Isobutane as a Refrigerator Freezer Refrigerant

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Abstract

Isobutane is considered as a possible candidate for the refrigerant to be used in the consumer refrigerator freezer. Results of an analytical analysis that predicts the performance of isobutane in the consumer refrigerator freezer and results of calorimetric measurements of compressors operating with isobutane are presented.

Both the analytical analysis and the experiment suggest that the use of isobutane as a refrigerant, compared to the presently used dichlorodifluoromethane, R-12, (or tetrafluorothene, R-134a) will result in a reduction in power.

Introduction

The refrigerant, dichlorodifluoromethane, R-12 or CFC 12, that has been used in the consumer refrigerator freezer for the past half a century almost certainly will not be used much longer. Because of its alleged contribution to both atmospheric ozone depletion and global warming it is being phased out. Tetrafluoroethane, R-134a or HFC 134a, is the present leading candidate to replace R-12 but nevertheless there is some drawbacks to the use of R-134a.

It is generally assumed, with some dissension, that R-134a does not work well with the presently used low cost mineral oil that is used with R-12. Some ester oil is likely to be used with R-134a but the use of this ester oil with R-134a does lead to some potential chemical incompatibility problems and some solubility problems that do not exist with R-12 and mineral oil and possibly would not exist or would be less severe with isobutane and mineral oil.

Isobutane As a Refrigerant

Several different hydrocarbons have been proposed for use as refrigerants for the consumer refrigerator freezer. Results of an evaluation of one of these, isobutane (R-600a), is presented herein.

Some desirable features and the only known significant undesirable feature of isobutane is listed in Table 1.

Table 1
Features of Isobutane As a Refrigerant

Desirable Features	Undesirable Features
High Efficiency Nontoxic Miscible and Compatible with Mineral Oil Relatively Inert Chemically Almost no Global Warming Potential Zero Ozone Depletion Potential Low Cost	Flammable

The fact that isobutane is flammable is undesirable everywhere but this undesirable feature is weighted differently at different places, and probably differently at different times. It is presently used in many refrigerator freezers in Germany. Other parts of Europe and Asia presently have some reservations about using isobutane. The United States presently has even greater reservations. The currently used R-12 is not flammable. The mineral oil that is used with R-12 is flammable but not so easily ignited. However if it is ignited the total amount of heat that would be liberated by burning this mineral oil normally used in an R-12 compressor is much greater than the heat that would be liberated by burning the isobutane that would be used in a isobutane refrigerator freezer. Mineral oil has been used for a long time and is generally acceptable. Isobutane is used much as a propellant in the home and this is acceptable also but a small amount of the same isobutane used in the sealed system in a refrigerator freezer may not be acceptable.

Analytical Analysis

No recommendations either pro or con is made herein for the use of isobutane as a refrigerant but some results of a thermodynamic evaluation of isobutane as a refrigerant is presented. Results of an analytical analysis that predicts the performance of the refrigerant and results of calorimeter testing of compressors operating with isobutane is presented.

Tables 2 and 3 presents some results of an analytical analysis that predicts the performance of R-12, R-134a and R-600a. Figures 1, 2, 3 and 4 presents graphically some of these results. For purpose of comparison the capacity of each compressor is assumed to be 750 Btu/hr at the ARI rating point and the required displaced volume is determined accordingly. Some things are significant.

First, based on this analytical analysis it is observed that isobutane will result in a reduction in power consumption of about 6% compared to R-12 (or R-134a). For purpose of this comparison the isentropic compression efficiency is assumed to be 59% for each refrigerant but the relative comparison is valid regardless of what the isentropic compression efficiency is provided it is the same for each refrigerant.

The second significant observation is that for equal capacities the cylinder volume of a R-600a compressor is about 2 times as great as it is for an R-12 compressor. If the bore to stroke ratio is equal in each case (assumed to be 1.75 to 1 for purpose of calculating bearing loads) then the piston diameter for a R-600a compressor is about 126% that of an R-12 compressor piston. For equal pressure differentials this would result in higher bearing loads and higher bearing friction power loss in the R-600a compressor but the pressure differential is not equal. The pressure differential is lower in the case of the R-600a compressor. The net effect is that the bearing loads and bearing friction power loss is slightly less in the R-600a compressor than it is in the R-12 compressor. The larger piston in the R-600a compressor results in more space for better placement and sizing of the valves. Everything considered the larger piston in the R-600a compressor is an asset not a liability.

