A LIQUID OVER-FEEDING MILITARY AIR CONDITIONER

by

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ABSTRACT

A 3-ton military air conditioning unit has been experimentally studied for baseline and liquid over-feeding operation (LOF). The test results indicate that LOF outperforms the baseline case over a wide ambient temperature range in terms of cooling capacity, power consumption, and system coefficient of performance (COP). At 95°F test point, the COP improvement for LOF is 19.8% over that of the baseline case. However, optimal refrigerant charge is essential for LOF to work properly.

INTRODUCTION

The army has unique requirements for compact, rugged air conditioners. These units are used to cool command, control, communications, and intelligence electronics in mobile shelters. These "window-type" units are available in a family of standardized designs that range from 6,000 to 60,000 BTUH, and include both horizontal and vertical configurations. These units utilize R-22 as their refrigerant. Efficiency and performance of these units has been constrained by the compact design and rugged construction necessary to fit and survive on mobile tactical shelters. Despite the relatively high cost of these units, small incremental increases in performance have been rejected in the past as non-cost effective. The performance gains promised by the liquid over-feeding (LOF) (Richards, 1970) technology developed at the Oak Ridge National Laboratory (Mei and Chen, 1993) however, offered an opportunity to dramatically improve performance with a minimum increase in per-unit cost. This paper discusses the test results of an Army air conditioner with 39,000 BTUH rated capacity modified for LOF operation. The test data indicate that LOF operation indeed improves the system performance by a good margin over the baseline performance in cooling capacity and in coefficient of performance (COP) at 95°F ambient and 80°F and 52% relative
humidity indoor conditions.

**BACKGROUND AND TEST SETUP**

Basically LOF operation is to add an accumulator-heat exchanger (AHX) in the refrigerant circuit and properly charge refrigerant into the system. When the system is properly overcharged, the refrigerant starts accumulated in the AHX. Figure 1 shows the schematic of the unit as modified for LOF operation; the modifications permit switching back and forth between normal and LOF operations. An additional expansion device is present in the original system to inject liquid refrigerant into the suction line to reduce superheat and hence discharge temperature (commonly known as a quench valve).

The liquid refrigerant from the condenser flows through the heat exchanger coil inside the AHX and boils the refrigerant in the accumulator. This heat exchanging between low-side and high-side refrigerant resulted in highly subcooled high-side refrigerant at the entrance to the expansion device. In addition, the refrigerant boiling in the AHX results in saturated (or near saturated) vapor going into the compressor, which improves compressor volumetric efficiency and results in increased refrigerant mass flow. With higher refrigerant mass flow and higher liquid subcooling, the evaporator cannot evaporate all the refrigerant, and therefore has two-phase refrigerant flow at its exit. The liquid refrigerant is trapped in the AHX and is boiled off by the hot liquid line from the condenser. 100% of the evaporator is now wetted, instead of the 85% or so used in conventional systems, and this increases the cooling capacity. Because of the increase in compressor efficiency, the compressor power consumption for LOF operation should still be at, close to, or even slightly lower than, the power consumption of a conventional system. This will be true even for high refrigerant mass flow rates.

An LOF system requires either capillary tubes or an orifice plate. Conventional thermal expansion valves that control refrigerant flow based on superheat cannot be used, as LOF operation generates little or no superheat. In this study, two 0.125" diameter orifice metering valves were installed in parallel as the expansion devices.

Figure 2 shows the air-side test setup. One thermocouple pile (6 thermocouples) was installed on the air inlet and another thermocouple pile (9 thermocouples) was at the air outlet for dry bulb temperature measurements. Wet bulb temperatures were measures with a thermocouple wire covered with a wetted wick. All measurements are on the air-side, so that dehumidification capability can be estimated. A three phase power meter were used to measure the system power consumption.

