EXPERIMENTAL STUDY OF A LIQUID OVERFEEDING MOBILE AIR-CONDITIONING SYSTEM

Vince C. Mei, Ph.D., P.E.
Member ASHRAE

F.C. Chen, Ph.D., P.E.
Member ASHRAE

R.A. Sullivan

ABSTRACT

Air-conditioning systems usually use only about 85% of their evaporator coils. The other 15% or so is used to superheat the refrigerant so that the compressor will be protected from liquid slugging. This practice results in excessive evaporator volume. In mobile air-conditioning (MAC) systems, where the space available for the evaporator is limited, the evaporator should be used fully to reach maximum evaporator efficiency. This study reports on the design and testing of a new liquid overfeeding (LOF) MAC system that can use 100% of the evaporator effectively.

This LOF system is designed so that not all of the liquid refrigerant is evaporated from the evaporator. The excess low-pressure liquid flows into an accumulator-heat exchanger where it is boiled off by the warm, high-pressure liquid leaving the condenser. This design not only allows 100% use of the evaporator but also reduces the system's power consumption (per unit mass flow) and improves compressor reliability. Test results for the LOF MAC, compared with thermal expansion valve and metering valve MAC systems, indicated an increase of 20% in the system's cooling capacity and coefficient of performance (COP) at a compressor speed of 2,020 revolutions per minute (rpm). Because the LOF system is easy to implement, it is expected to increase the cost of MAC systems only marginally.

INTRODUCTION

Future mobile cooling technology probably will emphasize methods that do not involve the application of hydrofluorocarbon (HFC) fluids because of their high global warming potential (Mei et al. 1992). For short-term MAC research and development (R&D) work, the focus is on improving the performance of HFC-134a, an accepted replacement for CFC-12 in MAC systems, by improving components such as the parallel-flow condenser (Struss et al. 1990) and expansion devices (El-Bourini et al. 1991). The authors think further improvement of HFC-134a MAC efficiency is possible using the LOF concept.

Refrigerant at the evaporator exit is usually superheated to prevent the slugging of liquid refrigerant into the compressor; consequently, 10% to 15% of the evaporator's capacity is used for refrigerant vapor superheating purposes that provide little or no cooling capability. In this study, a novel LOF MAC concept was explored that involves the use of an accumulator-heat exchanger, as shown in Figure 1. The warm liquid refrigerant from the condenser flows through the heat exchanger coil in the accumulator to be cooled further by leftover liquid refrigerant from the evaporator. The heat provided by the liquid refrigerant from the condenser evaporates the liquid refrigerant from the evaporator. The much-subcooled high-side liquid goes through the expansion device and evaporator without being fully evaporated, and part of the liquid flows back to the accumulator-heat exchanger only to be evaporated by the heat from the condenser liquid. The compressor suction line will always have saturated, or nearly saturated, vapor and, therefore, a higher refrigerant mass flow rate. The compressor discharge temperature will decrease, and thus the compressor power consumption per unit mass flow will decrease. In the meantime, the whole evaporator is used rather than the 85% or so used in conventional systems, and the system's cooling capacity is increased. It is estimated that this concept can improve overall MAC system efficiency by 15% to 20%.

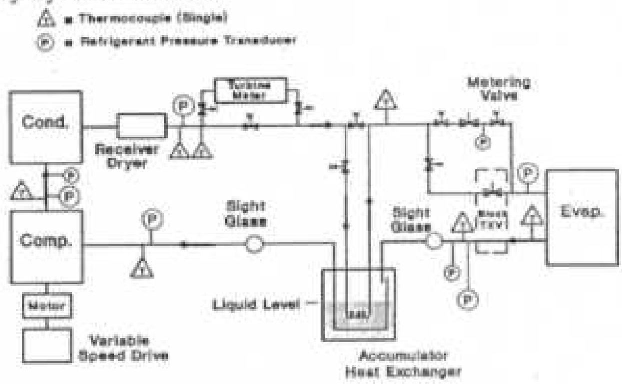

Figure 1 Schematic of mobile air-conditioning test setup.

Vince C. Mei is a researcher and **F.C. Chen** is a group leader in the Energy Division at Oak Ridge National Laboratory, Oak Ridge, TN. **R.A. Sullivan** is a program manager in the Advanced Propulsion Division, U.S. Department of Energy, Washington, DC.

