

Unitary HPAC System

Carrie Kowsky, Edward Wolfe, Lindsey Leitzel and Frederick Oddi
 Delphi Thermal Systems

ABSTRACT

The Unitary HPAC (Heat Pump Air Conditioner) System has been developed to enable a heat pump system in passenger vehicles. Unitary HPAC uses technology of reversing the coolant instead of refrigerant to distribute heat from where it is generated to where it is needed. Integrating this system in a plug-in hybrid vehicle reduces the energy required by the heating and air conditioning system, reducing the grams of CO₂ per mile by up to 25%.

Although this system can be applied to any passenger vehicle, it is most beneficial to hybrid and electric vehicles, because it provides an additional source of hot coolant. These vehicles provide less waste heat than conventional internal combustion engine vehicles so they must rely on electric heaters to provide the heat needed for comfort. The electric heaters are an energy draw that reduces the electric drive range. The Unitary HPAC system will extend the electric range significantly. In addition to maintaining passenger comfort in cooling mode, heat can be removed from the battery, inverter, and electronics with coolant and directed to the passenger compartment.

This paper will use a plug-in hybrid vehicle to demonstrate the operation of the Unitary HPAC. It will show how the Unitary HPAC can significantly reduce refrigerant charge and provide passenger comfort with less energy.

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INTRODUCTION

The Unitary HPAC is a vapor compression refrigerant system coupled with a coolant based system. [Figure 1](#) shows the components of this system and how they are arranged.

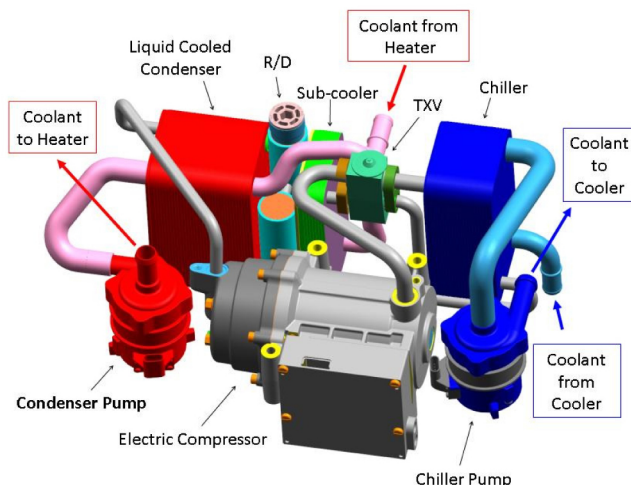


Figure 1. Unitary HPAC System

The system shown here is semi-hermetic. It uses no rubber hoses, reducing permeation and desiccant. The heat

exchanger joints are hermetic while the TXV and compressor joints are not. This system would have approximately 3.0 grams/year of refrigerant emissions per SAE J2727, 50% less than the lowest leakage rates of current production vehicles. [1] [2]

The compact size (approximately 450mm × 275mm × 225mm) reduces the amount of refrigerant by at least 50% and provides packaging flexibility. The fully assembled unit is shipped fully charged to assembly plants obviating the need for the OEM's (Original Equipment Manufacturer) complex, remote charging stations.

The next generation of this system is hermetic. It does not have elastomeric seals at the TXV and compressor.

BACKGROUND

Delphi has successfully demonstrated the use of a secondary loop system, vapor compression system used to cool coolant. [3] A secondary loop system offers several benefits to the vehicle's air conditioning system. It increases the refrigerant options by enabling the use of flammable refrigerants because the refrigerant is contained in the engine compartment. Other benefits include: less refrigerant charge than a direct system, no increase in refrigerant charge if multiple 'cooling points' exist, proper refrigerant charge that is not dependent on the number of 'cooling points' in

operation, no variation in air temperatures due to phase separation or mal-distribution of refrigerant, no risk for frost or ice formation anywhere on the cooling core as long as the inlet temperature of secondary fluid is above 0°C, none of the 'oil trapping' concerns present in direct systems with multiple evaporators when the rear unit is turned off, elimination of refrigerant noise from the TXV (Thermostatic Expansion Valve) or orifice tube and the compressor, and enables 'cold storage' for start / stop applications. [4]

It has been established from an energy perspective, that a secondary loop is not the most efficient way to provide cooling to the cabin. First, energy is used to cool the refrigerant, which then cools the coolant, and finally the coolant is used to cool the air. The benefits of a secondary loop are fully realized when the technology is applied to both the heating and cooling systems, as is the case with the Unitary HPAC.

The Unitary HPAC consists of a liquid condenser that heats the coolant and a chiller that cools coolant. In addition, the coolant can scavenge heat from other sources in the hybrid vehicle such as the battery, inverter, and electronics. The heat can then be distributed to any location in the system as the need arises. It is this ability that allows the system to use less energy.

