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EXPERIMENTAL ANALYSIS OF A WINDOW AIR CONDITIONER WITH R-22 AND R32/R125/R134a MIXTURE

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DISCLAIMER

ABSTRACT

Much experimental and theoretical analysis of potential R-22 replacements has been accomplished. However, published information about the experimental analysis of any off-the-shelf air conditioner with a potential R-22 replacement at realistic operating conditions is still rare. This type of work could be useful because it provides baseline data for comparing the performance of R-22 and its potential replacement at drop-in conditions.

In this study, an off-the-shelf window air conditioner was tested at Air Conditioning and Refrigeration Institute (ARI) -rated indoor conditions and at different ambient temperatures, including the ARI-rated outdoor condition, with R-22 and with its potential replacement, a ternary mixture of R-32(30%)/R-125(10%)/R-134a(60%) (the ternary mixture). A test rig was built that provided for baseline operation and for the option of operating the system with a flooded evaporator by means of liquid over-feeding (LOF).

The test results indicated the cooling capacity of the ternary mixture was 7.7% less than that of R-22 at 95°F ambient for baseline operation. The cooling capacity for both refrigerants improved when a flooded evaporator, or LOF, was used. For LOF operation, the cooling capacity of the ternary mixture was only 1.1% less than that of R-22. The ternary mixture had slightly higher compressor discharge pressure, a lower compressor discharge temperature, slightly lower compressor power consumption, and a higher compressor high/low pressure ratio.

Key words: air conditioning, air conditioner, R-32 mixture, ternary mixture, mixed refrigerant, flooded evaporator, R-22 replacement, liquid over-feeding.

INTRODUCTION

R-22 is one of the most widely used HCFCs for applications such as residential room air conditioners, heat pumps, and supermarket refrigeration systems. Although much work has been done to identify replacements for R-11 and R-12, relatively little experimental work with off-the-shelf window air conditioners has been published regarding the performance of a ternary mixture, R-32(30%)/R-125(10%)/R-134a(60%), a potential R-22 replacement. Radermacher and Jung (1993) theoretically analyzed the performance of several R-22 replacements, but the ternary mixture was not one of them. Fischer and Sand (1993) screened the potential R-22 replacements using a simplified calculation. Their modeling effort indicated that use of the ternary mixture could result in an increase of up to 4% in the coefficient of performance (COP) and an increase of up to 20% in capacity. Domanski and Didion (1993) evaluated R-22 alternatives with a semi-theoretical model. They conducted tests for drop-in performance, for performance in a modified system to assess the potential of the fluids, and for performance in a modified system with a liquid-to-suction line heat exchanger. For drop-in performance, using R-22 performance as the baseline data, they found that the ternary mixture had capacities and COP almost identical to those of R-22, but higher discharge pressures and lower discharge temperatures. Spatz and Zheng (1993) tested a 3-ton air-to-air heat pump with the baseline R-22 and several R-22 alternatives, including the ternary mixture. Their test results indicated that the ternary mixture demonstrated slightly higher cooling capacity but slightly lower system efficiency the R-22. However, they considered the performance results for the ternary mixture to be more uncertain because of more complex thermodynamic properties. All the tests and analyses have shown that the ternary mixture can be regarded as one of the most likely near-term R-22 replacements.

The purpose of this study is to analyze experimentally the performance of the ternary mixture—under normal and flooded-evaporator operation, under drop-in conditions, with an off-the-shelf window air conditioner—and to compare the test results with performance data for R-22.

The performance of air conditioners has been improving in recent years with newer but more expensive components such as scroll compressors and inner finned tubing. The performance of any R-22 replacement should be equal or better than that of the current coolants to be accepted. However, limited drop-in test data for R-22 replacements used in window air conditioners (ARI, 1993) indicated a degradation of the system performance. Operating the system with a flooded evaporator, or LOF (Mei and Chen 1993), could be a cost-effective way of improving system performance because it allows 100% use of the evaporator. LOF also increases the subcooling of the liquid refrigerant before it enters the expansion device without increasing the suction line vapor superheat. For nonazeotropic mixed refrigerants, greater liquid subcooling means lower evaporator inlet temperature because of temperature glide, which is an added advantage for mixed refrigerants such as the ternary mixture. LOF operation is expected to improve system performance for both R-22 and the ternary mixture, but the improvement for the ternary mixture will probably be greater than for R-22 because of the added advantage of higher liquid subcooling.

In this study, refrigerant-side performance of the air conditioner was measured. The experimental results were presented and discussed for both R-22 and the ternary mixture under normal and LOF operating conditions over a wide range of ambient temperatures. The results showed that LOF operation using the ternary mixture outperformed R-22 baseline operation in terms of cooling capacity and system COP.

Test Setup

An off-the-shelf window air conditioner with an energy efficiency ratio (EER) rating of 10 was modified and tested. Figure 1 is the schematic of the test setup. An accumulator-heat exchanger (AHX) was added to the system. For the baseline test, liquid from the condenser bypassed the AHX and flowed through a turbine meter and into the expansion device. No original component was replaced or modified. The air conditioner used four capillary tubes for four evaporator coil circuits. The air conditioner name plate calls for a 52-oz R-22 charge. After piping was added for the AHX and other instruments, 65 oz was charged for the baseline test. For the LOF tests, an additional 7 oz of R-22 was charged. At the end of the additional charge, liquid was accumulating in the AHX. Liquid from the condenser was routed through the heat exchanger coil in the AHX. Warm, high-pressure liquid boiled off the low-pressure liquid in the AHX. Additional liquid subcooling was obtained before the refrigerant entered the capillary tubes. The refrigerant mass flow rate increased because saturated or near-saturated vapor was at the compressor suction inlet. Because of the increased mass flow rate and high liquid subcooling level, refrigerant could not be completely evaporated in the evaporator. The low-pressure liquid was trapped in the AHX and was boiled off by the warm liquid from the condenser.