A laboratory model MAC system was designed, built, and tested to analyze a LOF MAC system experimentally. The outdoor temperature, simulated vehicle speed, and compressor speed are independent variables so that the results can be applied to electric vehicle MAC systems as well. The whole MAC system was tested in a two-room environmental chamber. This paper presents some of the test data.

TEST SETUP AND PROCEDURE

Figure 1 shows a refrigerant-side schematic of the MAC test setup. The block thermal expansion valve (TXV) was designed for HFC-134a MAC application. A metering valve was installed parallel to the TXV because the LOF MAC will have little or no superheat and therefore will not function with a conventional TXV. The system can be operated with or without the liquid refrigerant that flows from the condenser through an off-the-shelf accumulator-heat exchanger. The compressor was driven by a 5-horsepower motor that was coupled with a variable-speed drive to achieve variable-speed compressor operation. A turbine meter was used to measure the refrigerant mass flow rate. All the pressures were measured with pressure transducers, and the temperatures were measured by type-"T" thermocouples. The data collected were processed and reduced by a computer connected to the setup. All the MAC performance data were based on refrigerant-side measurements.

The whole setup was tested in a two-room environmental chamber. The indoor chamber, which simulated the vehicle passenger compartment, was kept at 80°F and 52% relative humidity (RH) throughout the tests. The outdoor chamber simulated the ambient conditions. In this study, the tests were performed at an ambient temperature range of 95°F to 105°F. All the tests were performed with 100% outdoor air at 105°F to 115°F, assuming that the air temperature under the engine hood was higher than the ambient conditions. The condenser fan speed was adjusted to simulate a vehicle driving speed of 35 miles per hour (mph). Tests were performed at a higher simulated vehicle speed of 45 mph, and system performance at that speed was found to be almost identical to that at 35 mph. Therefore, testing at simulated speeds higher than 35 mph was discontinued. Compressor speeds ranged from 880 to 2,020 rpm for the tests. With the compressor speed independent from the vehicle speed, the results can also be used for electric vehicle MAC systems. All tests were performed under steady-state operation.

The refrigerant charge was first optimized for TXV operation at ambient conditions of 95°F and 50% RH by adjusting the superheat to 7°F. In the same way, the refrigerant charge was then optimized for metering valve operation without the LOF feature. Finally, the system charge was optimized for metering valve operation with the LOF feature by visual observation that the refrigerant had accumulated in the accumulator-heat exchanger. MAC system operation was found to be very sensitive to the orifice opening of the metering valve, which was not changed for tests either with or without the LOF feature.

MAC performance with the TXV and metering valve was compared at the same operating conditions with and without the LOF. The results at 100°F ambient temperature are reported in this study.

TEST RESULTS AND DISCUSSION

Figure 2 shows the MAC refrigerant mass flow rate as a function of the compressor rpm. At 2,020 rpm, the mass flow rate for LOF operation is about 29% higher than for operation using the metering valve with no LOF feature. The reason for the higher mass flow rate is that the compressor suction line has saturated, or nearly saturated, vapor when the system is running. A higher mass flow rate has an added advantage—the refrigerant-side heat transfer coefficient is a function of the mass flow rate. A higher mass flow rate means a higher heat transfer coefficient. Figure 3 shows the system's cooling capacities as a function of the compressor rpm. At 880 rpm, LOF operation shows only a 7.6% improvement in cooling capacity over TXV operation. At 2,020 rpm, however, the LOF system outperforms the other two systems by more than 35%. While the cooling capacities for the TXV and metering valve operations do not change much, the cooling capacity for the LOF increases drastically from 880 rpm to 1,400 rpm and then levels off. Figure 4 shows the power consumption for each MAC system as a function of the compressor rpm. The LOF system actually has the lowest power consumption. While higher refrigerant mass flow rates should result in higher compressor power consumption, the lower compressor discharge temperature of the LOF operation, as shown in Figure 5, reduces the compressor power consumption. The net effect in this experiment is lower compressor power consumption. The discharge pressure for the LOF operation, shown in Figure 6, is the highest among the three MAC systems. However, Figure 7 shows that the compres-

