DOE/CE/23810-67

EVALUATION OF HFC-245ca FOR COMMERCIAL USE IN LOW PRESSURE CHILLERS

FINAL REPORT
Volume I

Prepared by:

Edward F. Keuper
Principal Investigator
and
F. Byron Hamm
Compressor Performance Analyst

Paul R. Glamm
Project Manager

The Trane Company
3600 Pammel Creek Road
LaCrosse, Wisconsin 54601

March, 1996

Prepared for:
The Air-Conditioning and Refrigeration Technology Institute
Under
ARTI MCLR PROJECT NO. 665-53300

This project is supported, in whole or in part, by U.S. Department of Energy, Office of Building Technology, grant number DE-FG02-91CE23810: Materials Compatibility and Lubricants Research (MCLR) on CFC-Refrigerant Substitutes. Federal funding supporting the MCLR program project constitutes 93.57% of allowable costs. Funding from the air-conditioning and refrigeration industry supporting the MCLR program consists of direct cost sharing of 6.43% of allowable costs, and significant in-kind contributions.

DISCLAIMER

NOTICE

COPYRIGHT NOTICE

(for journal publication submissions)

OTHER ACKNOWLEDGMENTS

HFC-245ca is not commercially available, so we give a note of thanks to AlliedSignal and the Electric Power Research Institute for providing the HFC-245ca (at their own considerable expense) needed to conduct chiller and heat transfer bench tests. In addition, AlliedSignal also provided the thermodynamic property correlations used to reduce the data.

EVALUATION OF HFC-245CA FOR
COMMERCIAL USE IN LOW PRESSURE CHILLERS
ARTI MCLR PROJECT NUMBER 665-53300

Paul Glamm, Byron Hamm, Ed Keuper

ABSTRACT

Federal regulations banned the production of CFC-11 on January 1, 1996. HCFC-123, the only commercial alternative, will be limited to service applications after. January 1, 2020 and will be eliminated from production on January 1, 2030. HFC-245ca has been identified as a potential replacement for CFC-11 in retrofit applications and for HCFC-123 in new chillers, but the marginal flammability of HFC-245ca is a major obstacle to its commercial use as a refrigerant in the United States. This report assesses the commercial viability of HFC-245ca based on its experimental performance in a direct drive low pressure centrifugal chiller exclusive of its flammability characteristics. Three different impeller diameters were tested in the chiller, with all impellers having identical discharge blade angles.

Experimental work included tests in a 200 ton 3 stage direct drive chiller with 3 impeller sets properly sized for each of three refrigerants, CFC-11, HCFC-123, and HFC-245ca. The commercial viability assessment focused on both retrofit and new product performance and cost. Conclusions from this project include the following:

- HFC-245ca will not perform satisfactorily when substituted for CFC-11 or HCFC-123 in existing chillers with no hardware changes due to surge concerns. For HFC 245ca to perform satisfactorily in a retrofit situation, the compressor must be modified with larger impellers, will likely need a larger motor and drive system, and in many instances will require a new compressor casing. The high cost of replacing compressors and drive systems is justified only in special situations driven by financial considerations at the job site.

- Chillers designed specifically for use with HFC-245ca can provide performance comparable to HCFC-123 chillers with some increase in heat transfer surface cost. This design is not commercially viable today because HFC-245ca is not available in commercial quantities, and the market resistance to refrigerants with Class 2 flammability ratings discourages the development of processing plants to commercially produce HFC-245ca.

- Although the flammability of HFC-245ca may be reduced by blending HFC-245ca with various flame suppressant compounds, addition of these compounds will degrade chiller performance and present significant technical challenges in heat exchanger design.

- The industry should continue to investigate cost effective methods for using high performance marginally flammable refrigerants such as HFC-245ca.

TABLE OF CONTENTS

Volume II is a separate document and contains the chiller test data in both Imperial and Metric units. Both raw data and reduced data such as heat transfer coefficients and compressor adiabatic efficiency are provided in Volume II.

List of Figures

SCOPE

Federal regulations banned the production of CFC-11 on January 1, 1996. HCFC-123, the only commercial alternative, will be limited to service applications after January 1, 2020 and will be eliminated from production on January 1, 2030. HFC-245ca has been identified as a potential replacement for CFC-11 in retrofit applications and for HCFC-123 in new chillers, but the marginal flammability of HFC-245ca is a major obstacle to its commercial use as a refrigerant in the United States. This report assesses the commercial viability of HFC-245ca based on its experimental performance in a direct drive low pressure centrifugal chiller exclusive of its flammability characteristics. Three different impeller diameters were tested in the chiller, with all impellers having identical discharge blade angles.

SIGNIFICANT RESULTS

BACKGROUND

This section describes the safety, environmental, and performance characteristics of HFC-245ca leading to its selection for this study.

Safety and Environmental Issues

In spite of an intensive and thorough search for CFC-11 substitutes, the air conditioning industry has not found an ideal refrigerant for application to centrifugal chillers. J. Calm stated that "in addition to having the desired thermodynamic properties, an ideal refrigerant should be non-toxic, nonflammable, completely stable inside a system, environmentally benign even with respect to decomposition products, and abundantly available or easy to manufacture .... There are additional criteria, but no current refrigerants are ideal even based on this partial list. Furthermore, no ideal refrigerants are likely to be discovered in the future."[1] Hence, compromises on the various attributes of refrigerants must be made. The industry has chosen to invest heavily in low pressure centrifugal chillers designed for HCFC-123 and in medium pressure centrifugal chillers designed for HFC-134a because of their excellent balance of performance and environmental characteristics as shown in Table 1. HFC-134a is not a low pressure refrigerant and thus not a drop in replacement candidate for CFC-11. However, HFC-134a has proven to be a very viable refrigerant for use in medium pressure centrifugal and positive displacement chillers.

Table 1. CFC-11 Alternatives for Centrifugal Chillers

Refrigerant	Ozone Depletion Potential	Atmospheric Life in Years	Direct GWP 100 year horizon	Theoretical COP	ASHRAE 34 Flammability Classification*
CFC-11	1.00	50	4000	7.57	1
HCFC-123	.016	1.4	93	7.43	1
HFC-245ca	0.00	7	610	7.33	2**
HFC-134a	0.00	14	1300	6.94	1

[1] Calm, J.M. "**Refrigerant Safety**" ASHRAE Journal, July 1994. p. 18

* Class 1=No flame propagation, Class 2=lower flammability, Class 3=higher flammability
** HFC-245ca has not been classified by SSPC34, but test data suggest a "lower flammability" rating would be appropriate.

The theoretical COP of HCFC-123 is close to that for CFC-11 and supports the manufacture of chillers with very high efficiency. HFC-134a has zero ozone depletion potential, but has higher direct global warming potential (GWP) and less attractive thermodynamic properties. HFC-245ca also has a very attractive theoretical COP, an atmospheric lifetime between that for HCFC-123 and HFC-134a, but has been shown to be marginally flammable. What's marginally flammable? Like all fluorocarbon refrigerants, HFC-245ca will participate in, and react with, an existing fire and decompose. In the process many fluorocarbons will release a small amount of heat depending on the hydrogen and carbon content. As shown in Table 2, HFC-245ca lies between HFC-134a (Class 1) and HFC-32 (Class 2) in terms of heat of combustion and so has been called "marginal".

Table 2. Flammability Data

Refrigerant	Heat of Combustion mJ/Kg	Heat of Combustion Btu/Lbm	Pressure Rise, kPa	Pressure Rise, psia
HFC-125	-1.5	-645	0	0
CFC-11	0.9	387	0	0
HCFC-123	2.1	903	0	0
HCFC-22	2.2	946	0	0
HFC-134a	4.2	1806	0	0
HFC-245ca	7.1	3053	6.9	1
HFC-32	9.4	4041	?	?
HFC-152a	16.9	7266	186 to 510	27 to 74
Ammonia	22.5	9673	?	?
Propane	50.3	21,625	?	?

In addition, the pressure rise for HFC-152a (Class 2) is 27 psi (186 kPa) while for HFC-245ca the pressure rise is 1 psi[2] (6.9 kPa) and zero for HFC-134a, again marginal. According to a study by Arthur D. Little[3], the nature of the damage from over-pressure by 0.1 to 1.0 psi is the shattering of glass windows. From 1 to 2 psi results in failure of wood siding panels, shattering of asbestos siding and corrugated steel and aluminum panel failure. Over-pressure of 15 psi would result in lung damage to people and severe damage to structures.

The industry recognizes that a -major effort would be required to work with the standards and codes organizations to identify cost effective methods of using HFC245ca as safely as we use Class 1 refrigerants today. However, that effort can only be

[2] Phone conversation with Rajiv Singh of Allied Signal, July 7, 1995.
[3] Arthur D. Little, Inc. "**Risk Assessment of Flammable Refrigerants for Use in Home Appliances**", Revised Draft Report, September, 1991.

justified if the performance of HFC-245ca has been proven in the laboratory and the application deemed commercially viable exclusive of the flammability issue.

How difficult will it be to identify cost effective methods of using HFC-245ca as safely as Class 1 refrigerants? Consider the following: HFC-245ca has no measurable flash point and will not sustain a flame in dry air at room temperature. However, by ASHRAE 34 and UL-2182 flammability test conditions, HFC-245ca is expected to carry a Class 2 rating of "lower flammability". Use of a Class 2 refrigerant according to ASHRAE 15 requires, in addition to the class 1 requirements, a one-hour fire-resistant rating for the machinery room and compliance with Class 1 Division 2 of the National Electrical Code. ASHRAE 15 and the NEC call a machinery room with a Class 2 refrigerant a "hazardous location." Thus, to use HFC-245ca as safely and cost effectively as a Class 1 refrigerant, the industry must resolve the safety and cost issues associated with ASHRAE 15 and the marketing issues of dealing with a "hazardous location."

Several studies have indicated that "true risk" does not come in discreet increments but is rather a continuum. For example, Calm writes "Recognition is growing that all refrigerants containing hydrogen (including HCFCs and HFCs) are potentially combustible under some conditions." [4] Dekleva writes: "...as the industry scrutinizes this parameter (flammability/combustibility) more closely (especially in light of the new refrigerants), the absolute measure of reactive and non-reactive (flammable and non-flammable/combustible) becomes smeared." [5] Thus, the potential Class 2 rating for HFC-245ca may be overstating the real risk associated with its use, but that may be sufficient to prevent its commercialization. Continued assessment of the risks associated with the use of marginally flammable refrigerants such as HFC-245ca is desirable along with a review of the technical requirements for classification of refrigerants.

Theoretical Performance

Many of the low pressure chillers produced today and in the past have contained 3 stages of compression plus economizers between stages, so an analysis of the theoretical performance of HFC-245ca in this class of equipment is appropriate.

Single and three stage refrigeration cycles are illustrated on temperature-enthalpy diagrams in Figures 1 and 2 respectively. The processes portrayed in Figure 1 are typically described as shown in Table 3.

Table 3. Single Stage Process

Process Line	Process	Process Line	Process
1 - 2'	Isentropic Compression	1 - 2	Adiabatic Compression
2 - 3	Desuperheating	3 - 4	Condensing
4 - 5	Adiabatic Expansion	5 - 1	Evaporation
6 - 7	Condenser Water Temp	9 - 8	Evaporator Water Temp

[4] Calm, J.M. "**Refrigerant Safety**" ASHRAE Journal, July 1994. p. 22

[5] Dekleva, T.W., Lindley, A.A., Powell, P. "**Flammability and reactivity of select HFCs and mixtures**" ASHRAE Journal, December, 1993.

The three stage cycle includes two economizers which separate the liquid and vapor refrigerant after partial expansion and direct the vapor into the compressor between the impellers. The processes portrayed in Figure 2 are typically described as shown in Table 4.

Table 4. Three Stage Process

Process Line	Process	Process Line	Process
1 - 2	Adiabatic Compression	7 - 8 & 5	Adiabatic Expansion
3 - 4	Adiabatic Compression	8 - 9 & 3	Adiabatic Expansion
5 - 6	Adiabatic Compression	9 - 10	Adiabatic Expansion
6 - 7	Desuperheat and Condensing	10 - 1	Evaporation

This process is more efficient than the single stage process because (1) the vapor separated by the economizers is recompressed from an intermediate pressure rather than from evaporator pressure and (2) the enthalpy of the liquid entering the evaporator is lower by the amount of latent heat of the vapor in the economizer.

Available property data indicate that the pressure-temperature relationship and theoretical efficiency of HFC-245ca are comparable to that of CFC-11 and HCFC-123. Hence HFC-245ca might be suitable both as a drop-in replacement for these refrigerants in existing chillers and as a new product refrigerant. Theoretical performance of the three refrigerants using the best available property data is compared in Table 5. Within experimental accuracy, the performance of the three low pressure refrigerants is indistinguishable in an ideal 3 stage compression cycle.

Table 5. Theoretical Performance for Single and Three Stage Cycles*

Refrigerant	Single Stage	Ratio	Three Stage	Ratio
CFC-11	0.52 kW/ton	Base	0.50 kW/ton	0.95
HCFC-123	0.53 kW/ton	1.01	0.50 kW/ton	0.95
HFC-245ca	0.53 kW/ton	1.01	0.50 kW/ton	0.95

* Boundary conditions: zero subcooling, zero superheat, 94% motors with liquid cooling, 83% efficient impellers, 6.1 C (43 F) saturated suction temperature, 35.6 C (96 F) saturated condensing temperature.

PROJECT OBJECTIVES

The objectives of this project include the following:

- Model the performance of HFC-245ca in centrifugal chillers, and estimate drop-in and optimized chiller performance. Drop-in performance estimates will reflect that obtained in CFC-11 and HCFC-123 optimized chillers. Optimized chiller performance estimates reflect the performance expected in a chiller designed specifically for use with HFC-245ca.

- Conduct parametric tests of HFC-245ca in a centrifugal chiller optimized for CFC-11 using saturated temperatures and compressor capacity as variables. The experimental results will be used to confirm the computer models and provide direct comparisons of performance between the three refrigerants.

- Assess the commercial viability of HFC-245ca to retrofit CFC-11 and HCFC-123 chillers in the field and for use in chillers optimized for HFC-245ca.

The technical approach for achieving these objectives includes experimental testing of a 3 stage centrifugal chiller with the three refrigerants, heat transfer testing of single tubes in a bench test facility, confirmation of our computer models for estimating drop-in and optimized performance, assessment of field retrofit experience to date from CFC-11 to HCFC-123, and finally assessing the commercial viability of HFC-245ca in retrofit and new product applications.

EXPERIMENTAL RESULTS

Low pressure centrifugal chillers have been available in single stage and multistage configurations for many years and large numbers of chillers of both designs are in use today. While this study will focus on the hermetic multistage direct drive configuration, the performance trends described in this report will generally apply to both single and multistage chillers.

Chiller Test Plan

A 200 ton 3 stage direct drive centrifugal chiller was selected as the test vehicle for this project because the charge requirements were small enough (about 400 lbm, 182 kg) to provide reasonable limits for the laboratory production of HFC-245ca. In addition, this chiller was built in 1981 and is a suitable representative of chillers which could be considered for retrofit. Three sets of impellers, three refrigerants and two oils were tested in the chiller according to the test matrix shown in Table 6. Trane 22 is a mineral oil and Solest 68 is a polyolester oil. (Trane centrifugal compressors in the field are operated with mineral oil for both CFC-11 and HCFC-123.)

Table 6. Chiller Test Matrix

Impeller Diameter inches	Impeller Diameter mm	Oil	CFC-11	HCFC-123	HFC-245ca
26/26/26	660/660/660	Trane 22	X		
26/26/26	660/660/660	Solest 68	X	X	X
25/25/24.5	635/635/622	Solest 68	X	X	X
24/24/24	610/610/610	Solest 68		X	

Baseline tests with both the mineral and polyolester oil were conducted with CFC-11 to verify that the performance of the chiller was insensitive to oil selection, and that the polyolester oil needed for use with HFC-245ca could be used for all subsequent tests without biasing the results. Further, new oil was charged every time refrigerant was changed. Thus, the only variables in the chiller tests were refrigerant selection, water temperatures, and compressor loading. The water flow rates were fixed at 480 gpm (30.3 liters/sec) for the evaporator and 600 gpm (37.9 liters/sec) for the condenser to minimize changes in the water side heat transfer coefficient.

The evaporator leaving water temperature was held at 44 F (6.67 C) for all tests. Condenser entering water temperatures were varied from 70 F (21.1 C) up to the onset of surge or high pressure cutout in 5 F (2.78 C) increments for each of four inlet guide vane settings: 90, 70, 40 and 10 degrees. The highest condenser water temperatures reported were either at surge or just short of high pressure cutout.

Surge is a condition that exists when the centrifugal compressor can no longer supply enough dynamic head to the refrigerant vapor to overcome the enthalpy rise from suction to discharge conditions. This condition is easy to create by simply imposing higher water temperature lift conditions (condenser water temperature minus evaporator water temperature) on the chiller than the compressor can tolerate. Surge manifests itself through significant reductions in mass flow through the compressor and a sharp change in the noise characteristics of the compressor. See Appendix A for a more thorough description of surge.

Although variable orifices (vee-ball valves) were installed in the chiller, the valve settings were not changed once they were optimized for the CFC-11 baseline case. While the results of the chiller tests would vary slightly with the active use of variable orifices, the conclusions from this project would not be affected.

Chiller Performance

All chiller performance data can be found in Volume II. Summaries of the full load results by refrigerant can be found on pages 97, 73 and 25 for the large, medium and small impeller data respectively in Volume II. In addition, the full load results can be found in Appendix B of Volume I.

Oil Effects. The baseline tests confirmed the negligible impact with CFC-11 of oil selection as shown in Figures 3 through 5. The differences in performance between oils were within experimental error, so all subsequent tests used the polyolester oil. We believe that oil selection would likewise have negligible effect on the performance of HCFC-123 and HFC-245ca.

Operating Range. The thermodynamic properties of the three refrigerants show that the compressor lift (enthalpy change through the compressor at fixed saturated temperature conditions) will be the lowest for HCFC-123 and highest for HFC-245ca. The diameters of the three impeller sets were chosen as optimum (providing enough margin in the lift capability to avoid surge during normal operation, while not being so oversized as to compromise efficiency) for each of the three refrigerants. Thus, surge problems would only occur in a retrofit situation with HFC-245ca dropped into a chiller optimized for CFC-11 or HCFC-123. The surge lines (entering condenser water temperature at the onset of surge vs guide vane position) for the 25/25/24.5 impellers (CFC-11 optimum) are plotted in Figure 6, and confirm the lower surge limit for HFC-245ca. This will be a significant problem at full load (90 degree vanes) as the 5F (2.8C) margin over the ARI rating condition will be unacceptable to the customer. Surge tests were not conducted with the 24/24/24 impellers because only HCFC-123 would show adequate margin to the onset of surge. Surge tests with the 26/26/26 impellers and CFC-11 and HCFC-123 refrigerants showed the surge line to be above the high pressure cutout setting.

Effect of Impeller Diameter. Chiller capacity, power consumption and efficiency have been cross plotted vs condenser entering water temperature for the two larger impeller sets as shown in Figures 7 through 12. Although these three refrigerants are very similar, the differences in specific volume and work input requirements are significant as dramatized in this drop-in situation. On the other hand, these differences can be managed very effectively in designs which are unique to each refrigerant, and give us the performance shown in Figures 13 through 15 where we plot the performance of each refrigerant only with its optimum impeller diameter. These data confirm the excellent performance of all three refrigerants. On the other hand, if power is plotted vs capacity for each refrigerant with its properly sized impeller, you find that retrofitting a chiller with larger impellers to handle HFC-245ca in an efficient manner also results in significantly more power being used by the motor as shown in Figure 16. Thus, retrofits with HFC-245ca will probably need larger motors and power supplies, or blockage of the guide vanes so that the ampere limits are maintained. Limiting the power consumption will significantly reduce the capacity of the chiller with HFC-245ca. Another option suggested by the results shown in Figure 16 is to accept the power and capacity reduction with HFC-245ca dropped into a CFC-11 chiller with no impeller diameter change. This logic is flawed by the surge data shown in Figure 6 which shows that inadequate surge margin exists when using HFC-245ca with impellers designed for CFC-11.

Compressor Performance. The theoretical estimates of performance described in the Background section of this report were based on constant compressor adiabatic efficiency, independent of refrigerant choice. Is this a valid assumption? Using the data obtained from the 26/26/26 and 25/25/24.5 inch impellers, compressor efficiency maps (Figures 17 and 18) were constructed by plotting adiabatic efficiency versus compressor suction volume flow rate at a variety of vane settings. These data show that over the range tested, compressor efficiency is not strongly affected by refrigerant choice, with the larger diameter impellers being about 1% more efficient than the medium size impellers. Thus, the constant adiabatic efficiency assumption is valid for comparing refrigerants.

Heat Exchanger Performance. The condenser performance has been reduced to refrigerant side coefficients for each refrigerant and cross plotted against heat flux as shown in Figure 19. The condenser tube tested is a 35 fin per inch design. The trend lines through the data points suggest only small differences between the refrigerants, with CFC-11 slightly better than HCFC-123 which is slightly better than HFC-245ca.

The evaporator performance has been reduced to refrigerant side coefficients for each refrigerant and cross plotted against heat flux as shown in Figure 20. The evaporator tube is a Wolverine Turbo BII design. The trend lines through the data points show that CFC-11 performance is about 10% better than HCFC-123 performance which in turn is about 10% better than HFC-245ca performance. The performance decrease at the higher heat fluxes results from fixed orifice operation holding up liquid in the condenser at the higher capacities and providing inadequate refrigerant to the evaporator to keep all the tubes wet.

Single Tube Performance. Bench tests of boiling and condensing performance were conducted with two generations of tube. Drop-in behavior was examined with a 35 fins/inch (1378 fins/meter) design commonly used during the 1980's, while newly optimized performance was examined with state of the art surfaces, Turbo BII for boiling and Turbo CII for condensing. The results of the bench tests are plotted against heat flux as shown in Figures 21 through 24. This performance confirms that the HFC-245ca heat transfer coefficients for these tube designs are not as high as those for either CFC-11 or HCFC-123. In addition, the shape of the HFC-245ca condensing curve is contrary to our experience with CFC-11 and HCFC-123 and has not been explained. Because a small error in saturated temperature properties could cause this phenomenon, AlliedSignal revisited the accuracy of their data and concluded no change was justified. Thus, we have no explanation for the shape of the HFC-245ca condensing curve.

Blend Performance.

While this final report was being prepared AlliedSignal suggested that we test a nonflammable blend of HFC-245ca consisting of 25% by weight of 3M's PF5060 (a blend of perfluorohexane compounds) and 75% HFC-245ca. From the beginning the chiller performed poorly with high power consumption. High power consumption is a symptom of system overcharge and significant liquid carryover. Fortunately, the chiller is equipped with a large number of sight glasses and the condition of liquid carryover in the compressor suction and in both economizer vapor lines was confirmed visually. We then began a charge optimization series of runs adjusting the orifices in an attempt to dry out the vapor lines. We were successful in this effort only at very low charge and at low loads where inlet guide vanes were no more than 30% open. We continued to experiment with charge size, orifice settings and guide vane settings for the next five days and were unable at any charge level or orifice setting to open the guide vanes above about 40% without wet suction and/or wet economizer vapor lines.

Consultation with AlliedSignal concerning properties of the mixture revealed that the surface tension of the blend is about half that of pure HFC-245ca and we believe that this is the source of the problem. Surface tension is a measure of a fluid's propensity to form spheres of liquid and reduce its surface to volume ratio. These spheres then separate by gravity from the vapor stream in the vapor spaces of the evaporator and economizer. With this particular blend this agglomeration tendency is greatly reduced. Vapor velocities must be reduced to use this fluid. Given the design of the chiller, the only way is by a low loading. As a consequence we were unable to get any useful performance measurements, but we did learn that the effect on blend surface tension must be considered for any blending compound.

COMMERCIAL VIABILITY ASSESSMENT

The commercial viability of HFC-245ca is addressed from both a retrofit and new product perspective.

Retrofit Applications

Retrofit applications must be concerned with material compatibility, drop-in performance and cost, viability of replacing the impellers, and economics of compressor replacement.

Material Compatibility. Twenty-four common motor materials were tested in a variety of refrigerant and lubricant mixtures as part of the 1995 ARTI/MCLR Project 23810 aimed at identifying retrofit material compatibility problems. Relative to retrofit from CFC-11 or HCFC-123 to HFC-245ca, only one problem was found with motor materials. Specifically, Nomex-Mylar-Nomex sheet insulation raised concern "when pockets of delamination appeared between the layers of sheet insulation".[6] Here the problem was neither the Nomex nor the Mylar but rather the adhesive which joined them. In the area of elastomers, two materials were tested in various refrigerants and lubricants: neoprene and nitrile. The neoprene exhibited shrinkage and may be unsatisfactory for use with HFC-245ca. Trane direct drive 3 stage chillers in use in the United States were not produced with either of these potentially incompatible materials. The materials of construction should always be examined when considering a retrofit.

Drop-in Performance. There are three methods of converting a chiller to HFC-245ca: 1) replacement of refrigerant, 2) replacement of refrigerant, impellers and motor, and 3) replacement of refrigerant and the entire compressor, with oil replacement to polyolester assumed for all three options. Modification of the refrigerant metering system may also be required with any conversion. All three methods of conversion are addressed below.

The largest concern with an HFC-245ca drop-in retrofit is the inability to achieve required lift. The surge limits for each refrigerant with 25/25/24.5 impellers were plotted in Figure 6 and selected data for 90 degree vane settings are shown in Table 7.

Table 7. Condenser Entering Water Temperature at the Onset of Surge for 90 degree Vane Setting

CFC-11	99.7 F	37.6 C
HCFC-123	104.2 F	40.1 C
H FC-245ca	90.1 F	32.3 C

[6] Doerr, R.G. and Waite, T.D. "**Compatibility of Refrigerants and Lubricants with Motor Materials under Retrofit Conditions**", International CFC and Halon Alternatives Conference, Washington D.C. October 24, 1995.

[7] Doerr, R.G. and Waite, T.D. "**Compatibility of Refrigerants and Lubricants with Motor Materials under Retrofit Conditions**", **Final Report DOE/CE23810-63**. Air Conditioning and Refrigeration Technology Institute (ARTI) Database, September, 1995.

The ability of the impeller set to provide adequate lift is a strong function of the isentropic work requirement for each refrigerant. HFC-245ca has significantly higher isentropic work than CFC-11 which is higher than HCFC-123. As the data in Table 7 show, the lift reduction in a drop-in situation would be about 10 F when substituting HFC-245ca for CFC-11, and about 14 F when substituting HFC-245ca for HCFC-123. Although chiller installations are designed with some margin to account for tube fouling, low water flow rates and extreme operating conditions, typical installations do not have enough margin to handle increases in lift as large as 10 to 14 F. This conclusion is supported by our experience with CFC-12 to HFC-134a conversions in air cooled centrifugal chillers. Some customers thought they could tolerate some reduction in lift capability with HFC-134a, but were disappointed. We now offer only compressor rebuilds which use larger diameter impellers and return the chiller to its original performance levels. Thus, we conclude that drop-in conversions of low pressure chillers to use HFC-245ca are not commercially viable.

Impeller Replacement. Oversized impellers will produce greater lift and lower performance than properly sized impellers. Therefore, for many sales orders, full size impellers are cut back in diameter to exactly match the customer's lift requirements. In those cases where the compressor casing is large enough to accommodate HFC-245ca impellers, conversion to HFC-245ca with impeller replacement to retain original lift will be possible. Capacity and power increases can be expected, so motor capability will have to be examined. Table 8 and Figures 13 through 15 show measured chiller performance with diameters sized for proper lift capability.

Table 8. Chiller Full Load Performance - Properly Sized Impellers

	Impeller Diameters Inches	Condenser Entering Water Temp, (F)	Tons	kW	kW/Ton
CFC-11	25/25/24.5	90	177.4	149.8	.84
HCFC-123	24/24/24	90	179.0	146.3	.82
HFC-245ca	26/26/26	90	186.0	155.1	.83
CFC-11	25/25/24.5	80	184.5	145.7	.79
HCFC-123	24/24/24	80	203.4	154.2	.76
HFC-245ca	26/26/26	80	220.2	168.4	.76
CFC-11	25/25/24.5	70	220.2	160.7	.73
HCFC-123	24/24/24	70	205.5	150.6	.73
HFC-245ca	26/26/26	70	245.2	176.5	.72

How many existing chillers have the space for large impellers? Trane has been building a database of shipped chillers for the past 12 years. We will assume these data to be typical of the spectrum of chillers in service today (130 to 1550 tons) and then estimate the potential for retrofitting them with HFC-245ca. Analysis of the database given in Table 9 shows the percentage of chillers which could be retrofitted with large enough impellers to maintain the original lift.

For example, the data show that 67% of the chillers in the 130 to 300 ton size range with CFC-11 had, at the time of shipment, compressor casings large enough to accommodate the installation of larger diameter impellers suitable for use with HFC-

245ca. The remainder of the 130 to 300 ton CFC-11 chillers had compressor casings without enough room to accommodate the installation of impellers suitable for HFC-245ca. In summary, approximately two-thirds of the chillers under 600 tons can accommodate HFC-245ca impellers, while less than one-fourth of the chillers over 600 tons can accommodate HFC-245ca impellers.

Table 9. Chiller Population Suitable for HFC-245ca Impellers

Tons	130-300	301-600	601-900	901-1200	1200+
CFC-11	67%	63%	41%	22%	21
HCFC-123	73%	68%	15%	1%	0%

The cost of converting low pressure chillers to either HCFC-123 or HFC-245ca has been estimated and is shown in Table 10. The CFC-11 to HCFC-123 conversion cost is included for comparison purposes to show the effect of the refrigerant properties. (Conversion from CFC-11 to HCFC-123 requires complete tear down, replacement of the motor and all gaskets and O-rings. Conversion from CFC-11 to HFC-245ca may or may not require a replacement motor. If a replacement motor is not required, tear down to replace impellers is all that is needed.)

