Newell Instruments Inc.
1103 N. High Cross Rd.
Urbana, IL 61802
Phone: 217-344-4526
www.newellinstruments.com

In Situ, Real Time Oil Concentration in a Mobile Air Conditioning System

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Ben Newell and Ty Newell

Introduction

Mobile air conditioning systems generally operate with sumpless compressors that rely on the steady circulation of lubricant mixed with the refrigerant. A nominal system lubricant concentration of 3 to 5% is mixed with the system's refrigerant. As driving conditions and environmental conditions change, however, the circulation of lubricant can vary by a significant amount.

This note describes *in situ*, real-time oil concentration data collected from an automobile air conditioning system. A Newell Instruments Series 600 refractive index sensor is used for oil concentration measurement. The Series 600 sensor also detects the presence of vapor and foam, allowing detection of system inefficiency due to vapor flow from high side to low side, detection of low charge conditions, and monitoring of refrigerant migration.

Background

A study performed at the University of Illinois Air Conditioning and Refrigeration Center (ACRC) examined the effect of evaporator superheat on oil circulation in a mobile air conditioning system [1]. A refractive index sensor based on similar principles to the one used for the present study was incorporated into a mobile air conditioning system in an ACRC environmental control facility. A manual expansion valve was operated such that varying levels of superheat could be controlled. The study showed significant reduction of oil circulation rate as evaporator superheat increased. Increasing evaporator superheat creates a viscous film of lubricant that is "stuck" to the evaporator surface near the evaporator exit region and effectively removed from circulation.

For the present study, a Newell Instruments Series 600 refractive index sensor was installed in the liquid line of a 1994 Dodge Caravan. The air conditioning system in the vehicle is a receiver-TXV system with R134a-PAG refrigerant and lubricant. The Series 600 sensor is based on technology patented by the University of Illinois that is licensed by Newell Instruments [2]. The sensor's operation is based on the shadow movement produced on an illuminated optical window. The Series 600 sensor is specially designed for operation with a wide range of miscible oil-refrigerant combinations. Typical oil concentration sensitivity is +/- 0.1%.

Figure 1 is a photograph of a Series 600 sensor. The sensor housing is similar in size to a pressure transducer. Refrigerant flows through the sensor with negligible pressure drop. Wetted materials in the sensor are brass, teflon and sapphire. The sensor housing is hydrostatically tested to 34MPa (5000 psia).

Figure 1 Photograph of Newell Instruments Series 600 sensor.

The Series 600 sensor is constructed for use in harsh environments such as a vehicle engine compartment. Figure 2 shows a photograph of a Series 600 sensor mounted in the 1994 Dodge Caravan used for the present study. The sensor used for this study had been continuously located in the vehicle for 11 months during which time the vehicle was driven approximately 10,000 miles. Prior to the present study, the sensor was removed and recalibrated.

In addition to the refractive index sensor, two pressure transducers, four thermocouples and a compressor clutch circuit sensor were installed in the Dodge Caravan. Pressure transducers were located in the compressor suction line and the condenser exit for measurement of low and high side pressures. Type T thermocouples were mounted in the interior and exterior ambient air. Also, a type T thermocouple was mounted in the exiting air stream of the evaporator and in the exiting air of the condenser. All data sensors were connected to a Fluke "Hydra" data acquisition system with 6.5 digit voltmeter resolution. After calibrating the oil concentration sensor and pressure transducers, the air conditioning system was charged with 1055 grams of R134a.

Figure 2 Photograph of the Series 600 refractive index sensor installed in the liquid line of a 1994 Dodge Caravan air conditioning system.

Experimental Data

The Dodge Caravan was driven from central Illinois to Florida for testing during March, 2004 with the Series 600 sensor installed in the air conditioning system. A variety of tests were conducted including stationary tests after heat soaking, city driving conditions, and highway driving conditions. The results presented in this bulletin represent samples from these tests.

Figure 3 shows temperature data from a trip between Key Largo and Deland (central Florida). Outdoor ambient temperatures ranged from 25 to 30C. The vehicle interior ranged from 20 to 25C with return air from the evaporator in the 3 to 5C temperature range. Condenser air temperatures were approximately 5C greater than the outdoor ambient temperature.

