Summary of Comments (Washington Revisions November 7, 2000)
Update November 27, 2000

To: Alternate Refrigerant Task Force Members
From: Ward Atkinson

This is the final review of supplied comments. At this point it is impossible to add any additional changes without considering the actual testing capabilities of the selected test facility and requirements of the technical experts that will conduct the test activity.

Therefore, this document is being forwarded to the CRP Alternate Refrigerant Core Group for their review and modifications as deemed necessary by the "Expert Advisors."

Program Target
The purpose of these bench tests is to investigate the performance and efficiency of a production HFC-134a automotive refrigeration system with an enhanced R134a refrigeration cycle and other alternate refrigerant cycles. The test cycles reflect vehicle users demands for hot climate conditions as well as middle and low ambient load conditions. The test conditions cover an estimated average load profile on these systems allowing comparison of the system COP for an estimated annual supplementary power consumption (fuel consumption) for a typical vehicle driving cycle and climate condition.

This document is a collection of test procedures and not all conversion information (English - metric) values have been included. The value indicated in the document prevails until conversion values are supplied.

Facility Requirements

Test Chambers

- The test procedure requires that there are three separate temperature control chambers containing the component to be tested.

- Each component shall be mounted in a separate temperature/humidity controlled chamber. Refrigerant flow connections between component test chambers (evaporator, condenser/gas cooler, compressor) shall not exceed 6 feet (total hose/rigid pipe length) and should be the same length for all test comparisons.

  HFC-134a systems are more sensitive to pressure drop due to lower operating pressures. The hose/pipe shall be outside dia. (OD) ¾ inch (19mm), inside hose dia. (ID) 5/8" (16mm) and shall be limited to a length of 6 feet (1.8m) in distance from the compressor inlet fitting and the evaporator outlet fitting for each system tested.

- Compressor Chamber

  The chamber shall have a variable speed drive motor (internal or external) to maintain the compressor at the various speeds and measure compressor torque requirements. (600 –3500 rpm compressor speed)

  The chamber shall be maintained at the specific operating temperature ±3% ^{o}C. and compressor speed conditions ±10 rpm or less.

- Evaporator Chamber

  The chamber shall be maintained at the specific temperature (±0.6^{o}C) and humidity test conditions (±3% RH).

  1. The evaporator shall be mounted, in the test chamber, flat face to the airflow and sealed on the inlet side. The evaporator outlet surface (cold side) shall have 4 rows of 4 thermocouples per row for a total of 16 equally spaced temperature locations.
  2. The outlet side of the evaporator shall have a transition duct 16 inches, 406 mm in length from the evaporator outlet surface that is reduced to represent the restriction of 4 panel outlets. At 300cfm the pressure drop (dry core fin) of the duct system shall be 200 Pa +/-25 Pa. The outer surface of the duct should be insulated. Duct outlet air temperature measurement shall consist of a temperature grid located 25mm rearward of the transition duct exit point containing 4 thermocouples.

  The test chamber airflow must be controllable from 60 CFM, 28.3 l/s, to 300 CFM, 141 l/s.

  Electrical heater and humidifier should compensate for sensible and latent capacity of the evaporator at steady state conditions.

  Evaporator inlet and outlet static pressure measurements should be made according to ASHRAE standards.
  Airflow rate shall be measured following ASHRAE/AMCA standards.

  The final data reading shall be taken after the system has stabilized. After the system has operated for 30 minutes and data recorded, two additional data points at least 5 minutes apart shall be recorded to verify stabilization.

  Collection and measurement of evaporator condensate (time vs. collect weight should be done with scale or load cell with no less than 0.1g accuracy.
  There should be agreement between three capacity balances (refrigerant, air and chamber balance. The main balance of refrigerant- and air side shall be within 3%. The chamber could be compromised.

- Secondary loop system
  The heat exchanger flow rates (airflow or liquid) and temperatures are applicable to secondary or split systems that provide cooling to the passenger compartment should be controllable from 60 to 300 CFM on the airside and 25 to 500 USgal/hr, 96 to 1920 l/h, on the coolant side.

- Vehicle Front End Chamber
  The chamber shall be maintained at the specific temperature ($\pm$0.6^{o}C).