For the ternary mixture tests, the compressor was removed from the air conditioner, washed, charged with PAG oil, and reinstalled. The amount of refrigerant charged was the same as for the R-22 baseline test (65 oz).

The tests were performed in a two-room environmental chamber. The indoor room was maintained at 80°F and 52% relative humidity, and the outdoor room temperature varied from 80 to 120°F. All tests were performed at steady-state operation. All the data collected were on the refrigerant side.

Test Results and Discussion

Figure 2 shows the cooling capacity as a function of ambient (outdoor) temperature. For baseline operation, the ternary mixture has lower cooling capacity over the tested outdoor temperature range. At 95°F, the cooling capacity of the ternary mixture is about 7.7% less than that of R-22. This result is consistent with drop-in test results reported by ARI (1993) for the ternary mixture for a cooling-only window unit. For LOF operation, the cooling capacity of the ternary mixture is only about 1.1% less than that of R-22 at 95°F ambient. It is clear that LOF operation improves the performance of the ternary mixture more than it improves the performance of R-22. The main reason for the increase in capacity using the ternary mixture is that the AHX becomes a separator.

When the warm liquid from the condenser boils off the liquid mixture trapped in the AHX, R-32 and R-125 will evaporate first because of their lower boiling points. The air conditioner will effectively circulate a richer R-32/R-125 mixture than the original composition of the ternary mixture indicated, resulting in higher cooling capacity. This is consistent with the findings of Pannock and Didion (1991) and Radermacher and Jung (1993). In their performance simulations of binary hydrofluorocarbon mixtures, they found that when the percentage of R-32 was increased, the cooling capacity increased as well.

Figure 3 shows the compressor discharge pressure as a function of ambient temperature. The ternary mixture has higher discharge pressures, as expected. In LOF operation, the discharge pressure of R-22 actually decreases compared with the discharge pressure of the baseline R-22 data. For the ternary mixture, however, the discharge pressure is higher than during baseline operation. This is additional proof that during LOF operation, the equipment circulated a richer R-32/R-125 mixture in the system.

Figure 4 shows the compressor discharge temperature as a function of ambient temperature. Baseline R-22 tests have the highest compressor discharge temperature. The discharge temperature for operation using the ternary mixture is about 18°F lower than that of the R-22 baseline data. LOF operation resulted in lower discharge temperature than in the baseline cases. One reason is that during LOF operation, the suction superheat is reduced; thus the discharge temperature is lower than during baseline operation in which the vapor at the suction line superheat is higher than that of LOF cases. For R-22, the discharge temperature for LOF operation is almost 20°F lower than the temperature in the baseline R-22 data.

Figure 5 shows the compressor high/low pressure ratio as a function of ambient temperature. The ratio for LOF operation is lower than that for baseline operation?, and the ratio for R-22 is lower than that for the ternary mixture. A lower high/low pressure ratio is a good indication that the compressor performs more efficiently when the evaporator is flooded.

Figure 6 shows the refrigerant mass flow rate as a function of ambient temperature. R-22 has a higher mass flow rate than the ternary mixture. At 95°F ambient, the mass flow rate of R-22 is about 20% higher than that of the ternary mixture for baseline operation. LOF coil operation increased the mass flow rate over non-LOF operation by 15% for R-22 and 20% for the ternary mixture.

Figure 7 shows the power consumption of the unit's compressor and fan motor as a function of ambient temperature. For the ternary mixture, LOF operation consumes about 5% more power than does baseline operation. For R-22, the difference between LOF and baseline operation is very small. At high ambient temperatures, 105°F and above, LOF operation actually consumes less power than baseline operation. Higher mass flow rate means higher compressor power consumption; but the lower compressor discharge temperature for LOF operation reduces the power consumption per unit of mass flow rate, and the compressor power consumption therefore increases only modestly.

Figure 8 charts system COP as a function of ambient temperature. At 95°F ambient, the COP for the ternary mixture is about 7.4% and 2.5% less than the COP for R-22 during baseline and LOF operation, respectively. LOF operation enhances the performance of the ternary mixture more than that of R-22: COP is improved by 6.8% for R-22 and by 9.7% for the ternary mixture over baseline operation.

Conclusions

An off-the-shelf, EER 10 window air conditioner was modified by adding an AHX to allow testing with LOF if necessary. All the other original components were kept without any modification. Both baseline and LOF tests were performed with R-22 and the ternary mixture. The following conclusions can be drawn from the test results:

1. Cooling capacity. For baseline operation, the cooling capacity of the ternary mixture is about 7.7% less than that of R-22. In the LOF tests, the cooling

capacity for both R-22 and the ternary fluid increased, by 8.0% for R-22 and 15.9% for the ternary fluid at 95°F ambient. During LOF operation, the cooling capacity of the ternary mixture is only 1.1% less than that of R-22. LOF operation enhances the cooling capacity of the ternary mixture more than that of R-22.

2. Compressor discharge pressure. The ternary fluid has a higher compressor discharge pressure, about 10 psi for the baseline test at 95°F ambient, and the difference increases to over 20 psi for the LOF operation.