Table 10. Estimated Cost of Impeller Replacement

Task	CFC-11 to HCFC-123	CFC-11 to HFC-245ca
Motor Replacement	$25,000 - $30,000	$25,000 - $30,000*
Cut back impellers	$700/impeller	Not Applicable
New Impellers	Not Applicable	$7000/impeller
Gaskets, O-rings	$2000	$1500
Oil	$100	$560
Flow Metering System	$1000	$1000
Labor	120-200 hours	100-120 hours

* For CFC-11 to HCFC-123 conversion motor replacement is required because of material compatibility issues. For CFC-11 to HFC-245ca conversions, motor and starter replacement will often be necessary because of increased power consumption.

The cost of the retrofit will not be covered by lower cost operation, but must be weighed against the cost of buying a more efficient chiller (see Table 11). Most CFC-11 to HCFC-123 conversions are done to remove CFC-11 and not to save energy. Conversions from either CFC-11 or HCFC-123 to HFC-245ca will likely be done for the same reason.

How large is the existing market for conversions? Trane has performed more than 800 conversions from CFC-11 to HCFC-123 in the first eight months of 1995 at an average cost to the customer of $60,000 for a 500 ton chiller. This figure includes motor replacement for every chiller due to material compatibility requirements but does not include the cost of refrigerant or a new purge. This cost includes many conversions where the starter was replaced and the control system was upgraded to add demand limit, better diagnostics and access to a building automation system. The converted chillers were mostly 7 to 15 years old but a few were as old as 30 years. In most cases the existing impellers were cut back and reinstalled; and new impellers were installed in the remainder. Table 11 below shows chiller efficiency by year of manufacture over recent years.

Table 11. Chiller Efficiencies by Year of Manufacture

Year	Typical Efficiency kW/Ton	Typical Efficiency COP	Best Efficiency kW/Ton	Best Efficiency COP
1975	.90	3.91	.80	4.39
1980	.75	4.69	.70	5.02
1990	.70	5.02	.65	5.41
1991	.68	5.17	.63	5.58
1992	.65	5.41	.60	5.86
1993	.63	5.58	.55	6.39
1994	.62	5.67	.52	6.76
1995	.60	5.86	.50	7.03

Most chillers shipped prior to 1991 were CFC-11 (a few were CFC-113), all chillers shipped after 1993 were HCFC-123 and from 1991 through 1993 they were mixed CFC-11 and HCFC-123. New chiller installations far outstrip the pace of chiller conversions due to the favorable economics from installing a higher efficiency chiller. Conversions from HCFC-123 to HFC-245ca will rarely if ever be performed because these chillers do not contain CFCs, are very efficient by today's standards, many cannot be converted and, for those that can be converted, the cost is high. Conversions from CFC-11 to HFC-245ca would be more likely but again efficiency gains will be small, and no more than half of the chillers can be retrofit to retain original lift, and the cost is high. A large scale market for converting chillers to HFC-245ca is very unlikely.

Compressor Replacement. Compressor replacement conversions from CFC-11 to HCFC-123 are being performed today in small numbers, estimated at about 100 per year industry-wide. The primary reasons for compressor replacement today instead of buying a new chiller include the high cost of chiller replacing chillers embedded in buildings, and long delivery times for new chillers. For example, Trane performed one compressor replacement conversion from CFC-11 to HCFC-123 in a building where the chiller was located on the 20th floor. Replacement would have required opening the roof, lifting out the old chiller with a helicopter, lifting in the new chiller the same way and reconstructing the roof. Chiller replacement was estimated at $750,000 while compressor replacement cost about $100,000. The cost of compressor replacement is typically in the range of $200 to $225 per ton complete which represents 80 to 100% of the cost of a new chiller without installation. In about 75% of the conversions, energy efficiency is improved because the new compressor is more efficient than the old one and, in some cases, because a smaller compressor is installed.

Demand for compressor replacement for conversions to HFC-245ca is not expected to be any larger than HCFC-123 conversions today due to the high cost. In addition, the small market for compressor conversions will not be large enough to justify development of HFC-245ca specific compressor designs, but must wait for an HFC-245ca chiller design to emerge.

Impeller Speed Change. Although gear driven chillers are outside the scope of this project, a couple of comments are in order. Gear driven compressors offer the option of changing the rotational speed of the impeller by simply changing the gear ratio, thus providing more flexibility in a retrofit situation. However, the impact on compressor adiabatic efficiency and bearing reliability from increasing the rotational speed has not been examined in this project. To provide confidence in the performance and reliability of a gear change solution to the surge problem, an experimental investigation of this option should be conducted.

New Products

The chiller test results show that CFC-11, HCFC-123 and HFC-245ca have comparable performance in centrifugal compressors. Further, the heat transfer characteristics of HFC-245ca in the chiller are only slightly inferior to HCFC-123. Therefore, chillers can be designed using HFC-245ca with about the same material cost as those for HCFC-123. This conclusion is illustrated in Figure 25 where we have cross plotted heat exchanger surface area vs chiller efficiency for HCFC-123, HFC-240ca and HFC-134a. This figure shows that chillers designed for HFC-245ca should be a competitive in the marketplace, disregarding the flammability issue, as HCFC-123 and, HFC-134a chillers are today.

The major obstacle other than flammability is the commercial unavailability of HFC-245ca. Since no chemical manufacturer has announced plans to build an HFC-245ca production facility, the industry is years away from being able to obtain commercial quantities at any price. In addition, the processes for manufacturing HFC-245ca are expected to be much more expensive than those used to produce HCFC-123. The price for HFC-245ca is expected to be high, with estimates from $6 to $10 per lbm ($13.20 to $22.00 per kg) at product maturity. Refrigerant cost in excess of $10/Ibm will be prohibitive in the market place, as the refrigerant cost starts contributing more than 10% of the product cost.

CONCLUSIONS AND RECOMMENDATIONS

- HFC-245ca will not perform satisfactorily when substituted for CFC-11 or HCFC-123 in existing chillers with no hardware changes due to surge concerns. For HFC-245ca to perform satisfactorily in a retrofit situation, the compressor must be modified with larger impellers, will likely need a larger motor and drive system, and in many instances will require a new compressor casing. The high cost of replacing compressors and drive systems is justified only in special situations driven by financial considerations at the job site.

- Chillers designed specifically for use with HFC-245ca can provide performance comparable to HCFC-123 chillers with some increase in heat transfer surface cost. This design is not commercially viable today because HFC-245ca is not available in commercial quantities, and the market resistance to refrigerants with Class 2 flammability ratings discourages the development of processing plants to commercially produce HFC-245ca.

- Although the flammability of HFC-245ca may be reduced by blending HFC-245ca with various flame suppressant compounds, addition of these compounds will degrade chiller performance and present significant technical challenges in heat exchanger design.

- The industry should continue to investigate cost effective methods for using high performance marginally flammable refrigerants such as HFC-245ca.

COMPLIANCE WITH AGREEMENT

The results documented in this report do not deviate from the contracted scope of work.

PRINCIPAL INVESTIGATOR EFFORT

Ed Keuper as principal investigator for this project has spent half of his time on this project from the contractual start date through 15 December 1995.

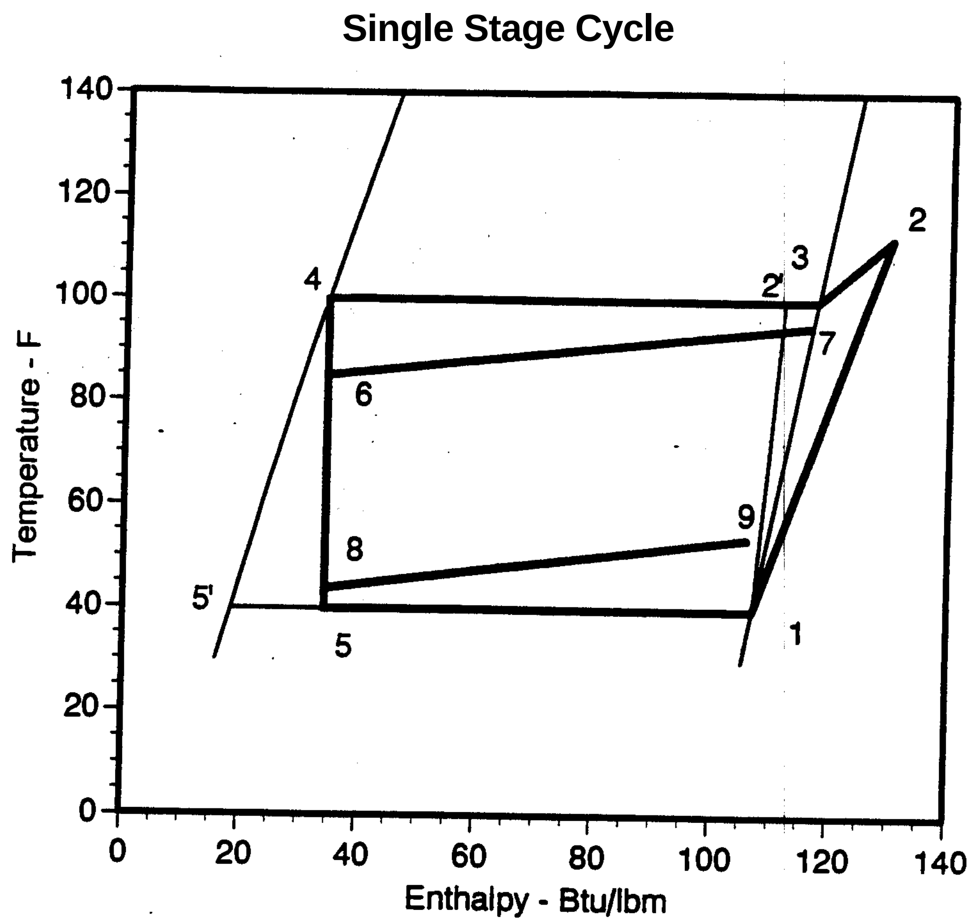

Single Stage Cycle
Temperature - F
Enthalpy - Btu/lbm
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
4
3
2
2'
7
6
9
8
5'
5
1

Figure 1

Three Stage Cycle with Economizers

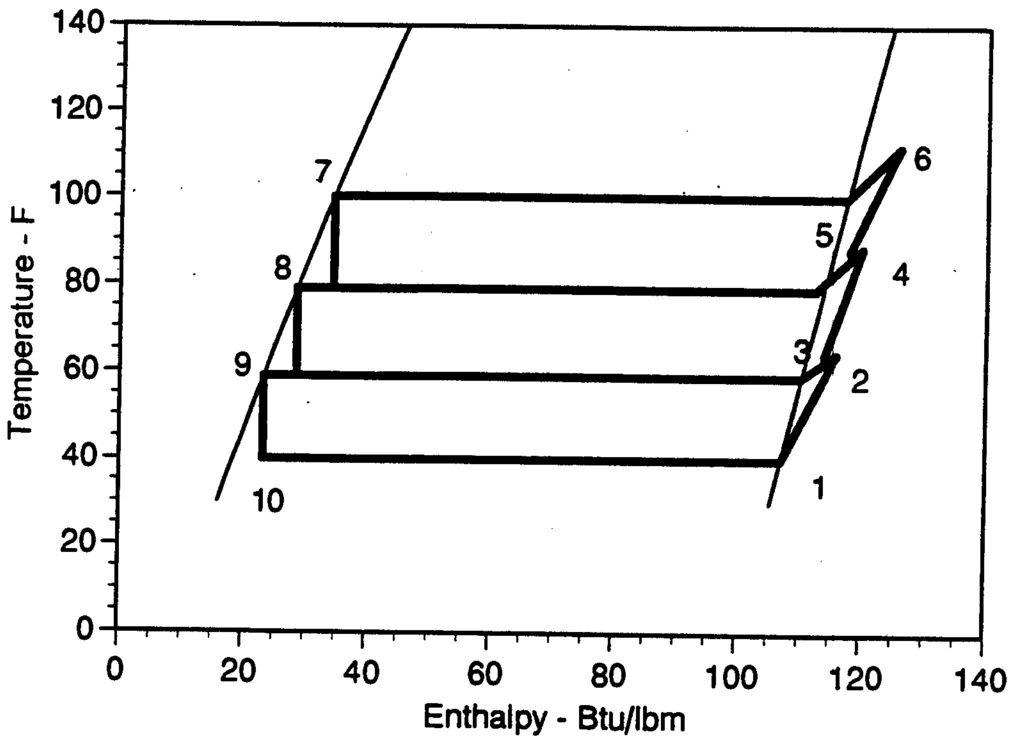


Figure 2

Fig. 3 Chiller Capacity Oil Comparison
CFC-11, Full Load, 26/26/26 Impellers

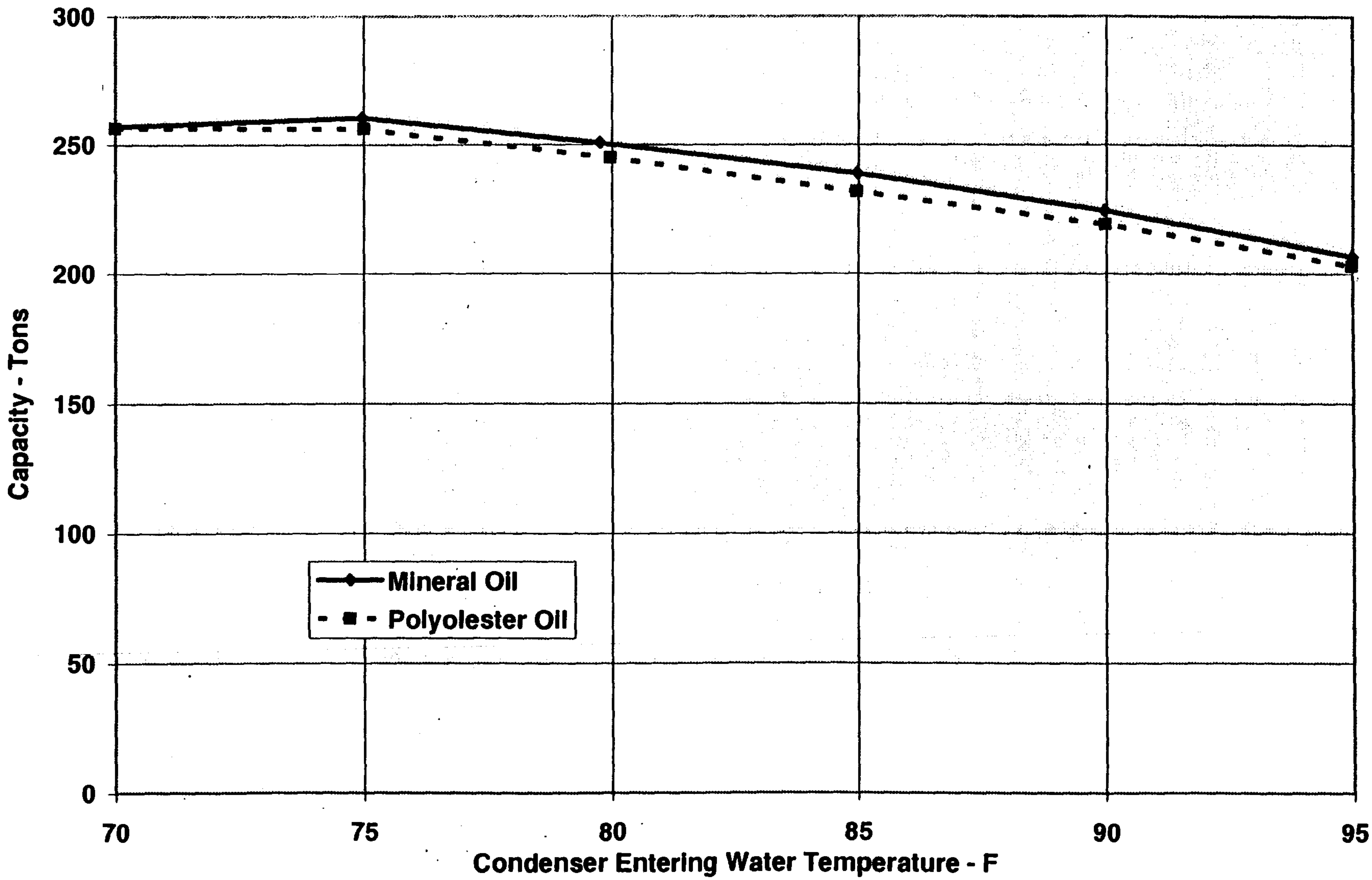


Fig. 3a Chiller Capacity Oil Comparison
CFC-11, Full Load, 660/660/660 Impellers

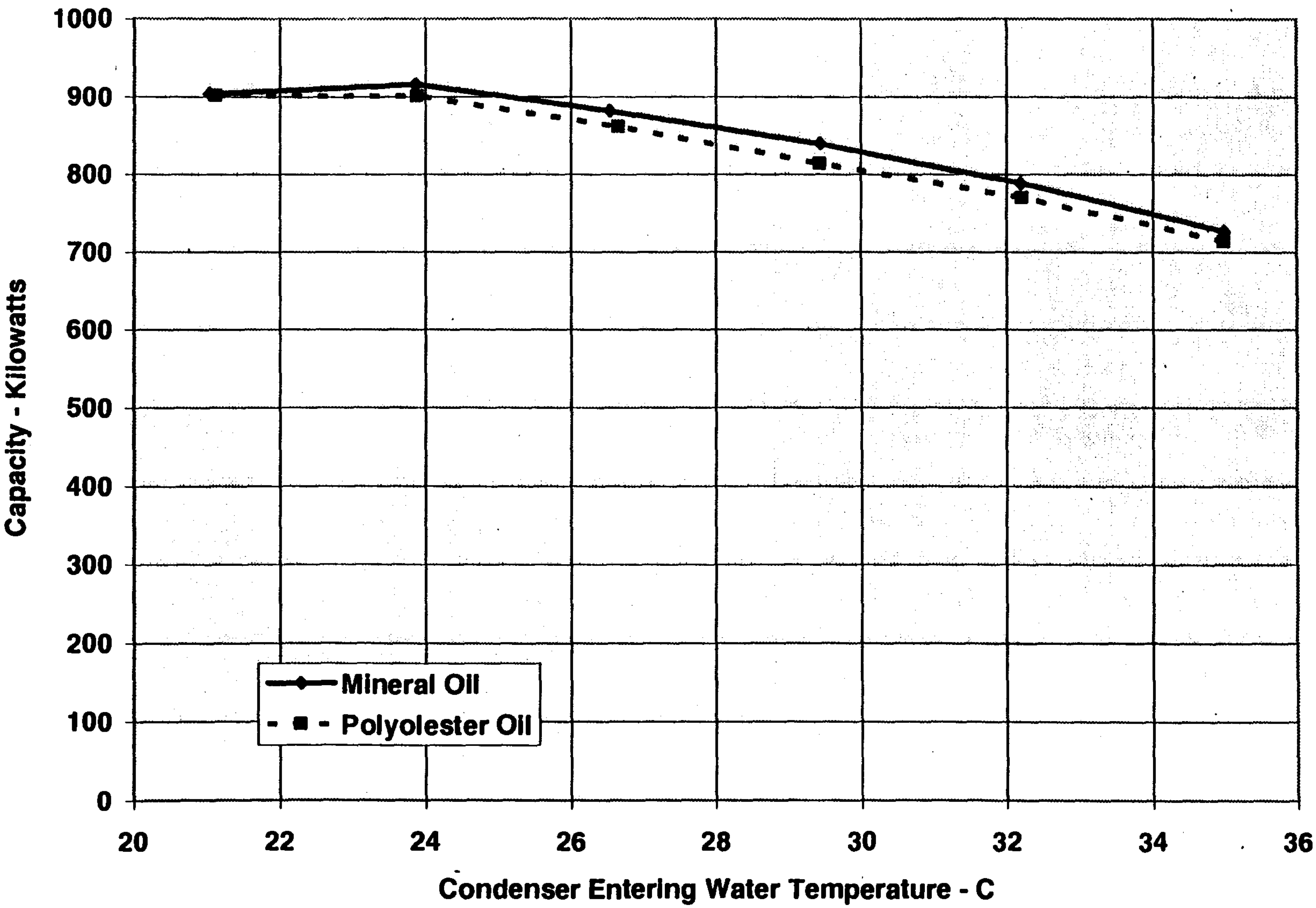


Fig. 4 Chiller Power Consumption Oil Comparison
CFC-11, Full Load, 26/26/26 Impellers

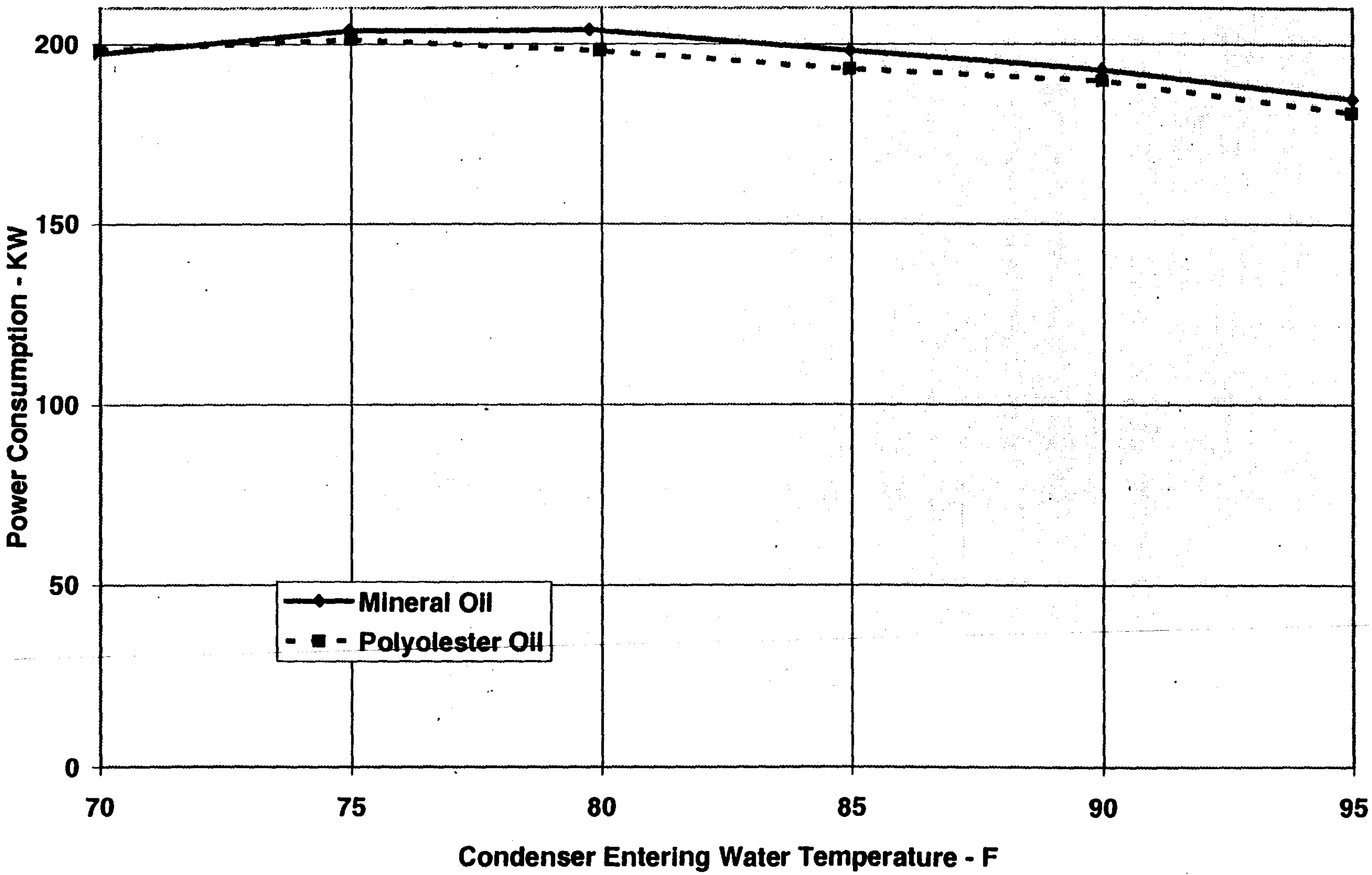
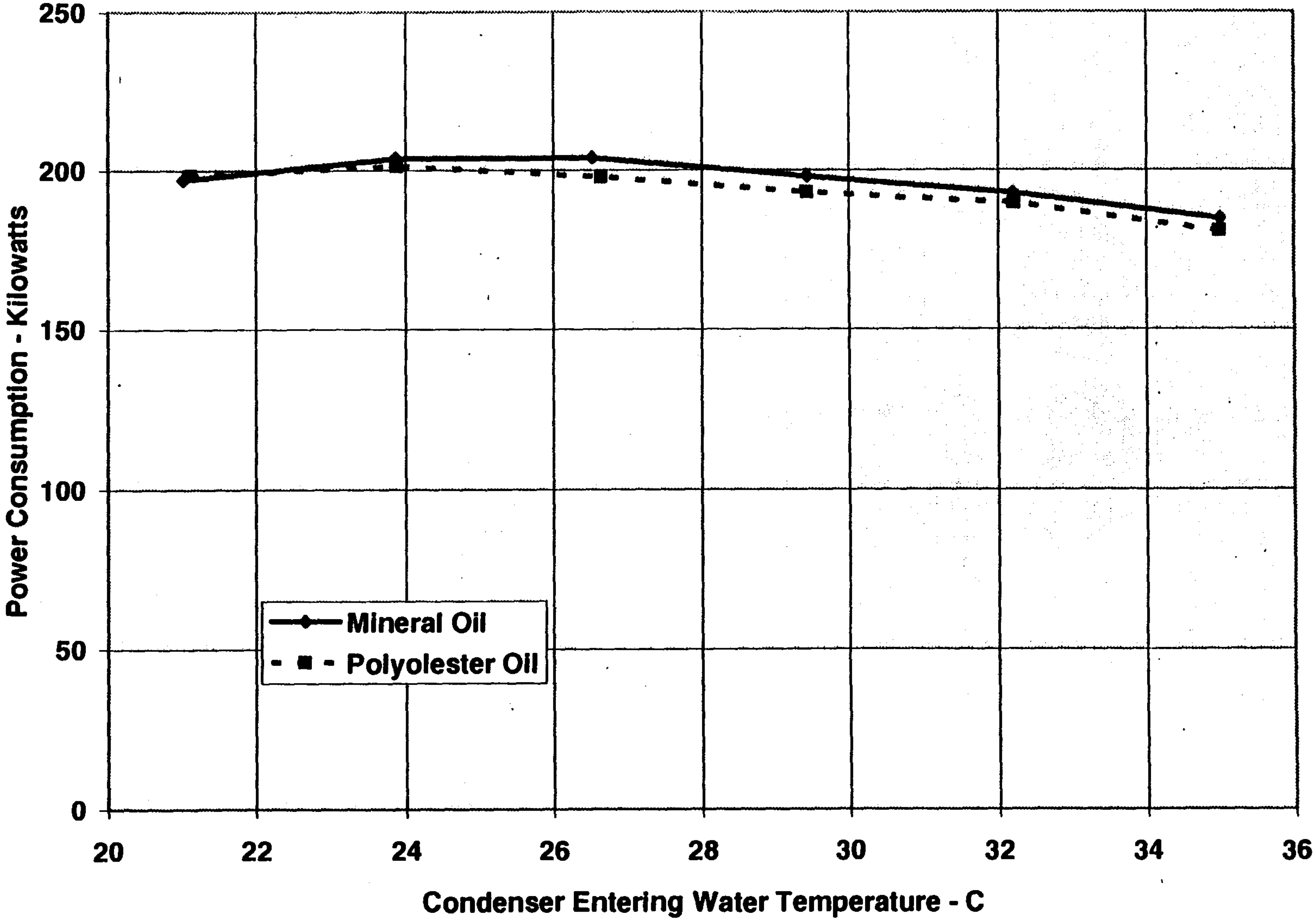


Fig. 4a Chiller Power Consumption Oil Comparison
CFC-11, Full Load, 660/660/660 Impellers



