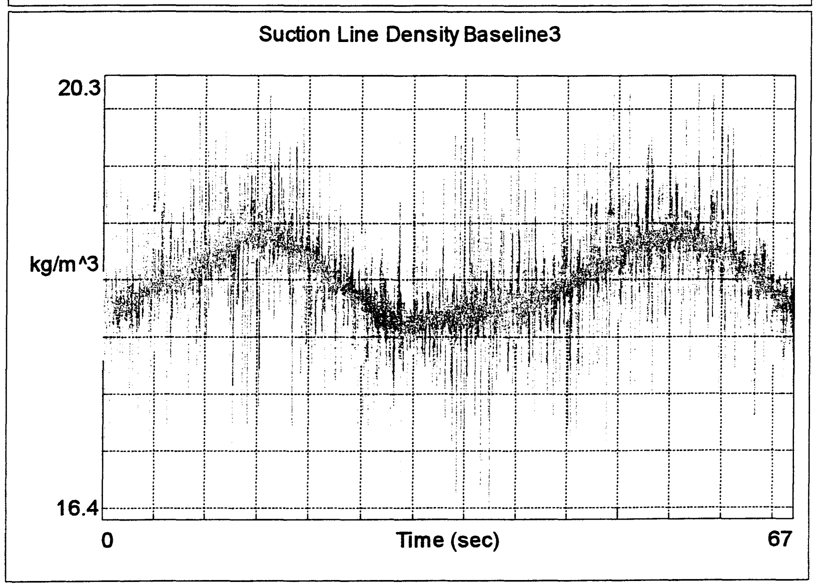
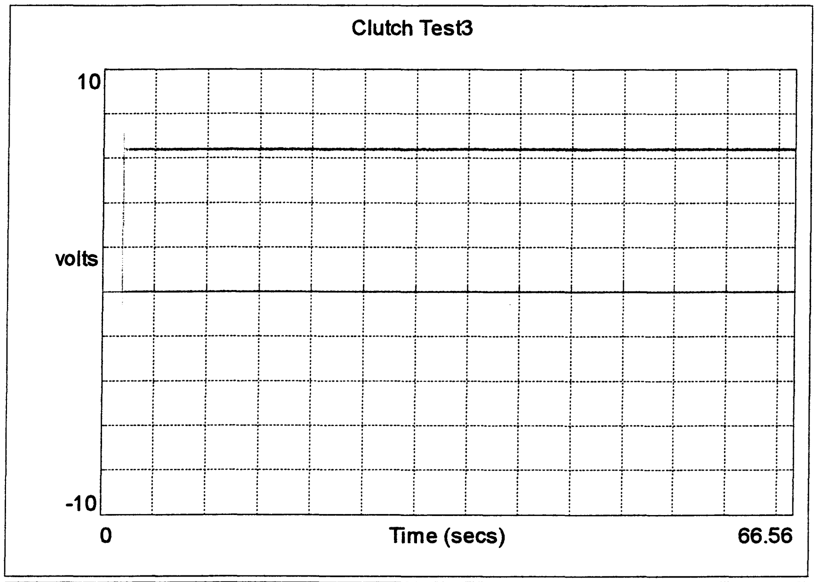
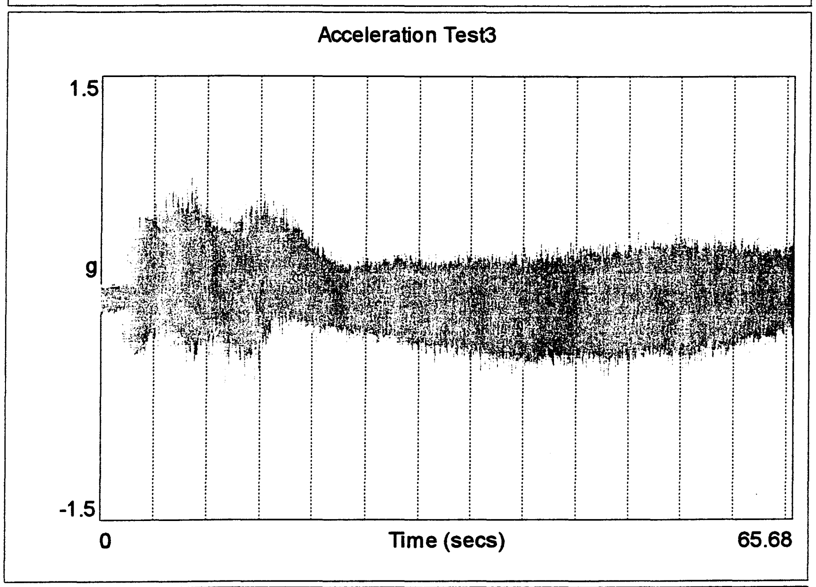


Plate Evap. Velocity (6 1/2 Plates) Baseline3
20
m/s
0
0
Time (sec)
67


Reference Temperature Baseline 3
40
C
20
0
Time (sec)
66.96


Suction Line Density Baseline3
20.3
kg/m^3
16.4
0
Time (sec)
67


Clutch Test3
10
volts
-10
0
Time (secs)
66.56


Acceleration Test3
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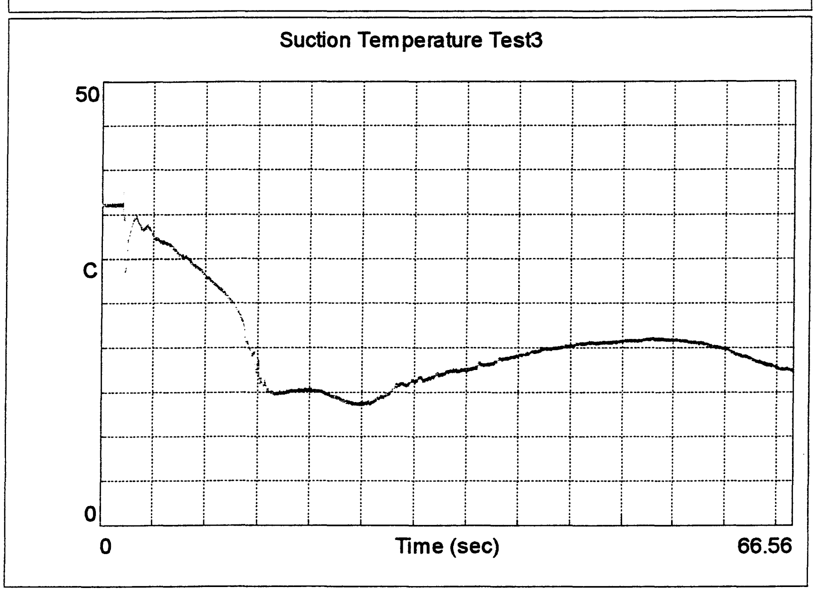
g
-1.5
0
Time (secs)
65.68


Suction Temperature Test3
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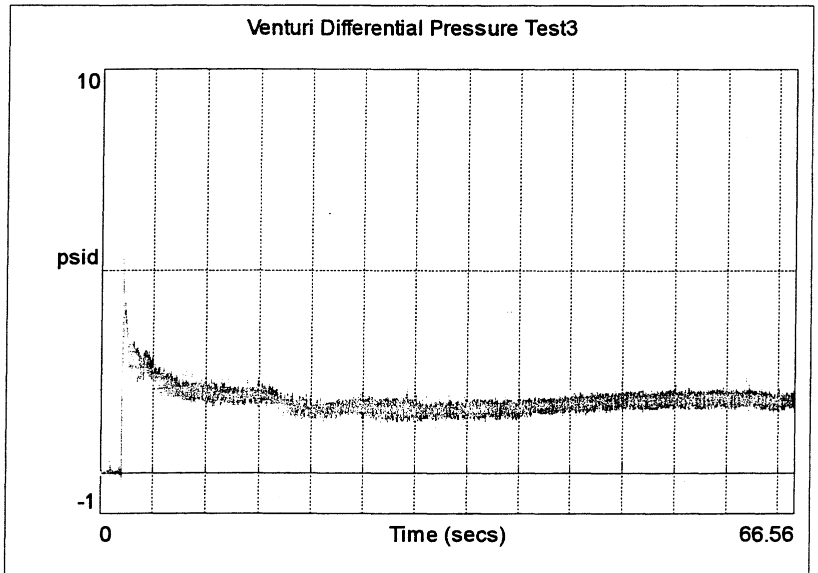
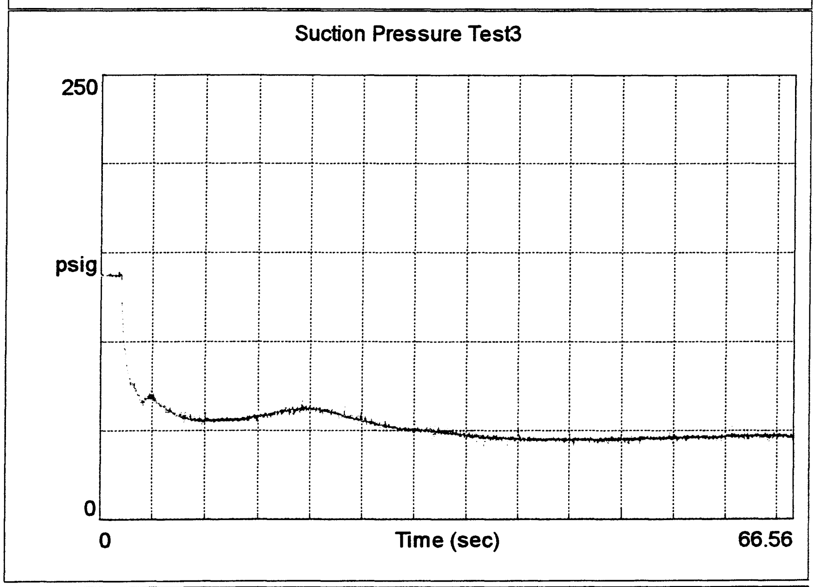
C
0
0
Time (sec)
66.56