The unit, before any modification, was first leak checked and then evacuated and charged 6.0 lb of R-22, the amount of refrigerant charge specified on the name plate. The baseline tests were performed. The unit was modified with LOF feature. The baseline tests were again performed with about 6.4 lb refrigerant charge for the extra piping involved. Additional 1.5 lb of R-22 was charged into the system for LOF to start functioning.

The tests were performed over a range of ambient temperature from 80 to 110°F. The unit was operated at an ambient temperature until it reached steady state.
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operation, and then the data were collected over a period of 3 to 4 minutes. The raw data were averaged over that period of time.

TEST RESULTS

The baseline test data before and after the system modification were almost identical. This indicates that the modification of the system has not affected its baseline performance. The specification of the unit was designed for 39,700 BTUH at 95°F ambient. The baseline test results showed a cooling capacity of 38,200 BTUH, which is less than 4% off the design capacity.

Figure 3 shows the cooling capacities of LOF and conventional system operations. The cooling capacity for LOF is about 11.8% higher than that of the baseline test. At high ambient conditions, the improvement becomes smaller. This is because at high ambient conditions, the refrigerant mass flow rate for baseline operation increases because of increased suction pressure and thus higher vapor density, which results in less dry evaporator coil portion. There will be less potential for LOF to improve.

Figure 4 shows the evaporator exit dry bulb and wet bulb temperature comparison. LOF operation has both lower dry bulb and wet bulb temperatures than that of baseline, which indicates that LOF has both higher sensible and latent load capacities. However, the majority of the improvement is from sensible load.

Figure 5 shows the comparison of system power consumption. When the ambient temperature is 83°F and higher, LOF operation actually consumes less power. This is because the compressor suction intakes close to saturated vapor, and thus resulted in lower discharge temperature and lower discharge vapor enthalpy. At higher ambient temperature, the power consumption for both operation becomes close to each other.

Finally, figure 6 shows the system COP comparison. At 95°F, the improvement for LOF over the baseline is 19.8%. This is because of the combined effect of lower power consumption and higher cooling capacity.

DISCUSSION AND CONCLUSIONS

A 3-ton military air conditioner was tested for both baseline and LOF operations. The LOF has 11.8% higher cooling capacity, lower power consumption, and almost 20% improvement in system COP over that of the baseline performance at 95°F ambient temperature. LOF also outperformed the baseline operation over a wide range of ambient temperatures. The test results are extremely encouraging. At a fixed charge, the improvement of LOF operation becomes smaller at higher ambient temperature, which indicates that, for LOF operation, optimal refrigerant charging is very important. For this study, the refrigerant charge for LOF was optimized at 95°F ambient. If we optimized the charge at 110°F, for example, we expect a better LOF system performance at 110°F. Excessively overcharging the system may result in loss of cooling capacity because of the suction pressure back-up due to more refrigerant boiling in the AHX at certain instances.

If the compactness is important, the improvement in cooling capacity by LOF can be transferred into smaller evaporator and condenser sizes and yet maintain the same cooling capacity. The addition of the AHX also means that the liquid
receiver can be eliminated. LOF operation also can replace the expensive expansion valves with low cost orifice plates or capillary tubes, lower the overall cost, and improve reliability. For future air conditioners using R-22 replacements, LOF provides a even more promising improvement (Mei, et al 1995). Currently, all the promising R-22 substitutes are HFC mixtures. For non-azeotropic refrigerant mixtures (NARM), higher subcooling level means lower evaporator inlet temperature after the expansion because of the temperature glide. LOF will, thus, further enhance the system performance with NARM. LOF presents an opportunity to up-date the design of the future Army air conditioning units with better performance in a cost effective way.

REFERENCES


Mei, V. C. et al., "Experimental Analysis of a Window Air Conditioner with R-22 and R32/R125/R134a mixture," accepted by ASHRAE for publication in the ASHRAE 1995 Summer Annual Meeting, June 25 to 28, at San Diego, CA


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Fig. 1. Refrigerant-side schematic

Fig. 2. Air-side schematic
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