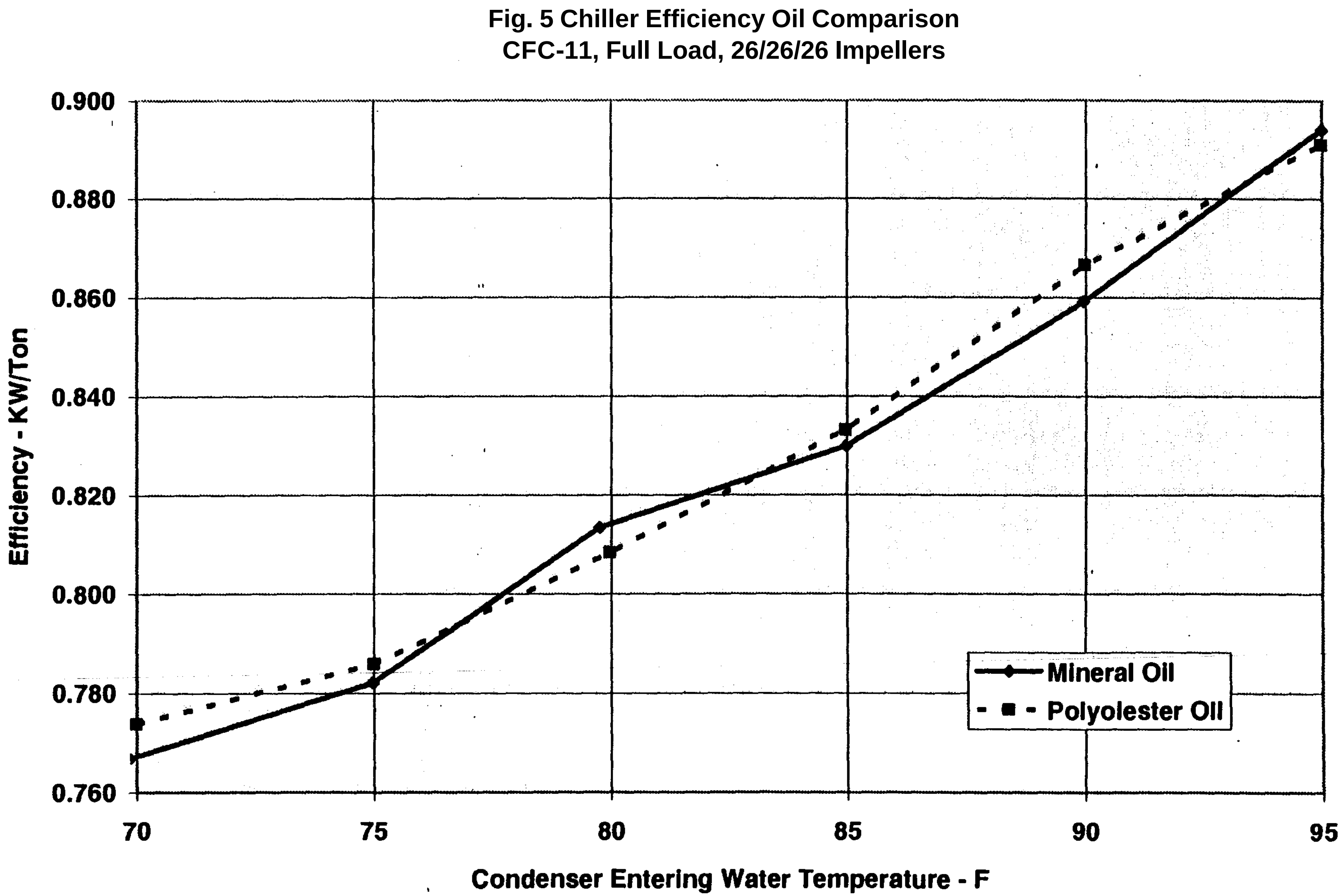


Fig. 5 Chiller Efficiency Oil Comparison
CFC-11, Full Load, 26/26/26 Impellers
0.900
0.880
0.860
0.840
0.820
0.800
0.780
0.760
Efficiency - KW/Ton
70
75
80
85
90
95
Condenser Entering Water Temperature - F
Mineral Oil
Polyolester Oil

Fig. 5a Chiller Efficiency Oil Comparison
CFC-11, Full Load, 660/660/660 Impellers

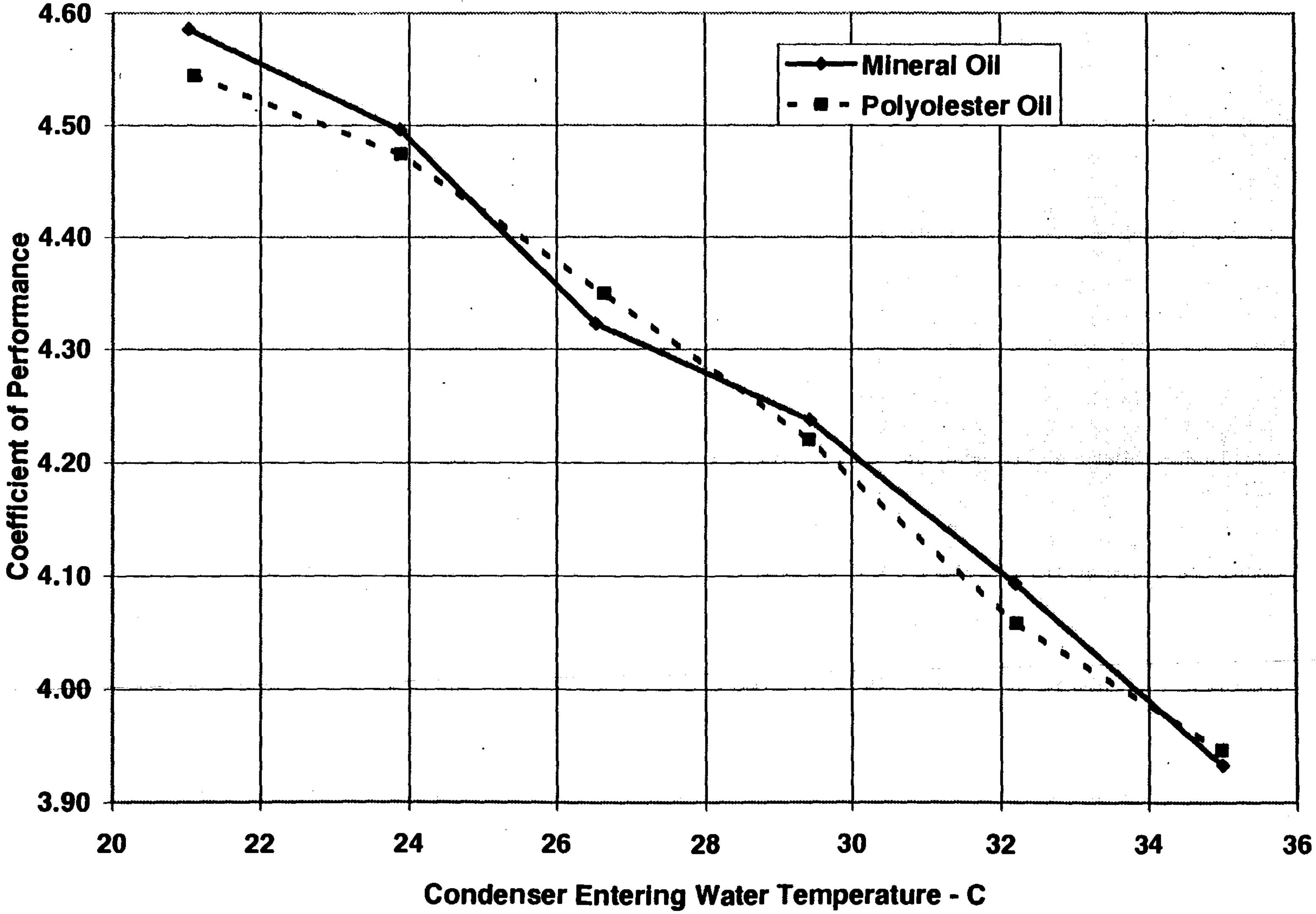
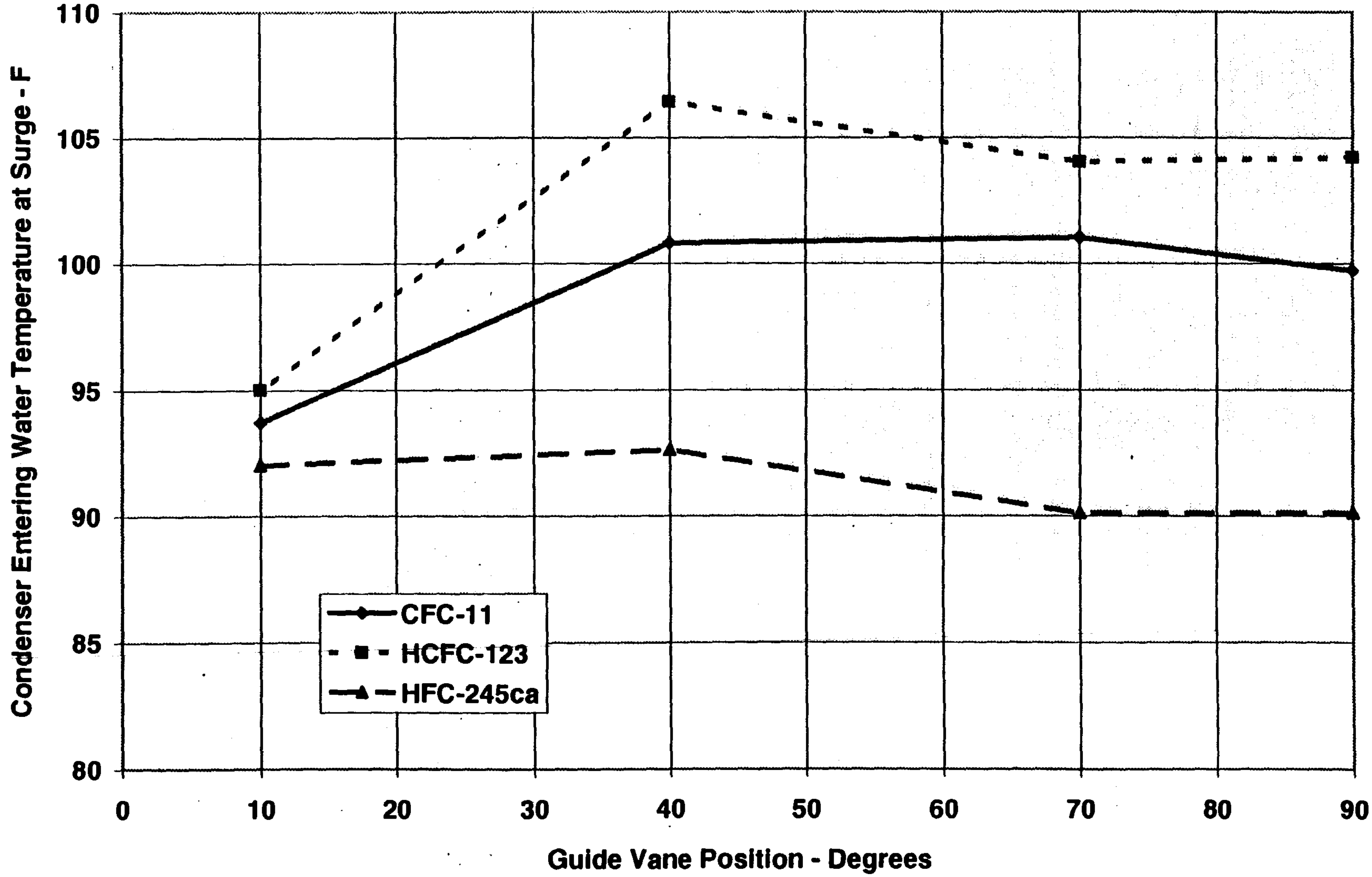


Fig. 6 Condenser Entering Water Temperature at Surge vs. Vanes
25/25/24.5 Impellers



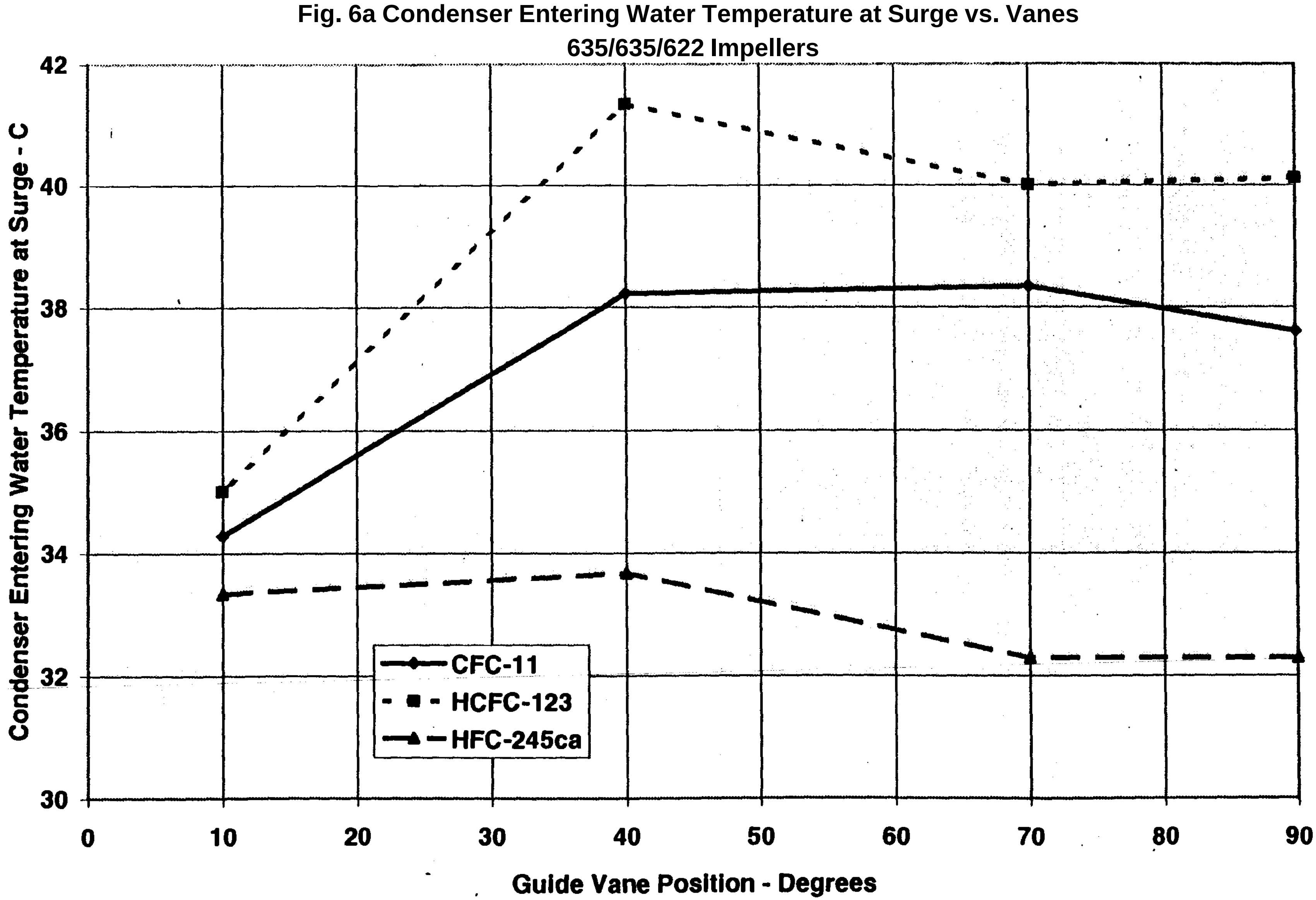


Fig. 6a Condenser Entering Water Temperature at Surge vs. Vanes
635/635/622 Impellers
Condenser Entering Water Temperature at Surge - C
42
40
38
36
34
32
30
0
10
20
30
40
50
60
70
80
90
Guide Vane Position - Degrees
CFC-11
HCFC-123
HFC-245ca

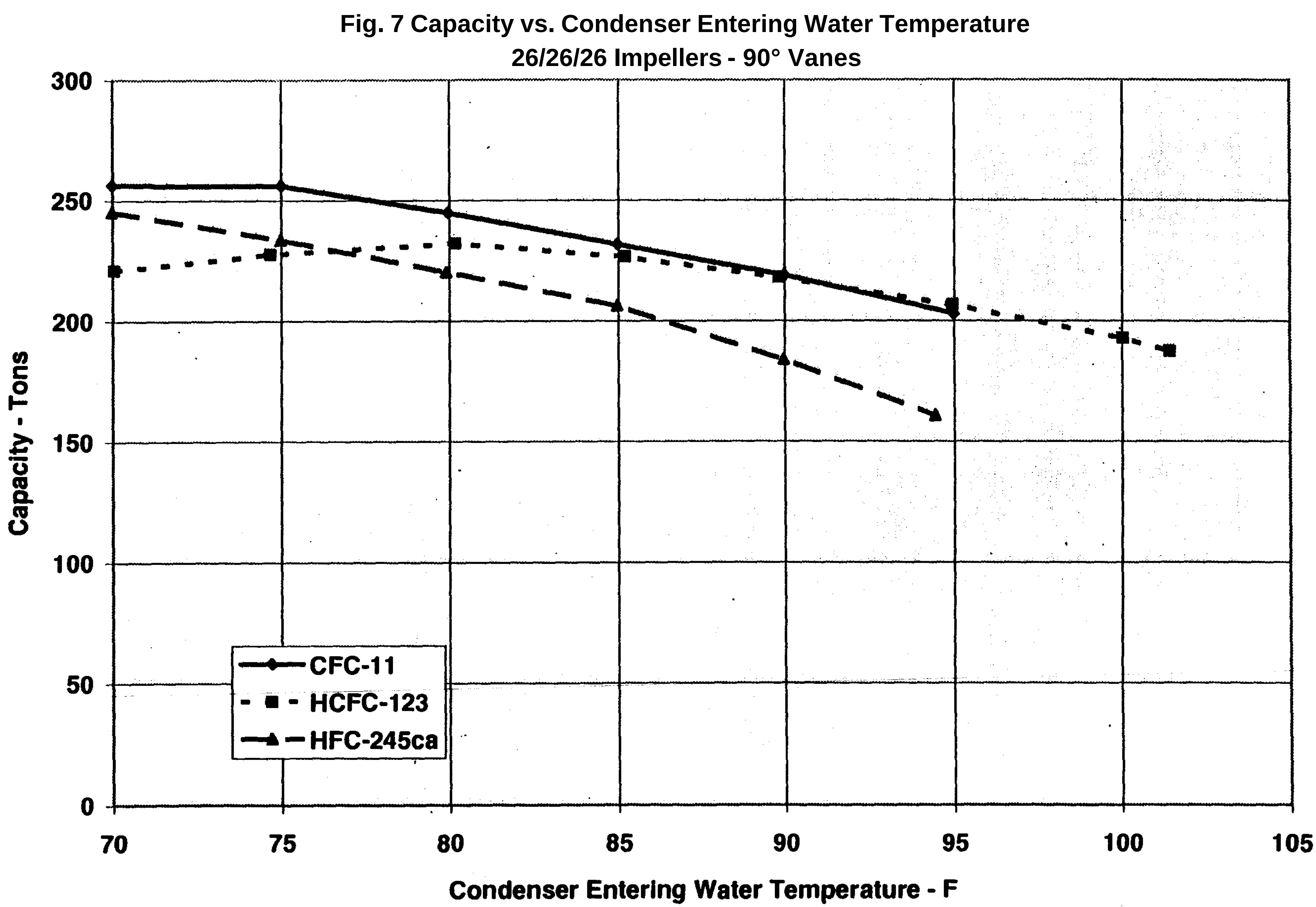


Fig. 7 Capacity vs. Condenser Entering Water Temperature
26/26/26 Impellers - 90° Vanes
Capacity - Tons
300
250
200
150
100
50
0
70
75
80
85
90
95
100
105
Condenser Entering Water Temperature - F
CFC-11
HCFC-123
HFC-245ca

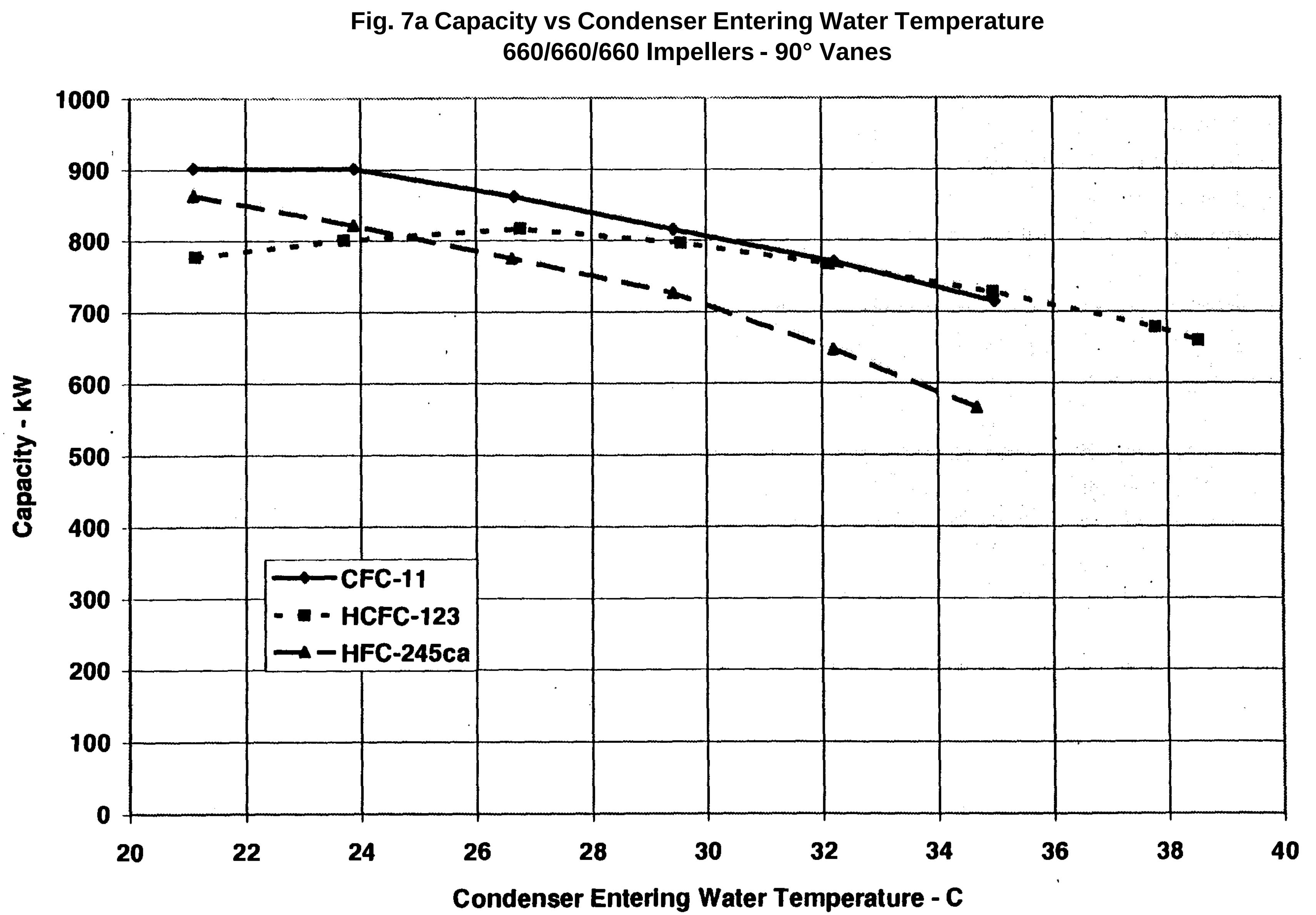


Fig. 7a Capacity vs Condenser Entering Water Temperature
660/660/660 Impellers - 90° Vanes
Capacity - kW
Condenser Entering Water Temperature - C
CFC-11
HCFC-123
HFC-245ca
1000
900
800
700
600
500
400
300
200
100
0
20
22
24
26
28
30
32
34
36
38
40

Fig. 8 Power vs. Condenser Entering Water Temperature

26/26/26 Impellers - 90° Vanes

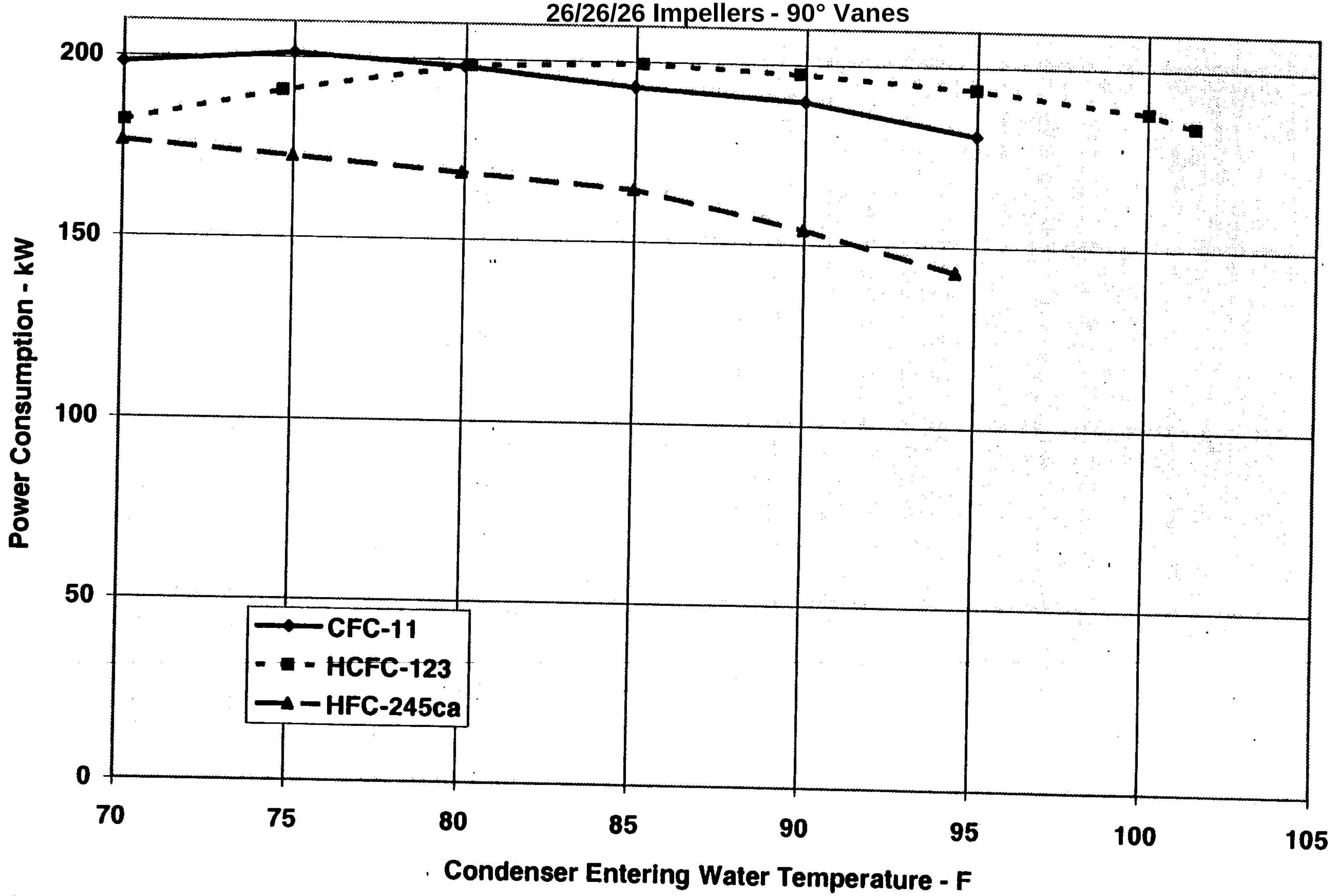


Fig. 8a Power vs. Condenser Entering Water Temperature
660/660/660 Impellers - 90° Vanes

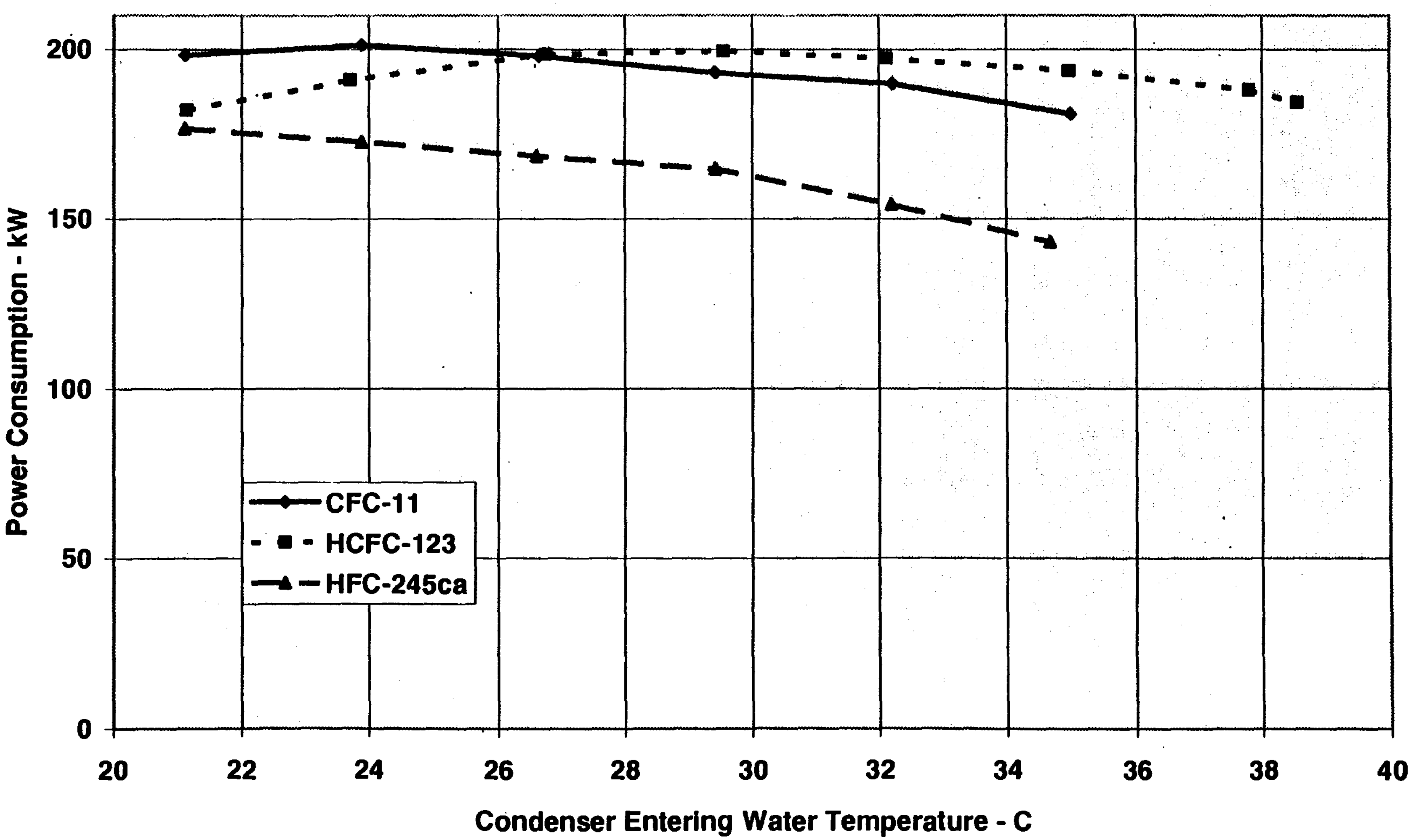


Fig. 9 Kw/Ton vs. Condenser Entering Water Temperature
26/26/26 Impellers - 90° Vanes