Venturi Differential Pressure Test3
10
psid
-1
0
Time (secs)
66.56



Suction Pressure Test3
250
psig
0
0
Time (sec)
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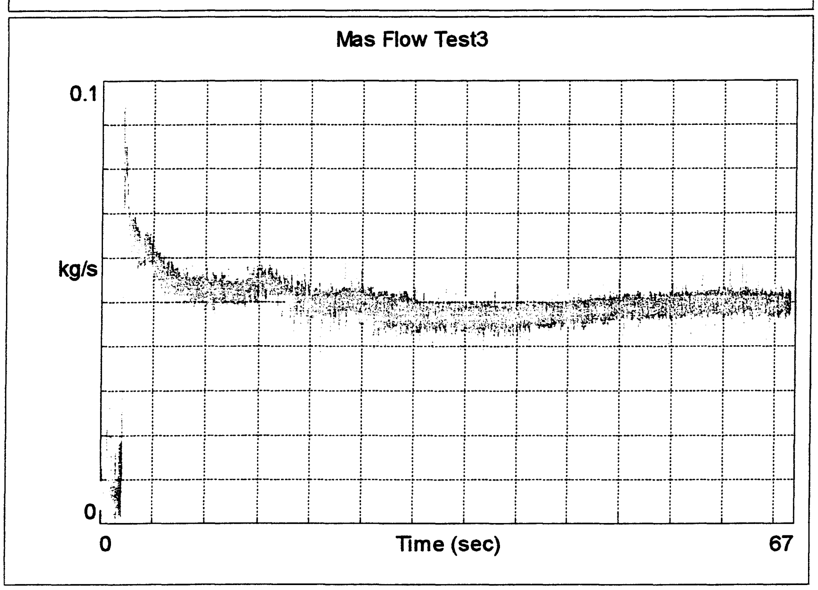


Mas Flow Test3
0.1
kg/s
0
0
Time (sec)
67

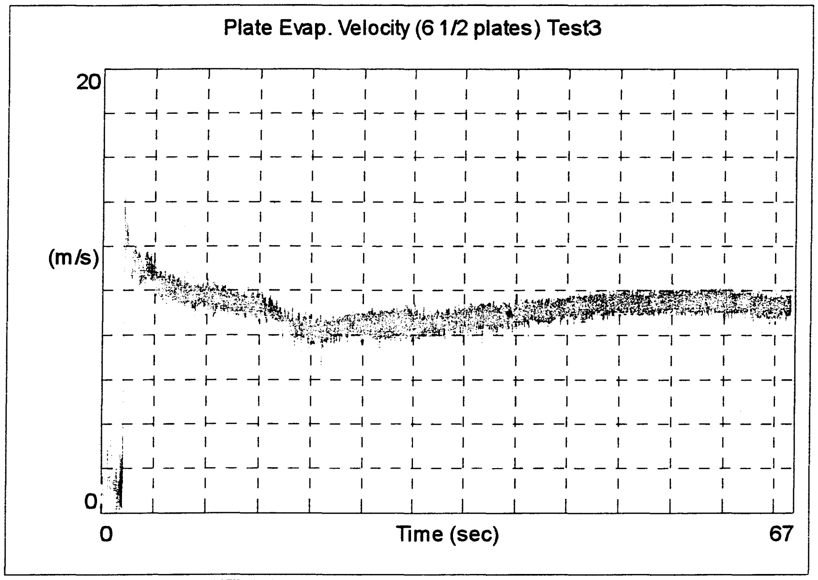
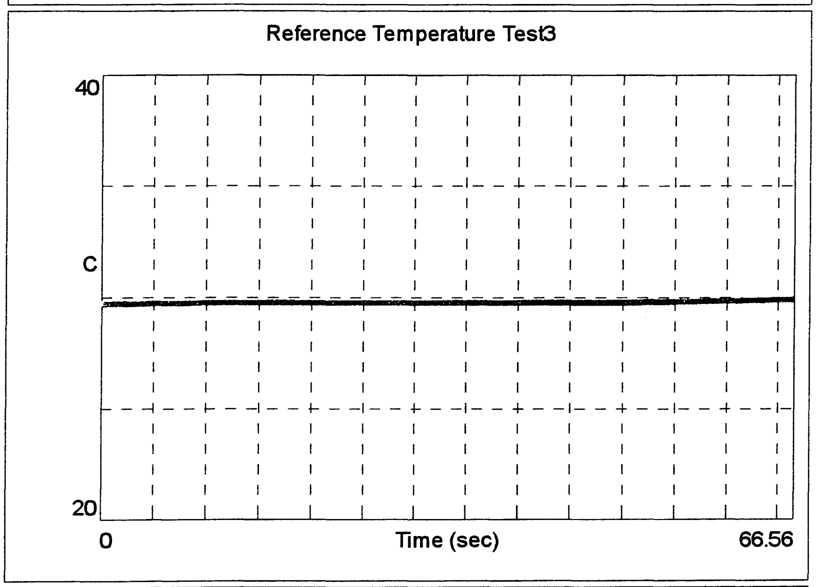
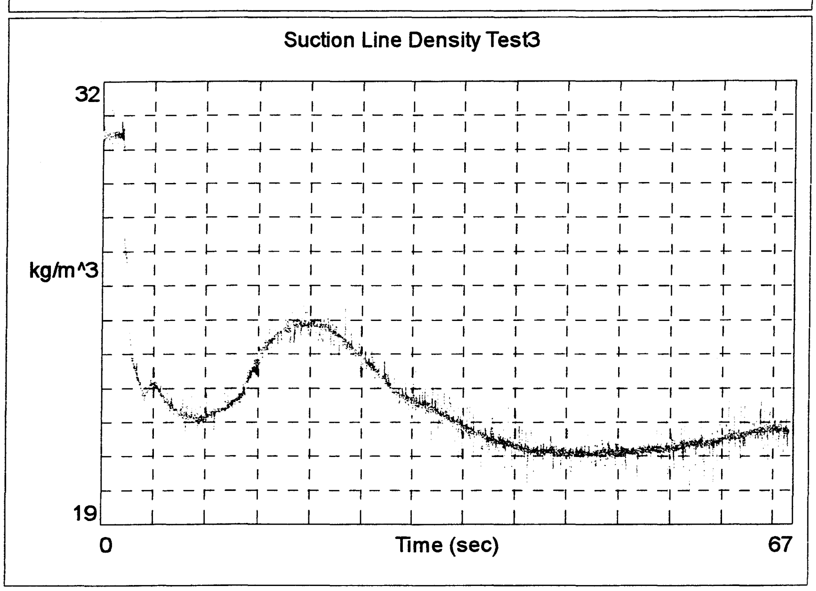
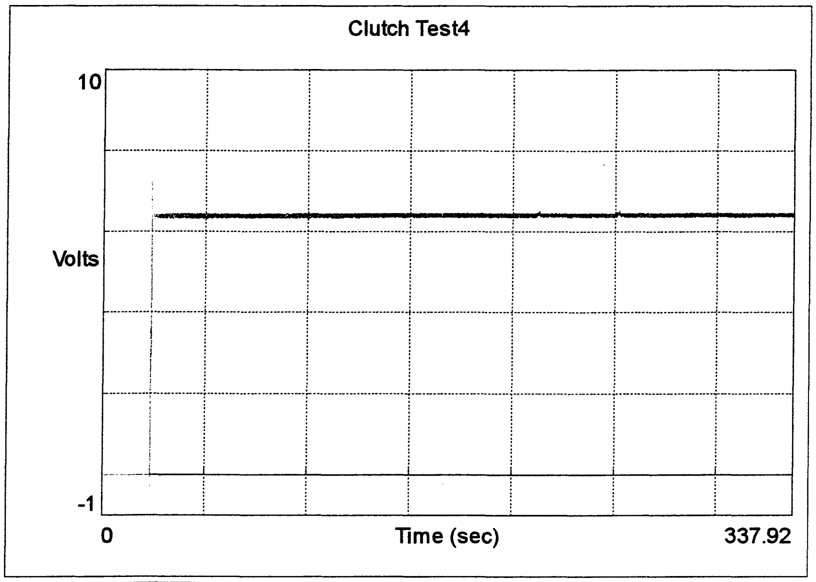
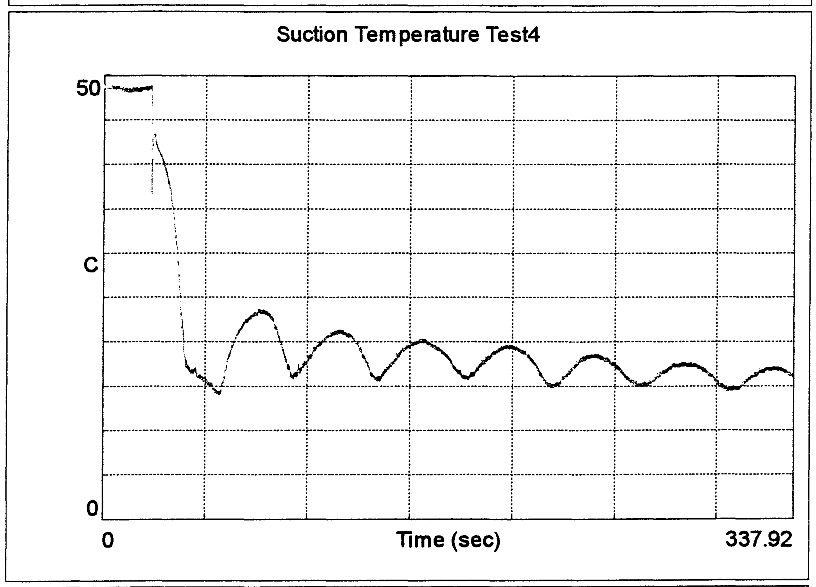