  The airflow must be controllable from 900 CFM, 425 l/s to 2,800 CFM (1322 L/m)

  The heat exchanger shall be mounted in a front-end module consisting of an enclosure housing a typical vehicle inlet grille, a support assembly that a vehicle engine coolant radiator (airflow restriction only) is attached and electric engine cooling fans. A panel shall be mounted downstream (behind) the cooling fan/fans to simulated engine airflow restriction.

  All other measurements should be done same as in the evaporator Test chamber

- System Performance Requirements
  Prior to conducting any test sequences as required in Phase III Stabilized conditions a refrigerant charge determination as required in Phase I and Phase II Evaporator Freeze Protection shall be completed.

Phase I
Charge Determination for HFC-134a systems. CO_2 and Secondary loop systems may require a modified method.

The test team shall establish the system operating refrigerant charge to be used during the testing. This refrigerant charge amount shall be used for all test sequences. Overcharge can cause problems under high load conditions during idle. The refrigerant overcharge amount should be established by the test team specialist.

The CO_2 specification for purity shall be industrial "beverage" grade. This is used to carbonate drinks, is the lowest cost, readily available and because of cost will be the grade used by the service industry.

CO_2 specification Industrial Grade:

Minimum purity 99.5%
Moisture 120 ppm
Dew Pt. Colder than -40°F
UN Number UN1013
CAS Number: 124-38-9

1. Ambient 104°F, - 40 C° 40% R.H
2. 2000 compressor RPM
3. Start at 0.5 kg. and increment in 0.05 kg.
4. Record the appropriate system pressures and temperatures required identifying the systems critical refrigerant charge value.
5. After establishing test stand refrigerant optimum charge value all testing shall be run at 0.2 Kg above optimum charge value.

Phase II

Evaporator Freeze Protection

Ambient 90°F - 32° C 50% r.h. 110 grains of moisture per pound of dry air 76°F (24° C) WB

1. Evaporator freeze protection test. Per Procedure SAE J1659 par. 5.0 except as modified for test chamber application.

Testing of Evaporator Control for freeze protection Testing of Replacement

- Evaporator freeze-up protection control setting changes must be established prior to testing. This includes pressure switches, electronic and mechanical temperature switches for compressor clutch operation, and control systems for variable displacement compressors.
- The purpose of this test is to establish the requirements that will assure that the mobile A/C system operation under high moisture loads will not result in loss of system performance due to evaporator core icing reducing system air flow.

Test Conditions

- The A/C system shall be operated with the system blower setting on low position (60 cfm), at an ambient of 90°F - 32 °C, at 50% relative humidity. The compressor shall be operated at a constant speed of 2,500 rpm with the condenser/gascooler airflow being 2,800 cfm for 2 hours.
- The air pressure differential between the evaporator core inlet and the evaporator outlet shall be measured with a device that will indicate the pressure drop in Pa (mm) of water.
- The differential pressure shall be recorded every 5 min for the 2 hour period.
- After the first 15 min of operation, the pressure differential shall not change more than 10% during the remaining 105-min of the test. When a significant change of pressure occurs, it is an indication of evaporator ice build-up, reducing system airflow, which indicates an incorrect evaporator freeze control setting.
- If the system exhibits evaporator ice build-up, the control setting shall be changed and the test re-run so that no excessive loss of system air flow occurs.
- All data shall be recorded every 5 min during the test period.
- A/C system blower voltage and amps shall be recorded.
- If a compressor cycling clutch system is used for evaporator control, the compressor cycle rate shall not exceed the 6 cycles per minute.

Phase III

Stabilized Performance
The HFC-134a system is first run as baseline and a final recheck for test and equipment validation is made after completion of the test series. Each alternate refrigerant system shall run the same test conditions.

When other alternate refrigerant systems are tested the first test sequence will be conducted at the indicated compressor speeds.

If the evaporator outlet temperature is not comparable with the HFC-134a test for the 113°F, - (45C°) 27% R.H. 116 grains of moisture per pound of dry air 82°F (28° C) WB a second series of tests are required.