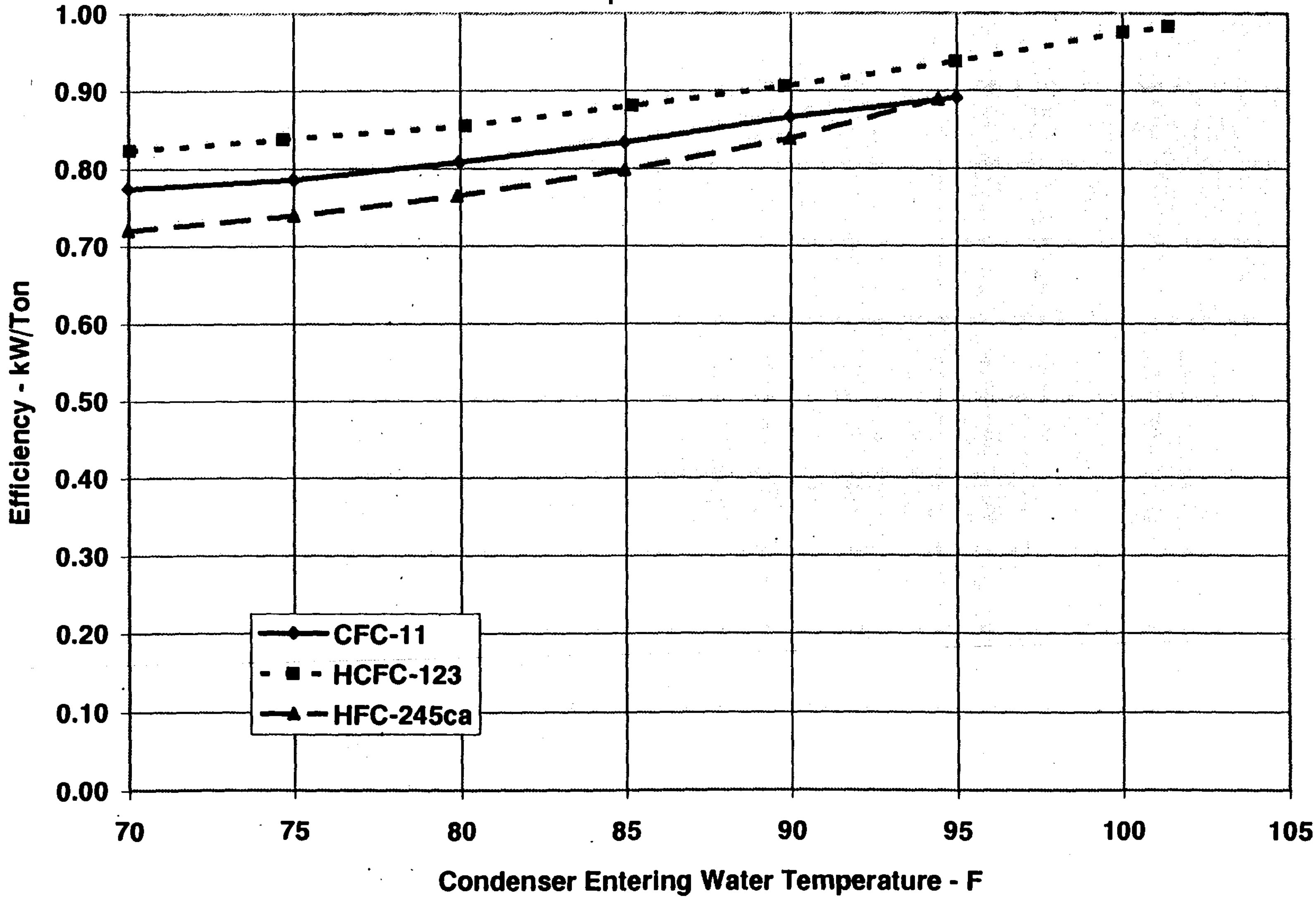


Fig. 9a Efficiency vs. Condenser Entering Water Temperature
660/660/660 Impellers - 90° Vanes

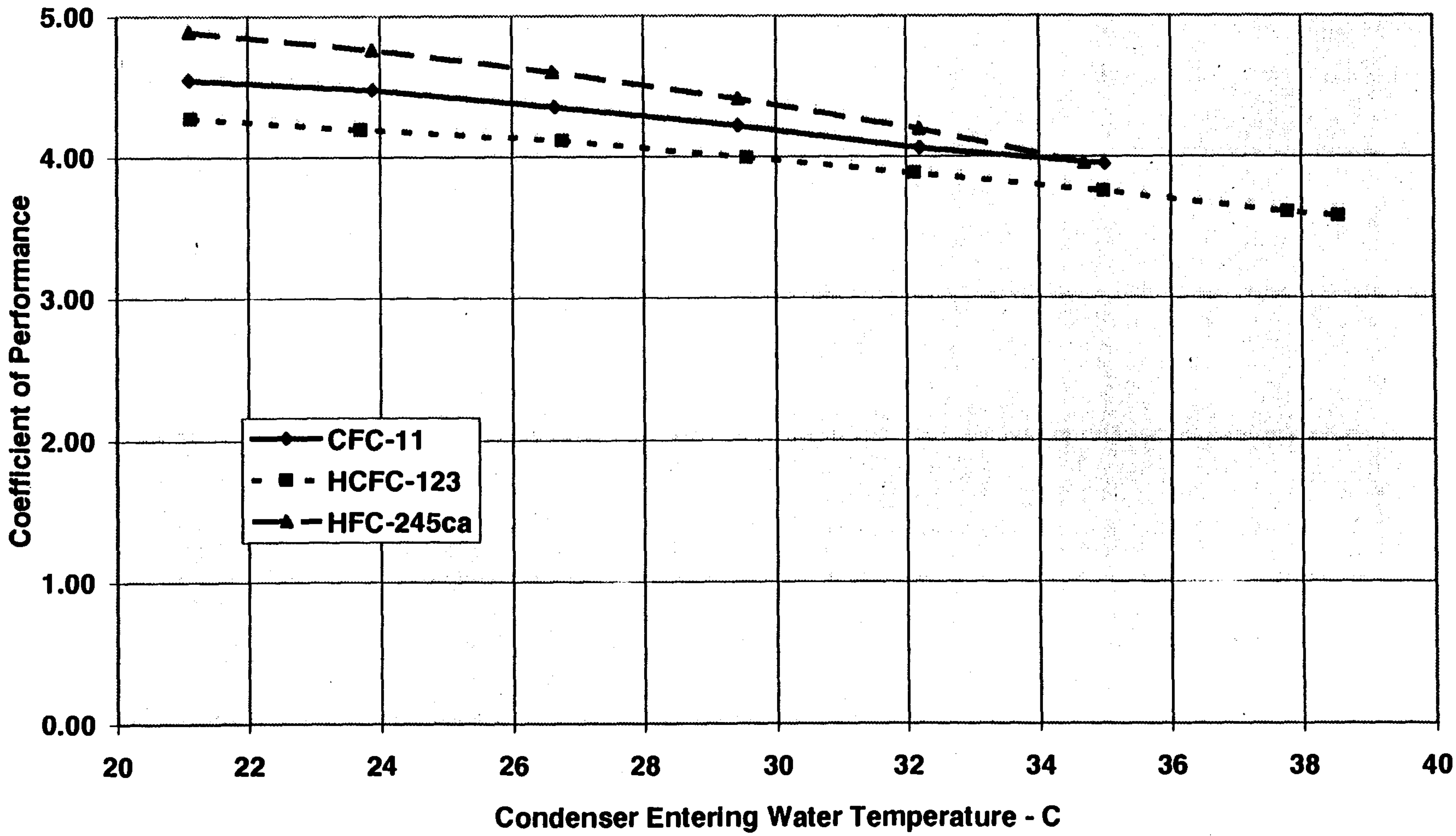


Fig. 10 Capacity vs. Condenser Entering Water Temperature
25/25/24.5 Impellers - 90° Vanes

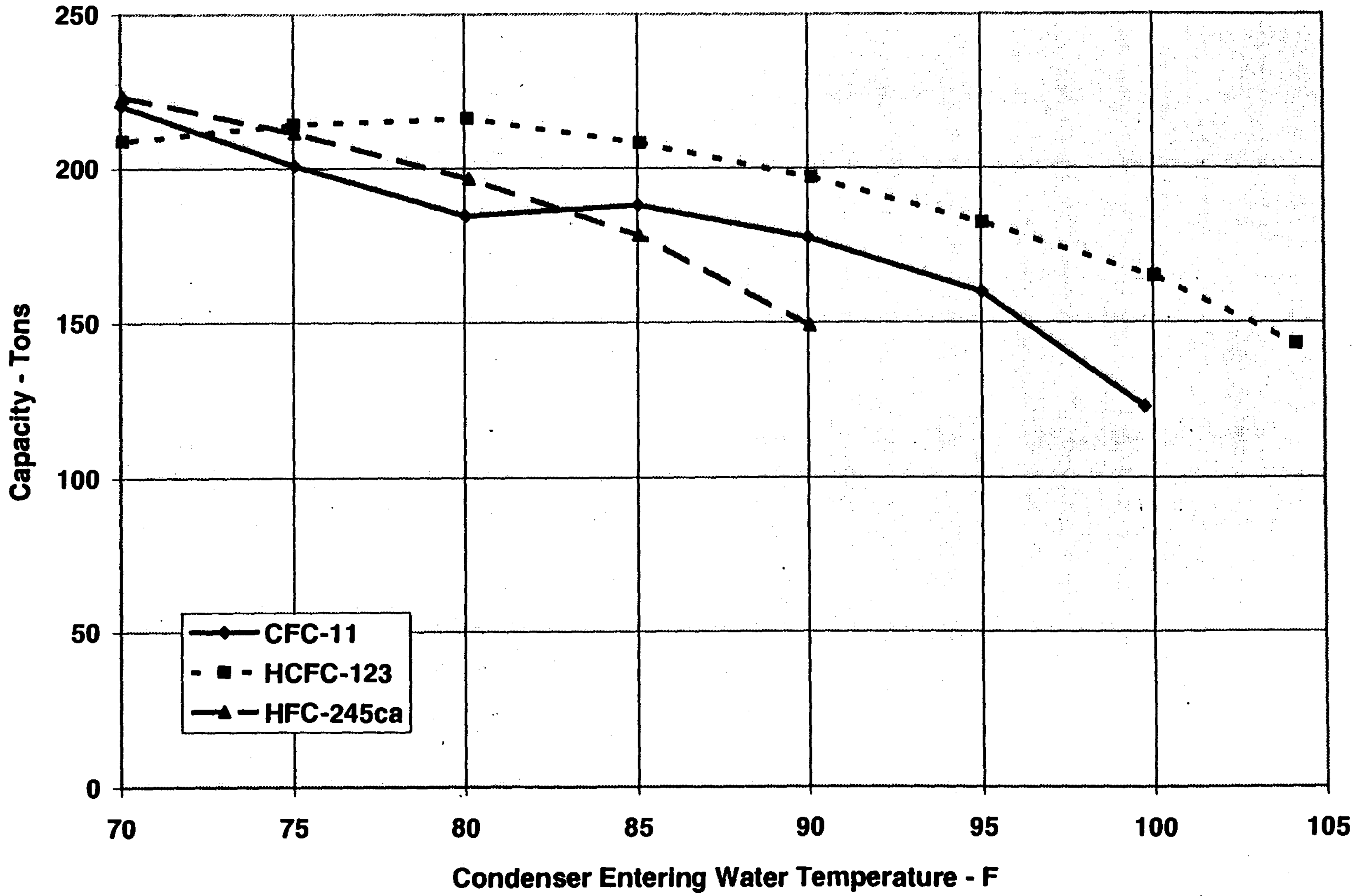


Fig. 10a Capacity vs. Condenser Entering Water Temperature
635/635/622 Impellers - 90° Vanes

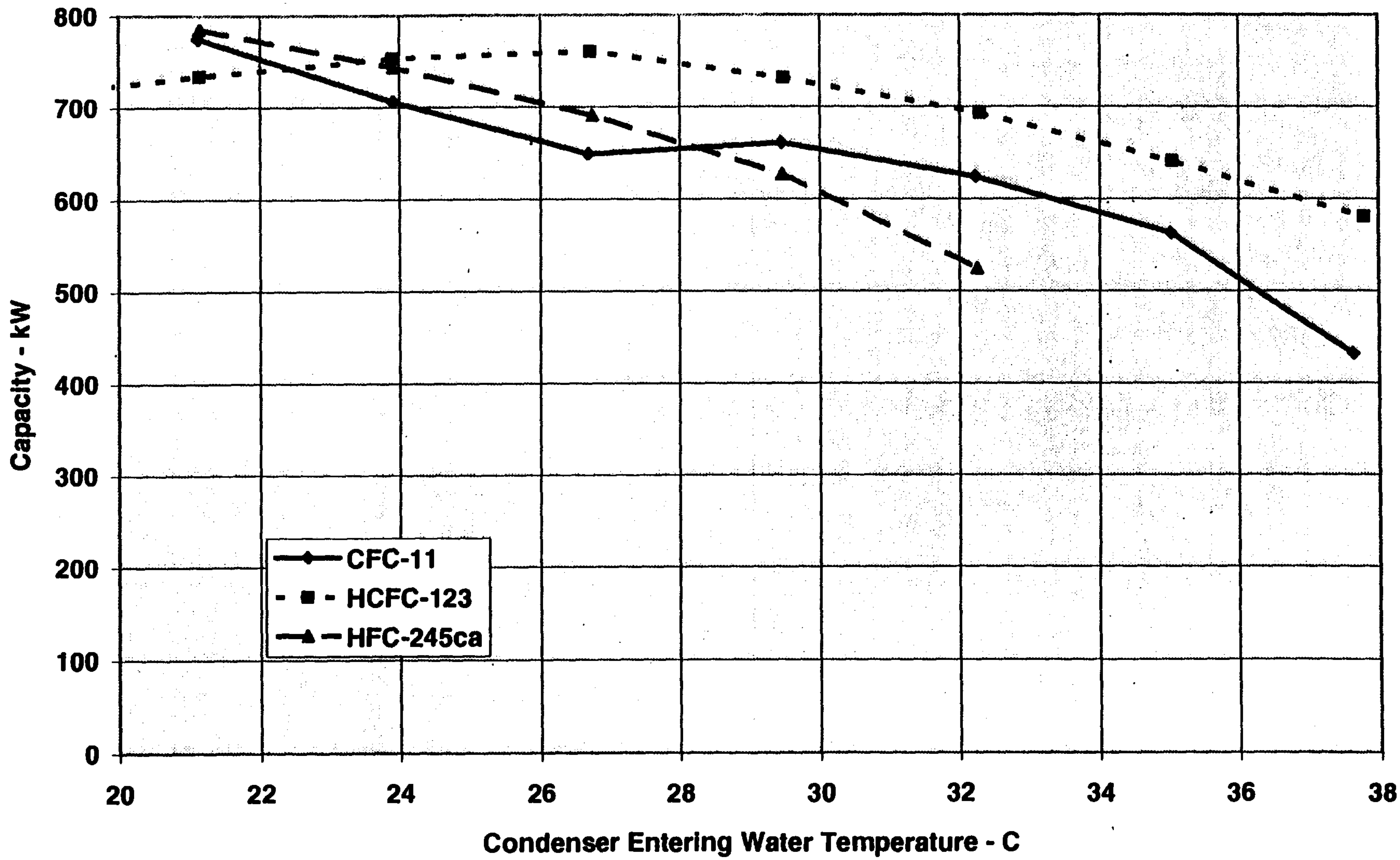


Fig. 11 Power vs. Condenser Entering Water Temperature
25/25/24.5 Impellers - 90° Vanes

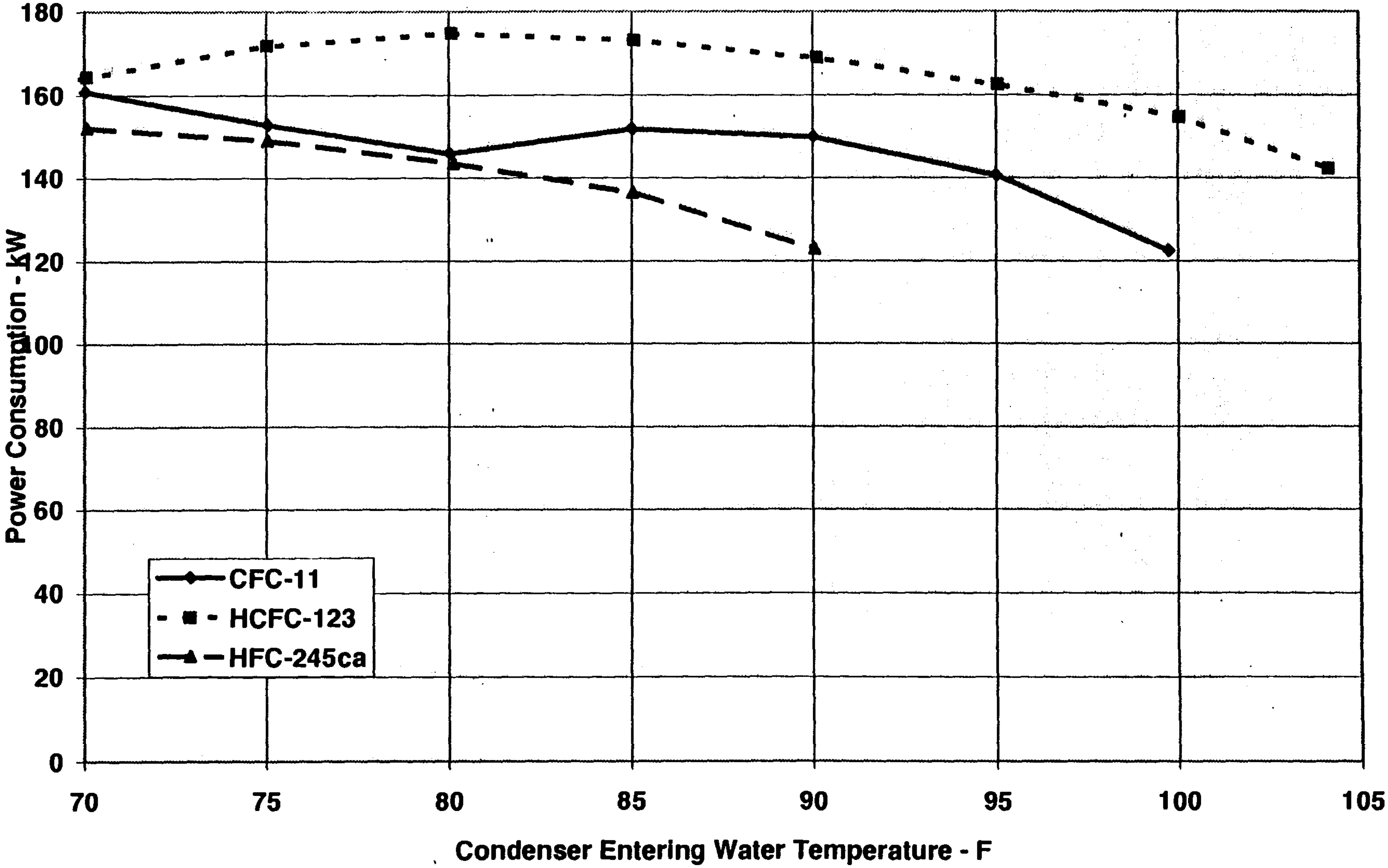


Fig. 11a Power vs. Condenser Entering Water Temperature
635/635/622 Impellers - 90° Vanes

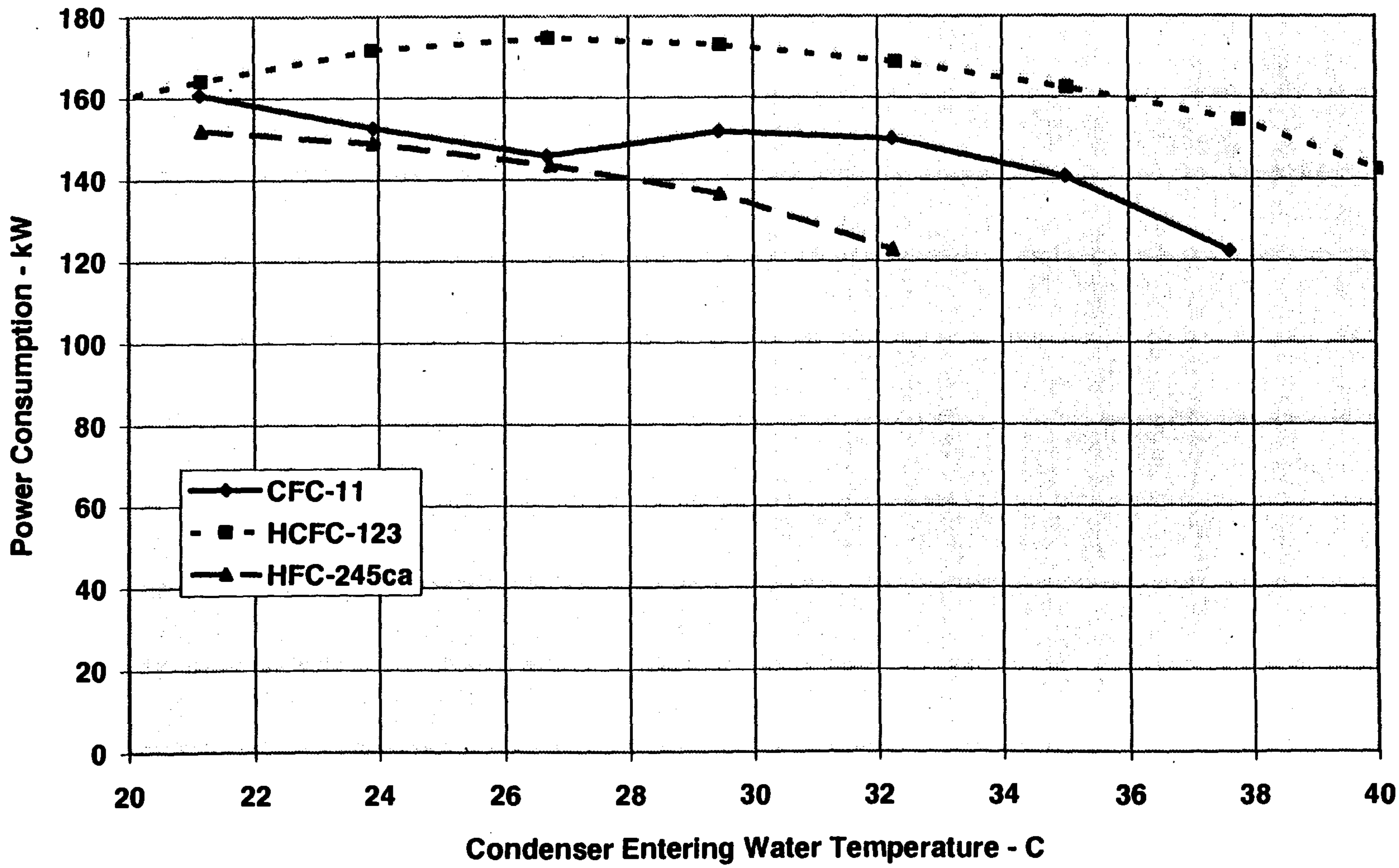


Fig. 12 KW/Ton vs. Condenser Entering Water Temperature
25/25/24.5 Impellers - 90° Vanes

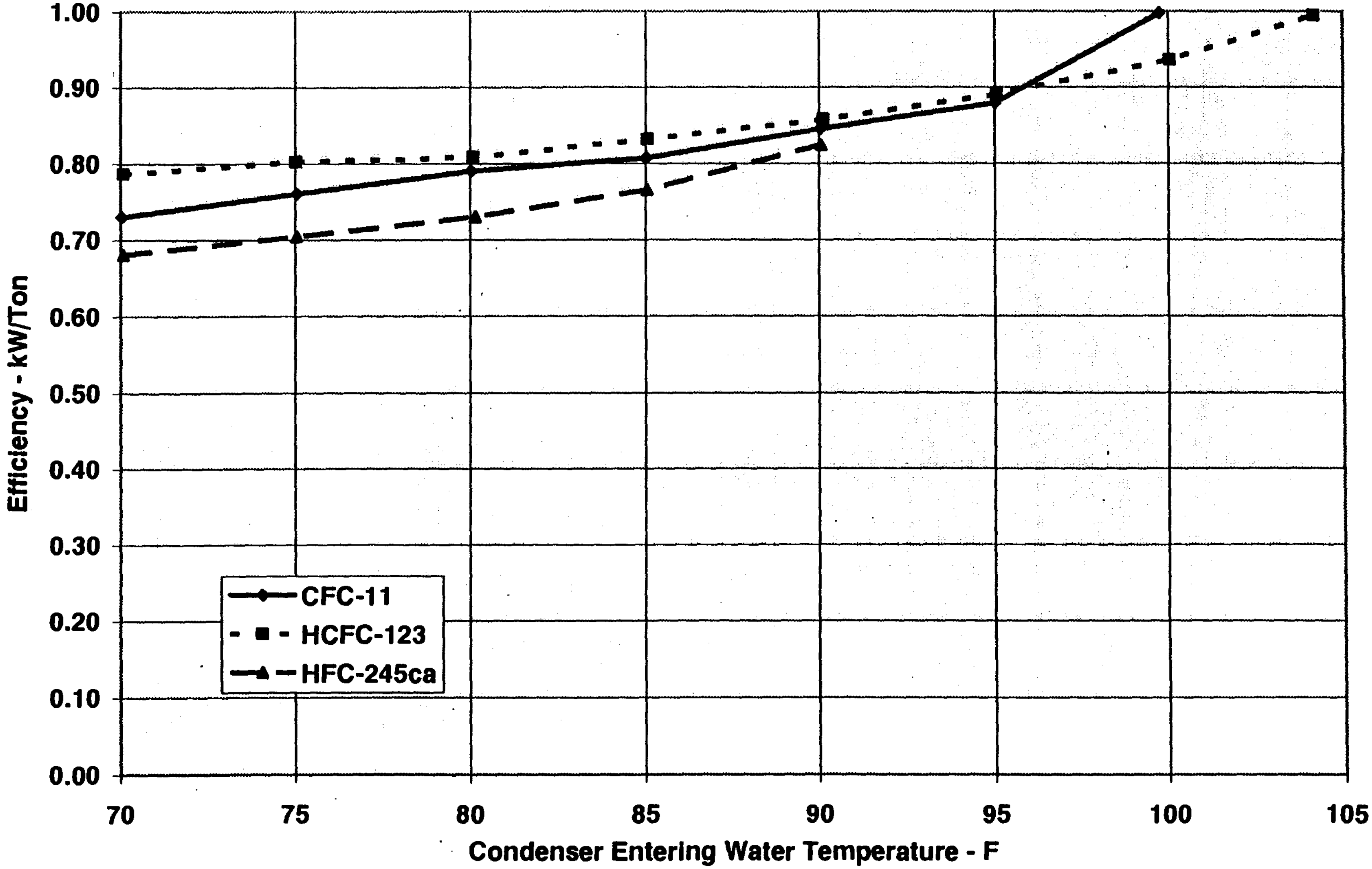
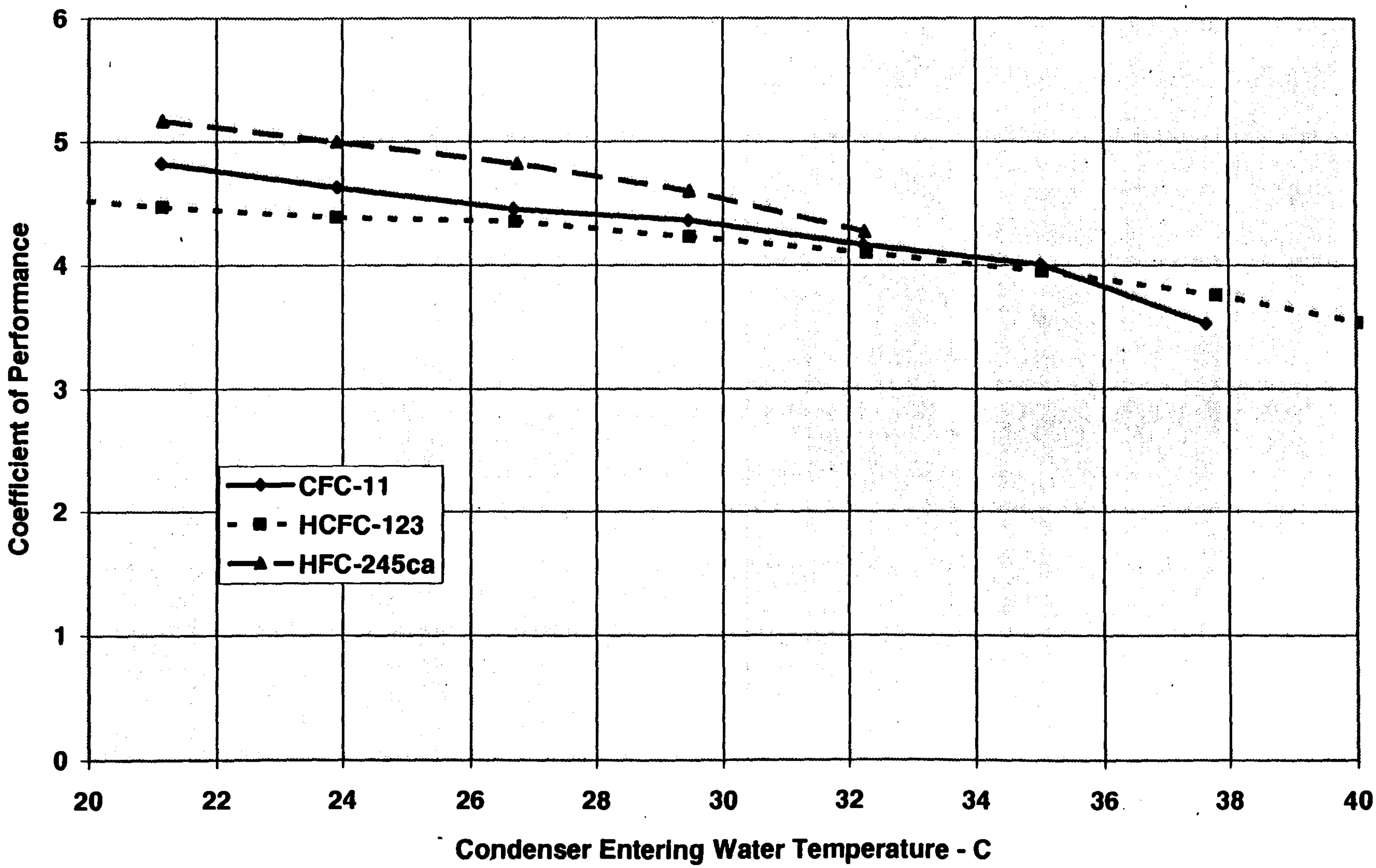