Experimental Evaluation

Calorimeter testing of several R-600a compressors tends to confirm, within the limits of experimental error, that the theoretical prediction of a 6% efficiency improvement is an actual reality. Actual test results indicate only about 2% improvement but it is believed that with a little more compressor optimization the 6% will be realized.

Table 4 presents results of the actual calorimeter measurements of the compressor performance. A precise one to one comparison is not possible because for equal capacity compressors the cylinder displacement volume is about 2 times greater in a R-600a compressor than it is in an R-12 compressor. The R-600a compressors are compared to a similar capacity but different displaced volume, R-12 compressors.

Table 2
Calculated Performance

Refrigerant	T Evap	T Cond	Power Watts	Capacity Btu/hr	EER Btu/W*Hr
R-12	-20°F	90°F	93.89	594.9	6.34
		105	104.63		5.69
		110	108.09		5.51
		130	121.54		4.90
	-10°F	90°F	103.02	750	7.28
		105	116.18		6.46
		110	120.44		6.23
		130	136.90		5.48
	0	90	111.06	935.1	8.42
		105	127.06		7.34
		110	132.18		7.08
		130	152.14		6.15
R-134a	-20°F	90°F	91.7	580.6	6.33
		105	101.9		5.70
		110	105.6		5.50
		130	118.0		4.92
	-10°F	90°F	103.2	750	7.27
		105	116.1		6.46
		110	120.3		6.24
		130	136.2		5.51
	-0	90°F	113.8	957.6	8.42
		105	129.9		7.38
		110	135.0		7.10
		130	154.9		6.19
R600a	-20°F	90°F	87.16	585.6	6.72
		105	96.76		6.05
		110	99.85		5.87
		130	111.72		5.24
	-10°F	90°F	97.80	750	6.67
		105	109.84		6.83
		110	113.73		6.60
		130	128.58		5.83
	0	90°F	107.37	950.0	8.85
		105	122.33		7.76
		110	127.14		7.47
		130	145.57		6.52

liquid temp = 90°F; return gas temp = 90°F

Table 3
Calculated Performance

	Note 1				Note 2		
Refrig	P_S	P_D psia	R_C psia	Ref Btu/lb	Work Btu/lb	COP	EER Btu/W-hr
R-12	19.13	195.3	10.2	61.82	38.51	1.605	5.48
R-134a	16.60	213.9	12.9	80.48	49.88	1.613	5.50
R600a	9.15	110.5	12.1	143.68	84.05	1.710	5.84

	Note 3	Note 4		Note 5			
Refrig	Flow	Flow	Cyl Vol	Bore	Stroke	Area	Piston max force
	lb/hr	ft^3/hr	$in.^3$	in.	in.	$in.^2$	lb
R-12	12.13	30.18	0.35	.920	.526	.665	117.1
R-134a	9.32	31.81	0.37	.937	.535	.690	136.1
R600a	5.22	56.95	0.67	1.143	.653	1.023	103.7

Note 1: Rating Point: -10°F evap; 130°F cond; 90°F liquid; 90°F return gas

Note 2: Assumes 59% isentopic compressor efficiency

Note 3: Assumes 750 Btu/hr at rating point; displaced volume determined accordingly

Note 4: Assumes 70% volumetric efficiency

Note 5: Assumes bore to stroke ratio of 1.75

TABLE 4

CALORIMETER TEST RESULTS

REFRIGERANT: R-600a (Isobutane)			
Lab Number	Capacity	Power	EER
Y-0628	696.0	128.25	5.43
Y-0629	686.0	125.25	5.48
Y-0630	721.4	131.70	5.48
Y-0631	705.4	128.00	5.51
Y-0632	702.3	128.50	5.47
Y-0633	725.0	130.20	5.57
Average	706.0	128.65	5.49

Bore: 1.075 inch
Stroke: 0.705 inch
Displacement: 0.640 cu.in.

REFRIGERANT R-12 *		
Capacity	Power	EER
708.0	131	5.40

*Average of many compressors

Bore: 0.8125 inch
Stoke: 0.602 inch
Displacement: 0.312 cu.in.

Conclusion

It can be concluded that from a thermodynamic performance point of view isobutane is superior to R-12 (or any other commonly proposed refrigerant) for use in the consumer refrigerator freezer compressor. It is believed that isobutane will result in a 6% power savings compared to the presently used R-12 or the leading candidate R-134a.