The HFC-134a baseline run at an ambient of 113°F, - (45C°) 27% R.H. 116 grains of moisture per pound of dry air 82°F (28° C) WB at the indicated compressor speeds (900, 1500, 2500 rpm) ~~average~~ and the evaporator outlet air temperature is used as baseline. The average evaporator outlet air temperature surface (cold side shall have 4 rows of 4 thermocouples per row for a total of 16 equally spaced temperature locations 5mm from the cold side evaporator surface) defines the average outlet air temperature directly after the evaporator.
Each alternate refrigerant system must have a comparable evaporator outlet temperature at the 900-rpm test condition. If the temperature is not comparable a second series of tests are required to compare the alternate refrigerant to the HFC-134a system. Compressor speeds are to be adjusted, faster or slower, to obtain a comparable evaporator outlet temperature +/- 1°C of the base HFC-134a system at 900 rpm test condition. With the new compressor speed established the changed (faster or slower) speed will be run for all additional data points. (eg. Equal temperature required an increase compressor speed of 350 rpm) The new series of data points will be run at the percentage of change required, eg. 1,250 idle, 2,083 low speed and 3,472 high speed. These adjusted speeds shall be run at all test conditions.

6. Ambient 113°F, - (45C°) 27% R.H. 116 grains of moisture per pound of dry air 82°F (28° C) WB
   <u>Test condition to be run = High Load</u>

   Stabilized idle

   Stabilized low speed

   Stabilized high speed

   Idle and rapid acceleration evaluation
   From previous stabilized point
   1 - within 3 second decrease compressor to idle speed
   2 - idle compressor for 30 seconds
   3 - within 10 seconds increase compressor speed to 2000 rpm.

Note this test condition requires discussion regarding what data are to be recorded to determine system stability. Evaporator and condenser/gas cooler airflow must be established (based upon test stand capability) for the different conditions.

7. Ambient 95°F, - (35 C°) 45% R.H. 112 grains of moisture per pound of dry air - 77°F (25° C) WB

   Test condition to be run = High Load

   Stabilized idle

   Stabilized low speed

   Stabilized high speed

8. Ambient 77°F, - (25°C) 65% R.H. 90 grains of moisture per pound of dry air - 68°F (20° C) WB

   Test condition to be run = High Load and Low Load

   Stabilized idle

   Stabilized low speed

   Stabilized high speed

   Idle and rapid acceleration evaluation
   From previous stabilized point
   1 - within 3 second decrease compressor to idle speed
   2 - idle compressor for 30 seconds
   3 - within 10 seconds increase compressor speed to 2000 rpm.

   Note this test condition requires discussion regarding what data are to be recorded to determine system stability. Evaporator and condenser/gas cooler airflow must be established (based upon test stand capability) for the different conditions.

9. Ambient 59°F, - 15° C 80% R.H. 60 grains of moisture per pound of dry air - 56°F (13° C) WB

   Test condition to be run = High Load and Low Load

   Stabilized idle

   Stabilized low speed

   Stabilized high speed

Test Conditions

For ambient conditions of 113°F and 95°F the "High Load" requirements shall be run. For ambient conditions of 77° F and 59° F both the "High Load" and "Low Load" test points shall be run.

Test Condition High Load

- Idle

System evaporator airflow 230 CFM, 109 l/s, Condenser/gas cooler 900 CFM, 425 l/s

- Test condition 1
  - Ground heat and engine compartment air recirculation can increase the condenser / gascooler air inlet temperature at Idle conditions.
  - Condenser/ gas cooler inlet temperature to be 15°C above test ambient at idle condition – due to ground heat and engine compartment air recirculation
  - For investigating purpose an increase of 25°C at gascooler/condenser inlet should be also considered This is not be used for efficiency calculation.
- Test Condition 2
  - Due to varying wind direction and velocity, and changing ground surfaces temperature (rain, sun, night) the inlet temperature can be equal to ambient.
  - Condenser/ gas cooler inlet temperature to be the same as test ambient at idle condition.

Compressor - 900 rpm

- Low speed
  System evaporator air flow 275 CFM,
  Condenser/gas cooler airflow 1,800 CFM, 850 l/s,
  Compressor –1,500 rpm

- High Speed
  System evaporator airflow 275 CFM, Condenser/gas cooler airflow 2,800 CFM
  Compressor – 2,500 rpm

Test Condition Low Load

- Idle
  System evaporator airflow 60 CFM, Condenser/gas cooler 900 CFM, 425 l/s

  Condenser inlet temperature to be 15°C above ambient at idle condition – due to ground heat and engine compartment air recirculation

Compressor - 900 rpm

- Low speed
  System evaporator air flow 60 CFM,
  Condenser/gas cooler airflow 1,800 CFM, 850 l/s, 51cmm
  Compressor –1,500 rpm

- High Speed
  System evaporator airflow 60 CFM, Condenser/gas cooler airflow 2,800 CFM
  Compressor – 2,500 rpm

Test Conditions

All test conditions unless otherwise specified must meet following requirements.

