Reduced Pressure Carbon Dioxide Cycle for Vehicle Climate Control

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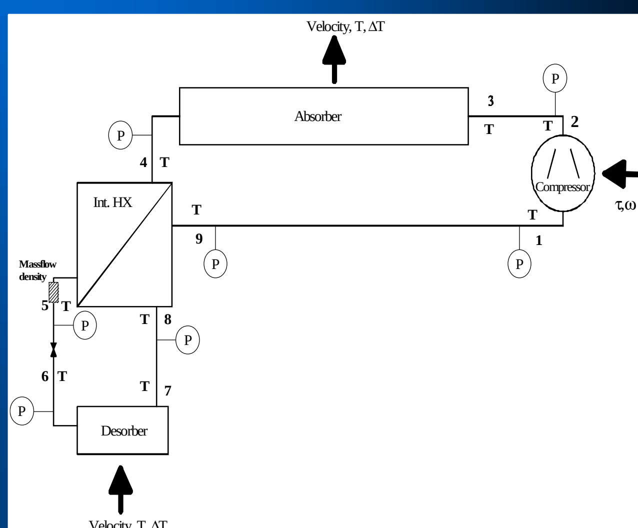
Challenges for the CO_2 Transcritical Cycle

- **System Performance at Diverse Vehicle Operating Conditions**
- **High Pressure Gas Leakage**
- **Component Safety at High Pressures**
- **New Compressor**
- **Compressor Lubrication**
- **New Heat Exchangers**

Advantages of the Low Pressure CO_2 Cycle

- Environmental Acceptability - Now and in the Foreseeable Future
- Safety - Maximum Operating Pressure not to exceed conventional systems (35 bar)
- Low Cost - Utilize Compressor and Components similar to present mobile a/c products
- Performance
  - Matching temperature glide to the heat transfer medium
  - Capacity control options

Low Pressure CO_2 Cycle



Required Properties of Co-Fluids

- Non-Toxic
- High Flash Point
- Non-Hazardous
- Stable at all Operating Conditions
- Efficient Transport Agent for CO_2
- "Good" Thermal Properties
  - Heat Capacity
  - Thermal Conductivity
  - Viscosity
  - Density
- Available in Commercial Quantities

Test Facility Features

- Variable Volume Flow, Variable Air Distribution for the Resorber and Desorber
- Temperature ranges
  - Resorber 15 - 65°C
  - Desorber 10 - 65°C
- Volume Flow
  - Resorber 0 - 1.89 m^3/s
  - Desorber 0 - 0.15 m^3/s
- Compressor Drive
  - Speed Range 0 - 6,000 RPM
  - Power to 13.75 kW

Test Facility Features (cont.)

- Sensors for Measurement
  - Air and Refrigerant-side Temperatures and Pressures
  - Flow Rates
  - Air Humidity
  - Compressor Torque and Speed
- Computer Driven Data Acquisition System
- Error Analysis, Compressor Speed and Torque

  +\- 2% Actual Power
- Energy Balance on the desorber air stream

  +\- 7% Desorber Load

Components - Compressor

- Same size and weight as HFC-134a compressors
- Same manufacturing and assembly processes
- Future Designs will lead to size reduction

Low Pressure CO_2 R-134a

Components - Desorber

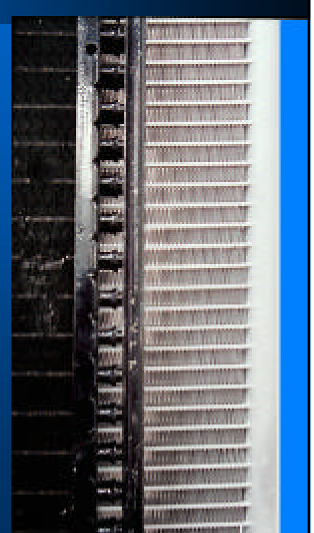
- Same size and weight
- Identical parts and assembly processes as R-134a evaporators
- Advantage in matching temperature glide of air stream to refrigerant mixture

Low Pressure CO_2

R-134a

Components - Resorber

- Tube and flattened tube designs
- Optimized for high heat transfer and low pressure drops
- Identical parts and assembly processes as R-134a condensers
- Same volume and face area as R-134a condensers



Components - Internal Heat Exchanger

- Necessary for low pressure operation
- 1st and 2nd generation - not practical
- 3rd generation - 9% larger than evaporator -currently in use
- 4th generation - smaller than evaporator

1st and 2nd generation Internal Heat Exchangers (compressor shown for scale)

• Future - use R-134a evaporator assembly processes

Weighting Factors Based on Vehicle Air Conditioning Usage Profile

- Assumptions: Average Driver, Moderate Climate, One Year Period
  - 15,000 Miles: 65% Highway (63 MPH) 20% Intermediate (40 MPH) 15% Idle (10 MPH)
  - Two Major Trips 25 hours each One Minor Trip 9 hours
    - Ambient Temperatures High (2Mo) Moderate (3 Mo) Low (7 Mo)
    - Compressor Engaged: 100% at High 75% at Moderate 50% at Low