Plate Evap. Velocity (6 1/2 plates) Test3
20
(m/s)
0
0
Time (sec)
67


Reference Temperature Test3
40
C
20
0
Time (sec)
66.56


Suction Line Density Test3
32
kg/m^3
19
0
Time (sec)
67


Clutch Test4
10
Volts
-1
0
Time (sec)
337.92


Suction Temperature Test4
50
C
0
0
Time (sec)
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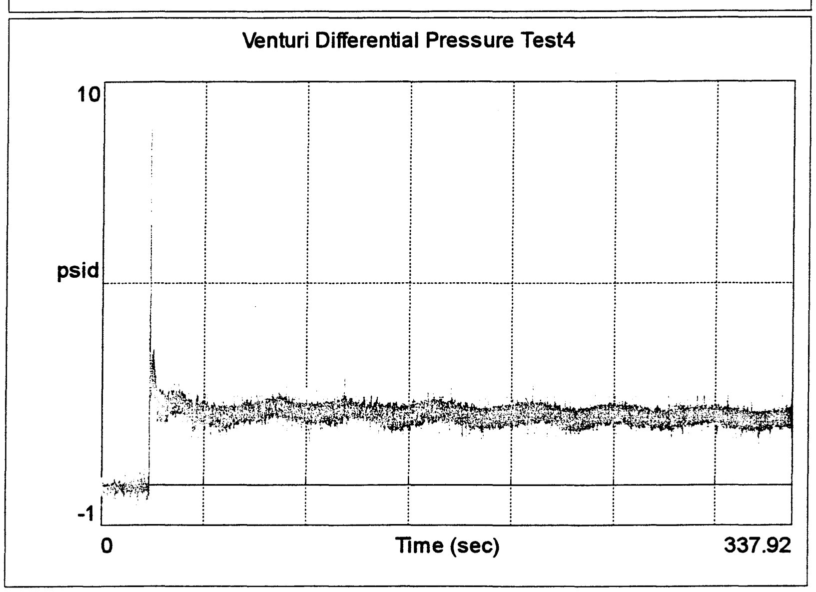
Venturi Differential Pressure Test4
10
psid
-1
0
Time (sec)
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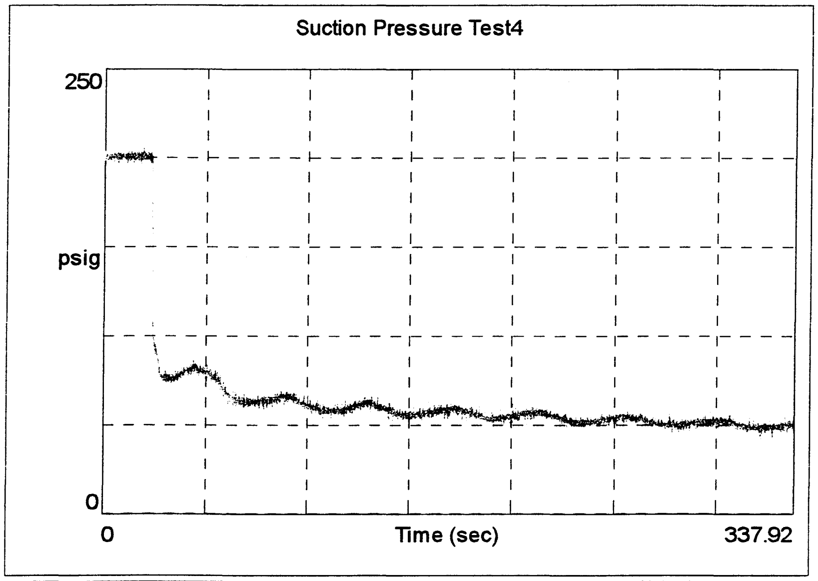
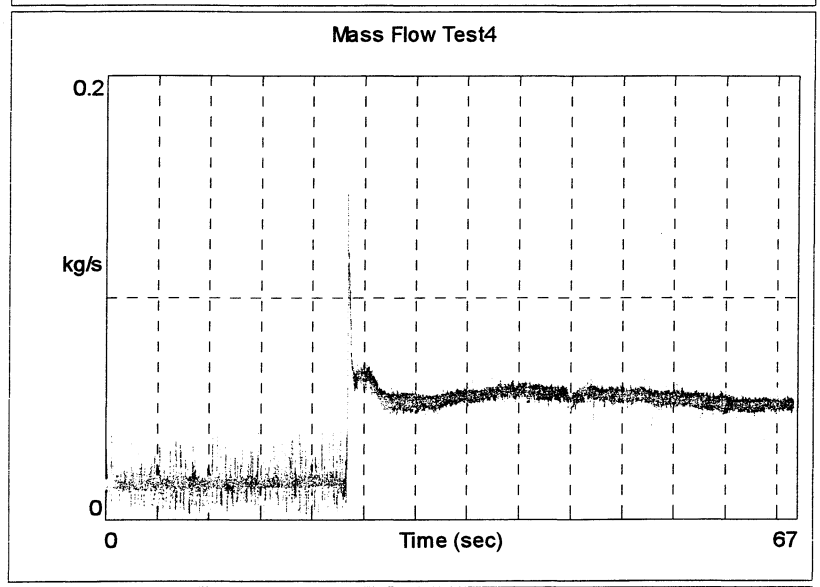