3. Compressor discharge temperature. The ternary mixture has a lower compressor discharge temperature, about 20°F lower than that of R-22 at 95°F ambient during baseline operation. During LOF operation, the discharge temperature differential is around 15°F.

4. Compressor high/low pressure ratio. The ternary mixture has a higher compressor high/low pressure ratio than R-22 for both baseline and LOF operation.

5. System power consumption. The ternary mixture results in lower system power consumption. The power consumption for the R-22 baseline and LOF operation are almost identical. For the ternary mixture, the power consumption during LOF operation is about 6% higher than during baseline operation at 95°F ambient.

6. System COP. For baseline operation, the system COP of R-22 is 4.4% higher than the COP of the ternary mixture at 95°F ambient. However, once the evaporator is flooded, COP for R-22 is only about 2.5% higher than that of the ternary mixture. LOF operation enhances the system COP by 6.8% for R-22 and 9.7% for the ternary mixture.

Overall, the test results are consistent with the published data. It is interesting to note that once the evaporator is flooded, system performance—in terms of cooling capacity and system COP—is enhanced. Even though LOF operation enhances the performance of both R-22 and the ternary mixture, the ternary mixture benefits more from LOF operation than does R-22. If the evaporator were modified to use a counter-cross-flow heat exchanger instead of a concurrent-cross-flow heat exchanger, the performance of the ternary mixture could be improved further (Kuo 1994), and might even out-perform R-22.

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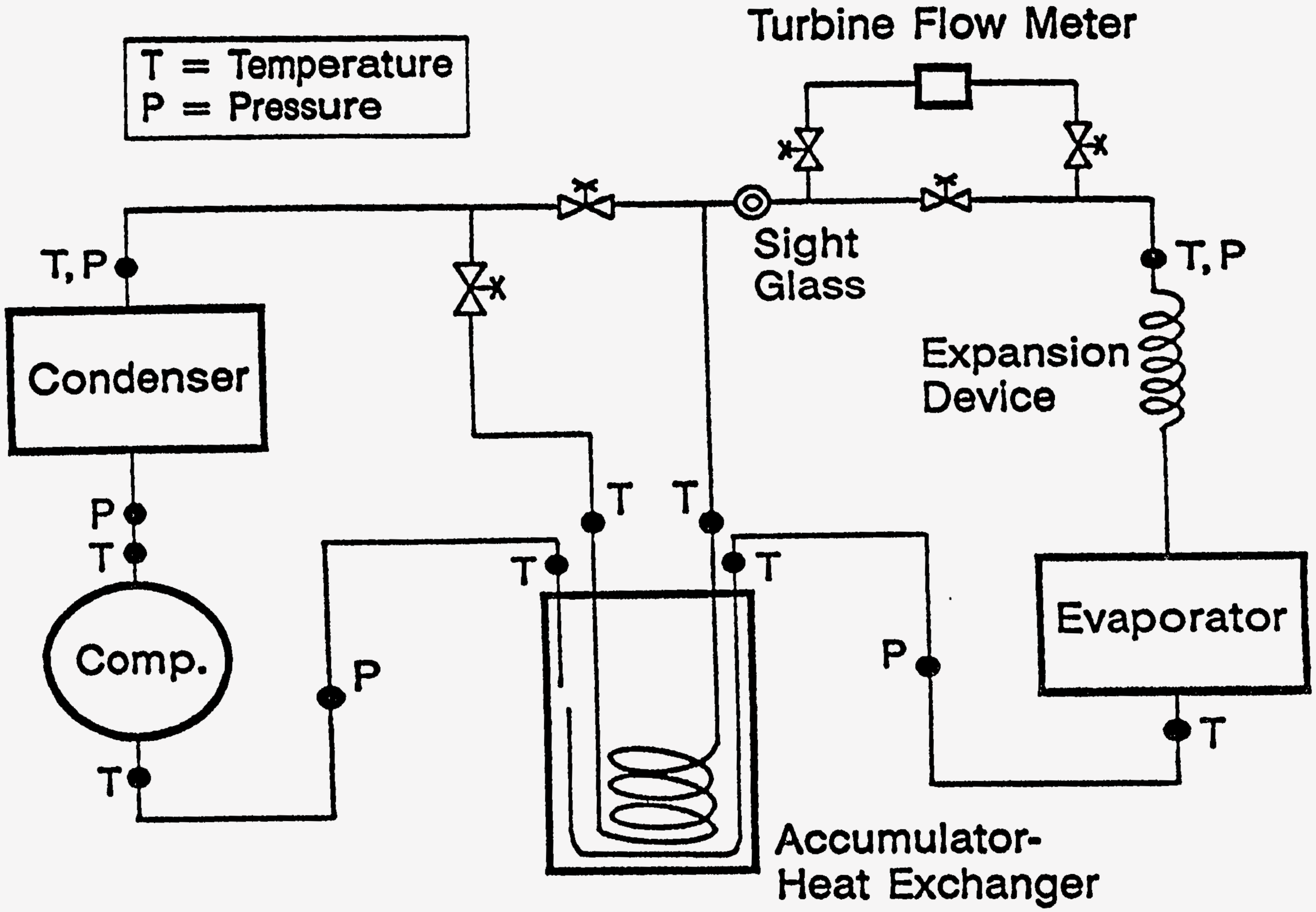

Fig. 1 Schematic of test setup.