Test Protocols

Table 1.
Most Probable Conditions Seen by Automotive Air Conditioning Systems

Evaporator Temp	Condenser Temp	Engine Speed	Ambient Temp	Vehicle Speed	Vent Mode	Pull Down	Sun	Wind
L	M	L	Cool	Idle	Recirc.	End	Cloudy	Head
L	M	M	Warm	Moderate	Recirc.	End	Cloudy	Minimal
L	L	H	Cool	Highway	Recirc.	End	Cloudy	Minimal
M	H	L	Hot	Idle	Recirc.	Middle	Sunny	Minimal
M	M	M	Warm	Moderate	Fresh	End	Sunny	Minimal
M	L	H	Cool	Highway	Recirc.	End	Cloudy	Minimal
H	H	L	Hot	Idle	Recirc.	Start	Sunny	Minimal
H	M	M	Warm	Moderate	Recirc.	Start	Sunny	Minimal

Test Protocols (cont.)

Table 2.
Values for Each Level

	Evaporator Heat Transfer			Condenser Heat Transfer		Compressor Speed
Level	Temp (^oC)	Humidity (%RH)	Air Flow (m^3/s)	Temp (^oC)	Air Flow (m^3/s)	RPM
Low (L)	21	Measured	0.118	21	1.888	800
Med. (M)	32	Measured	0.118	43	1.133	2,100
High (H)	43	Measured	0.118	65	0.378	3,400

Test Data

- Extensive test data are acquired and computer logged for each test run
- Data recorded includes:
  - System charge - co-fluid and carbon dioxide
  - Compressor speed, torque and power
  - Mass flow and fluid density
  - Pressures and temperatures in the refrigerant circuit
  - Air side temperatures and velocity profiles

Cycle performance values including:

- Cooling Capacity, Coefficient Of Performance, Q_{cond}

Performance Results: Low Pressure CO_2 (Comparison with HFC-134a)

Weighted Percentage of 2nd and 3rd Generation Components compared to baseline R-134a system

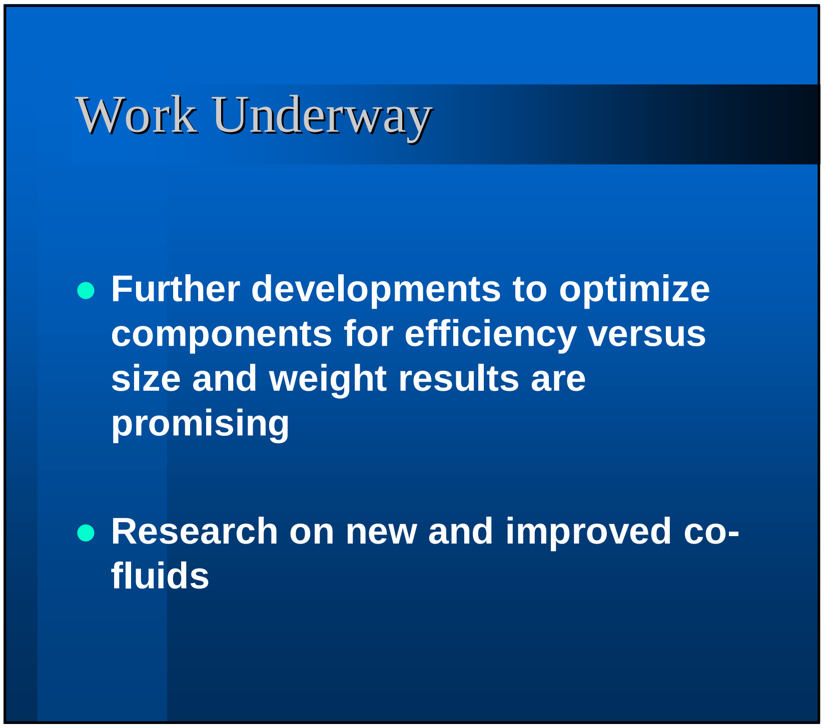
Engine Speed	Cooling Capacity	COP
Idle Speed (⑩ 800 RPM)	0.93	0.73
Mod. Speed (⑩ 2100 RPM)	0.94	0.70
High Speed (⑩ 3400 RPM)	1.11	0.95
Totals	1.00	0.77

Conclusions

- Carbon Dioxide air-conditioning cycles are environmentally attractive alternatives for vehicle climate control
- Features of the low pressure cycle include operation at conventional pressures (35 bar max.)
- Utilization of components manufactured by existing air conditioning plants

Conclusions (cont.)

- Cooling capacity of this hybrid cycle competes on par with HFC-134a systems
- Improvements in coefficient of performance of about 20% are needed to be competitive with HFC-134a systems
- Development approaching Transcritical CO_2 and Enhanced R-134a technologies


Work Underway
Further developments to optimize components for efficiency versus size and weight results are promising
Research on new and improved co-fluids