Suction Pressure Test4
250
psig
0
0
Time (sec)
337.92


Mass Flow Test4
0.2
kg/s
0
0
Time (sec)
67

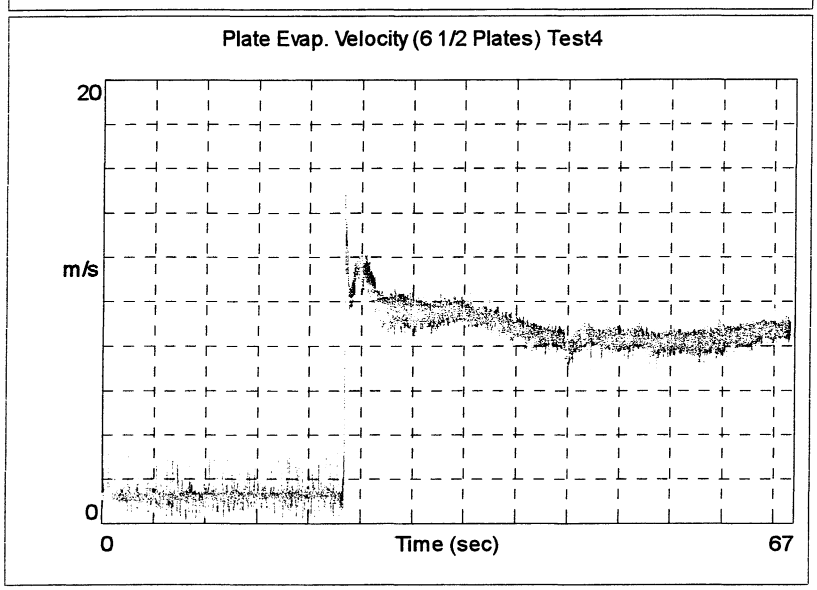
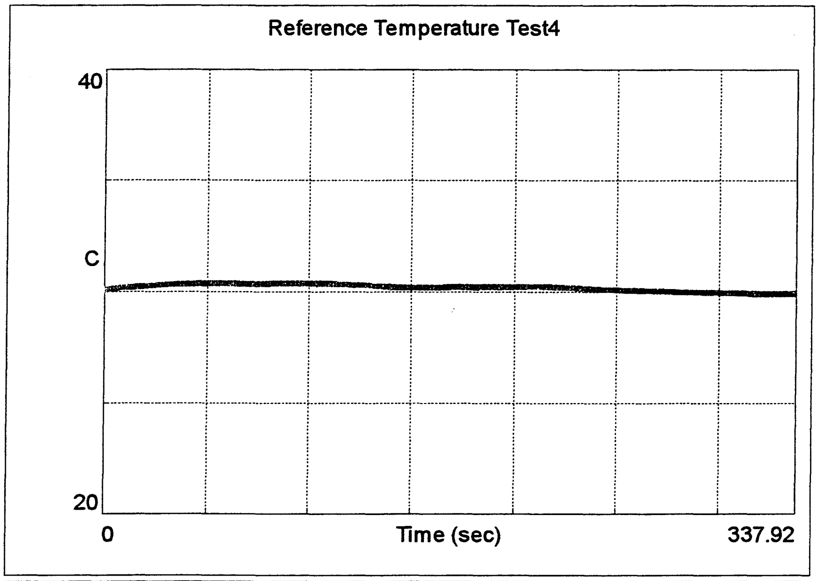
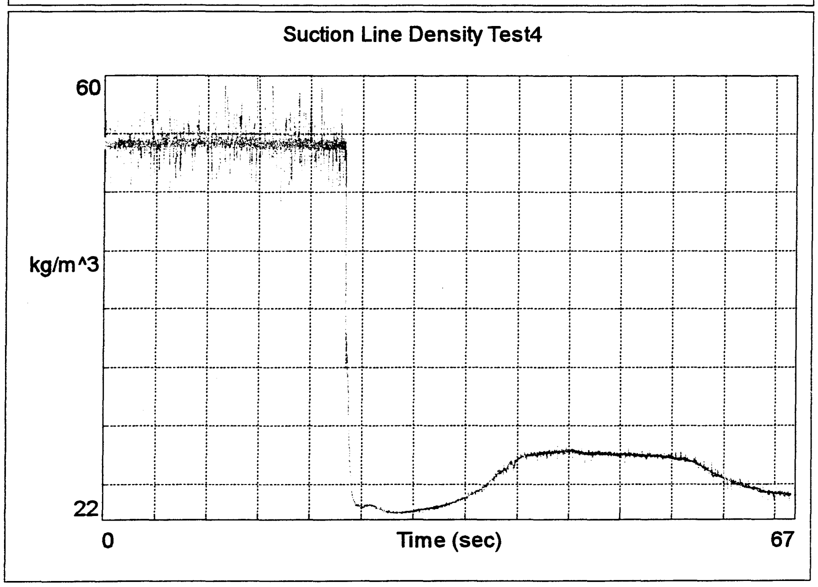
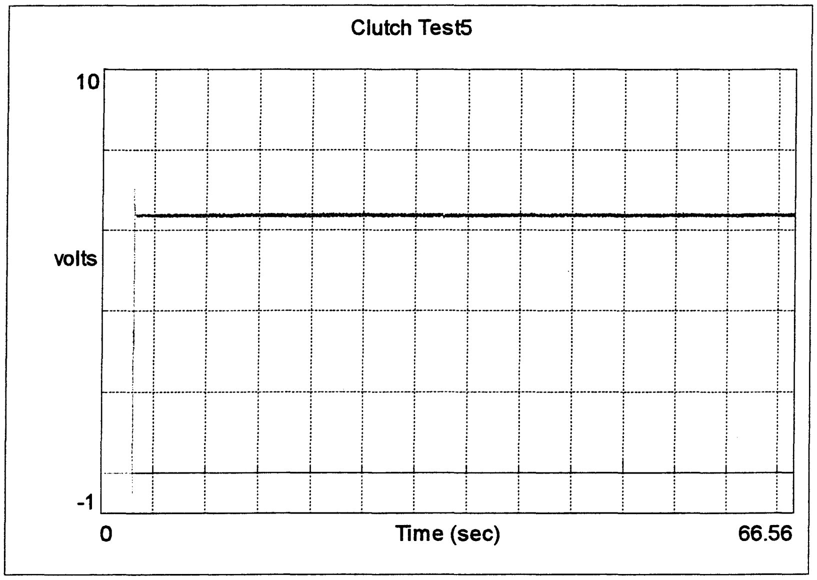
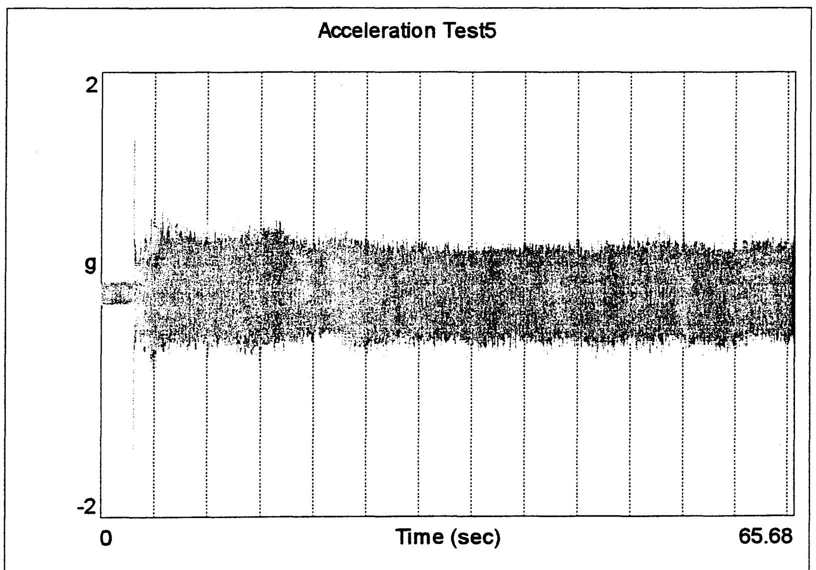


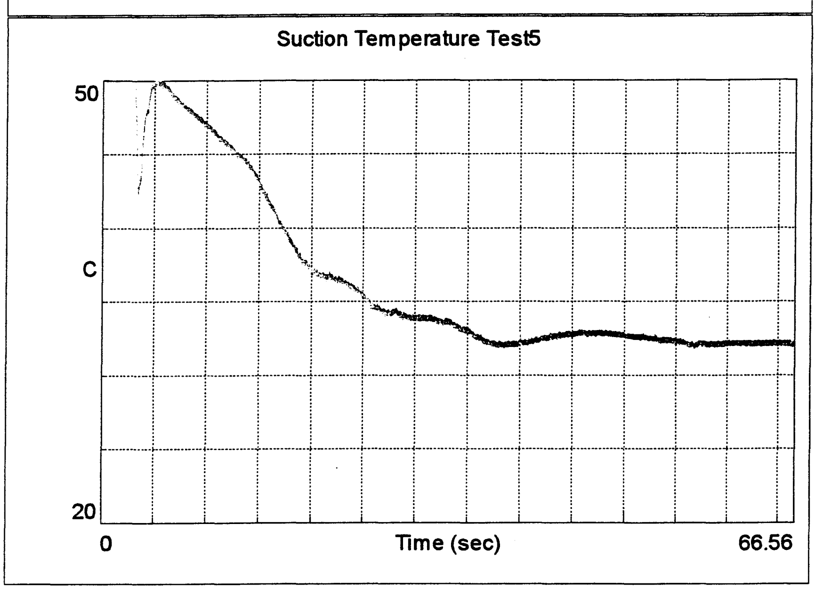
Plate Evap. Velocity (6 1/2 Plates) Test4
20
m/s
0
0
Time (sec)
67