A coolant based heat pump does not have the issues common to a refrigerant based system. A coolant based system can use today's components in the HVAC (Heating Ventilation and Air Conditioner) module and heat exchangers optimized for unidirectional flow. A refrigerant heat pump system, on the other hand, must compromise the cabin heat exchanger design and refrigerant charge. The cabin heat exchanger requires a unique design because it must function as both an evaporator and a condenser. The charge amount must be chosen to satisfy both flow directions. The system may also need an additional heat exchanger in the HVAC module to address flash fogging.

SYSTEM OPERATION

The Unitary HPAC integrated in the hybrid vehicle's coolant system is shown in [Figure 2](#). The hot coolant loop is highlighted and demonstrates how the system provides heat. The Unitary vapor compression system is driven by an electric compressor. The heat rejected by the liquid condenser is absorbed by the coolant. The hot coolant travels to the heater in the HVAC module for cabin heating. It can also be directed to the battery pack if it requires heating. The low temperature coolant is directed to the inverter and drive motor where it can scavenge additional heat. There is also the potential to scavenge heat from the cabin air exiting by incorporating a recovery heat exchanger at the body relief valve.

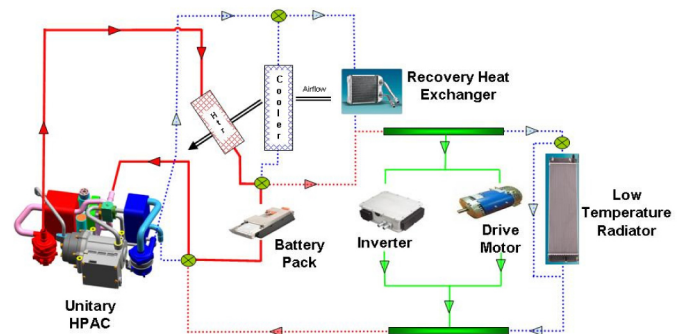


Figure 2. Heating Mode with a Unitary HPAC System

Operation in cooling mode, shown in [Figure 3](#), is similar. The cold coolant from the chiller goes to the cooler in the HVAC module for cabin cooling. It can also be directed to the battery pack, inverter, and drive motor for cooling. Waste heat within the system is rejected by the low temperature radiator.

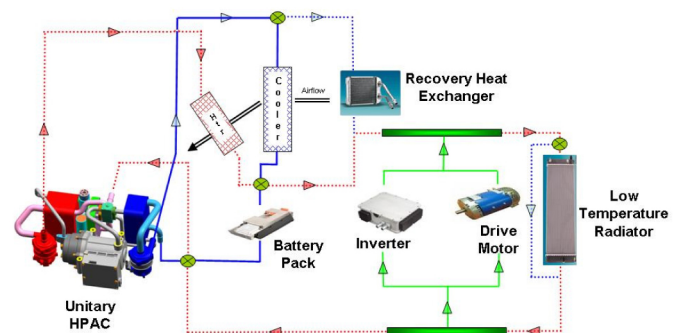


Figure 3. Cooling Mode with a Unitary HPAC System

The heating and cooling strategy with the Unitary HPAC differs dramatically from that used in today's plug-in hybrid vehicles. It does not require as much heat from the electric or PTC (Positive Temperature Coefficient) heaters and engine coolant. Not being as dependent on these heat sources reduces the energy required for its operation. [Figure 4](#) illustrates the differences.

In cooling mode, the current plug-in hybrid vehicles use the traditional A/C (air conditioner) system. With the traditional A/C system, the tempering (a mix of heating and cooling) done at mid-ambient temperatures, requires the use of a PTC heater. As the ambient temperature decreases, more electric heat is needed. The PTC heater must draw more energy from the batteries. When the PTC heater can no longer provide enough heat, the internal combustion engine is turned on.

Adding the Unitary HPAC to this vehicle will significantly reduce the energy needed for PTC heating. This system can provide comfort in the cooling and tempering modes without PTC heating. Even though some amount of energy is needed for PTC heating in the colder ambient

temperatures, it is much less than the amount used by today's vehicle. The electric drive range is increased by the reduction in energy used for PTC heating and by delaying when the internal combustion engine must be turned on. Supplemental heat from the internal combustion engine and PTC heater is also needed with the Unitary HPAC; however, it is not needed until a lower ambient temperature.