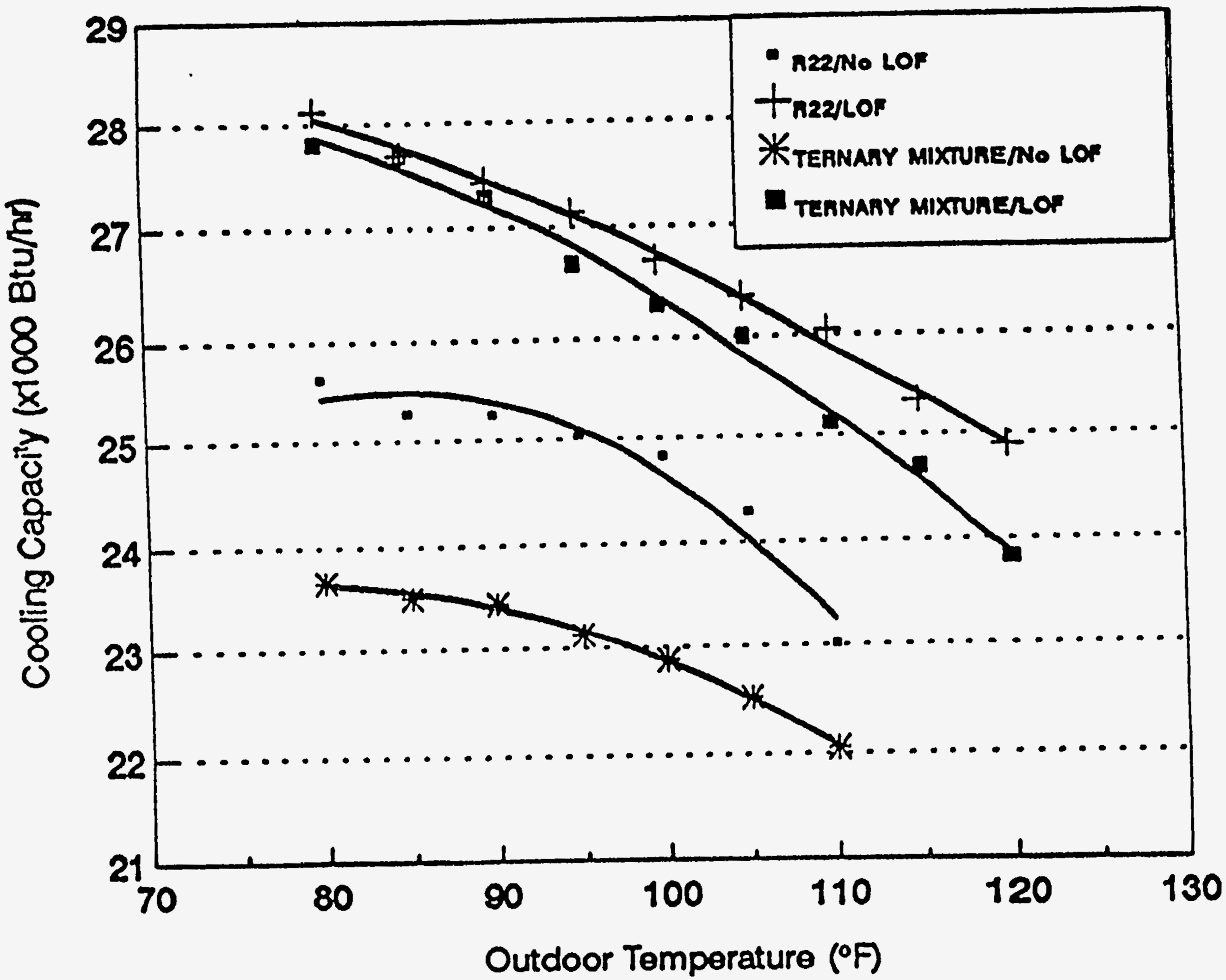

Fig. 2 Cooling capacity as a function of outdoor temperature with R22 and ternary mixture