Reference Temperature Test4
40
C
20
0
Time (sec)
337.92

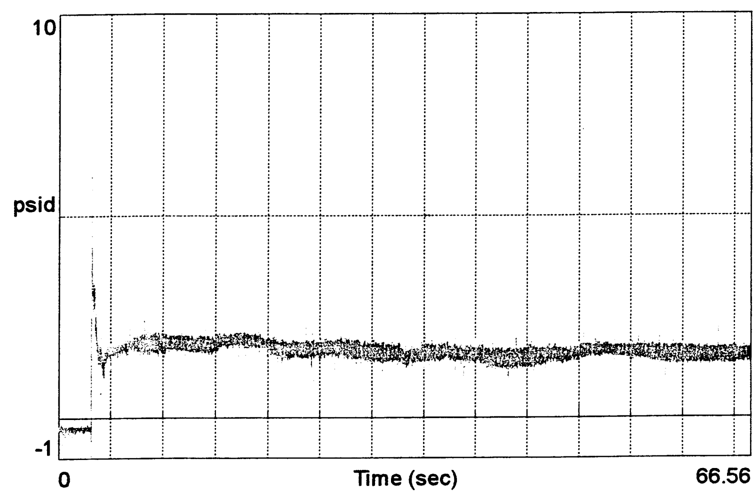

Suction Line Density Test4
60
kg/m^3
22
0
Time (sec)
67


Clutch Test5
10
volts
-1
0
Time (sec)
66.56

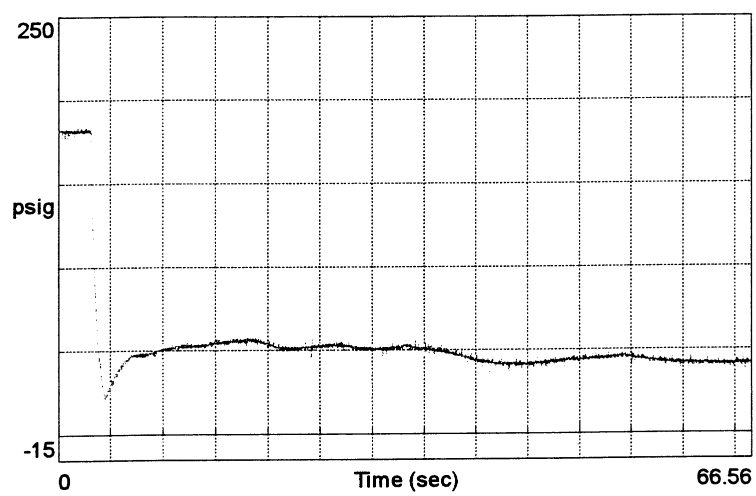

Acceleration Test5
2
g
-2
0
Time (sec)
65.68


Suction Temperature Test5
50
C
20
0
Time (sec)
66.56

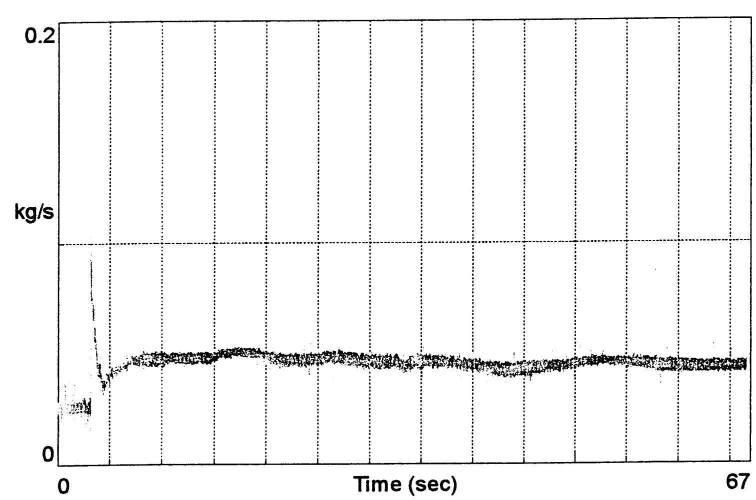
Venturi Differential Pressure Test5



Suction Pressure Test5



Mass Flow Test5



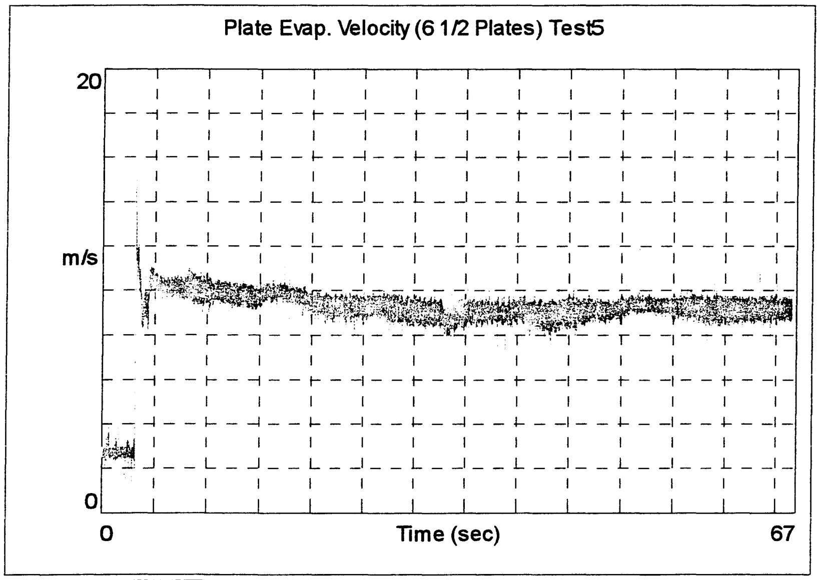
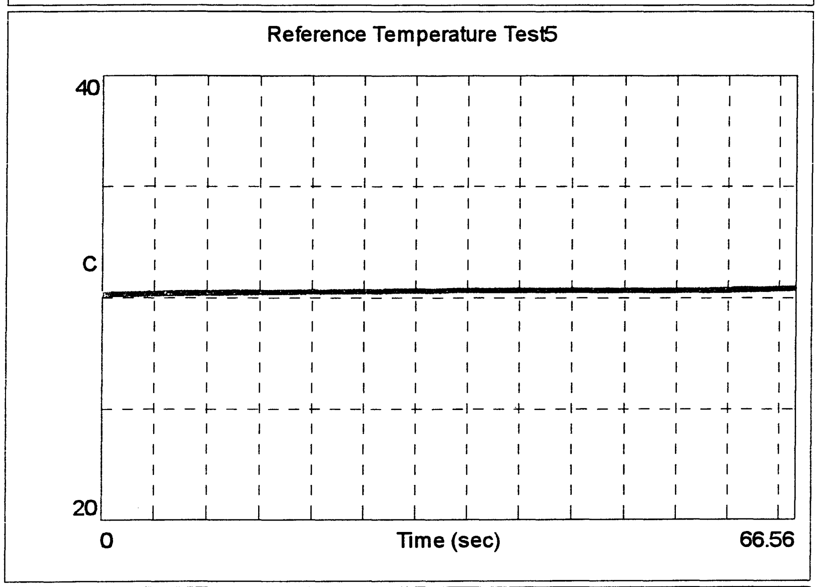
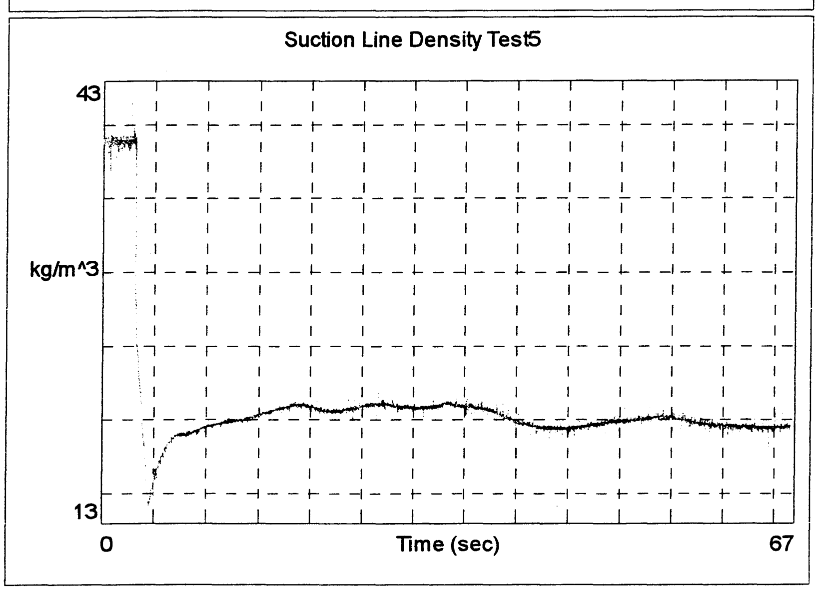
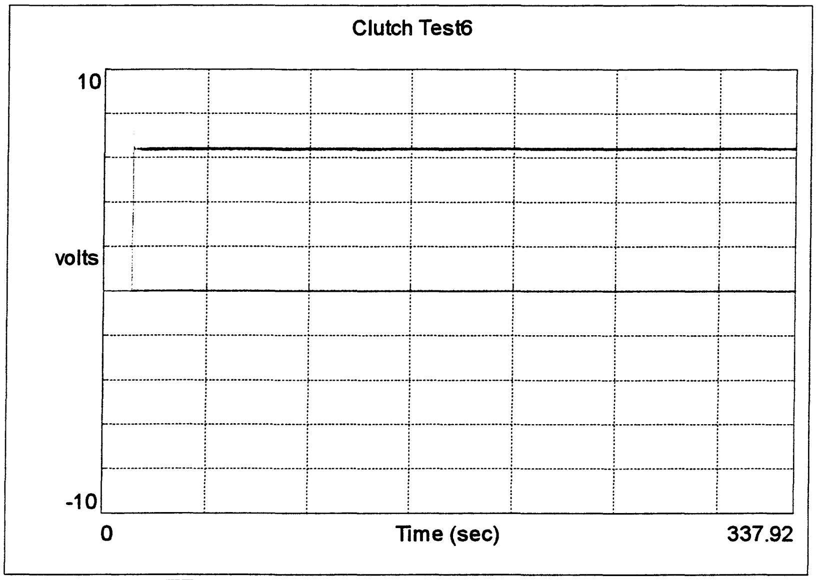
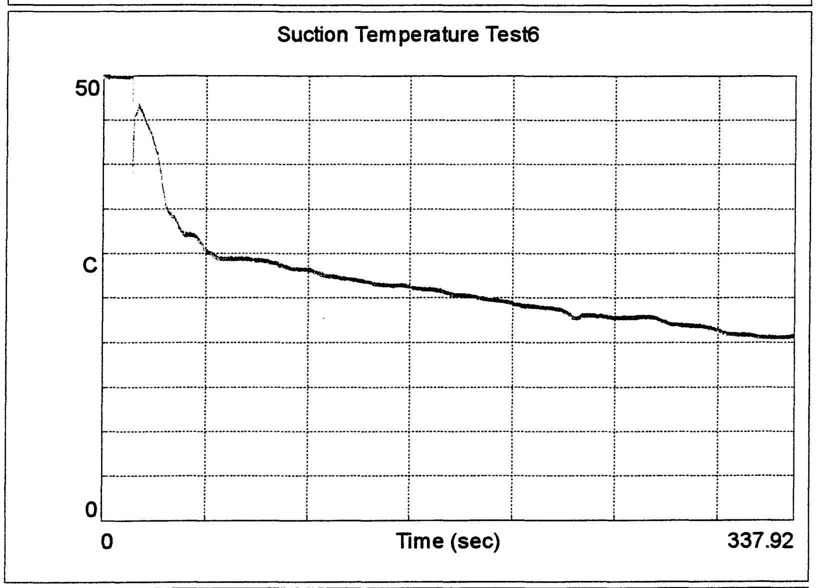