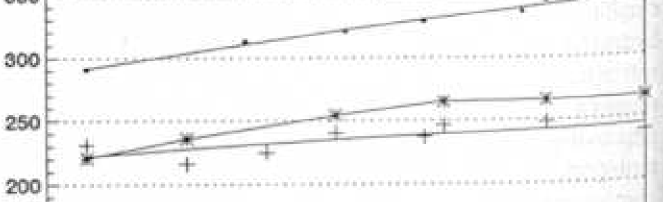

Figure 2 *R-134a mass flow rate as a function of compressor rpm.*

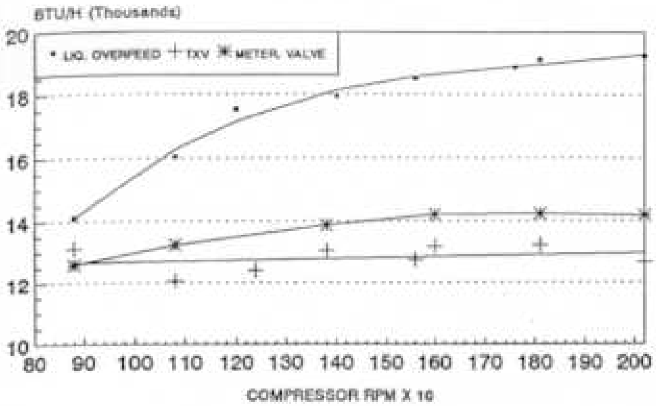

Figure 3 *Cooling capacity as a function of compressor rpm.*

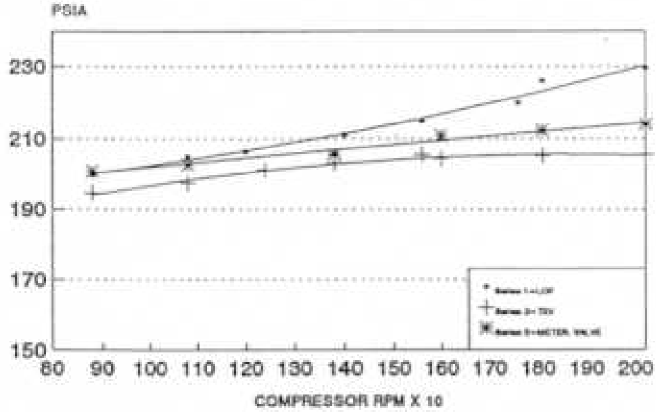

Figure 6 *Discharge pressure as a function of compressor rpm.*

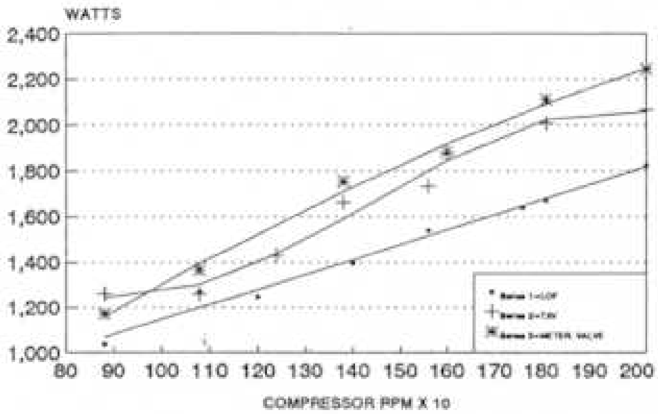

Figure 4 *Power consumption as a function of compressor rpm.*

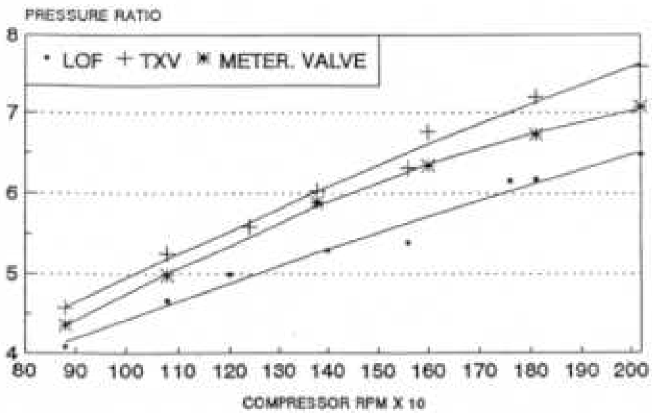

Figure 7 *Compressor high-low pressure ratio.*

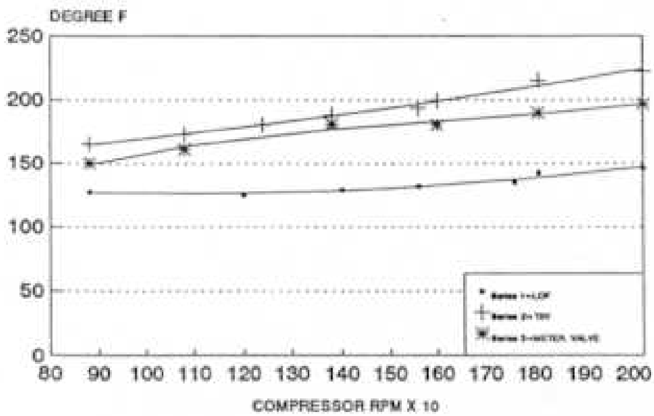

Figure 5 *Discharge temperature as a function of compressor rpm.*

sor high-low pressure ratios for the LOF are the lowest among the three MAC systems, indicating a higher compressor efficiency. Finally, Figure 8 shows the system COP as a function of the compressor rpm. Because of the LOF system's higher cooling capacity, coupled with lower compressor power consumption, the COPs for the LOF operation are much higher than for the other two MAC systems.

Except for the higher discharge pressure, the LOF MAC outperforms the TXV and metering valve MACs. The goal of achieving a 15% improvement over current MAC systems, in terms of system cooling capacity and COP, has been met with the LOF concept.

CONCLUSIONS

The concept of a LOF MAC system was explored experimentally, and the test results were compared with those of an ordinary MAC system with a TXV and a metering valve as the expansion device. The results indi-

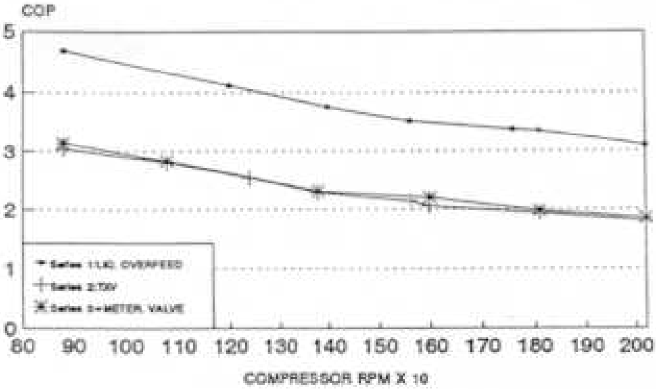

Figure 8 *Coefficient of performance as a function of compressor rpm.*

cated that the LOF system performed much better than the MAC using a TXV, achieving about 26% higher cooling capacity, a much higher COP, a higher refrigerant mass flow rate, and lower system power consumption at different compressor rpm. Although the results are encouraging, more laboratory testing of the LOF MAC operation will be needed—such as tests at higher compressor speeds up to 3,000 rpm and air-side measurement to confirm the refrigerant-side findings—to provide a clearer understanding of LOF MAC performance.