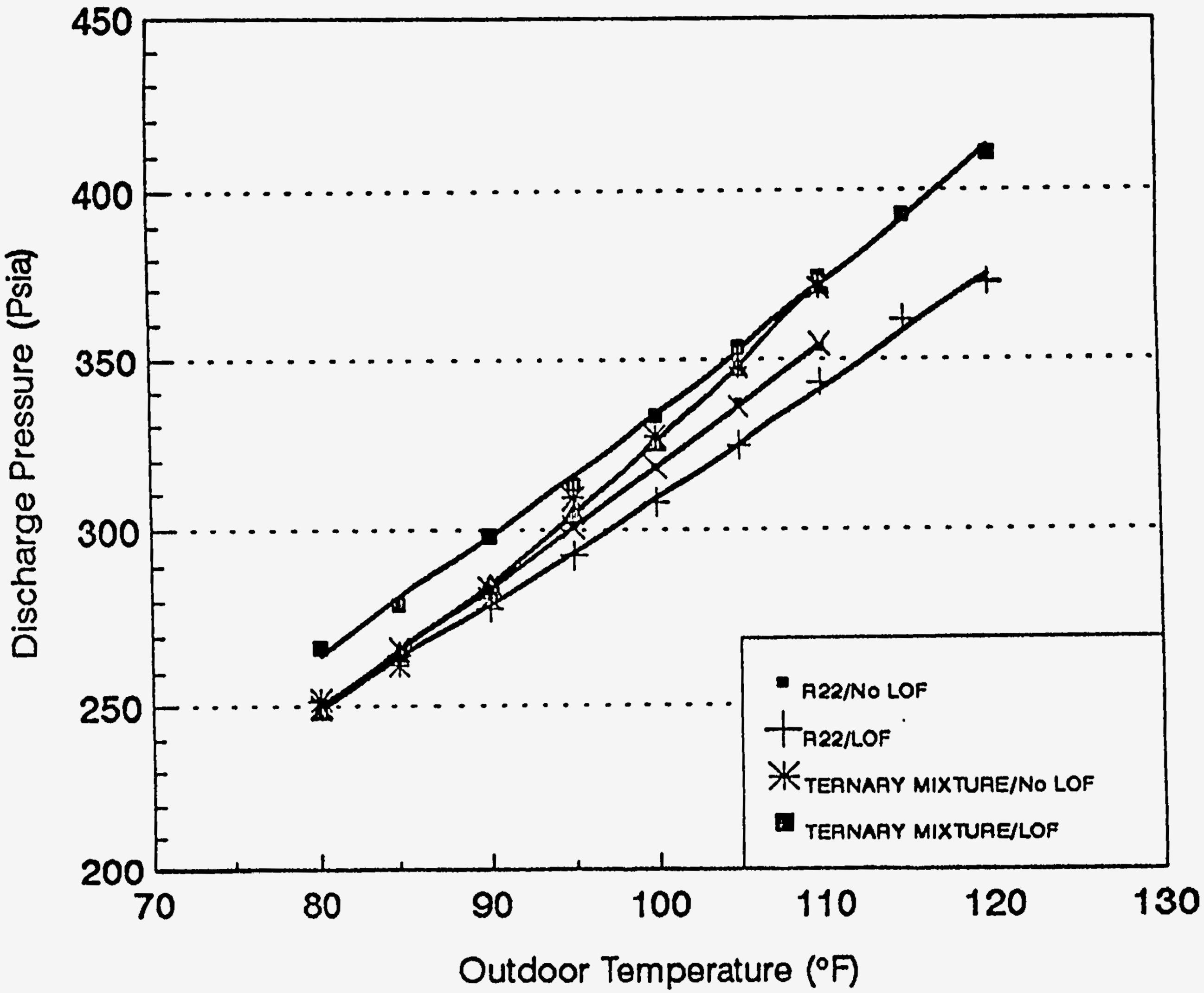

Fig. 3 Compressor discharge pressure as a function of outdoor temperature with R22 and ternary mixture

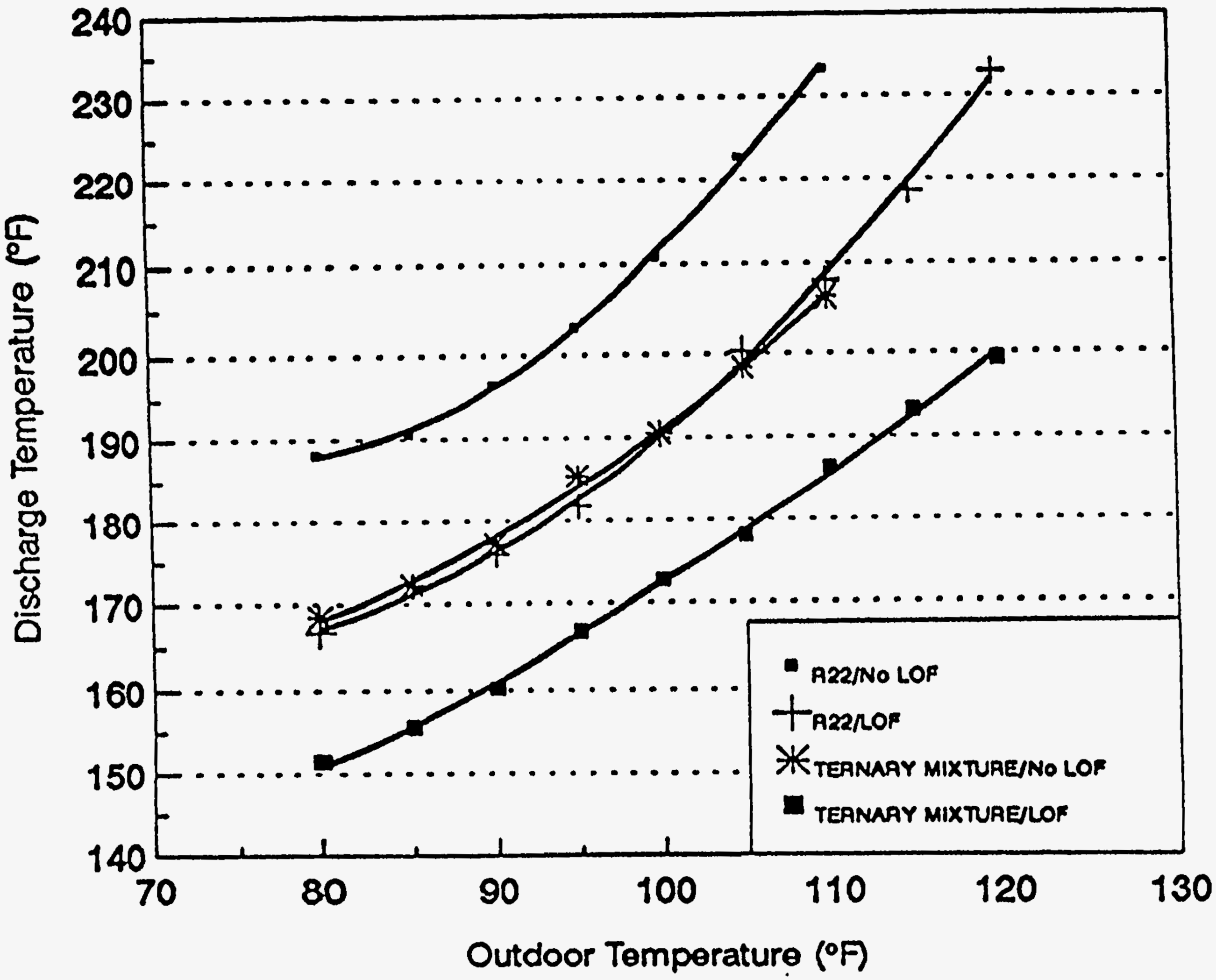

Fig. 4 Compressor discharge temperature as a function of outdoor temperature with R22 and ternary mixture