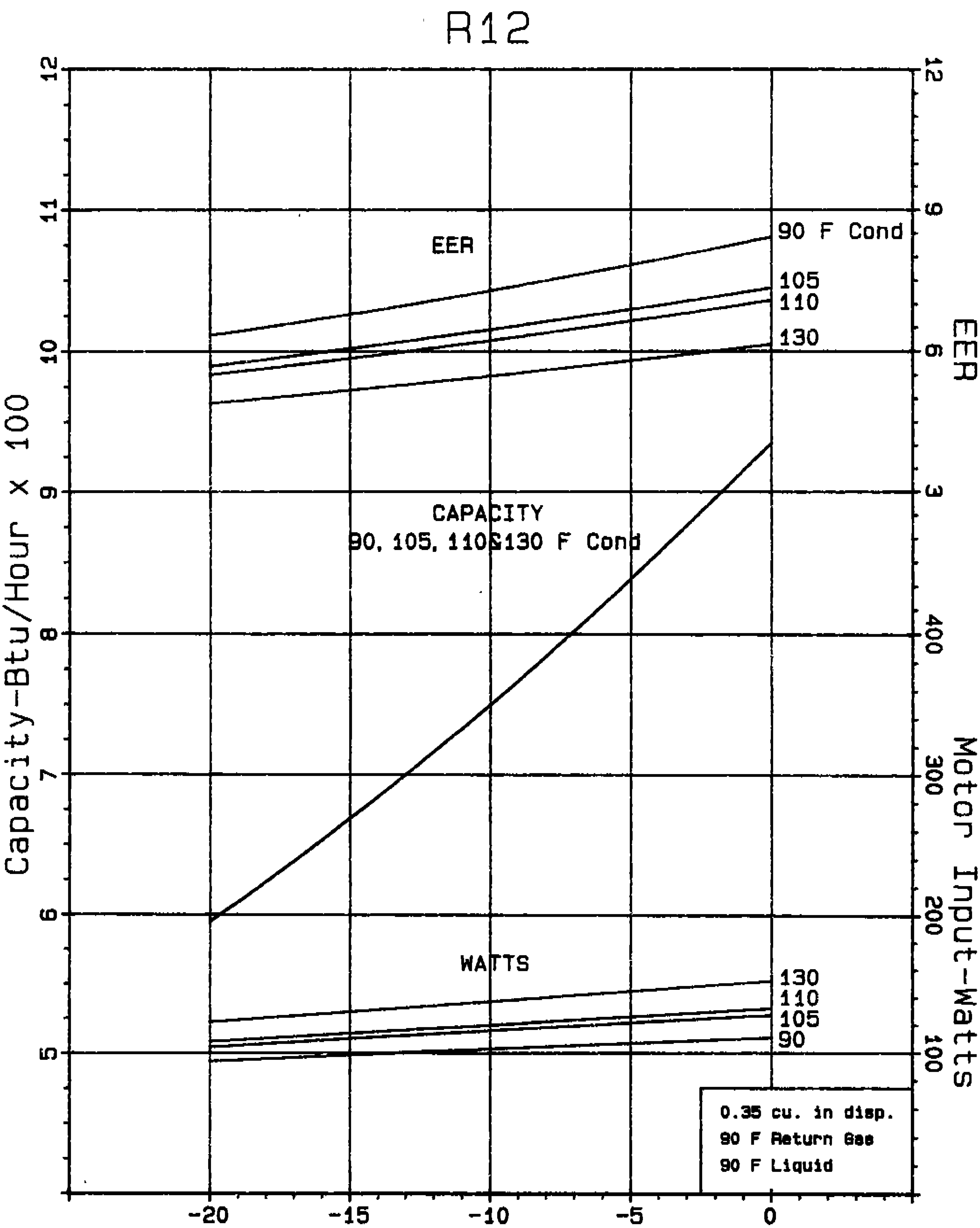
R12
Capacity-Btu/Hour x 100
EER
Motor Input-Watts
EER
90 F Cond
105
110
130
CAPACITY
90, 105, 110&130 F Cond
WATTS
130
110
105
90
0.35 cu. in disp.
90 F Return Gas
90 F Liquid
Evaporating Temperature