Fig. 12a Efficiency vs. Condenser Entering Water Temperature
635/635/622 Impellers - 90° Vanes



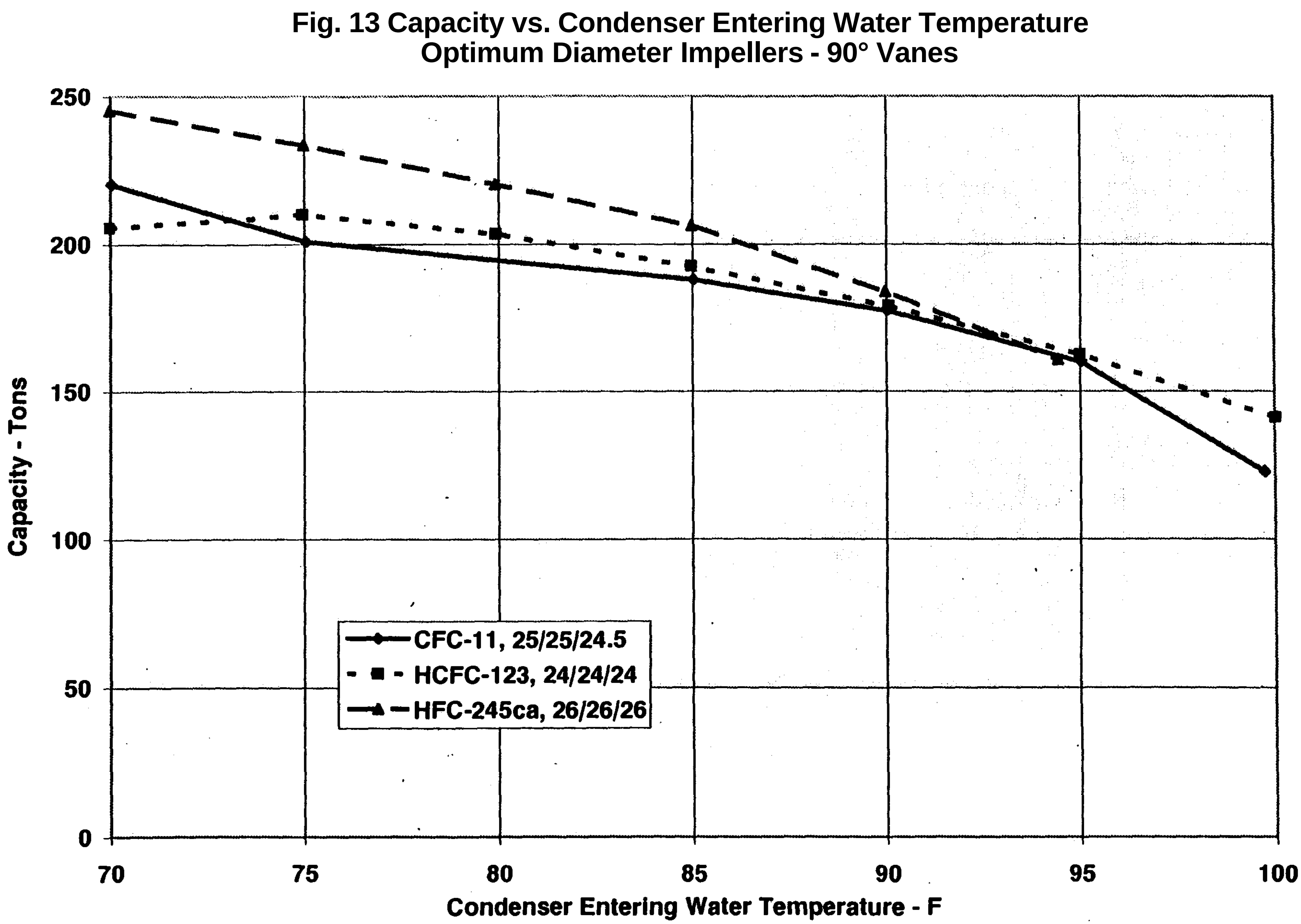


Fig. 13 Capacity vs. Condenser Entering Water Temperature
Optimum Diameter Impellers - 90° Vanes
Capacity - Tons
250
200
150
100
50
0
70
75
80
85
90
95
100
Condenser Entering Water Temperature - F
CFC-11, 25/25/24.5
HCFC-123, 24/24/24
HFC-245ca, 26/26/26

Fig. 13a Capacity vs. Condenser Entering Water Temperature
Optimum Diameter Impellers - 90° Vanes

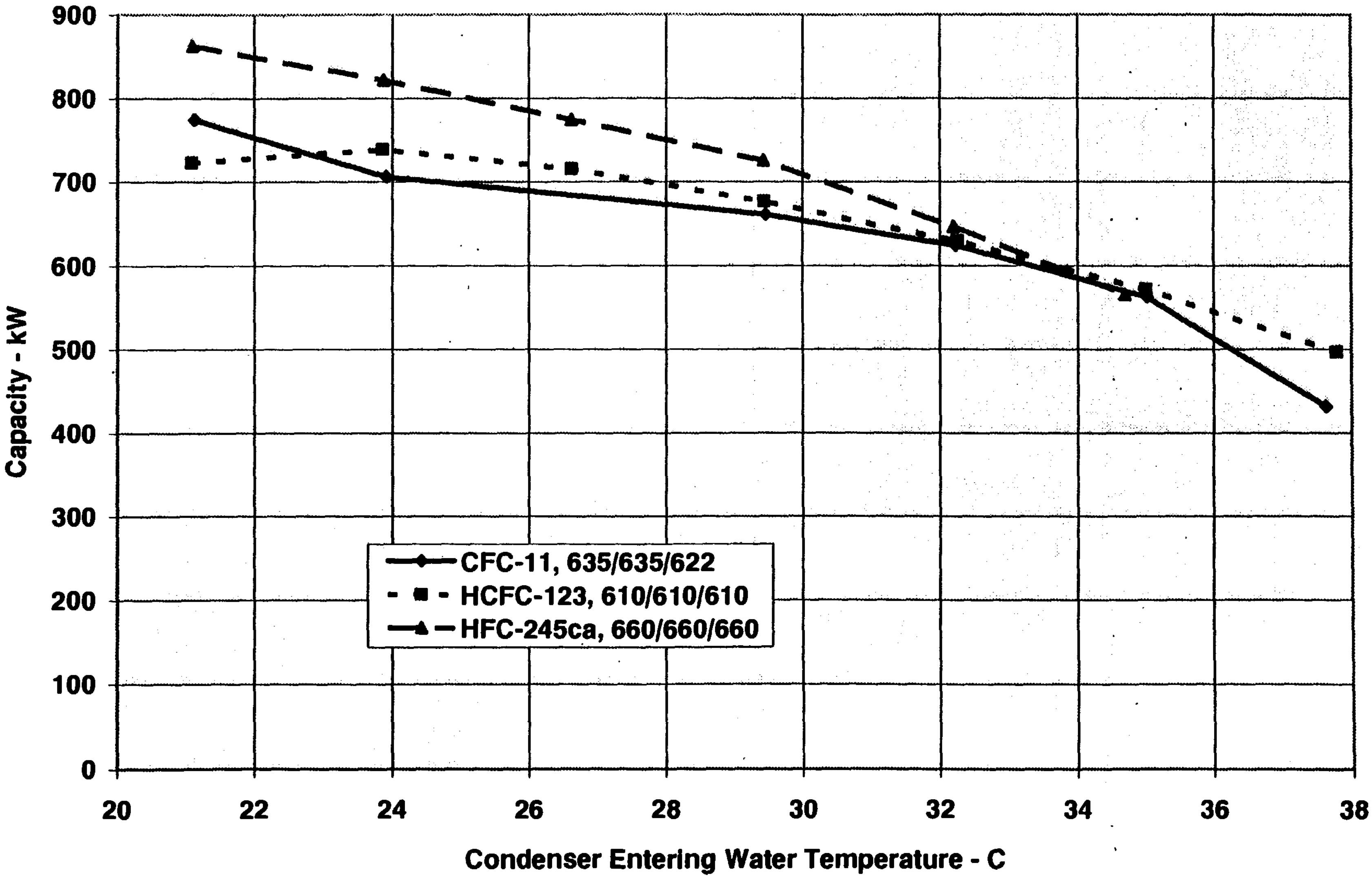


Fig. 14 Power vs. Condenser Entering Water Temperature
Optimum Diameter Impellers - 90° Vanes

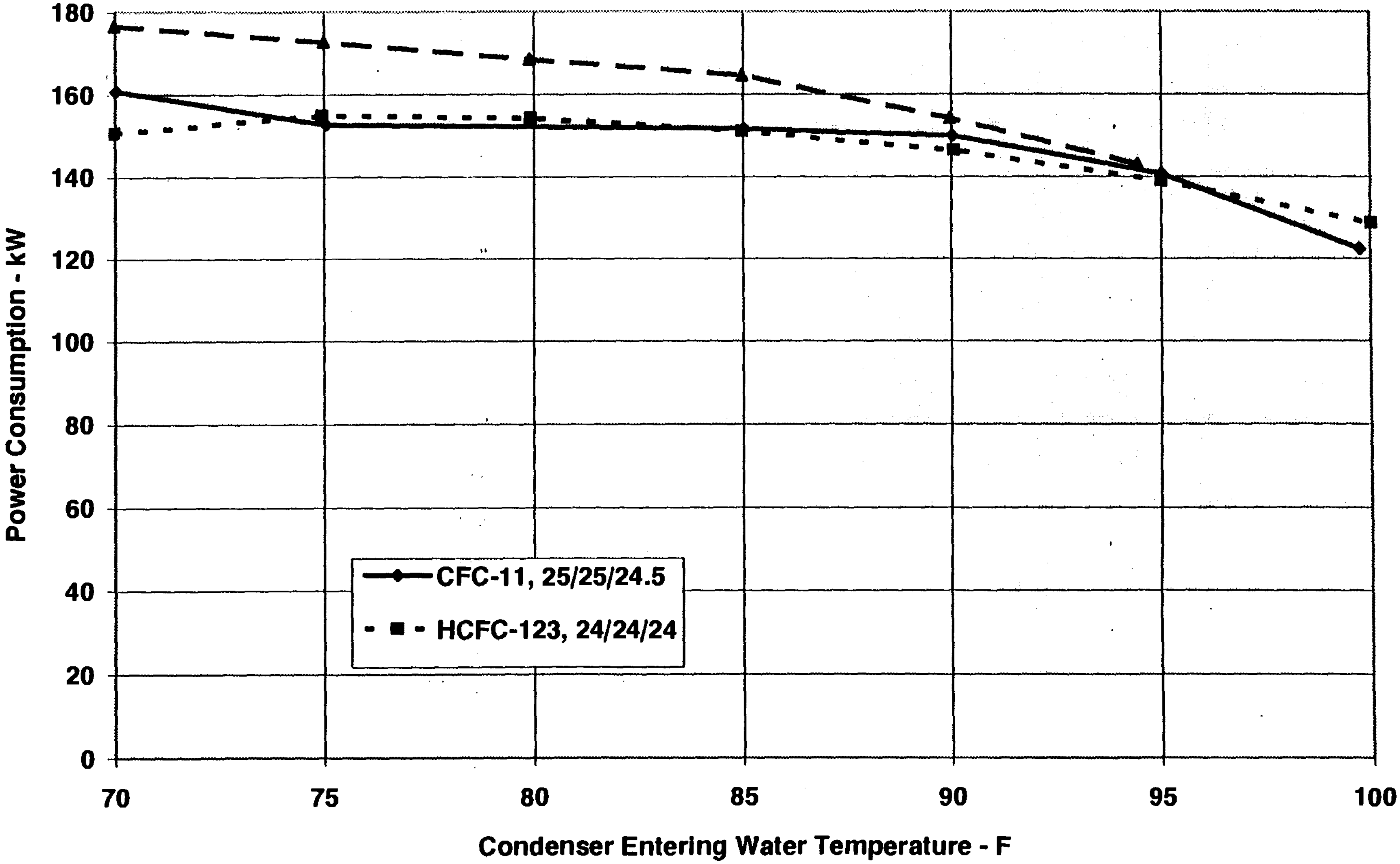


Fig. 14a Power vs. Condenser Entering Water Temperature
Optimum Diameter Impellers - 90° Vanes

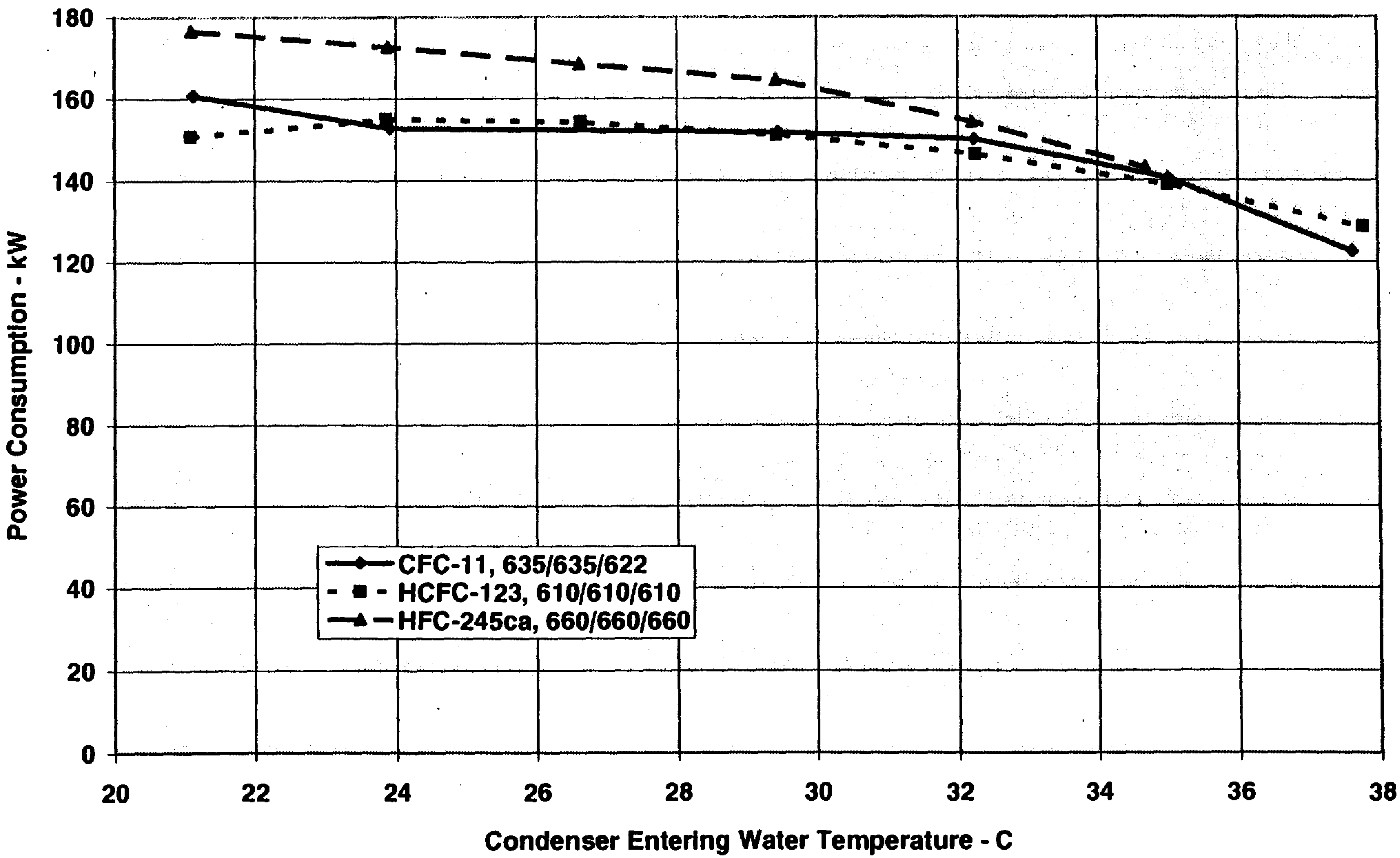


Fig. 15 KW/Ton vs. Condenser Entering Water Temperature
Optimum Diameter Impellers - 90° Vanes

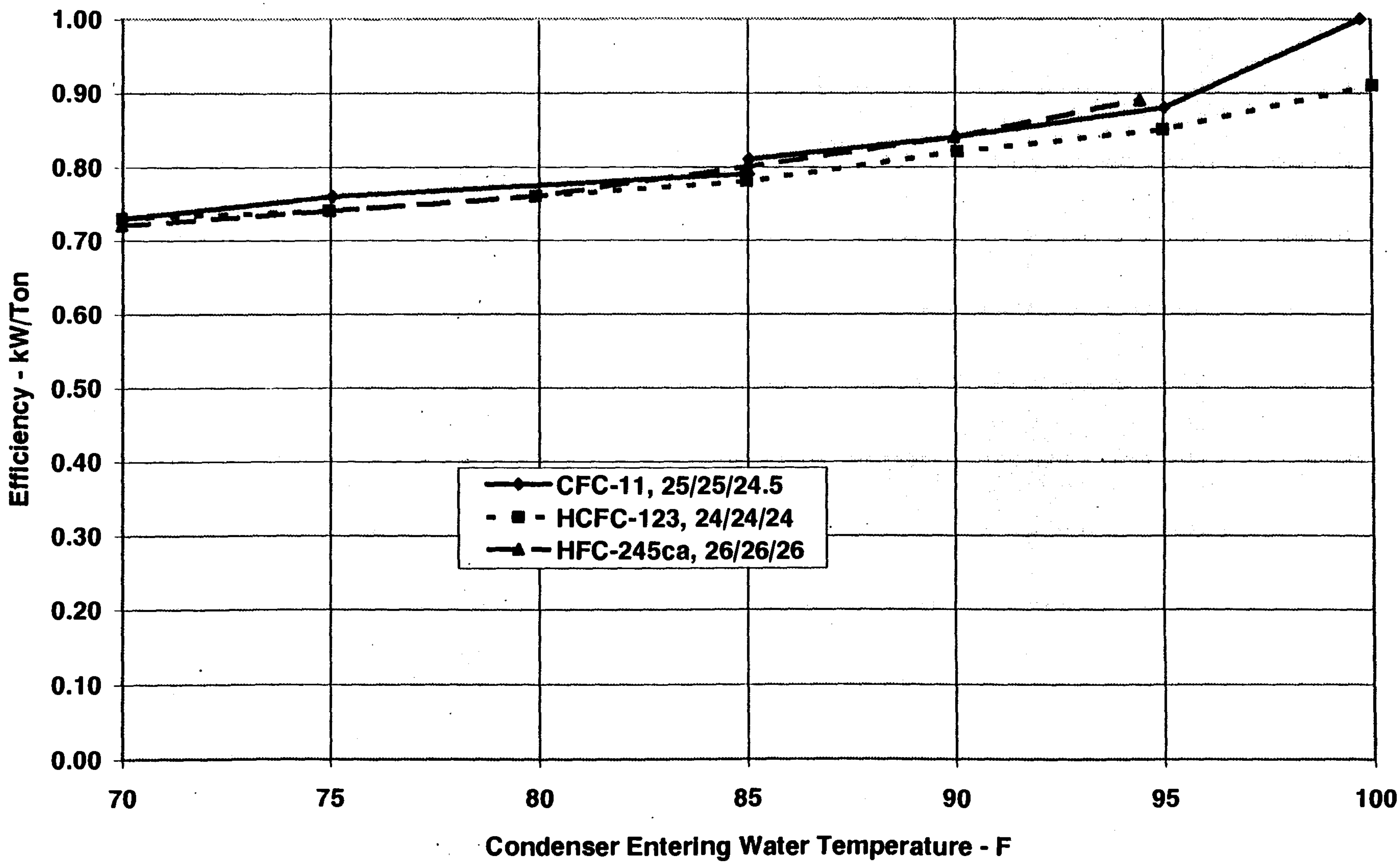


Fig. 15a Efficiency vs. Condenser Entering Water Temperature
Optimum Diameter Impellers - 90° Vanes

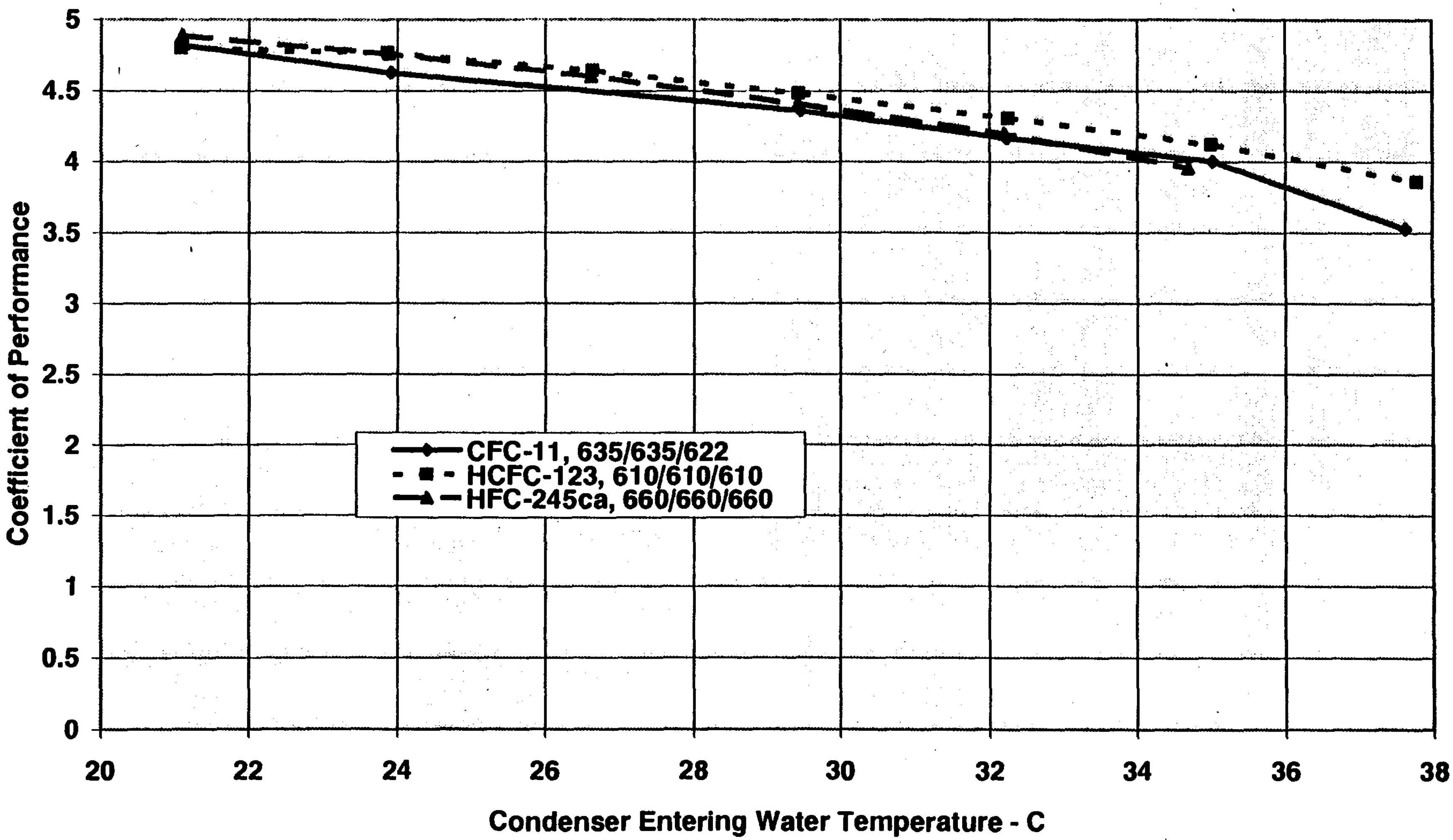


Fig. 16 Power vs. Capacity for CFC-11 Conversion with and without Impeller Replacement

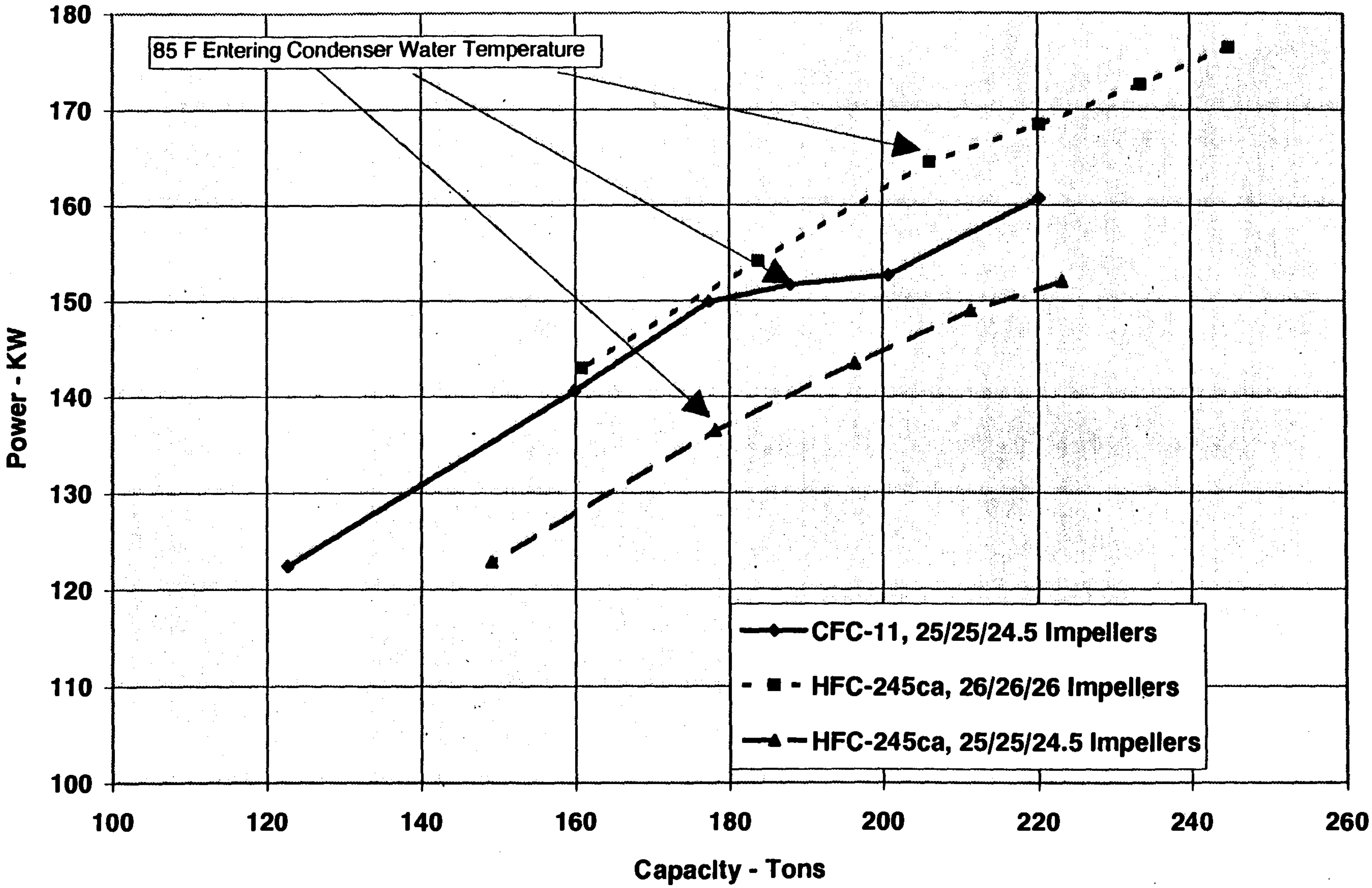
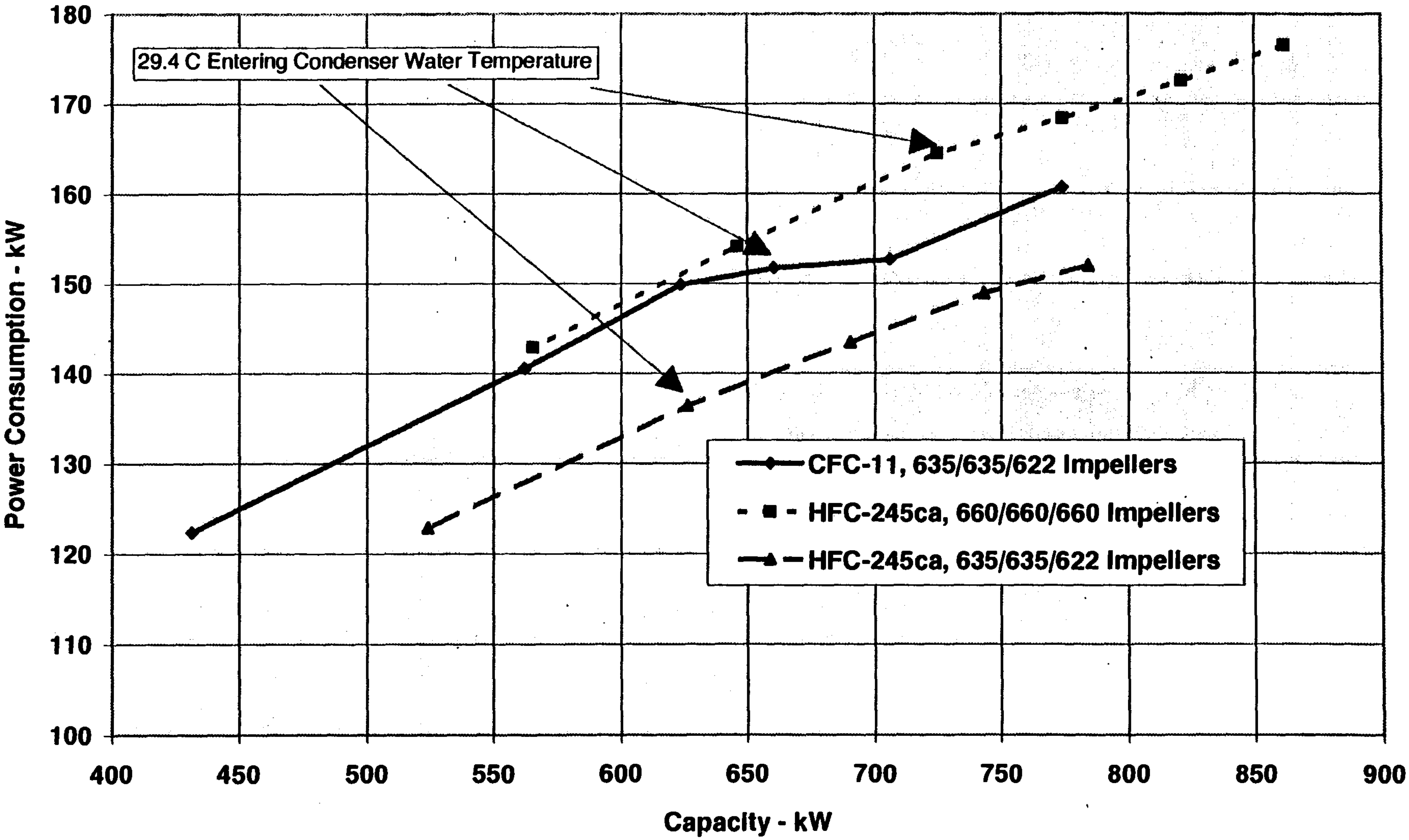