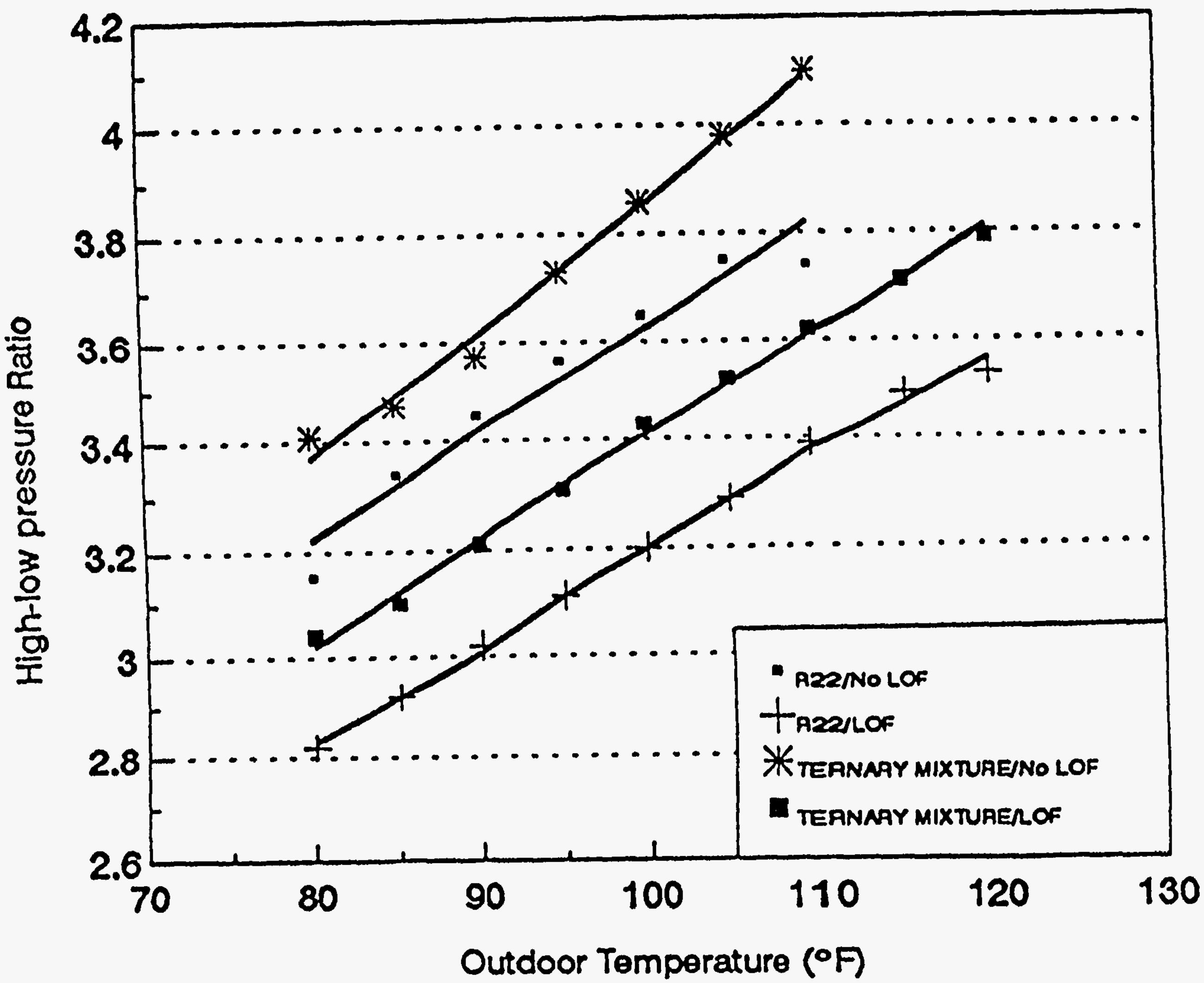

Fig. 5 High-low pressure ratio over compressor as a function of outdoor temperature with R22 and ternary mixture