ACKNOWLEDGMENTS

This work was part of the Transportation Environmental Control activities at Oak Ridge National Laboratory sponsored by the Office of Transportation Technologies, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc. The authors appreciate the valuable assistance provided during this study by Mr. P. Malone of Eaton, Mr. R. Struss of Modine, and Mr. J. Nelson of Refrigeration Research.

REFERENCES

El-Bourini, R., et al. 1991. Performance evaluation of an automotive air conditioner with expansion valve control using CFC-12 and HFC-134a refrigerant. SAE technical paper 910218. Warrendale, PA: Society of Automotive Engineers.

Mei, V.C., et al. 1992. *Alternative non-CFC mobile air conditioning*. ORNL/CON-335. Oak Ridge, TN: Oak Ridge National Laboratory.

Struss, R.A., et al. 1990. Performance comparison of HFC-134a and CFC-12 with various heat exchangers in automotive air conditioning systems. SAE technical paper 900598. Warrendale, PA: Society of Automotive Engineers.

DISCUSSION

Dave Young, Ontario Hydro, Toronto, Canada: Is this idea (similar to the old Hi-Re-Li cycle) an advantage that should be applied to stationary air conditioning?

Vince C. Mei: Definitely, the idea should be applied to stationary air conditioning. In fact, we already did. Our preliminary laboratory test results on an EER 10 two-ton window air conditioner showed a substantial improvement in cooling capacity and system EER at a rated point of 82.0°F (27.8°C) ambient with the liquid overfeeding (LOF) feature, compared with that of a conventional cycle. The evaporator outlet air with LOF is cooler and drier. The results will be published in the near future.