- Temperature ± 0.6°C
- Humidity $\pm$ 3%
- Airflow $\pm$ 3% Total chamber system air flow (closed loop system) shall be measured by a calibrated orifice or equivalent device located within the chamber
- Compressor speed $\pm$ 10 rpm or less.
- All system electrical power consumption, e.g. Pumps or motors (engine cooling fan(s)) required for the refrigerant system to operate shall be included in all energy calculations.
- Additional refrigerant circuit components not identified as an evaporator, condenser/gas cooler and compressor, such as but not limited to as, heat exchanger, oil separator or control shall be identified as follows:
  - Component function and physical size
  - Component weight

Instrumentation
Maximal allowable instrument uncertainties:
Pressure transducers: Pressure transducers $\pm$ 5 kPa for R134a and $\pm$ 10 kPa for CO_2
Temperature: 0.2°C (0.4°F)
Torque: 0.5%
Compressor speed: 1rpm
Dew point: 0.2°C (0.4°F), Relative humidity consequence
Air flow rate – nozzles with differential pressure transducers max 0.3% of reading
Refrigerant flow: 0.2% of reading
Oil concentration: 0.5%
Water condensate weight measurements: 0.1g for total flow rate.
Watt transducers: 0.3% of reading
Refrigerant flow devices shall have minimum restriction and equipped with a visual device to determine the state (vapor or liquid) of the flow being measured.

Components (Heat Exchanger) Physical Size Limitations
To provide comparable packing size restrictions the evaporator, condenser/gas cooler maximum dimensions are identified for the test parameters. The dimensional limits are an average of industry components for an intermediate size vehicle.

- Evaporator

  The evaporator size (exchanger face area excluding header/end tanks) shall not exceed 75 mm depth and a total effective face area of 64,000 sq. mm.

1. The mounting surface of the evaporator shall be sealed on the inlet side (warm airside).

2. The evaporator outlet surface (cold side) shall have 4 rows of 4 thermocouples per row for a total of 16 equally spaced temperature locations.

3. Airflow to be measured with a nozzle.

4. Dry bulb and dew point to be measured downstream of the nozzle within 1.0 meter of evaporator inlet

5. Dry bulb and wet bulb temperature to be measured at outlet of evaporator (HVAC) within a distance of 300 mm

6. Refrigerant evaporator inlet outlet temperatures/pressures. Thermometers (thermocouples) for refrigerant temperatures should be inserted in the refrigerant and not restrict flow.

7. Measure chamber airflow, using ASHRAE/ANSI recommended procedure, evaporator inlet static pressure and pressure drop.

- Condenser/gas cooler

  The condenser/gas cooler shall be mounted in a simulated front end, within ½ inch of the radiator inlet surface, consisting of an enclosure including a grille, radiator and cooling fans. (Baffle restriction to simulate downstream restriction of engine.)

  The condenser/gascooler size (exchanger face area excluding header/end tanks) shall not exceed a depth of 20 mm. and an effective total face area of 318,000 sq. mm.

1. Refrigerant condenser inlet outlet temperatures/pressures. shall be measured in the same manner as on the evaporator side. (Inserted in ref. Flow)
2. Refrigerant flow rate shall be determined with the instrument as described in "Test Conditions" If refrigerant flow rate is measured when in (liquid state) (typical) special care should be taken that there is no flashing before or in the meter.
3. Measure inlet and outlet air temperatures with a corresponding 5 row, 5 locations (25) point grid

- Compressor

The compressor shall be mounted in a closed temperature controlled chamber. (maintained at 110°C +/- 5°C)
Chamber temperature shall be measured 100mm (4in) above the compressor.
Compressor body temperature is to be measured near discharge port.

1. Refrigerant compressor inlet outlet temperatures/pressures. Thermometers shall be inserted in refrigerant flow.

2. Compressor torque measurements shall be made directly on the shaft. If it is not possible and transmission (pulley) losses are the part of the measured value calibration should be provided.