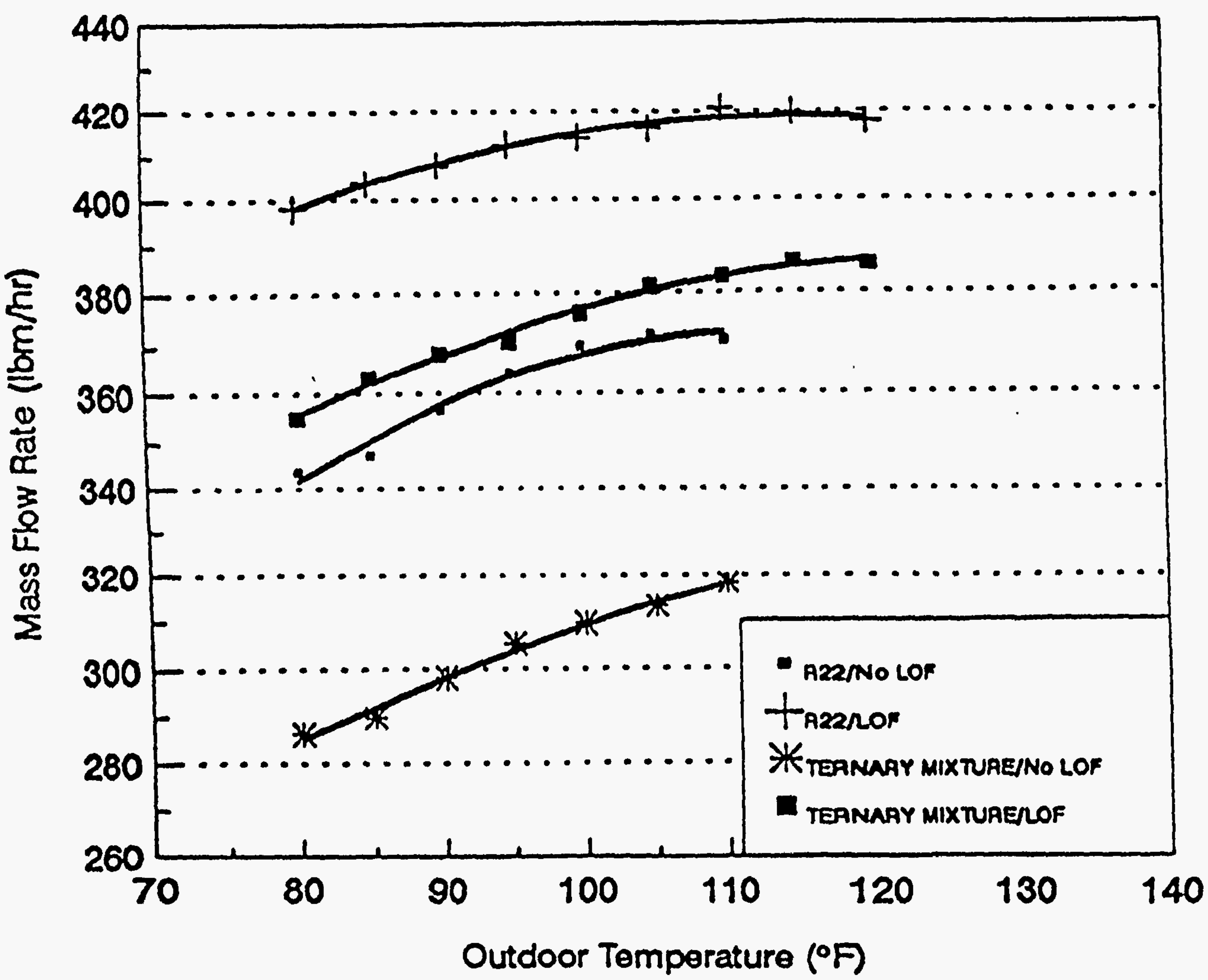

Fig. 6 Mass flow rate as a function of outdoor temperature with R22 and ternary mixture