Fig. 16a Power vs. Capacity for CFC-11 Conversion With and Without Impeller Replacement



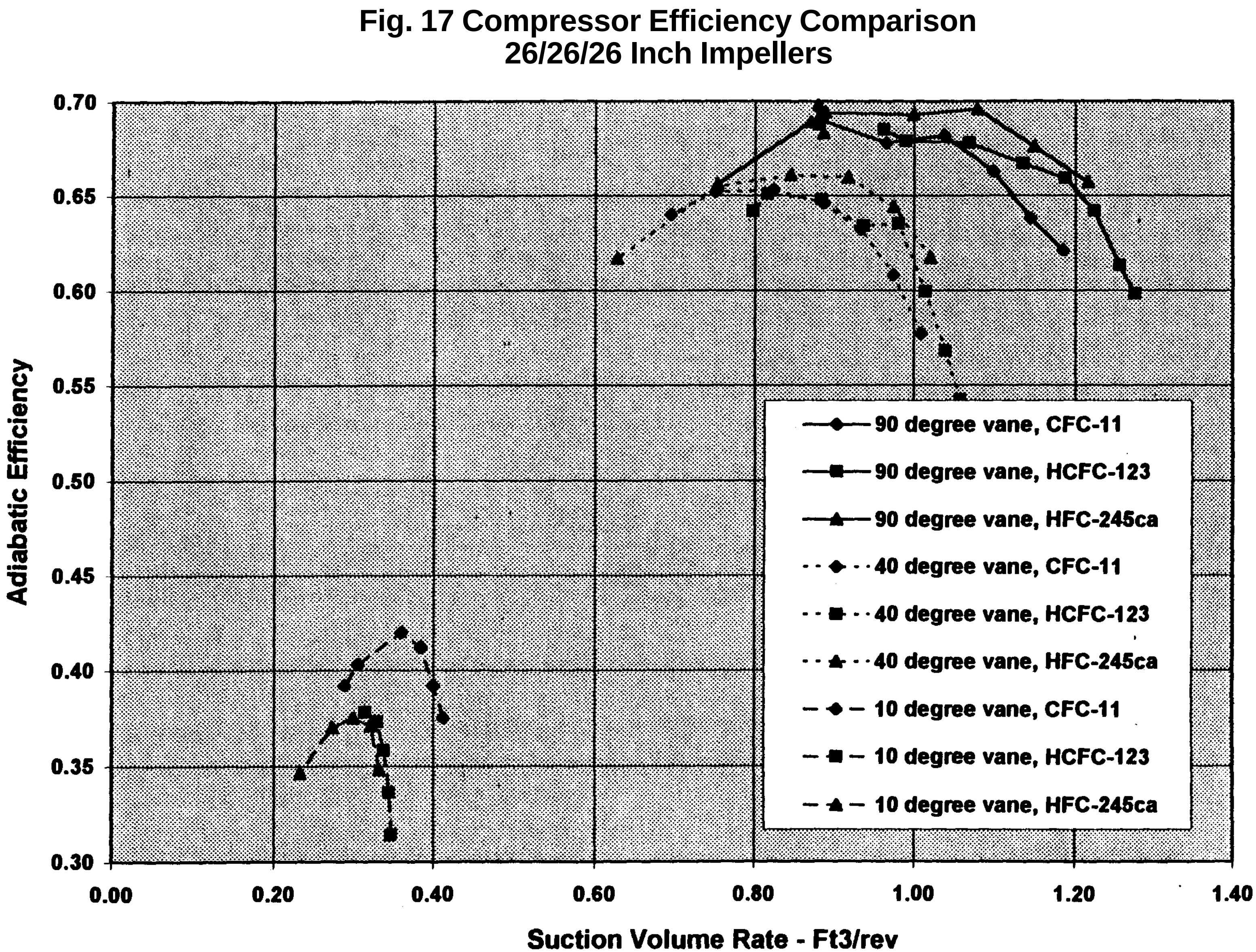
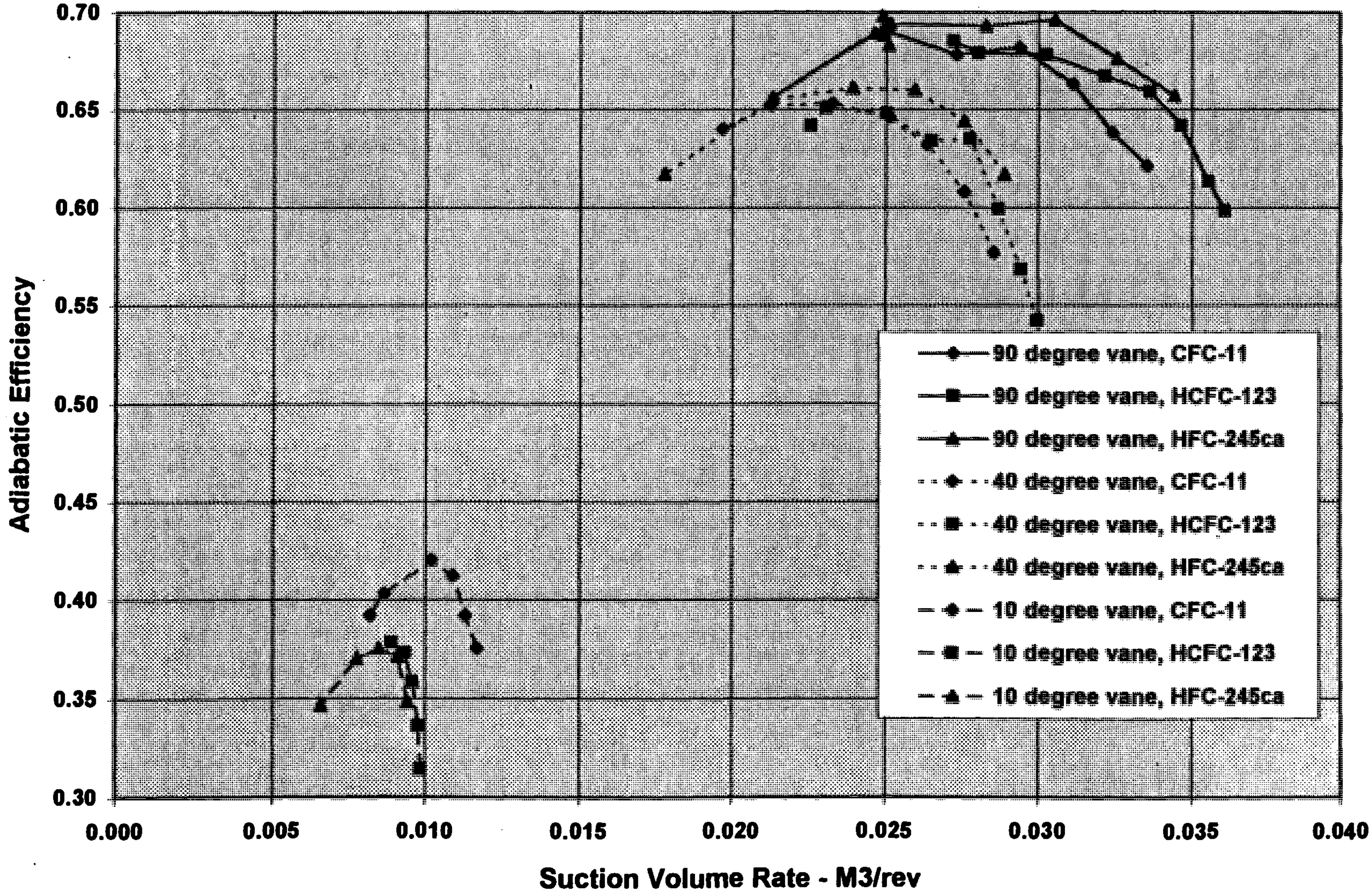


Fig. 17 Compressor Efficiency Comparison
26/26/26 Inch Impellers
Adiabatic Efficiency
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Suction Volume Rate - Ft3/rev
90 degree vane, CFC-11
90 degree vane, HCFC-123
90 degree vane, HFC-245ca
40 degree vane, CFC-11
40 degree vane, HCFC-123
40 degree vane, HFC-245ca
10 degree vane, CFC-11
10 degree vane, HCFC-123
10 degree vane, HFC-245ca

Fig. 17a Compressor Efficiency Comparison
660/660/660 mm Impellers



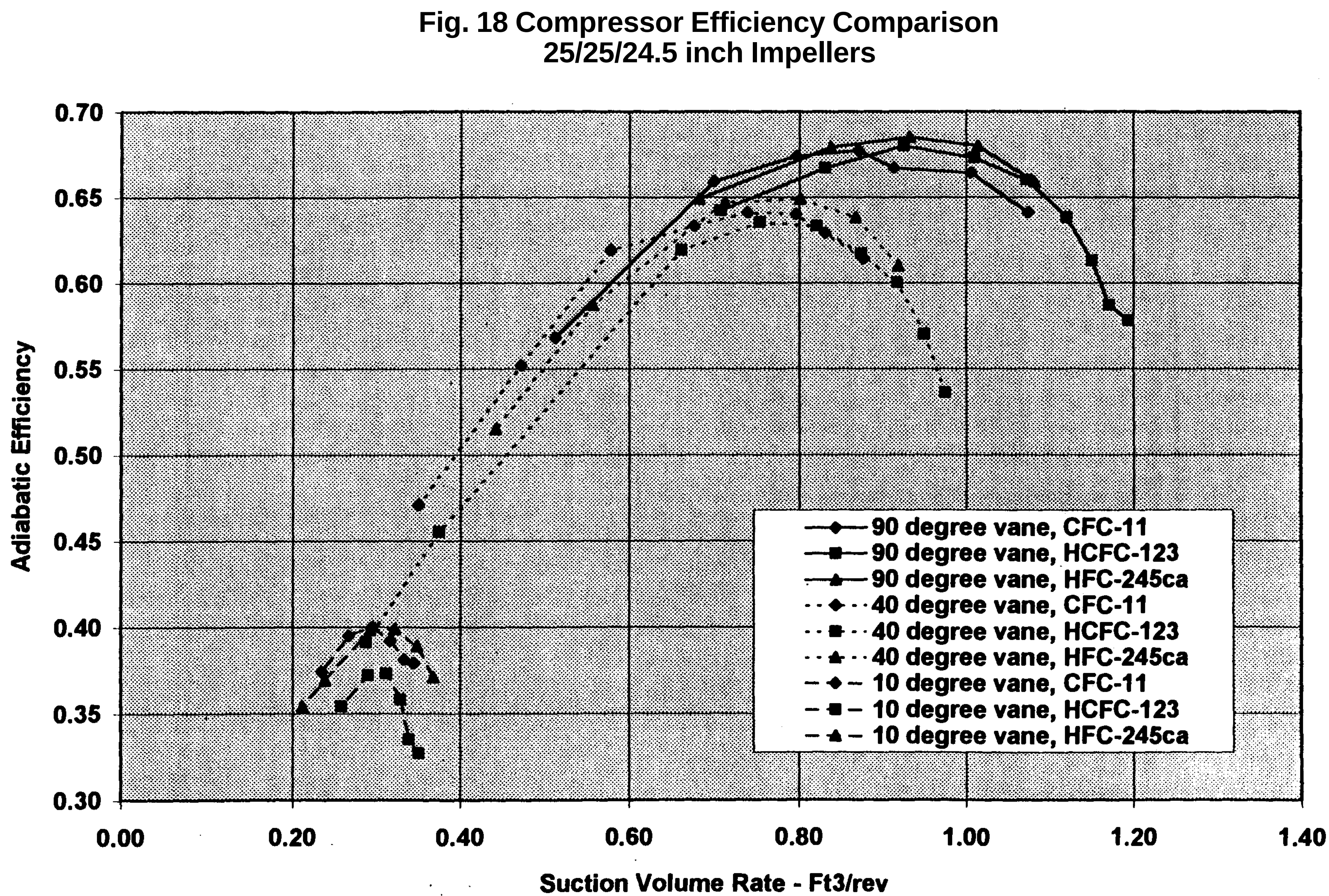


Fig. 18 Compressor Efficiency Comparison
25/25/24.5 inch Impellers
Adiabatic Efficiency
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Suction Volume Rate - Ft3/rev
90 degree vane, CFC-11
90 degree vane, HCFC-123
90 degree vane, HFC-245ca
40 degree vane, CFC-11
40 degree vane, HCFC-123
40 degree vane, HFC-245ca
10 degree vane, CFC-11
10 degree vane, HCFC-123
10 degree vane, HFC-245ca

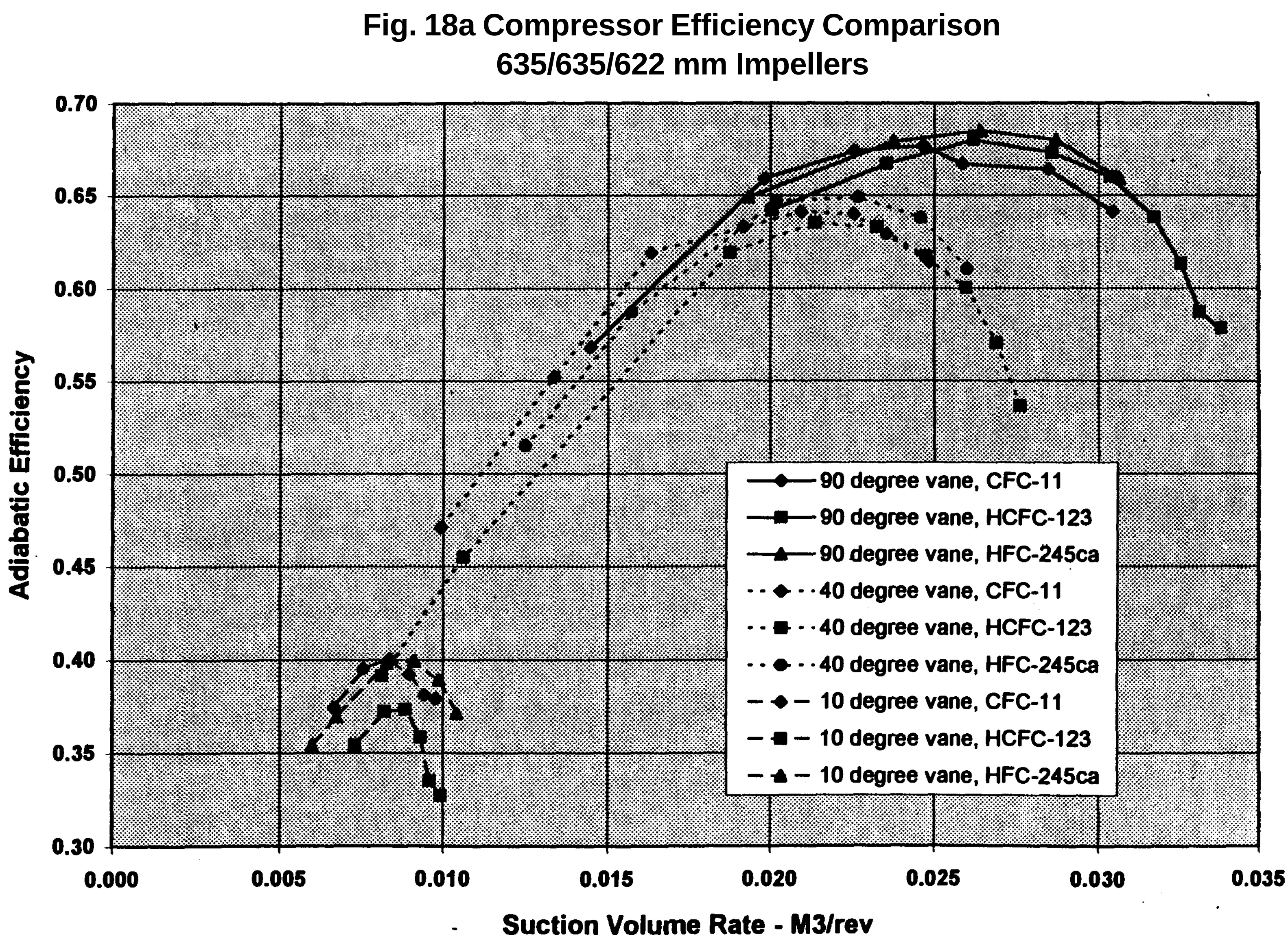
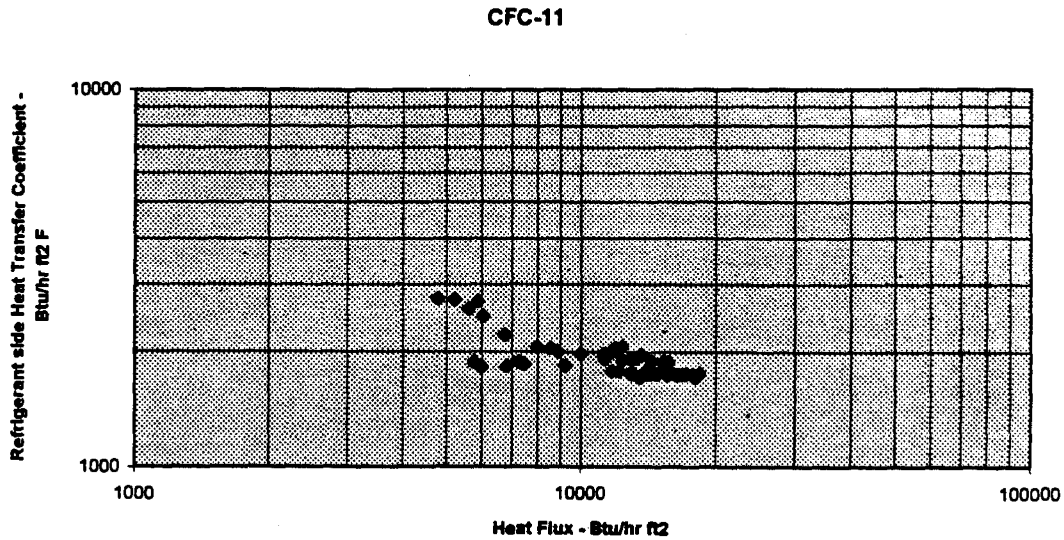
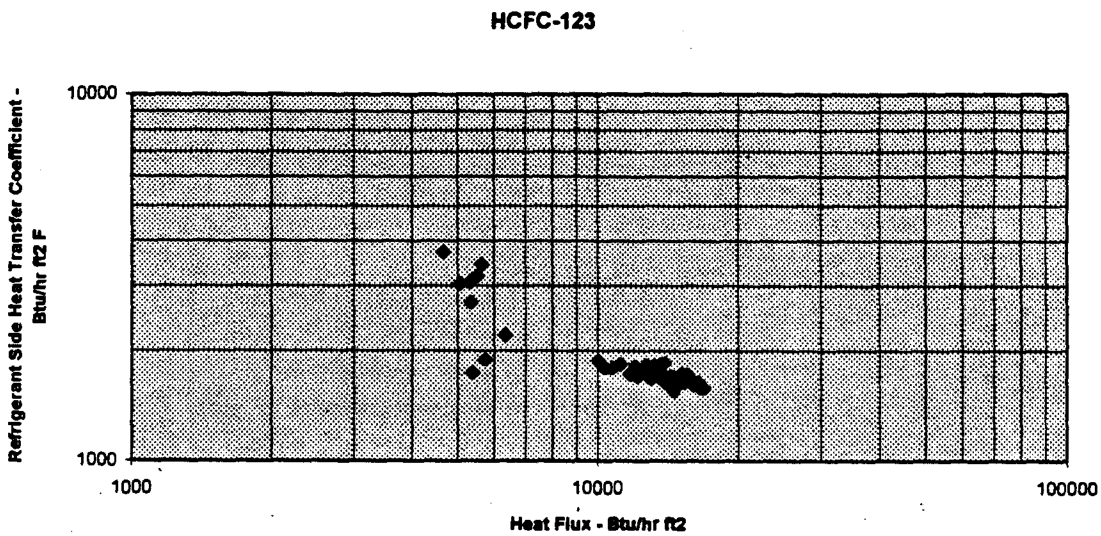


Fig. 18a Compressor Efficiency Comparison
635/635/622 mm Impellers
Adiabatic Efficiency
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
Suction Volume Rate - M3/rev
90 degree vane, CFC-11
90 degree vane, HCFC-123
90 degree vane, HFC-245ca
40 degree vane, CFC-11
40 degree vane, HCFC-123
40 degree vane, HFC-245ca
10 degree vane, CFC-11
10 degree vane, HCFC-123
10 degree vane, HFC-245ca

Fig. 19 Condenser Refrigerant Side Heat Transfer Coefficient vs Heat Flux 1" 35 FPI Tubes, Ester Oil, Nominal Area Basis





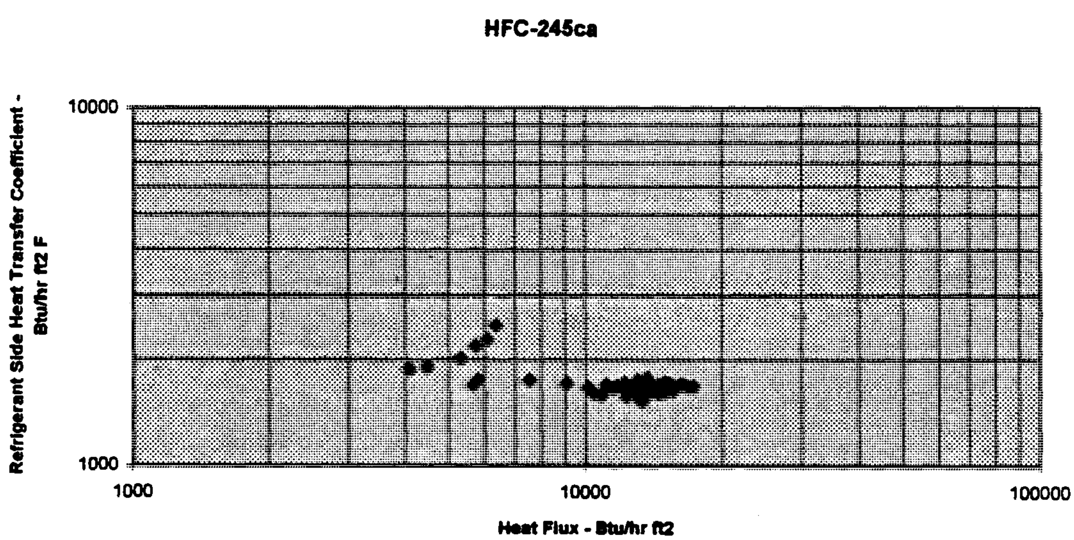
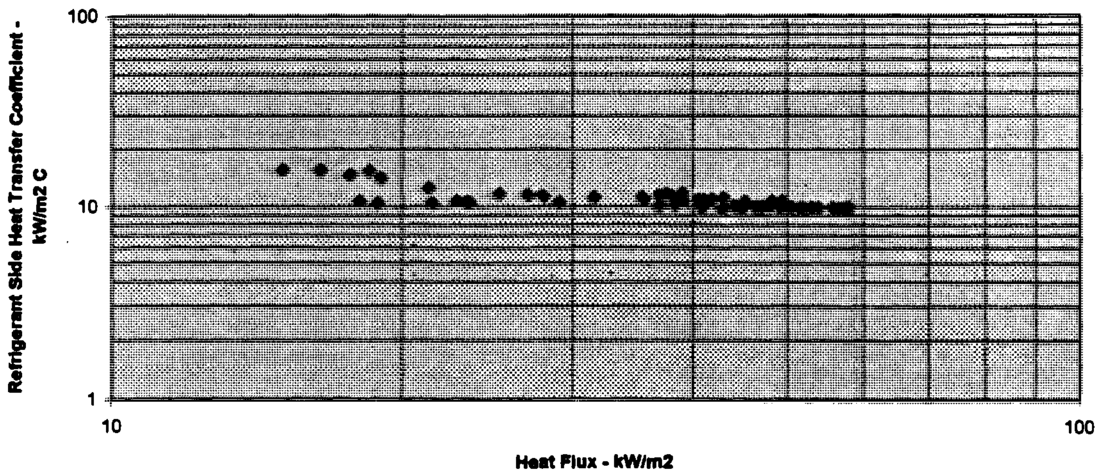
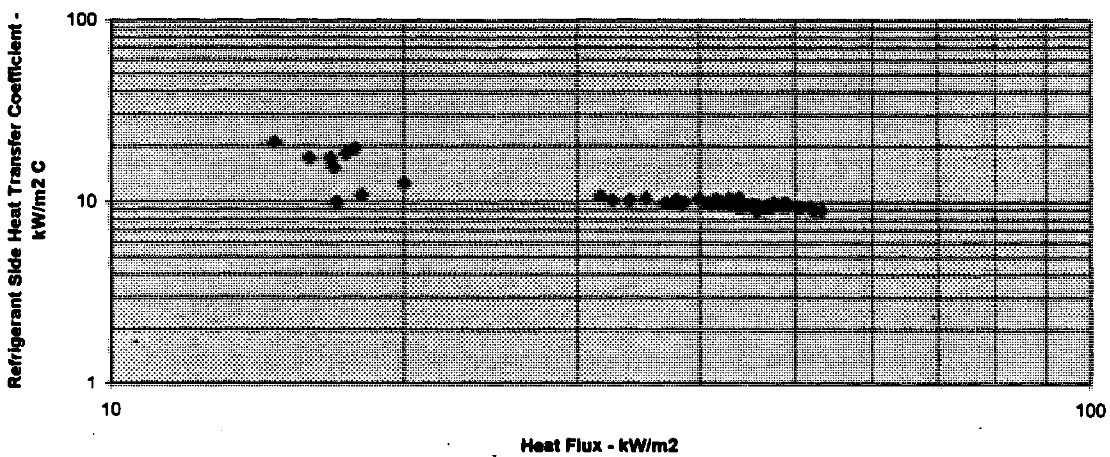


Fig. 19a Condenser Refrigerant Side Heat Transfer Coefficient vs Heat Flux
1" 35 FPI Tubes, Ester Oil, Nominal Area Basis