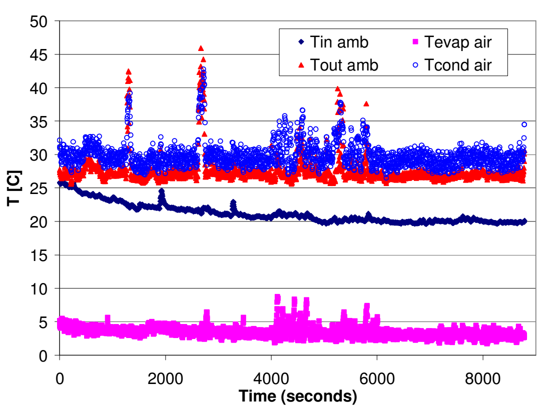

Figure 3 Temperature data from the Key Largo to Deland drive.

Most of the drive in Figure 3 was steady highway driving. The vertical lines observed in the condenser temperatures represent times when the vehicle was stopped in traffic.

Figure 4 shows oil concentration data and compressor activation data for the conditions shown in Figure 3. The oil concentration data shows a broad variation. As will be shown in succeeding figures, the oil concentration data systematically varies due to operational conditions imposed on the system. The compressor activation circuit is "high" (approximately 12-13 volts) when the compressor clutch circuit is off. A low voltage reading (< 1 volt) indicates activation of the compressor. For most of the conditions shown in Figure 4, the compressor duty cycle is approximately 30%.

Three regions of data from Figures 3 and 4 will be examined in closer detail. First, relatively steady driving conditions at 6400 seconds are described. Second, at 2600 seconds, an isolated traffic stop's impact on system conditions is examined. Finally, at 4200 seconds, a series of stop-and-go traffic conditions are presented.

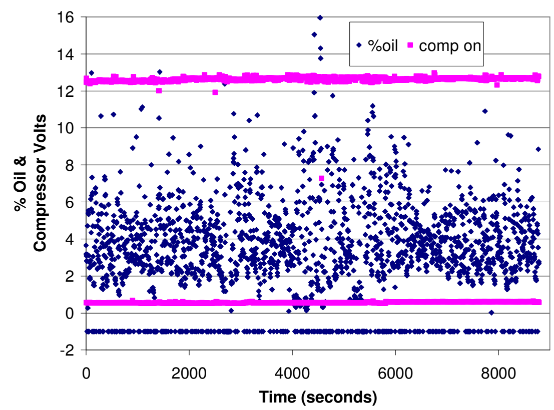

Figure 4 Oil concentration data and compressor activation data for Figure 3 conditions.

Figure 5 shows interior and outdoor ambient temperatures along with the condenser outlet air and evaporator outlet air temperatures during a time period with relatively steady driving conditions. The time period consists of a time interval from 6400 seconds to 6800 seconds shown in Figure 3. Figure 6 shows the oil concentration and compressor activation data for the same time period. The interior ambient temperature is steady at 20C and the outdoor ambient is steady at 26 to 27C. Oscillations in the condenser outlet air temperature and evaporator outlet air temperature occur due to compressor clutch cycling. Figure 6 shows the oil concentration in the liquid line to oscillate between 2% and 6% with an average concentration of 4% concentration. Significant variations in oil concentration occur even though the operating conditions are very steady. The oil concentration variations do not correlate with compressor clutch cycling frequency and are more likely due to modulation of the TXV. Periodic "spikes" occur in the oil concentration data. The spikes showing "-1%" are vapor readings. That is, these conditions show when flashing of the refrigerant has occurred in the liquid line. Vapor conditions reduce system capacity. Periodic high concentration readings indicate fluctuations in oil moving through the system. Such oil variations will occur due to slight fluctuations of superheat in the evaporator as the TXV adjusts refrigerant flow.

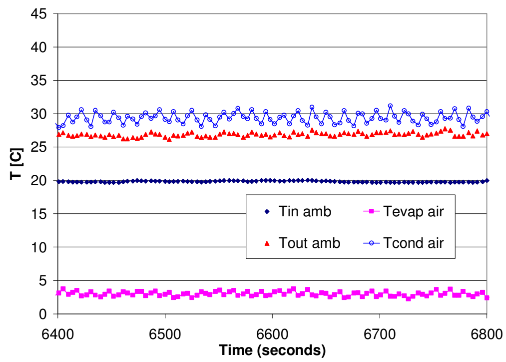

Figure 5 Temperature data during steady driving conditions.