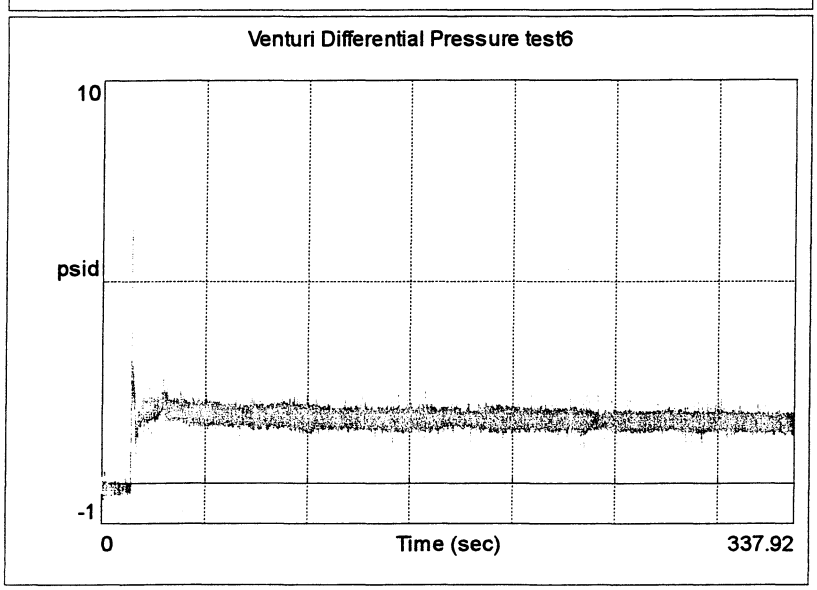
Plate Evap. Velocity (6 1/2 Plates) Test5
20
m/s
0
0
Time (sec)
67

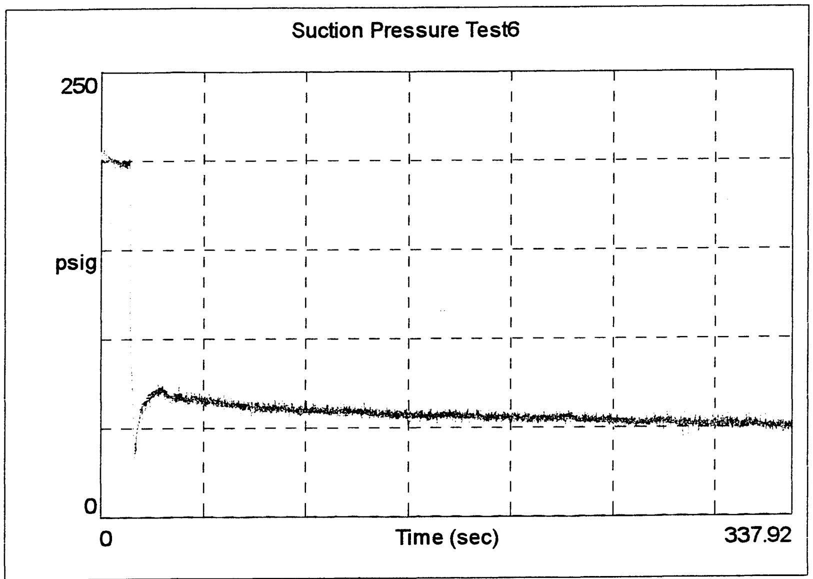

Reference Temperature Test5
40
C
20
0
Time (sec)
66.56

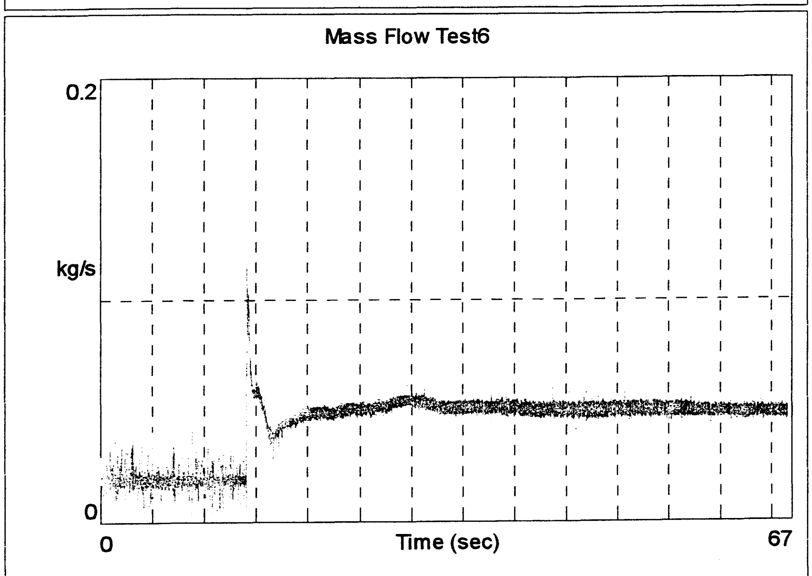

Suction Line Density Test5
43
kg/m^3
13
0
Time (sec)
67


Clutch Test6
10
volts
-10
0
Time (sec)
337.92


Suction Temperature Test6
50
C
0
0
Time (sec)
337.92


Venturi Differential Pressure test6
10
psid
-1
0
Time (sec)
337.92


Suction Pressure Test6
250
psig
0
0
Time (sec)
337.92


Mass Flow Test6
0.2
kg/s
0
0
Time (sec)
67

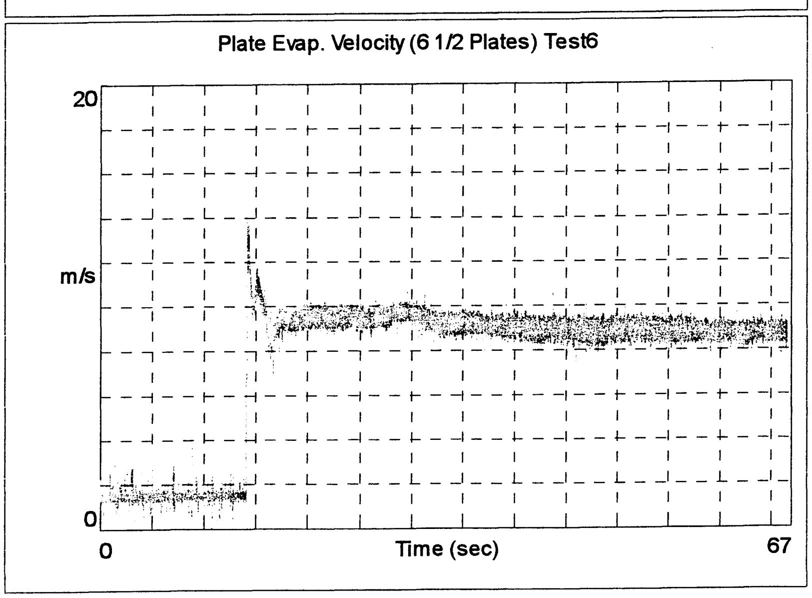
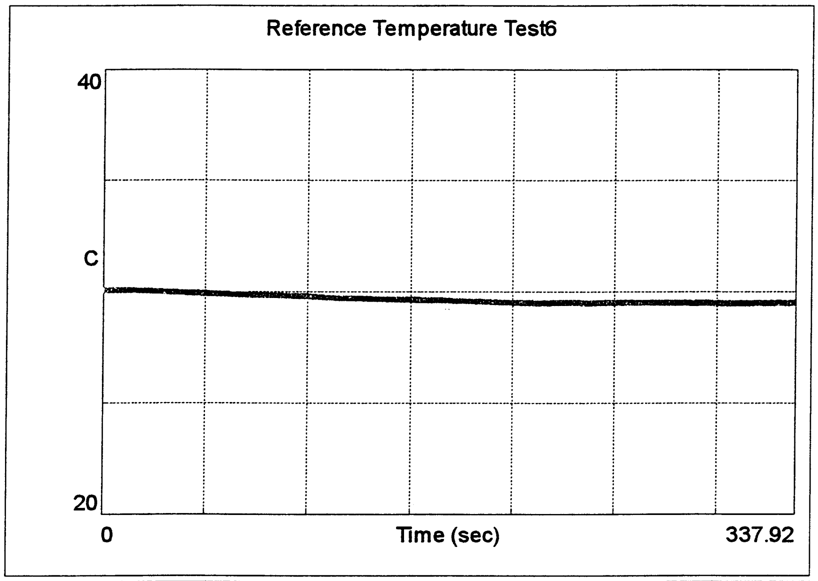
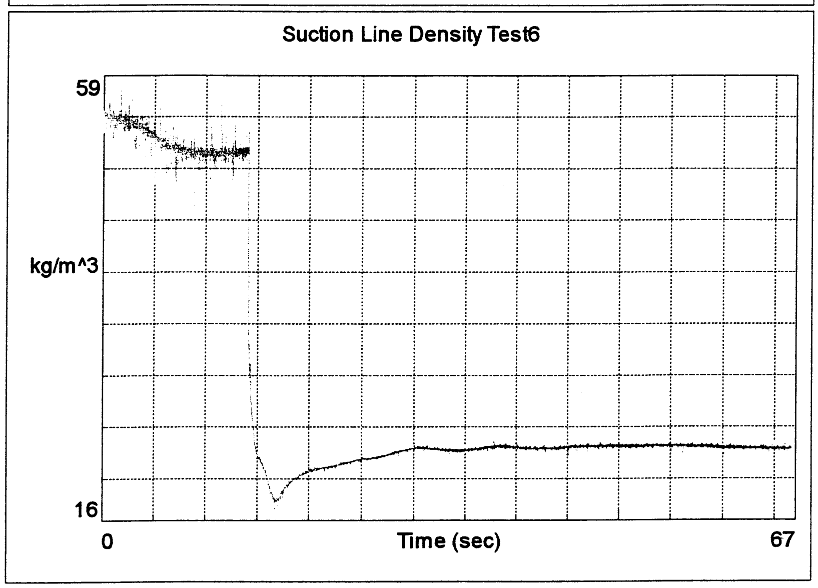