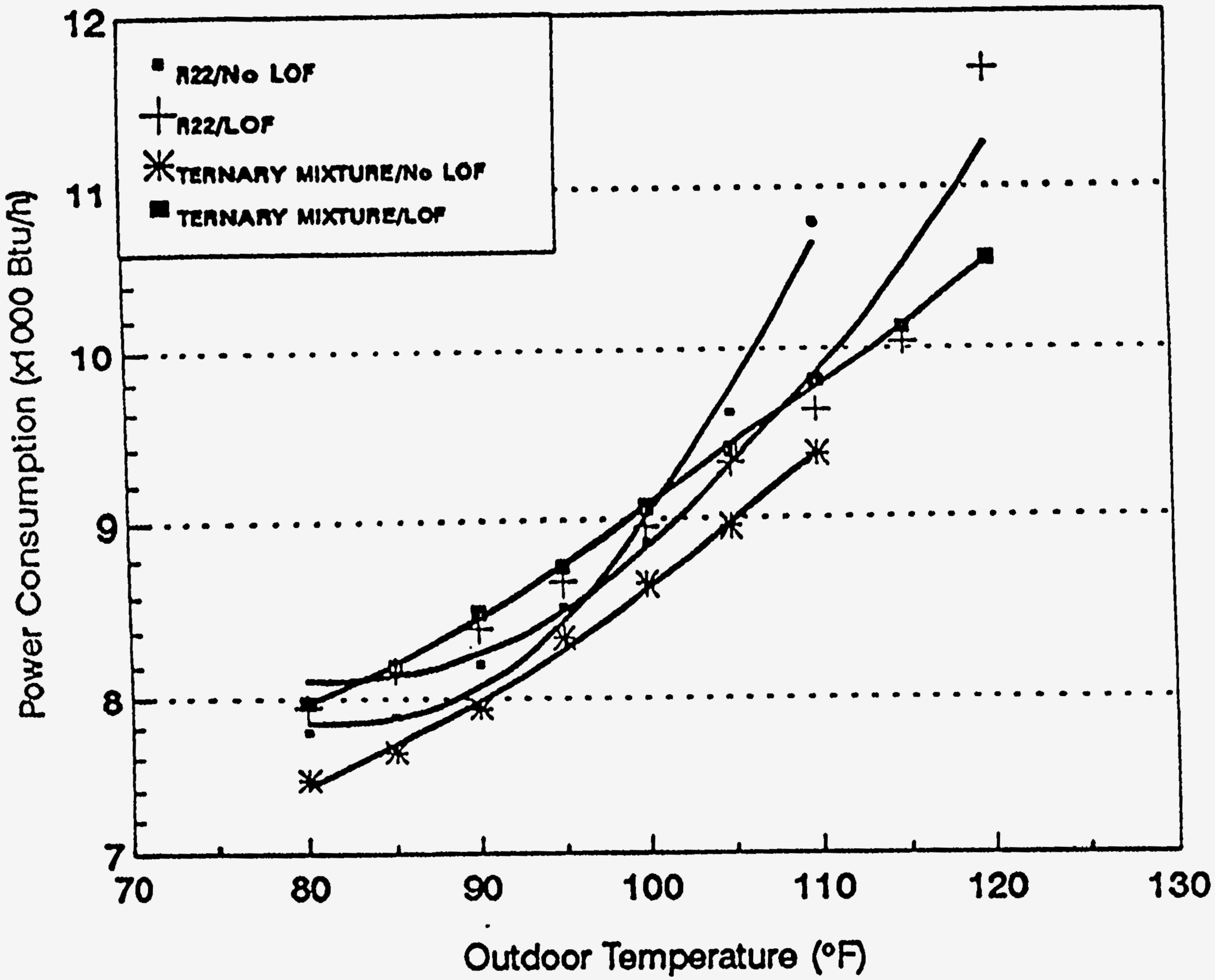

Fig. 7 Power consumption as a function of outdoor temperature with R22 and ternary mixture

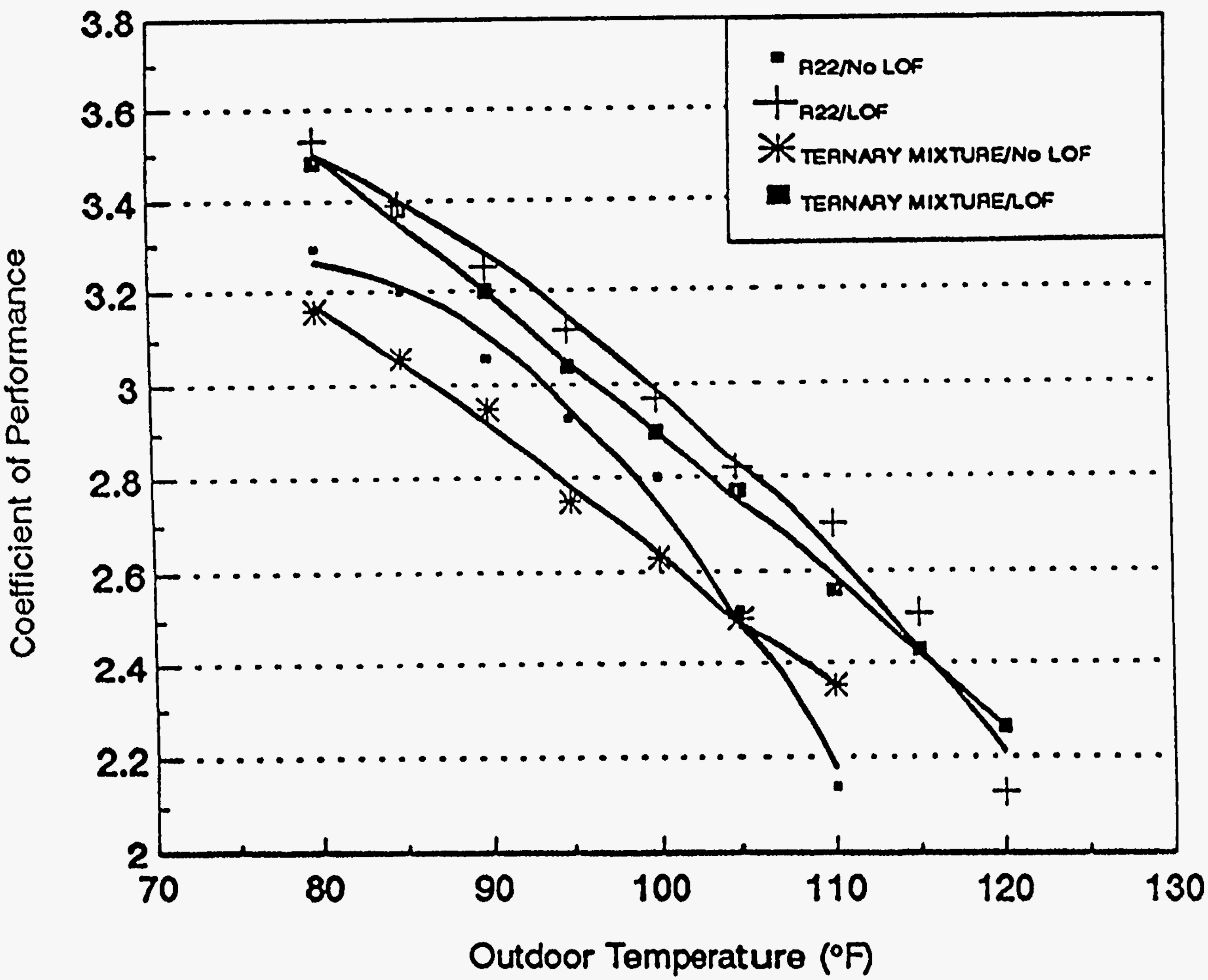

Fig. 8 Coefficient of performance as a function of outdoor temperature with R22 and ternary mixture