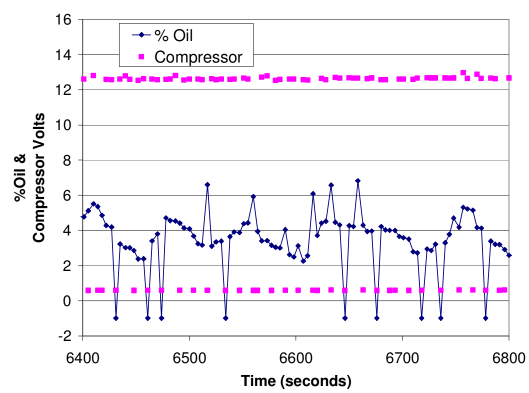

Figure 6 Oil concentration variation during steady driving conditions.

Figures 7, 8 and 9 show the effects of an isolated traffic stop on oil circulation. The time period shown is from 2600 to 3000 seconds and can be seen in Figure 3 as a sharp spike in the condenser temperature. The thermocouple for outdoor air conditions is mounted directly in front of the condenser with a narrow air space between it and the condenser surface. When the vehicle is stopped, the air in this region warms to levels similar to that of the condenser. The deceleration, stop, and acceleration time period is approximately two minutes of the 400 second time period. The associated oil concentration readings show significant variations of oil concentration ranging from nearly 0% to 12%. During vehicle acceleration, the liquid line shows a continuous stream of vapor readings. The vapor flow through the evaporator shows up as a loss in capacity as shown by the evaporator outlet air temperature in Figure 7.

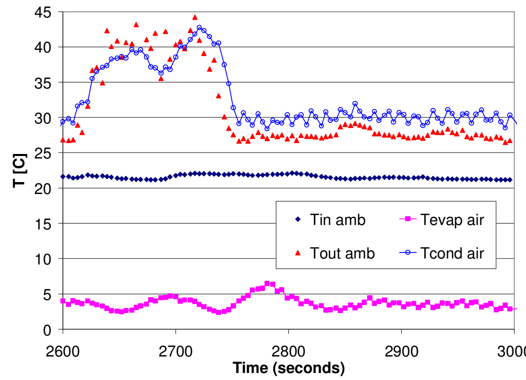

Figure 7 Temperature variations due to an isolated traffic stop.

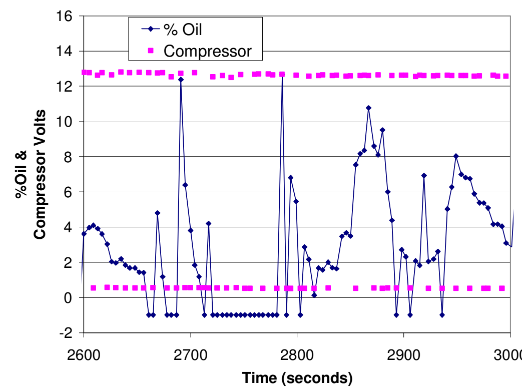

Figure 8 Oil concentration variation during an isolated traffic stop.

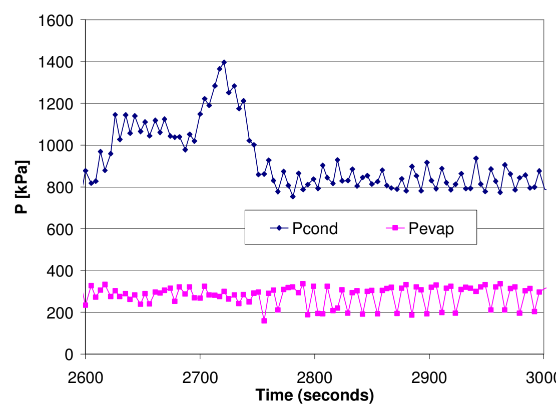

Figure 9 High and low side pressure variations during an isolated traffic stop.

Figure 9 shows the saturation pressure in the high and low sides of the air conditioning system. The most significant variations during the isolated stop occur on the high side of the system as the compressor's rotational speed changes. During vehicle acceleration, the high side pressure reaches its highest level, returning to a steady condition once the vehicle's engine speed has stabilized.