3. Compressor speed shall be measured with tachometer within ±1rpm.

A/C system control device:

The method and type of evaporator and compressor pressure control shall be identified. Any external energy required to operate these controls shall be included in the total system energy requirements

Data Collection/reduction

- Measure Compressor torque and rpm — Calculate Compressor Power
- Measure evaporator inlet humidity and temperature — Calculate inlet enthalpy
- Measure evaporator outlet humidity and temperature — Calculate outlet enthalpy
- Measure air flow rate
- Calculate evaporator capacity on the air side
- Measure condensate and compare it to difference in inlet and outlet humidities times air flow rate
- Measure evaporator inlet refrigerant pressure and temperature — Calculate inlet refrigerant enthalpy
- Measure evaporator outlet refrigerant pressure and temperature — Calculate outlet refrigerant enthalpy
- Measure refrigerant flow rate
- Measure oil concentration in refrigerant
- Calculate evaporator capacity on the refrigerant side

Compare refrigerant and air sides

- Calculate superheat and supercool
- Evaporator and condenser airflow pressure drop is to be recorded at all test conditions to determine static pressure restriction and work load requirements.

Compare refrigerant and air sides

- Evaporator and condenser airflow pressure drop is to be recorded at all test conditions to determine static pressure restriction and work load requirements.
- Measure Gascooler/condenser outlet refrigerant pressure and temperature to check its performance, especially R134a condenser must be checked.
- Measure Gascooler/condenser inlet refrigerant pressure and temperature to check its performance, especially R134a condenser must be checked.
- Measure compressor outlet refrigerant pressure and temperature (Only R134a is OK)
- Measure compressor inlet refrigerant pressure and temperature (Only R134a is OK)

Measure electrical input to the evaporator chamber
Measure humidity input to the evaporator chamber

- Calculate COP for each test condition by dividing capacity by shaft power.

- Plot COP and evaporator capacity for each test condition

Repeat the same procedure for the front end HX except for humidity.
Add compressor power to the evaporator capacity and compare it to front end HX (condenser or gas cooler)
COP = air side cooling capacity (heat transfer) / total system power required to attain that performance

COP = Q_{evap} / Total System Power Required to deliver Q_{evap}

Where: Q evap = **air** mass flow x **air** enthalpy change across evaporator

(Comment: (Wertenbach) For Q evaporator calculation the air inlet temperature to be measured after the external blower device.
The blower motor is an additional "heater". The power consumption of this motor depends on the airside pressure drop of the evaporator (fin pitch differences). This effects the "effective cooling capacity, if temperature measurement is only before/after evaporator: Qo eff=Qeva-Pblower motor.
To eliminate this effect, is better to control the air inlet of evaporator as constant (defined) temperature after the blower, and not influenced by external blower motor).

Instrumentation:

1. All refrigerant inlet and outlet temperatures/pressures in an internal heat exchanger shall be measured in the same manner as on the evaporator side. (Inserted in ref. Flow)

2. All refrigerant and coolant flow inlet and outlet temperatures/pressures in a liquid/refrigerant heat exchanger shall be measured with a minimum of 3 thermocouples inserted the liquid flow. The liquid volume flow should measured by a liquid flow meter.

- humidity measurements and condensed water recovery (for thermal balance)
- as air outlet temperature homogeneity at the evaporator is an issue for HVAC design. This must be identified for each system with IR thermograph camera measurements or temperature sensors.
- for indirect system. Both primary and secondary loop must be equipped.

Test chambers:
- Relative altitude of each component must be take into account and harmonized (for example: receiver versus condenser)
- Temperature of the compressor test chamber must be specified with a conditions T° compressor chamber = T° outside air + a defined delta t.

Data collection/ reduction:
- For each system COP must be well defined. Engine shaft power to generate the electrical power for the liquid pump, additional refrigerant control required for the system.
- Measurements for cooling power?
- Target as to be defined concerning thermal balance to validate the experimental point. A reasonable target for thermal balance accuracy is 3%. This will impose accuracy of each measurement techniques

Component and Test Verification

The "Expert Advisor" team will provide an overview and verification of the systems tested, verifying the components as being representative of production (capable) "state of art" systems. This may also include verification by dissipation of the components prior to being used for test. They will also validate the testing procedures, accurate data collection and reporting.