Plate Evap. Velocity (6 1/2 Plates) Test6
20
m/s
0
0
Time (sec)
67

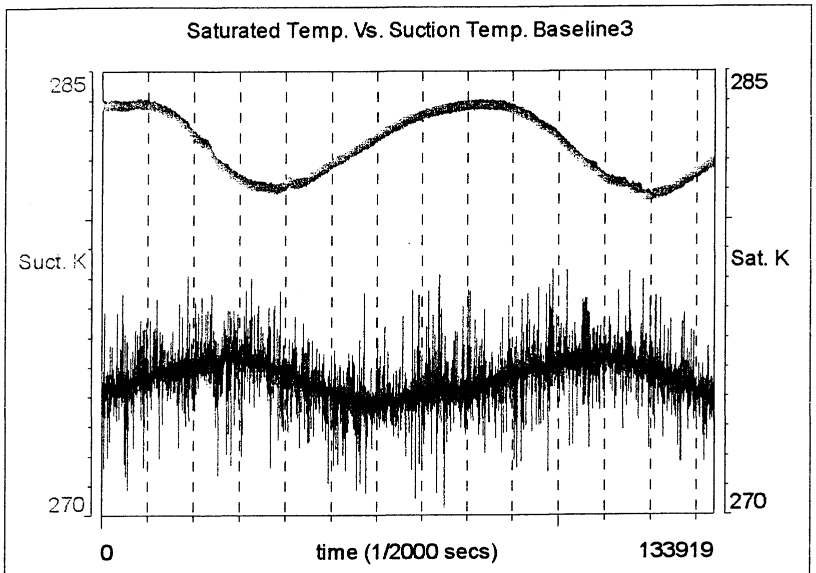


Reference Temperature Test6
40
C
20
0
Time (sec)
337.92

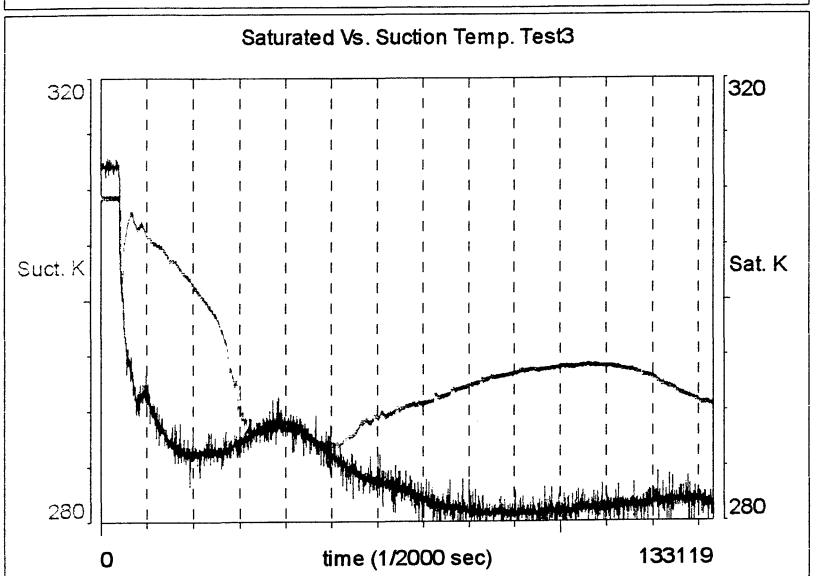


Suction Line Density Test6
59
kg/m^3
16
0
Time (sec)
67

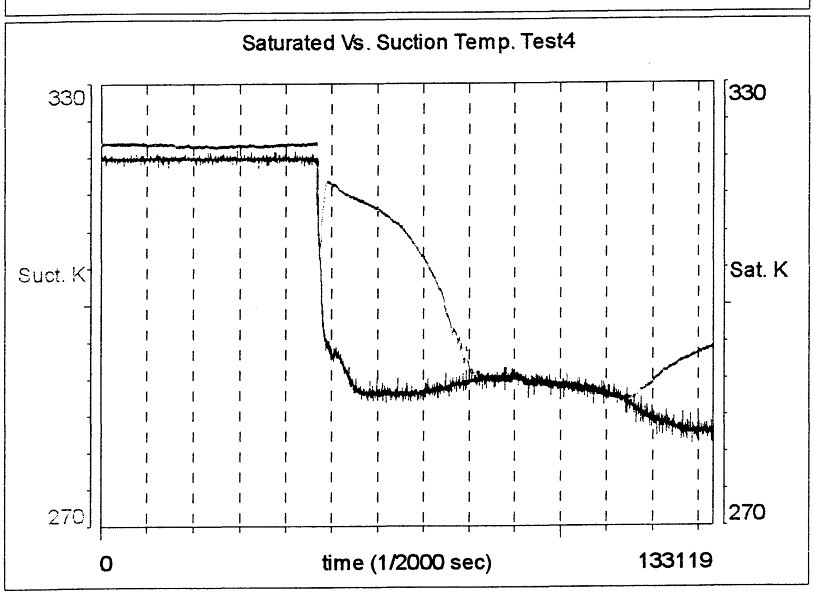
Appendix B: Suction Temperature Vs. Saturation Temperature Graphs



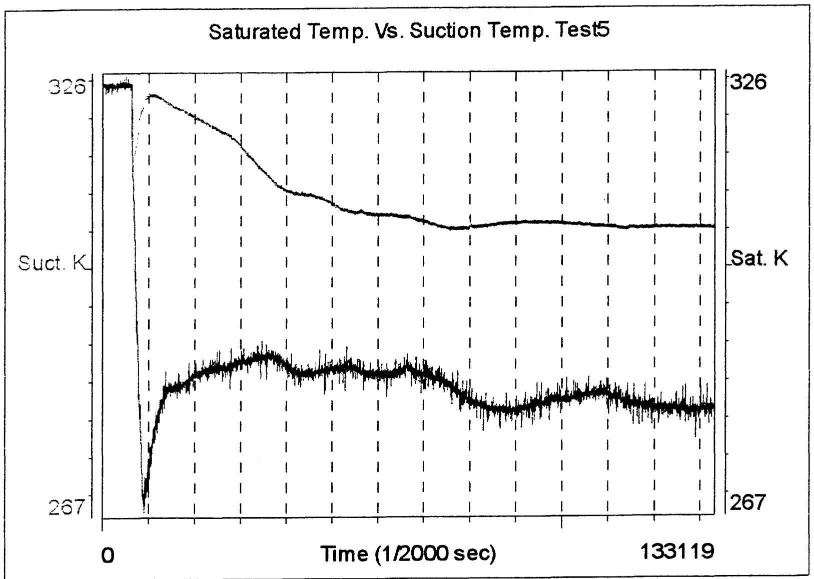
Saturated Temp. Vs. Suction Temp. Baseline3

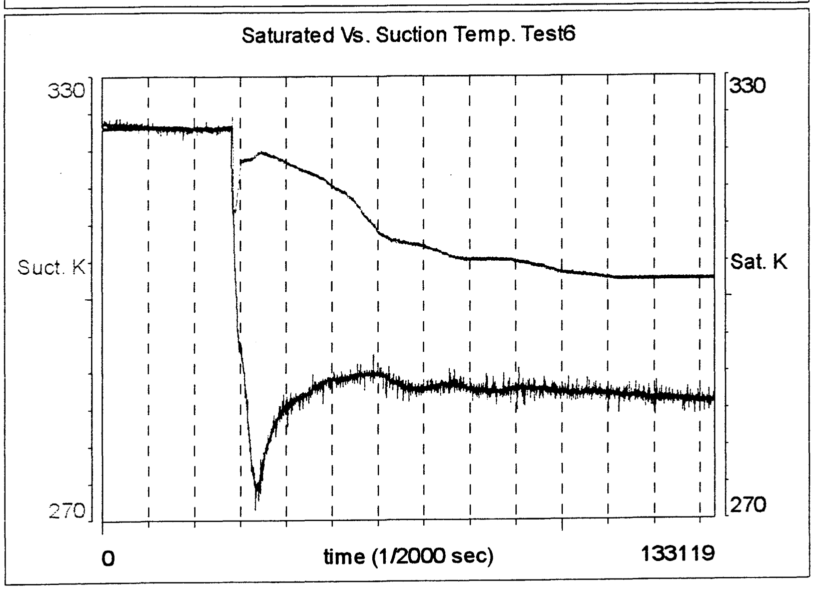


Saturated Vs. Suction Temp. Test3



Saturated Vs. Suction Temp. Test4


Saturated Temp. Vs. Suction Temp. Test5
326
Suct. K
267
326
Sat. K
267
0
Time (1/2000 sec)
133119