CFC-11



HCFC-123



HFC-245ca

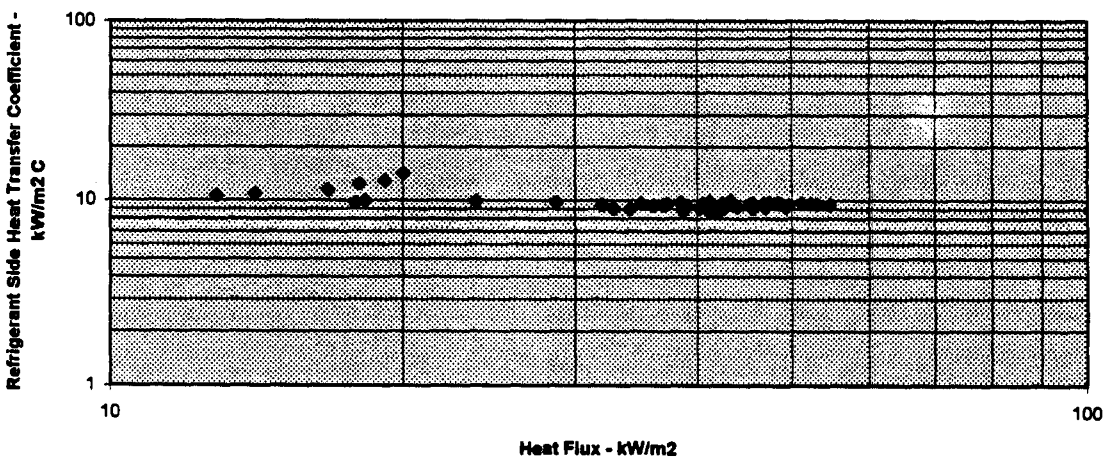
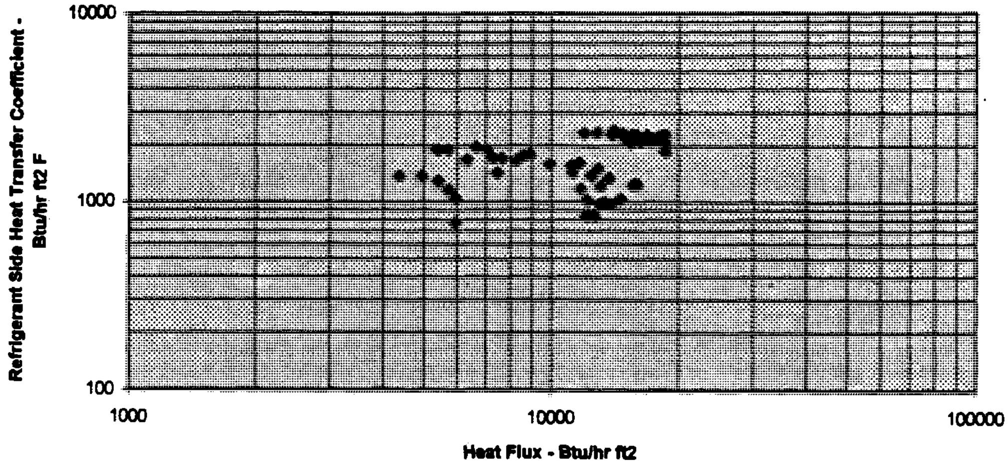
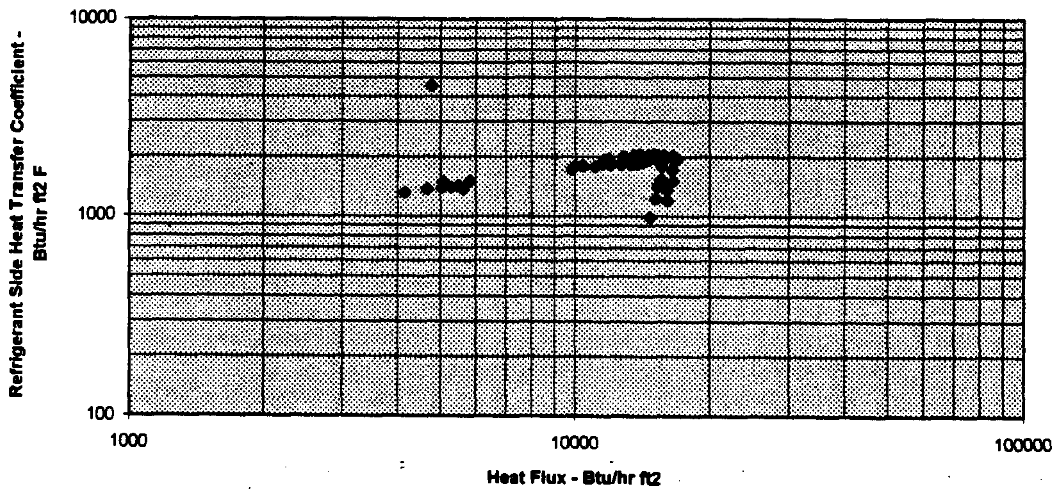


Fig. 20 Evaporator Refrigerant Side Heat Transfer Coefficient vs Heat Flux 1" Turbo BII Tubes, Ester Oil, Nominal Area Basis

CFC-11



HCFC-123



HFC-245ca

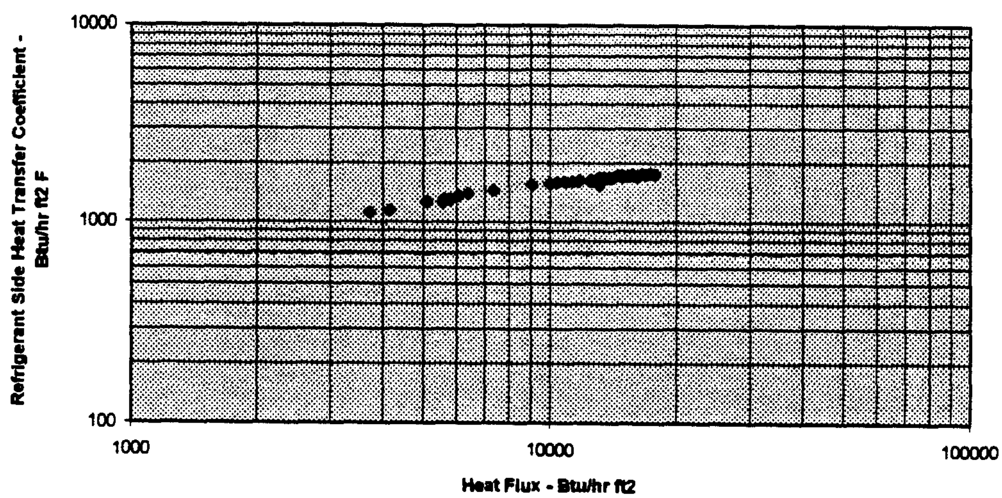
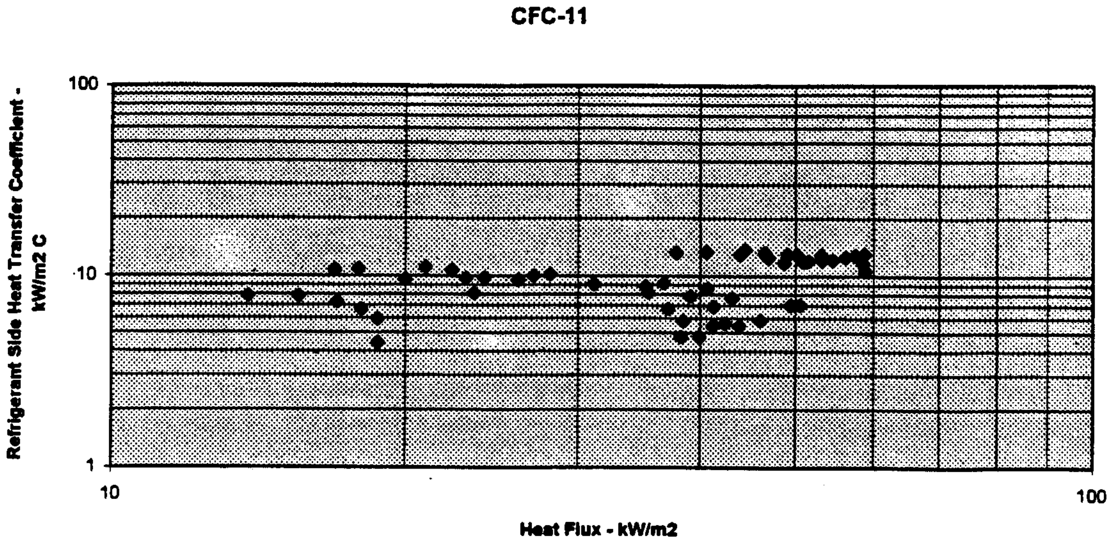
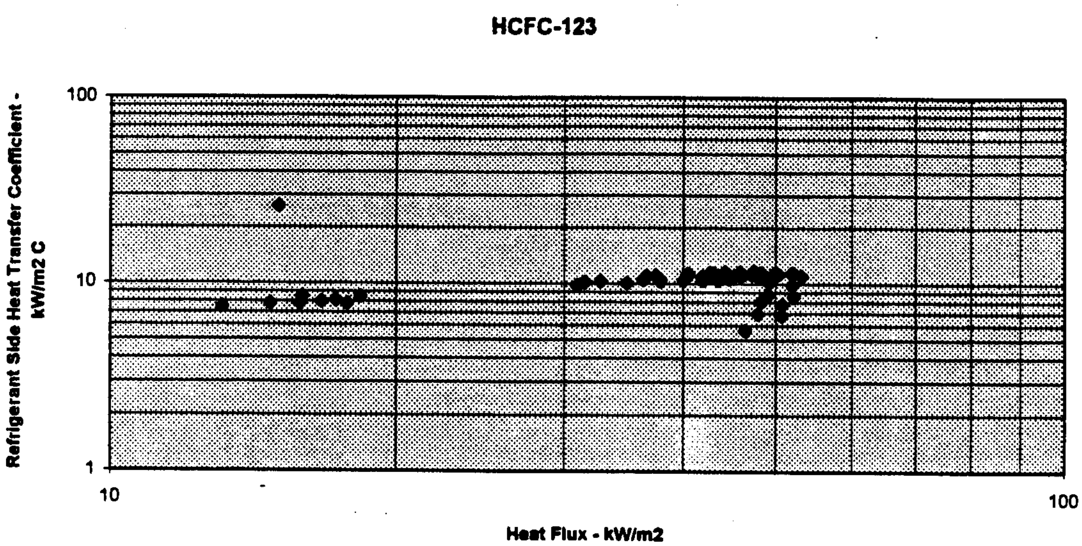


Fig. 20a Evaporator Refrigerant Side Heat Transfer Coefficient vs Heat Flux
1" Turbo BII Tubes, Ester Oil, Nominal Area Basis