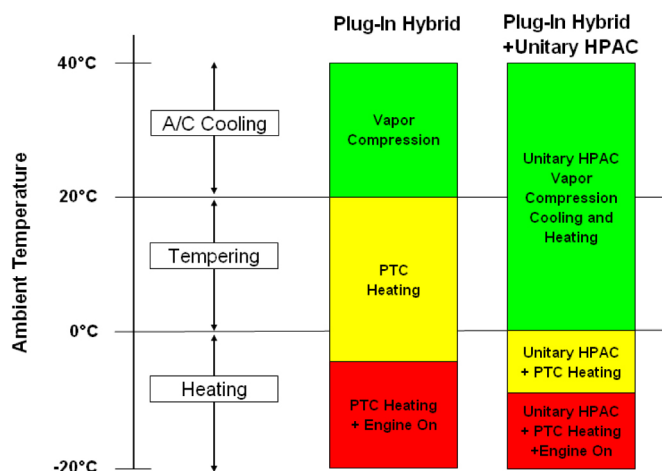


Figure 4. Heating and Cooling Strategy

CHARGE DETERMINATION

The design intent of the Unitary HPAC system is to have charge determination characteristics similar to an air-cooled conventional TXV system with an integral R/D (receiver/dryer). Experiments were performed to study the effect of the receiver design on the charge plateau length. The initial Unitary HPAC system used separate plate style heat exchangers for the chiller, condenser, and sub-cooler connected by refrigerant lines.

Various receiver designs were placed between the condenser and sub-cooler and charge determination tests were performed on a system test bench. All testing used R-134a as the refrigerant and a mixture of 50/50 water and glycol for the coolant. The inlet coolant temperatures and flows were controlled by auxiliary coolant heater and chiller systems.

Figure 5 illustrates how the condenser and sub-cooler outlet refrigerant temperatures vary with refrigerant charge. The temperatures are plotted versus relative charge. A value of 0 for the relative charge is where the sub-cooler outlet sub-cooling begins. Using this convention for charge amount allows easy comparisons to conventional A/C system data.

For a charge determination test, there are 3 regions that result when filling the different high pressure side components. From the data shown in Figure 5, the relative charge range from 0 to 210 grams is where the sub-cooler is filling up with liquid refrigerant. From 210 to 390 grams of relative charge, the receiver is filling up with liquid. This region of a charge determination is typically referred to as the charge plateau. For proper operation of the system, a charge

level should be selected on this plateau (typically near the center). This plateau length (180 grams for this receiver design) should be long enough to account for loss of charge over time and the variation of system charge requirements under different operating conditions. The charge required for possible charge loss is less with the Unitary HPAC because it is semi-hermetic. Once the receiver is filled with liquid (above 390 grams), the liquid then begins to fill the condenser. This behavior is the same as in a conventional air-cooled system with an integral receiver/dryer.

The refrigerant temperature response versus relative charge illustrates the liquid filling process of the various components. Another observation from this data is that the "sub-cooler out" refrigerant temperature eventually cools down to the coolant inlet temperature. The coolant inlet temperature is the lowest temperature that the refrigerant can reach. To lower the refrigerant temperature more would require lowering the coolant inlet temperature.

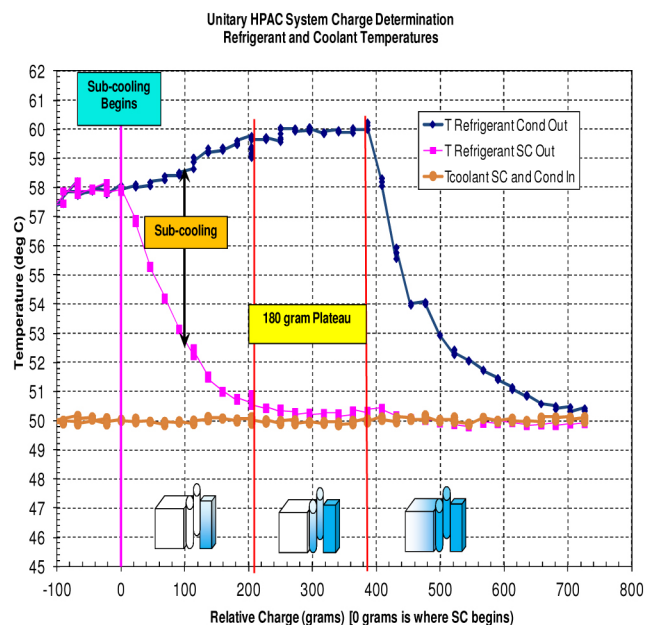


Figure 5. Unitary HPAC System Charge Determination Temperatures

The high side refrigerant pressure was also monitored during the charge determination tests. Figure 6 shows the condenser inlet refrigerant pressure response versus relative charge. This pressure increases while the sub-cooler is filling up with liquid refrigerant, from 0 - 210 grams of relative charge. During the charge plateau, or while the receiver is filling from 210 - 390 grams, the pressure is stable. Once the liquid refrigerant begins to fill the condenser (above 390 grams), the high side pressure increases with increased refrigerant charge. This behavior is the same as in a conventional air-cooled system with an integral receiver/dryer.