Fig. 1

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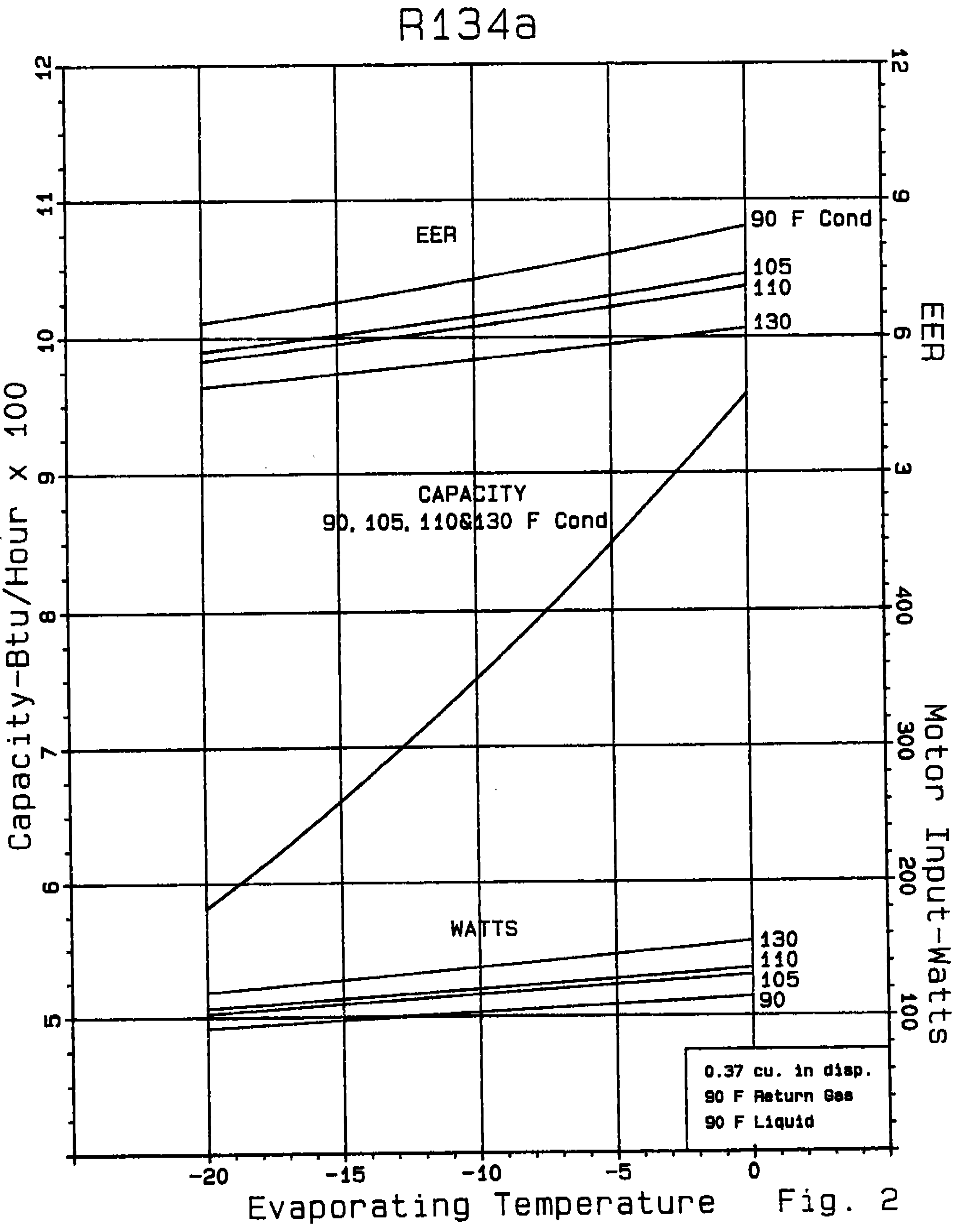
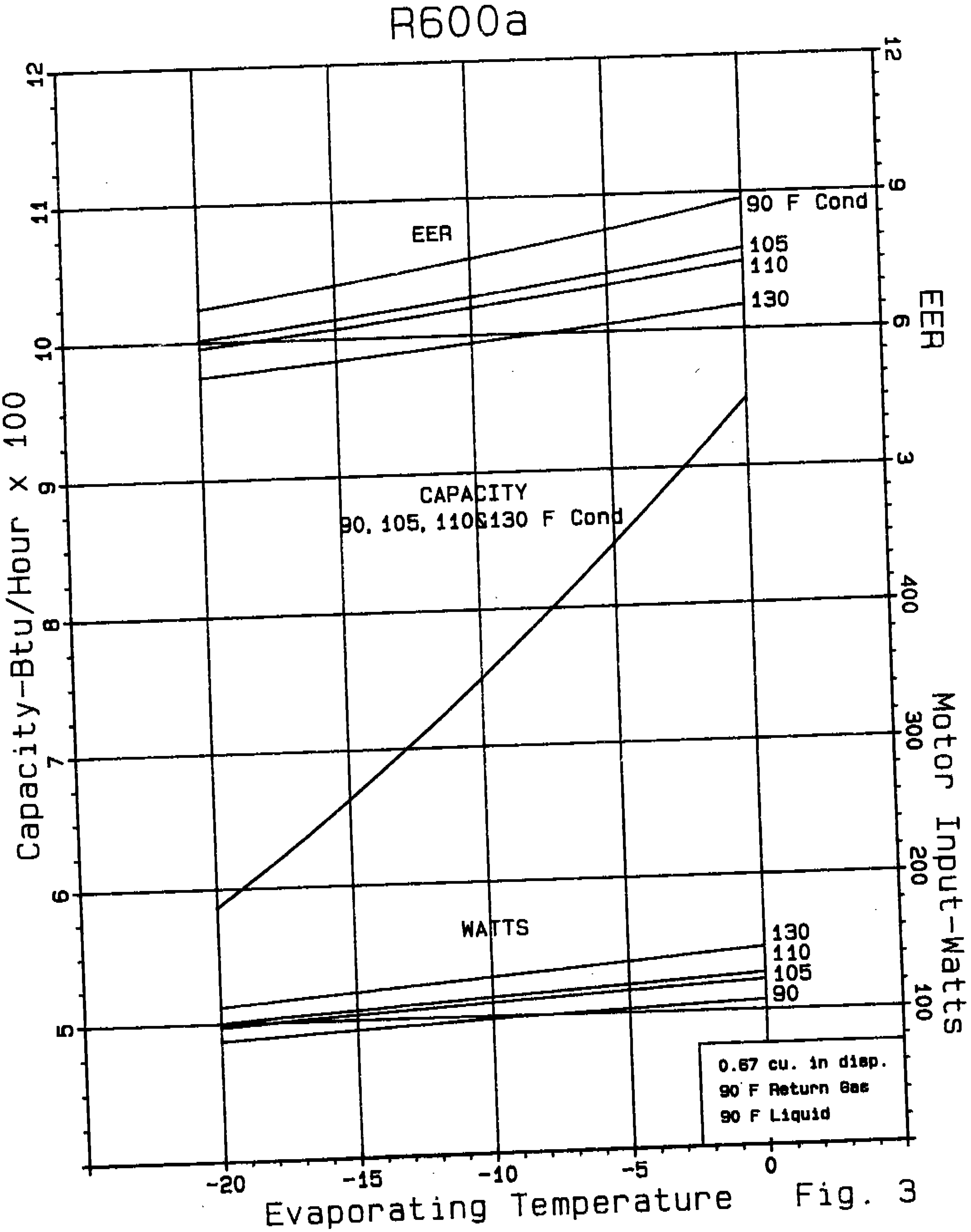