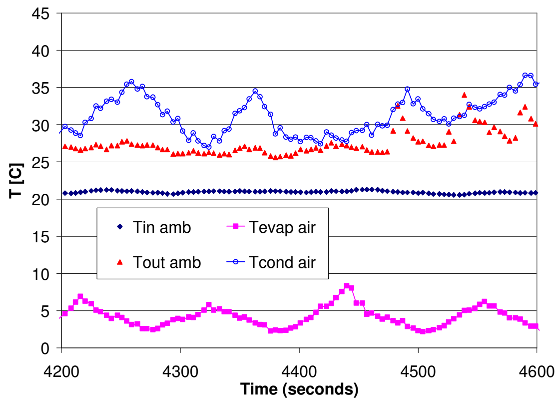

Figure 10 Temperature variations during a series of stop-and-go traffic conditions.

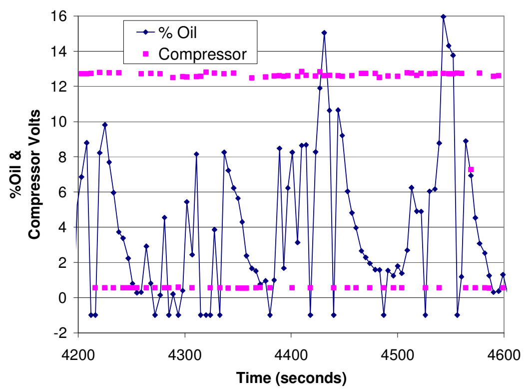

Figure 11 Oil concentration variations during a series of stop-and-go traffic conditions.

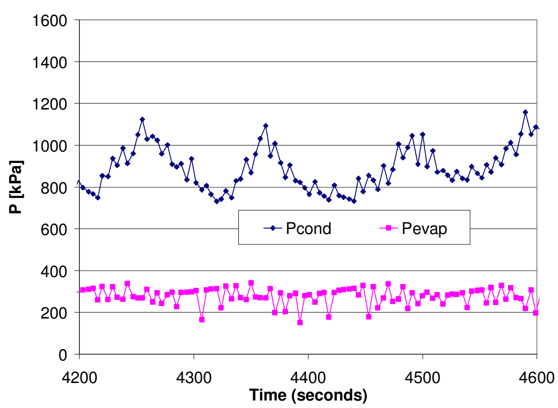

Figure 12 High and low side pressure variations during stop-and-go traffic conditions.

Figures 10, 11, and 12 show a period of stop-and-go traffic conditions that occurred between 4000 and 6000 seconds. Figure 10 shows the variations in system temperatures. The vehicle interior remained quite steady while the condenser air outlet temperature and the evaporator air outlet temperature oscillated a significant amount. Associated with the temperature variations are significant variations of oil concentration in the liquid line. The system's oil flow rate becomes quite unsteady with variations between 0% and 16% for the 400 second time period shown in Figure 11. Brief periods of vapor bubbles are observed, however most of the data indicates a steady liquid flow as the vehicle speed changes. The evaporator outlet temperature shows periodic increases in its outlet temperature that follow the peak excursions in oil concentration.

Figure 12 shows the high and low side saturation pressures, and in a similar manner to the isolated vehicle stop, the high side pressure varies significantly as the vehicle speed changes while the low side pressure remains unaffected by vehicle engine speed. A constant pressure in the evaporator should result in a uniform refrigerant saturation temperature, however, the oscillations in evaporator outlet air temperature observed in Figure 10 indicate that the saturation temperature is varying due to oil concentration mixture effects on the refrigerant's saturation temperature.

Summary

Continued investigation of real time oil concentration variation with *in situ* oil concentration sensors will contribute to increased understanding of conditions that cause air conditioning system failure. Sample oil concentration data for a receiver-TXV vehicle system has shown oil circulation to be very dynamic. Under steady driving conditions, oil circulation rates are relatively steady with concentration variations that may be linked to TXV modulation. During unsteady vehicle operation conditions, oil circulation undergoes complex oscillations. Stop-start driving conditions cause oil concentration to oscillate from nearly 0% oil to 18% oil. Low oil concentration may return insufficient lubricant to the compressor while high oil level circulation rates affect system capacity and refrigerant saturation temperature levels.

References

1. "Conditions the Limit Oil Circulation in a Mobile Air Conditioning System", E. Wandell, W. Dunn, N. Miller, and T. Newell, SAE paper 98PC-21, 1998.
2. U.S. patent 5,694,210 by T. Newell and E. Hurlburt, Univ. of Illinois, 1997.