Saturated Vs. Suction Temp. Test6
330
Suct. K
270
330
Sat. K
270
0
time (1/2000 sec)
133119

Appendix C

Density Estimation Equations.

$$R = \frac{8.314}{102}$$

$$Tc = 374.2$$

$$Pc = 4067$$

$$a = 0.4275 \cdot R^2 \cdot \frac{Tc^{2.5}}{Pc}$$

$$b = 0.08664 \cdot R \cdot \frac{Tc}{Pc}$$

$$\rho pred = c \cdot \left[\frac{0.5 \cdot \left(\sqrt{Tk} \cdot (b \cdot Pf1 + R \cdot Tk) + \sqrt{\left| -4 \cdot a \cdot Pf1 \cdot \sqrt{Tk} + Tk \cdot (b \cdot Pf1 + R \cdot Tk)^2 \right|} \right)}{Pf1 \cdot \sqrt{Tk}} \right]^{-1}$$

$$Tk = Tf1 + 273.2$$

$$Tf1 = tsat + 50$$

$$tsat_{cal} = -38.29 + 1.163 \cdot Ppsi - 0.00758 \cdot Ppsi^2 + 0.00002832 \cdot Ppsi^3 - 4.115 \times 10^{-8} \cdot Ppsi^4$$

$$Pf1 = Ppsi \cdot \left[6.895 \cdot \frac{kPa}{psia} \right]$$

$$\rho = \rho(R134a, P=Pf1, T=Tf1)$$

$$tsat = T\left[R134a, P=Ppsi \cdot \left(6.895 \cdot \frac{kPa}{psi} \right), x=0.5 \right]$$

$$error = 100 \cdot \left[\frac{|\rho - \rho pred|}{\rho pred} \right]$$

$$c1 = 1.02 + 0.00006632 \cdot Pf1 + 6.124 \times 10^{-8} \cdot Pf1^2 - 6.001 \times 10^{-11} \cdot Pf1^3$$

$$c2 = -0.001539 \cdot Tf1 + 0.00002327 \cdot Tf1^2 - 2.645 \times 10^{-8} \cdot Tf1^3 - 2.201 \times 10^{-7} \cdot Pf1 \cdot Tf1$$

$$c3 = -2.714 \times 10^{-8} \cdot Pf1 \cdot Tf1^2 + 2.783 \times 10^{-10} \cdot Pf1^2 \cdot Tf1 + 1.173 \times 10^{-11} \cdot Pf1^2 \cdot Tf1^2$$

$$c = c1 + c2 + c3$$

Mass Flow Estimation Equations.

$$Dt = 0.375 \cdot 0.0254$$

$$Di = 0.8 \cdot 0.0254$$

$$At_{venturi} = \pi \cdot \frac{Dt^2}{4}$$

$$Ck = 0.948$$

$$k = 1.09$$

$$DPpsid = 3$$

$$Tf1 = 25$$

$$Pf1 = 90 \cdot \left[6.895 \cdot \frac{kPa}{psi}\right]$$

$$\delta_P = DPpsid \cdot \left[6895 \cdot \frac{Pa}{psi}\right]$$

$$\rho = \rho(R134a, T{=}Tf1, P{=}Pf1)$$

$$mdot = Ck \cdot Y \cdot At_{venturi} \cdot \left[\sqrt{\frac{2 \cdot \delta_P \cdot \rho}{1 - \left(\frac{Dt}{Di}\right)^4}}\right]$$

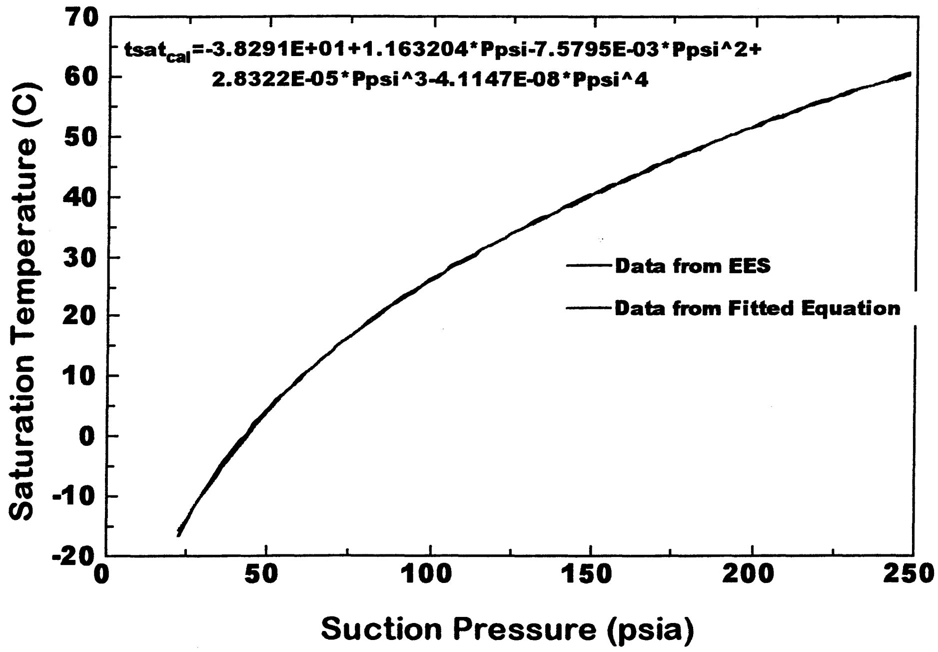
$$Y = \left[\frac{\left(\left[1 - \left(\frac{Dt}{Di}\right)^4\right] \cdot \left[\frac{k}{k-1}\right]\right) \cdot \left(\frac{pf2}{Pf1}\right)^{\left(\frac{2}{k}\right)} \cdot \left(1 - \left[\frac{pf2}{Pf1}\right]^{\left[\frac{k-1}{k}\right]}\right)}{\left(1 - \left[\frac{Dt}{Di}\right]^4 \cdot \left[\frac{pf2}{Pf1}\right]^{\left[\frac{2}{k}\right]}\right) \cdot \left(1 - \frac{pf2}{Pf1}\right)}\right]^{(1/2)}$$

$$pf2 = Pf1 - \delta_P \cdot \left[0.001 \cdot \frac{kPa}{Pa}\right]$$

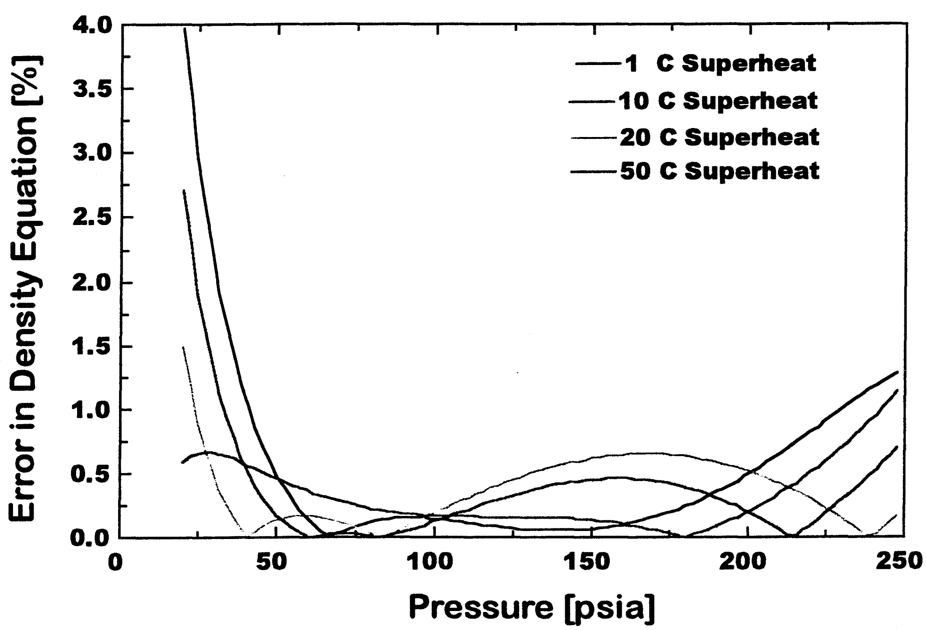
$$Tsat = T(R134a, P{=}Pf1, x{=}0.5)$$

$$Dt_{superheat} = Tf1 - Tsat$$

Saturated Temperature Equation Fit.



Density Equation Accuracy Check.



Appendix D: Photographs