R134a
EER
90 F Cond
105
110
130
CAPACITY
90, 105, 110&130 F Cond
WATTS
130
110
105
90
0.37 cu. in disp.
90 F Return Gas
90 F Liquid
Capacity-Btu/Hour x 100
12
11
10
9
8
7
6
5
EER
12
9
6
3
Motor Input-Watts
400
300
200
100
-20
-15
-10
-5
0
Evaporating Temperature
Fig. 2

03/11/94


R600a
EER
90 F Cond
105
110
130
CAPACITY
90, 105, 110&130 F Cond
WATTS
130
110
105
90
0.67 cu. in disp.
90 F Return Gas
90 F Liquid
Capacity-Btu/Hour x 100
EER
Motor Input-Watts
12
11
10
9
8
7
6
5
9
6
3
400
300
200
100
-20
-15
-10
-5
0
Evaporating Temperature
Fig. 3

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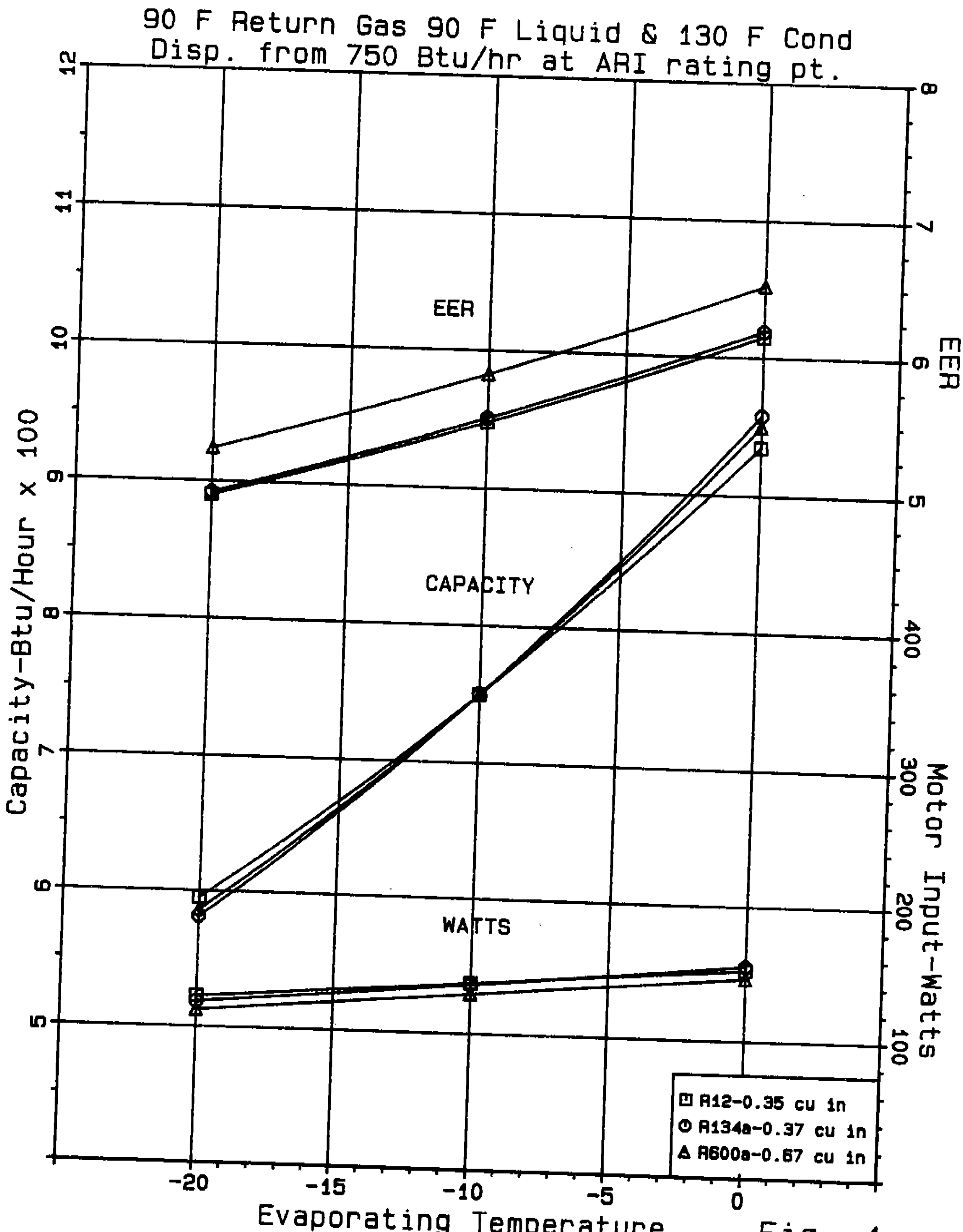

90 F Return Gas 90 F Liquid & 130 F Cond
Disp. from 750 Btu/hr at ARI rating pt.
EER
CAPACITY
WATTS
Capacity-Btu/Hour x 100
12
11
10
9
8
7
6
5
EER
8
7
6
5
Motor Input-Watts
400
300
200
100
-20
-15
-10
-5
0
Evaporating Temperature
R12-0.35 cu in
R134a-0.37 cu in
R600a-0.67 cu in

Fig. 4

03/14/94