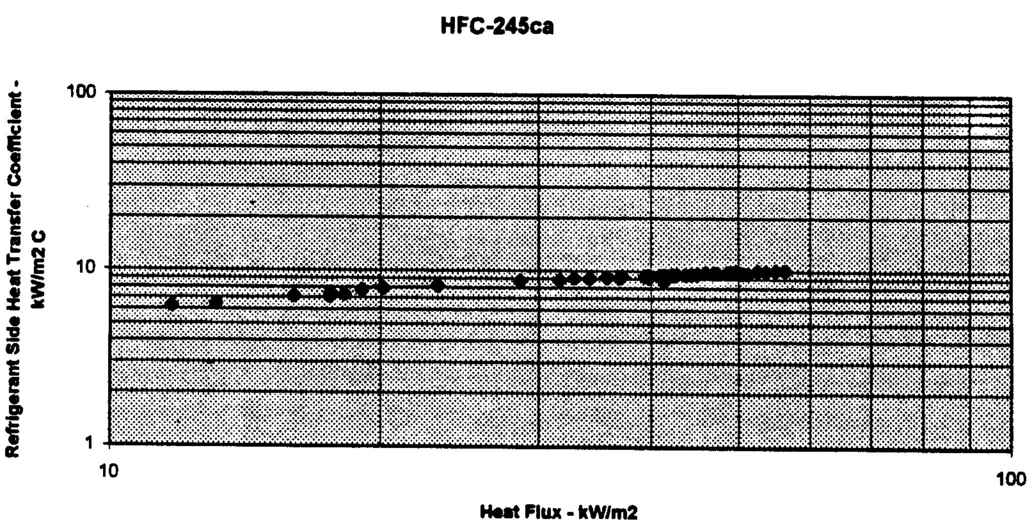


Fig. 21 Pool Boiling Coefficient vs. Heat Flux
1" 35 fins/inch

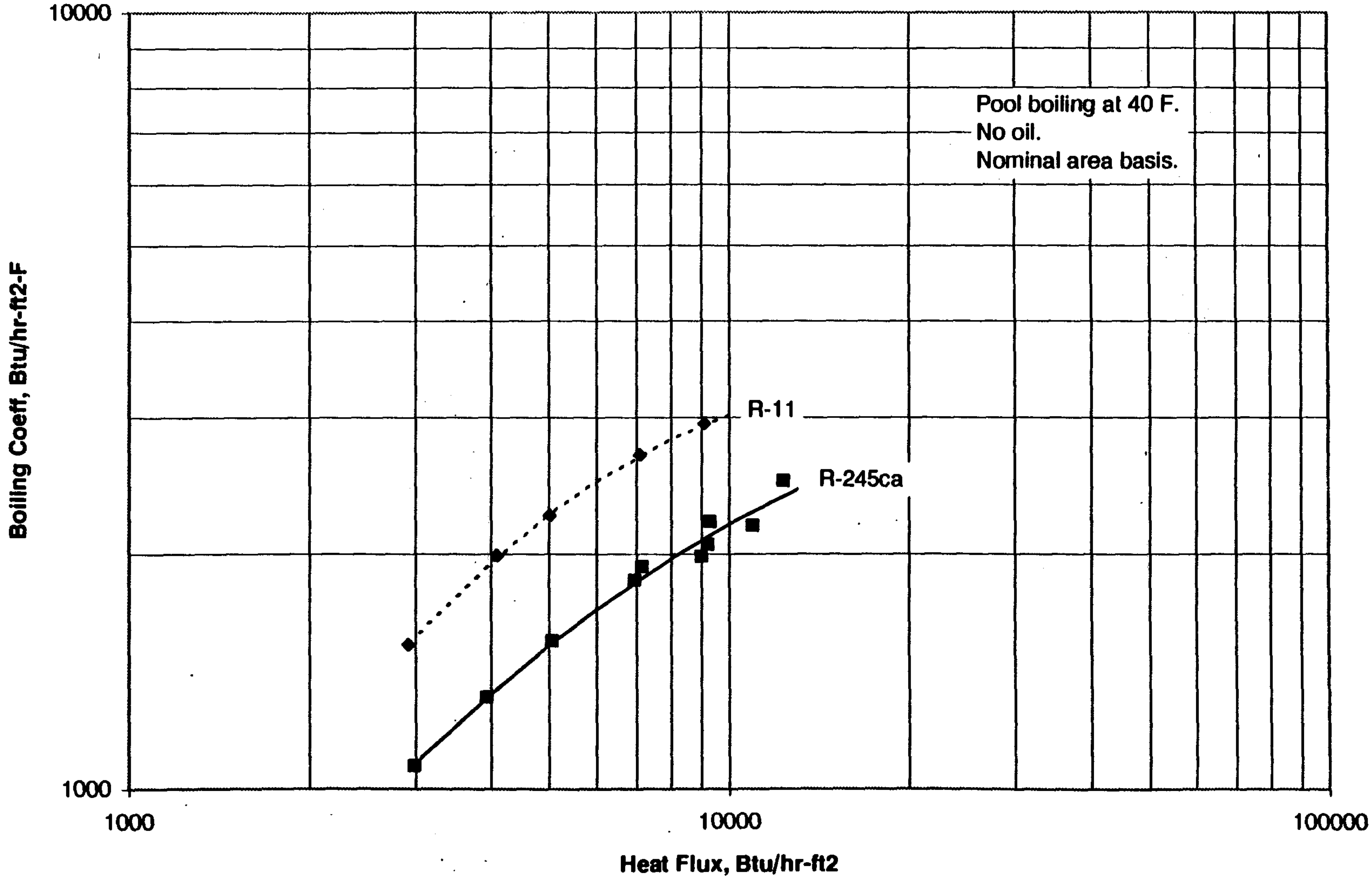


Fig. 22 Condensation Coefficient vs. Heat Flux
1" 35 fins/inch

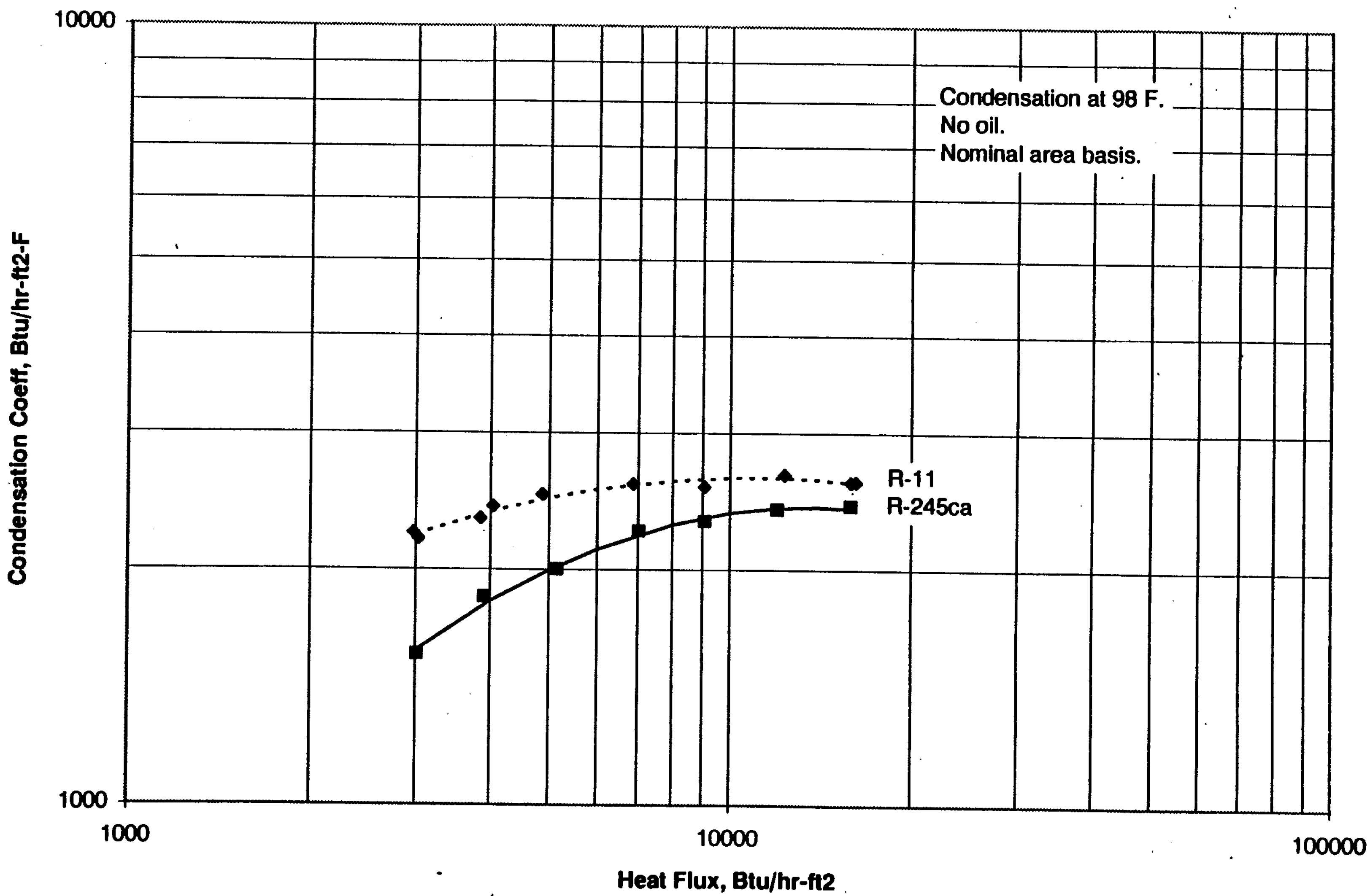


Fig. 23 Pool Boiling Coefficient vs. Heat Flux
1" Turbo-BII

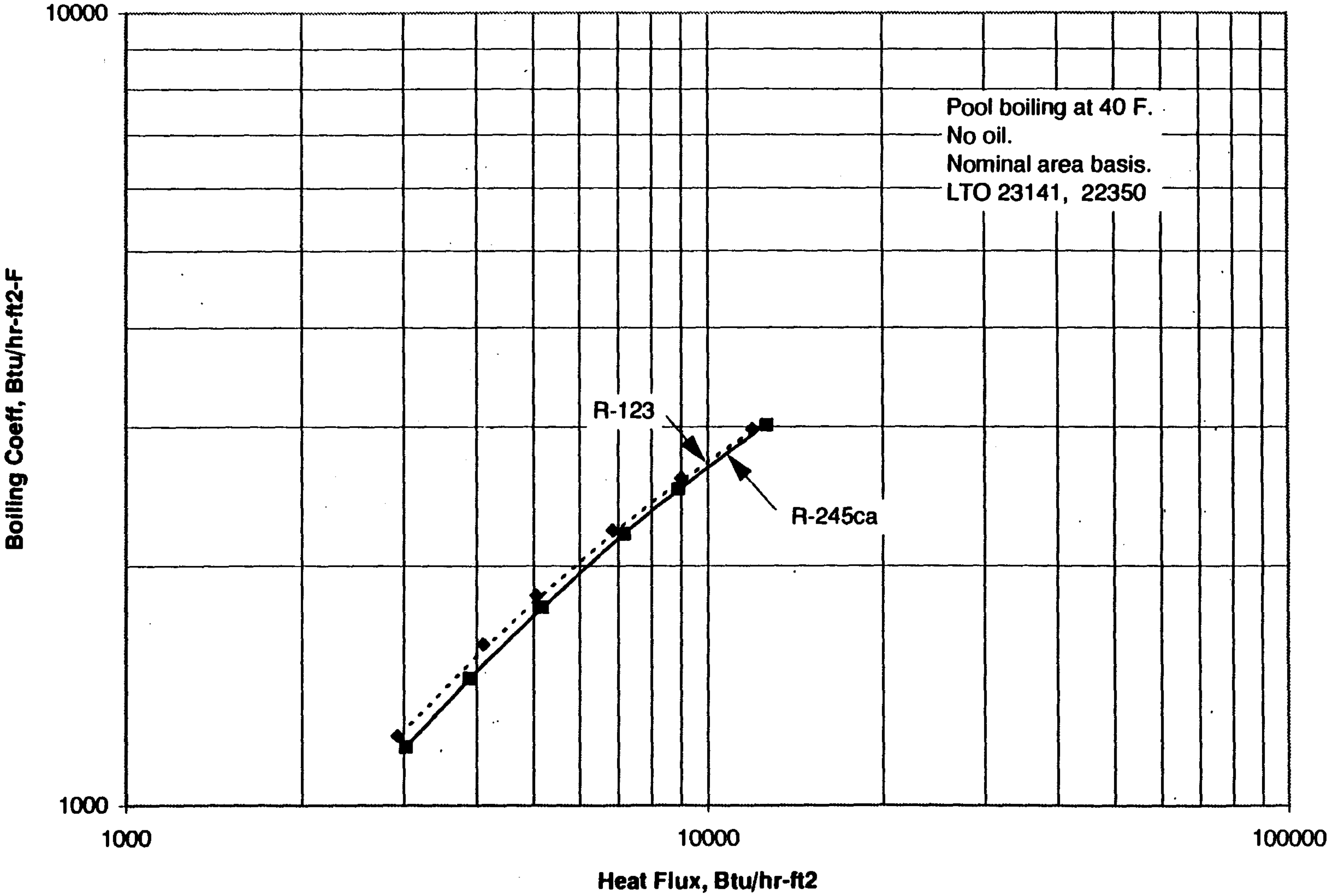


Fig. 24 Condensation Coefficient vs. Heat Flux
3/4" Turbo-CII

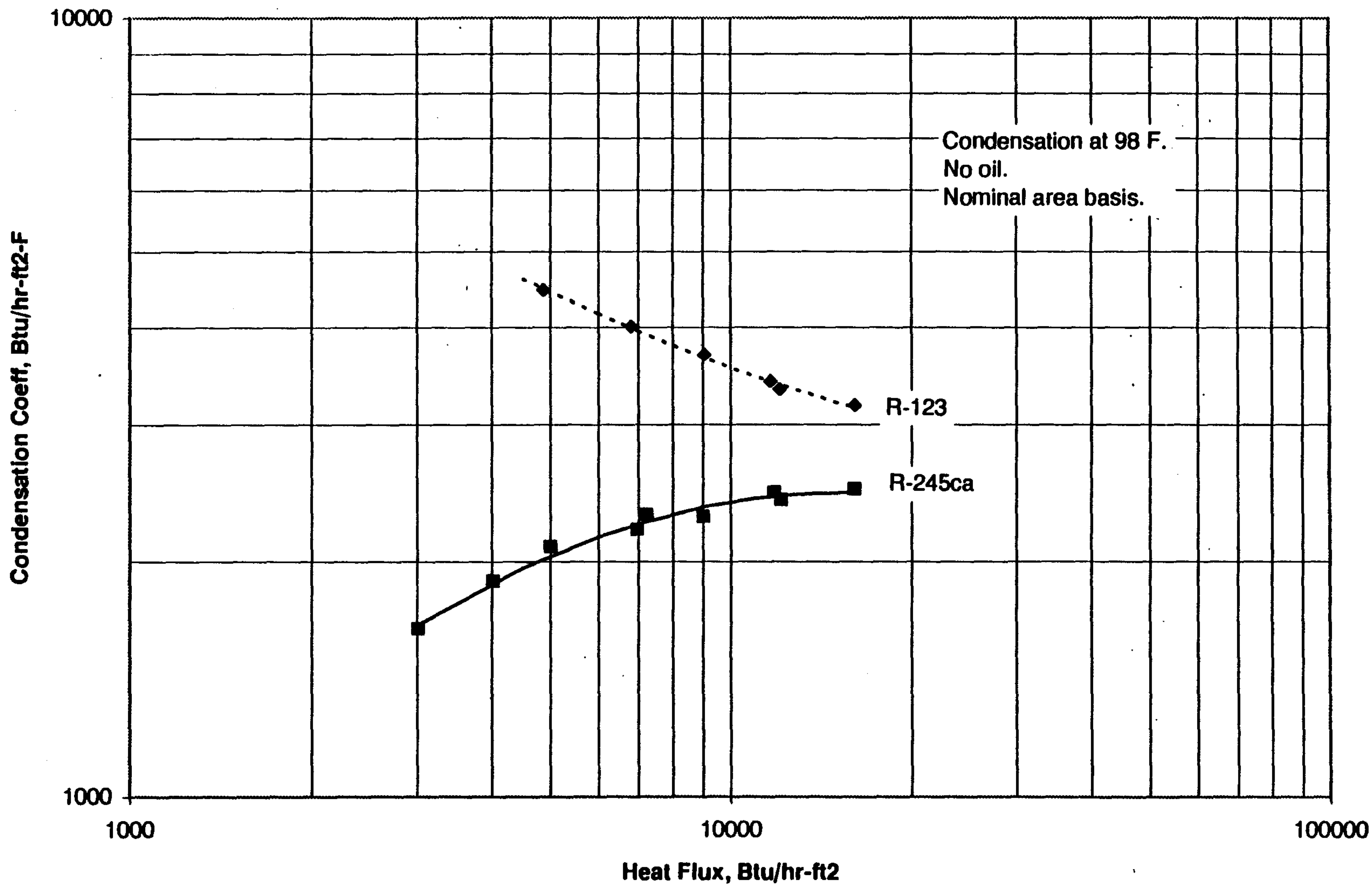


Fig. 25 Heat Transfer Area vs. Efficiency

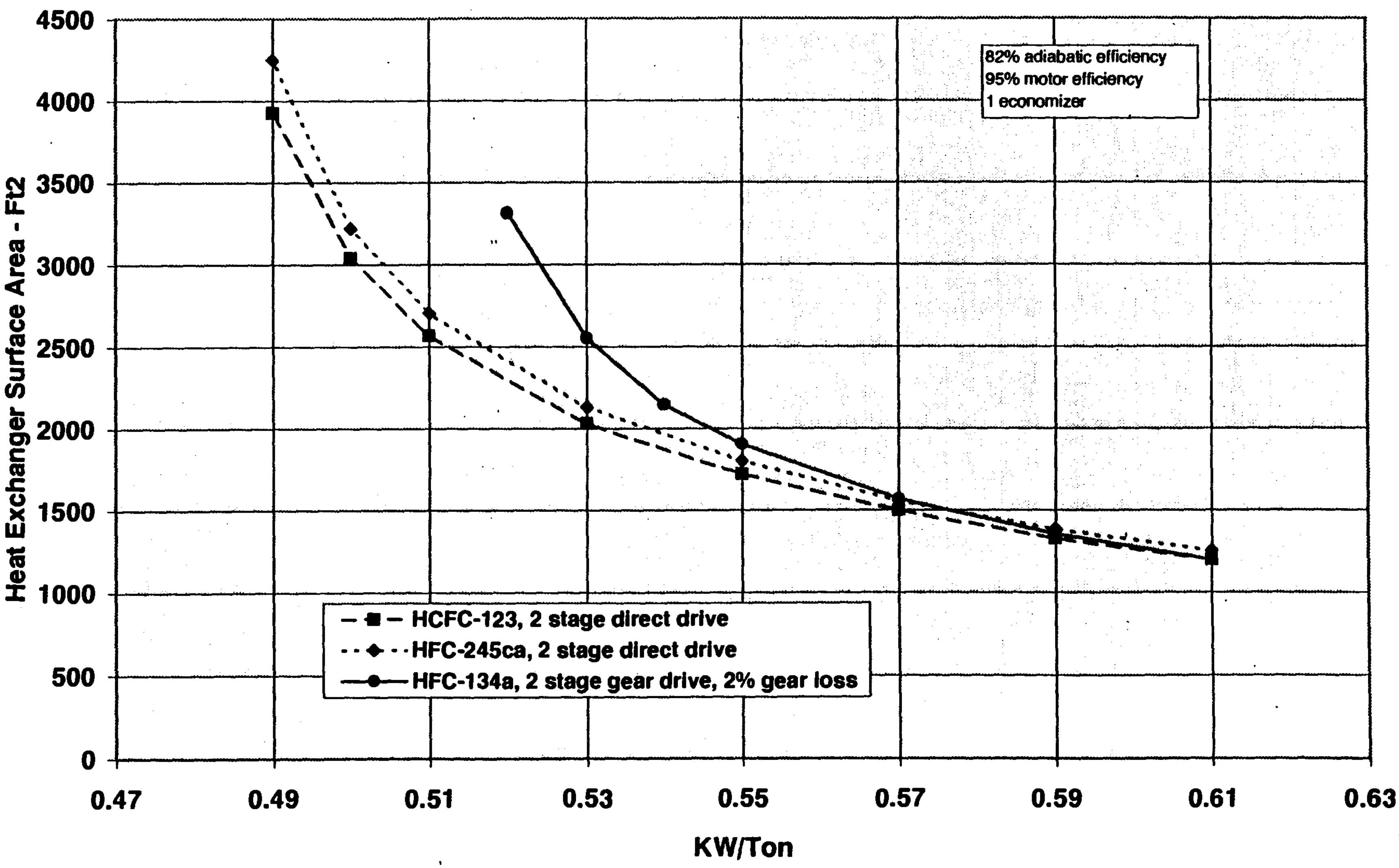
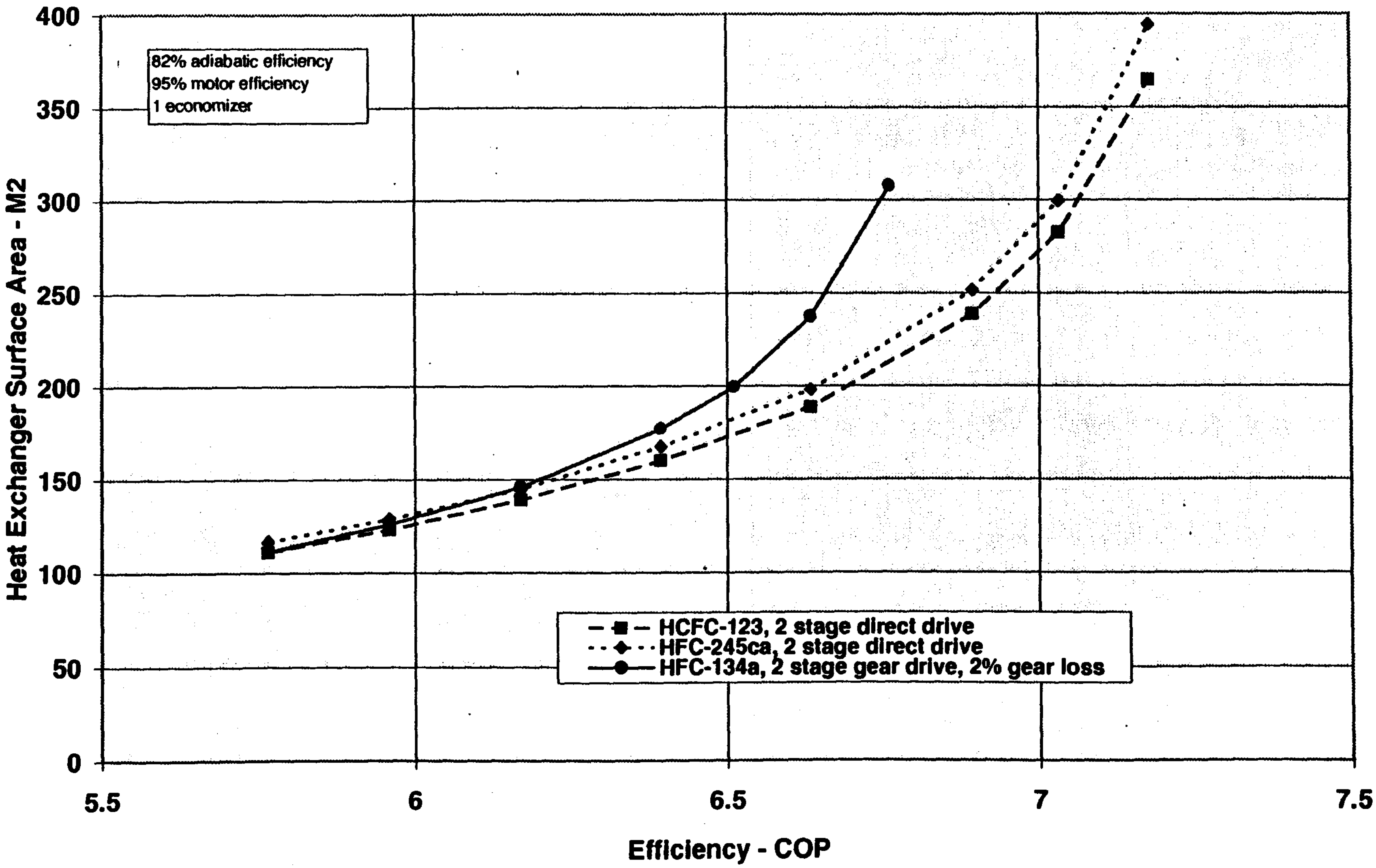


Fig. 25a Heat Transfer Area vs. Efficiency

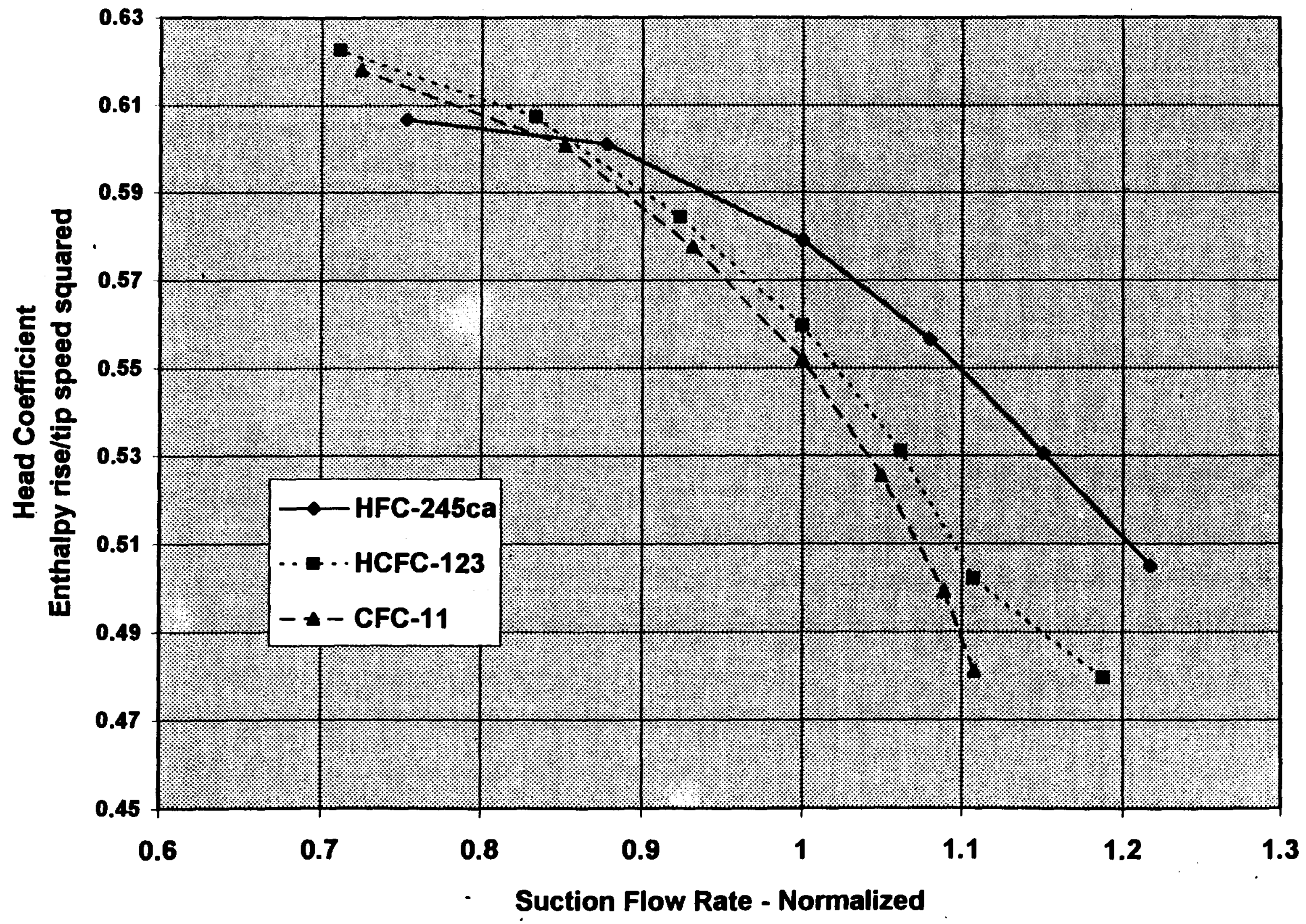


APPENDIX A
DESCRIPTION OF SURGE

Surge of refrigerant gas in a centrifugal compressor results in sporadic backflow of refrigerant through the compressor. Surge occurs when the pressure on the condenser side exceeds the discharge pressure from the compressor. Conditions that contribute to surge include high condenser temperatures, overly restrictive guide vane settings, low evaporator temperatures and low impeller tip speeds. Refrigerants such as R-245ca with higher head requirements are more susceptible to surge.

The onset of surge is shown in Figure A-1 as a function of head coefficient and suction flow rate. This plot is based on the first law of thermodynamics expressed as enthalpy rise across the compressor is proportional to the square of the discharge gas velocity. The discharge velocity can be approximated by the impeller tip speed. For an isentropic compression process, the enthalpy rise is also proportional to the pressure rise divided by the refrigerant density. Head coefficient is simply the enthalpy rise divided by the square of the tip speed. As shown in Figure A-1, the ability of the compressor to deliver higher and higher heads as the flow rate is reduced is restricted by the surge limit. Attempts to raise the system pressure above the surge limit results in sporadic backflow of refrigerant through the compressor with reduced compressor efficiency and increased noise. If surge occurs, either the impeller tip speed must be increased or the system head pressure must be reduced.

Figure A-1 Surge Limits



APPENDIX B
SUMMARIES OF FULL LOAD CHILLER TEST RESULTS

Large Impellers - Imperial

LTO 23127 Note: Impeller diameters are 26.0/26.0/26.0		Full Load Performance Comparison at 44/85				
Run Number		20	42	64	93	
Refrigerant		11	11	123	245ca	
Oil		Trane 22	Solest 68	Solest 68	Solest 68	
1st Stage Guide Vane Setting	Degrees	90	90	90	90	
Capacity	Tons	238.60	231.60	226.40	206.20	
Power	KW	198.00	192.96	199.32	164.46	
KW/Ton	KW/Ton	0.830	0.830	0.880	0.800	
Evaporator Leaving Water Temperature	Deg F	44.00	44.00	44.04	43.99	
Condenser Entering Water Temperature	Deg F	84.98	84.97	85.21	84.97	
Energy Balance	%	-0.73	-0.65	-0.90	-0.92	
Evaporator Entering Water Temperature	Deg F	55.86	55.55	55.16	53.83	
Evaporator Leaving Water Temperature	Deg F	44.00	44.00	44.04	43.99	
Evaporator Water Flow Rate	GPM	481.90	480.10	487.50	501.90	
Condenser Entering Water Temperature	Deg F	84.98	84.97	85.21	84.97	
Condenser Leaving Water Temperature	Deg F	96.91	96.46	96.52	95.09	
Condenser Water Flow Rate	GPM	599.70	604.50	607.60	606.60	
Evap Sat Press	Psia	6.43	6.33	5.17	5.48	
Sat Temp	Deg F	36.18	35.50	35.27	34.78	
Approach	Deg F	7.80	8.50	8.80	9.20	
LMTD	Deg F	12.85	13.46	13.58	13.54	
ITD/Delta T		1.66	1.74	1.79	1.94	
Q/Ao	B/hr-ft2	17362.49	16853.44	16471.02	15001.09	
Uo	B/hr ft2 F	1351.11	1252.21	1212.93	1107.97	
ho'	B/hr ft2 F	2435.97	2136.98	2012.02	1721.97	
Cond Sat Press	Psia	26.14	25.94	23.49	24.48	
Sat Temp	Deg F	106.21	105.77	106.68	103.61	
Approach	Deg F	9.30	9.30	10.20	8.50	
Refrigerant Leaving Temp	Deg F	104.93	104.63	105.34	101.46	
LMTD	Deg F	14.45	14.29	15.12	12.93	
Q/Ao	B/hr-ft2	17268.02	16764.58	16593.67	14832.95	
Uo	B/hr ft2 F	1194.72	1172.88	1097.73	1147.49	
ho'	B/hr ft2 F	1803.27	1749.51	1584.05	1693.44	
Cond Sat Temp	Deg F	106.21	105.77	106.68	103.61	
Evap Sat Temp	Deg F	36.18	35.50	35.27	34.78	
Estimated Motor Efficiency (1)		0.929	0.929	0.928	0.935	
Estimated Motor RPM (1)		3537	3539	3537	3550	
Compressor Suction CFM (2)	CFM	3733	3675	4200	3545	
Isentropic KW/T (2)		0.564	0.566	0.580	0.554	
Adiabatic Efficiency (3)		0.680	0.682	0.659	0.693	
Q/N (4)		1.055	1.038	1.188	0.999	
(1) From motor curves at measured power input						
(2) Cycle calculation using evap and cond sat, motor efficiency,						
and equal head split						
(3) Ratio of isentropic and test KW/T						
(4) CFM from cycle calculation / estimated motor RPM						
(5) Heat transfer coefficient calculations use bulk fluid properties						

Large Impellers - Imperial

Evap Water Velocity	Fps	9.37	9.34	9.48	9.76	
Re		48323.89	48034.55	48608.46	49538.19	
Pr		9.28	9.31	9.34	9.45	
R		10.79	10.78	10.79	10.81	
F		-5.22	-5.22	-5.22	-5.23	
hi		3504.05	3493.23	3527.41	3588.96	
Cond Water Velocity	Fps	9.33	9.41	9.46	9.44	
Re		82688.57	83184.53	83776.36	82835.16	
Pr		5.06	5.07	5.06	5.11	
R		11.32	11.33	11.34	11.32	
F		-5.37	-5.38	-5.38	-5.37	
hi		4088.99	4110.18	4129.78	4111.03	
Curve fit for motor efficiency						
A1		8.80E-01	8.80E-01	8.80E-01	8.80E-01	
A2		1.49E-03	1.49E-03	1.49E-03	1.49E-03	
A3		-1.09E-05	-1.09E-05	-1.09E-05	-1.09E-05	
A4		2.91E-08	2.91E-08	2.91E-08	2.91E-08	
A5		-2.57E-11	-2.57E-11	-2.57E-11	-2.57E-11	
KW (input)		198.00	192.96	199.32	164.46	
Hp (estimated assuming eff of .933)		246.63	240.35	248.28	204.85	
Motor efficiency		0.928	0.929	0.928	0.935	
Curve fit for motor RPM						
A1		3.60E+03	3.60E+03	3.60E+03	3.60E+03	
A2		-2.30E-01	-2.30E-01	-2.30E-01	-2.30E-01	
A3		8.10E-05	8.10E-05	8.10E-05	8.10E-05	
A4		-9.47E-07	-9.47E-07	-9.47E-07	-9.47E-07	
A5		8.88E-10	8.88E-10	8.88E-10	8.88E-10	
Motor RPM		3537.241	3539.175	3536.731	3549.678	

Large Impellers - Imperial

ID	Description	Units					
1	EVAP WATER FLOWMETER DELTA P	PSID	16.11	15.99	16.49	17.48	
3	ENT EVAP WATER TEMP LOC 1	Deg F	55.85	55.53	55.14	53.80	
4	ENT EVAP WATER TEMP LOC 2	Deg F	55.88	55.57	55.18	53.85	
5	LVG EVAP WATER TEMP LOC 1	Deg F	44.01	44.00	44.05	44.00	
6	LVG EVAP WATER TEMP LOC 2	Deg F	44.00	43.99	44.03	43.98	
15	COND WATER FLOWMETER DELTA P	PSID	24.83	25.23	25.49	25.41	
17	ENT COND WATER TEMP LOC 1	Deg F	84.98	84.97	85.23	84.98	
18	ENT COND WATER TEMP LOC 2	Deg F	84.97	84.96	85.18	84.95	
19	LVG COND WATER TEMP LOC 1	Deg F	96.91	96.46	96.53	95.11	
20	LVG COND WATER TEMP LOC 2	Deg F	96.90	96.45	96.51	95.08	
50	ABOVE EVAP DISTRIB TEMP - SUPPLY	Deg F	39.34	39.81	40.63	37.65	
51	ABOVE EVAP DISTRIB TEMP - MIDDLE	Deg F	38.24	36.59	38.02	37.24	
52	ABOVE EVAP DISTRIB TEMP - RETURN	Deg F	38.33	38.84	38.50	38.89	
61	EVAP SHELL STATIC PRESS - AVERAGE	PSIA	6.43	6.33	5.17	5.48	
215	ENT 2nd IMPELLER TOTAL PRESS #1	PSIA	10.80	10.68	8.91	9.35	
216	ENT 2nd IMPELLER TOTAL PRESS #2	PSIA	10.85	10.72	8.97	9.41	
218	ENT 2nd IMP SHROUD STATIC PRESS #1	PSIA	10.09	9.99	8.10	8.88	
315	ENT 3rd IMPELLER TOTAL PRESS #1	PSIA	18.40	17.90	15.43	26.38	
316	ENT 3rd IMPELLER TOTAL PRESS #2	PSIA	17.45	17.28	14.62	15.35	
318	ENT 3rd IMP SHROUD STATIC PRESS #1	PSIA	16.27	16.11	13.65	14.59	
431	COND SHELL STATIC PRESS - AVERAGE	PSIA	26.14	25.94	23.49	24.48	
440	REFRIGERANT LVG COND TEMP	Deg F	104.93	104.63	105.34	101.46	
484	HIGH PRESS ECONOMIZER STATIC PRESS	PSIA	16.98	16.82	14.60	15.38	
485	HIGH PRESS ECONOMIZER TEMP	Deg F	81.81	81.29	81.51	79.55	
486	LOW PRESS ECONONOMIZER STATIC PRESS	PSIA	10.78	10.67	9.06	9.51	
487	LOW PRESS ECONOMIZER TEMP	Deg F	59.20	58.57	58.99	57.75	
530	ENT EVAP ORIFICE ASS'Y PRESS	PSIA	10.85	10.72	9.39	9.60	
531	ENT EVAP ORIFICE ASS'Y TEMP	Deg F	59.27	58.63	59.36	57.77	
532	LVG EVAP ORIFICE ASS'Y PRESS	PSIA	8.89	8.74	7.69	7.65	
533	LVG EVAP ORIFICE ASS'Y TEMP	Deg F	50.58	49.34	52.37	48.38	
534	ENT COND ORIFICE ASS'Y PRESS	PSIA	25.92	25.65	23.29	24.18	
535	ENT COND ORIFICE ASS'Y TEMP	Deg F	104.97	104.50	105.43	101.84	
536	LVG COND ORIFICE ASS'Y PRESS	PSIA	19.70	19.41	18.09	18.14	
537	LVG COND ORIFICE ASS'Y TEMP	Deg F	90.75	90.14	92.79	88.40	
560	ATMOSPHERIC PRESS	PSIA	14.30	14.46	14.40	14.34	
580	MOTOR VOLTAGE - AB	Volts	3.864	3.861	3.887	3.900	
581	MOTOR VOLTAGE - AC	Volts	3.888	3.883	3.902	3.902	
582	MOTOR VOLTAGE - CB	Volts	3.865	3.866	3.886	3.884	
583	MOTOR CURRENT - A	Volts	2.686	2.612	2.707	2.277	
584	MOTOR CURRENT - B	Volts	2.810	2.743	2.831	2.348	
585	MOTOR CURRENT - C	Volts	2.667	2.616	2.650	2.190	
586	MOTOR POWER - PHASE 1	Volts	1.240	1.200	1.259	1.038	
587	MOTOR POWER - PHASE 3	Volts	2.060	2.016	2.063	1.703	
595	TC CARD #1 CHECK (LVG COND TEMP)	Deg F	96.93	96.49	96.20	95.11	
601	MAXIMUM MOTOR TEMPERATURE	Deg F	183.50	177.50	182.50	130.50	
605	1st STAGE VANE SETTING	Degrees	90.00	90.00	90.00	90.00	
607	3rd STAGE VANE SETTING	Degrees	68.00	68.00	68.00	68.00	
608	UNIT HOUR METER READING	Hr	350.10	390.50	403.40	419.60	
609	UNIT START COUNTER READING		98	109	112	115	
610	CURRENT REFRIGERANT CHARGE	Lbm	360	360	360	361	
700	TIME (HOURS)	HOURS	359.92	1.39	0.00	0.00	
701	ENERGY BALANCE	%	-0.73	-0.65	-0.90	-0.92	
702	EVAP CAPACITY	Tons	238.60	231.60	226.40	206.20	

Large Impellers - Imperial

703	EVAP WATER FLOWRATE	GPM	481.90	480.10	487.50	501.90	
704	COND WATER FLOWRATE	GPM	599.70	604.50	607.60	606.60	
710	AVE ENT EVAP WATER TEMP	Deg F	55.86	55.55	55.16	53.83	
711	AVE LVG EVAP WATER TEMP	Deg F	44.00	44.00	44.04	43.99	
712	AVE ENT COND WATER TEMP	Deg F	84.98	84.97	85.21	84.97	
713	AVE LVG COND WATER TEMP	Deg F	96.91	96.46	96.52	95.09	
715	MOTOR VOLTAGE - AB	Volts	463.70	463.30	466.40	468.00	
716	MOTOR VOLTAGE - AC	Volts	466.60	466.00	468.20	468.20	
717	MOTOR VOLTAGE - CB	Volts	463.80	463.90	466.30	466.10	
718	MOTOR CURRENT - A	Amps	268.60	261.20	270.70	227.70	
719	MOTOR CURRENT - B	Amps	281.00	274.29	283.10	234.80	
720	MOTOR CURRENT - C	Amps	266.70	261.60	265.00	219.00	
721	UNIT POWER	KW	198.00	192.96	199.32	164.46	
722	AVERAGE VOLTAGE	Volts	464.70	464.40	467.00	467.40	
723	AVERAGE CURRENT	Amps	272.10	265.70	272.93	227.17	
725	KW/TON	KW/Ton	0.83	0.83	0.88	0.80	
730	EVAP DELTA T	Deg F	11.86	11.55	11.12	9.84	
731	COND DELTA T	Deg F	11.93	11.49	11.31	10.13	
735	EVAP WATER FLOWRATE	Lbm/min	4020.50	4005.50	4067.60	4188.00	
736	COND WATER FLOWRATE	Lbm/min	4985.30	5025.30	5051.00	5043.20	
740	EVAP CAPACITY	Btu/min	47726.60	46327.30	45276.10	41235.50	
741	COND CAPACITY	Btu/min	59335.80	57605.90	57018.60	50968.50	
743	EVAP SAT'N TEMP (BASED ON ID #61)	Deg F	36.18	35.50	35.27	34.78	
744	COND SAT'N TEMP (BASED ON ID #431)	Deg F	106.21	105.77	106.68	103.61	
750	RUNNING TIME	Hr	21.20	61.60	74.50	90.70	
751	STARTS		3	14	17	20	
752	EVAP APPROACH TEMP	Deg F	7.80	8.50	8.80	9.20	
753	COND APPROACH TEMP	Deg F	9.30	9.30	10.20	8.50	
800	EVAP AVG H2O TEMP	Deg F	49.93	49.78	49.60	48.91	
801	EVAP WATER DENSITY	Lbm/Ft3	62.43	62.43	62.43	62.43	
802	EVAP H2O VISCOSITY(LBM/SEC-FT)	Lbm/Sec-I	0.000874	0.000876	0.000879	0.000888	
803	EVAP H2O SPECIFIC HEAT (Cp)	Btu/lbm-F	1.0009	1.0009	1.0010	1.0010	
804	EVAP H2O CON(K) (BTU/HR-FT-F)		0.3392	0.3392	0.3391	0.3387	
810	COND AVG H2O TEMP	Deg F	90.94	90.72	90.87	90.03	
811	COND WATER DENSITY	Lbm/Ft3	62.12	62.12	62.12	62.13	
812	COND H2O VISCOSITY(LBM/SEC-FT)	Lbm/Sec-I	0.000506	0.000507	0.000506	0.000511	
813	COND H2O SPECIFIC HEAT (Cp)	Btu/lbm-F	0.9977	0.9977	0.9977	0.9977	
814	COND H2O CON(K) (BTU/HR-FT-F)		0.3594	0.3592	0.3594	0.3590	
815	ITD/DELTA T		1.66	1.74	1.79	1.94	
850	RTD DIFFERENCE CHECK - ECWT	Deg F	0.01	0.01	0.05	0.03	
851	RTD DIFFERENCE CHECK - LCWT	Deg F	0.01	0.01	0.02	0.03	
852	RTD DIFFERENCE CHECK - EEWT	Deg F	-0.03	-0.04	-0.04	-0.05	
853	RTD DIFFERENCE CHECK - LEWT	Deg F	0.01	0.01	0.02	0.02	
870	TC/RTD CARD #1 CHECK (#19-#595)	Deg F	-0.02	-0.03	0.33	0.00	

Medium Impellers - Imperial

LTO 23127 **Note: Impeller diameters are 25.0/25.0/24.5**		**Full Load Performance Comparison at 44/85**			
Run Number		121	154	185	204
					ARI
Refrigerant		11	123	245ca	245ca
Oil		Solest 68	Solest 68	Solest 68	Solest 68
1st Stage Guide Vane Setting	Degrees	90	90	90	90
Capacity	Tons	187.90	208.10	178.20	173.50
Power	KW	151.62	173.04	136.38	134.10
KW/Ton	KW/Ton	0.810	0.830	0.770	0.770
TOE	Deg F	44.03	44.05	44.05	44.05
TIC	Deg F	85.02	85.07	85.05	85.08
Energy Balance	%	-1.38	-1.20	-1.29	-0.63
TIE	Deg F	53.06	53.95	52.77	53.91
TOE	Deg F	44.03	44.05	44.05	44.05
GPME	GPM	497.80	503.50	489.40	421.20
TIC	Deg F	85.02	85.07	85.05	85.08
TOC	Deg F	94.37	95.44	93.83	95.02
GPMC	GPM	602.20	604.10	601.80	516.20
Evap Sat Press	Psia	6.04	5.23	5.62	5.64
Sat Temp	Deg F	33.50	35.73	35.79	35.93
Approach	Deg F	10.50	8.30	8.30	8.10
LMTD	Deg F	14.58	12.63	12.10	12.40
ITD/Delta T		2.17	1.84	1.95	1.82
Q/Ao	B/hr-ft2	13671.36	15139.84	12963.46	12620.48
Uo	B/hr ft2 F	937.55	1198.74	1071.29	1017.48
ho'	B/hr ft2 F	1346.84	1948.63	1652.17	1615.04
Cond Sat Press	Psia	24.33	22.33	23.53	23.82
Sat Temp	Deg F	102.08	103.90	101.52	102.16
Approach	Deg F	7.70	8.50	7.70	7.10
Refrigerant Leaving Temp	Deg F	100.77	103.01	99.31	100.25
LMTD	Deg F	11.77	12.96	11.53	11.40
Q/Ao	B/hr-ft2	13597.94	15121.44	12761.78	12379.09
Uo	B/hr ft2 F	1155.05	1166.70	1107.02	1086.22
ho'	B/hr ft2 F	1715.64	1737.21	1612.63	1655.25
Cond Sat Temp	Deg F	102.08	103.90	101.52	102.16
Evap Sat Temp	Deg F	33.50	35.73	35.79	35.93
Estimated Motor Efficiency (1)		0.938	0.933	0.941	0.942
Estimated Motor RPM (1)		3554	3547	3559	3560
Compressor Suction CFM (2)	CFM	3097	3803	2981	2894
Isentropic KW/T (2)		0.548	0.548	0.523	0.526
Adiabatic Efficiency (3)		0.677	0.660	0.679	0.683
Q/N (4)		0.871	1.072	0.838	0.813
(1) From motor curves at measured power input					
(2) Cycle calculation using evap and cond sat, motor efficiency, and equal head split					
(3) Ratio of isentropic and test KW/T					
(4) CFM from cycle calculation / estimated motor RPM					
(5) Heat transfer coefficient calculations use bulk fluid properties					

Medium Impellers - Imperial

Evap Water Velocity	Fps	9.68	9.79	9.52	8.19
Re		48859.11	49751.90	47927.54	41619.73
Pr		9.51	9.44	9.53	9.44
R		10.80	10.81	10.78	10.64
F		-5.22	-5.23	-5.22	-5.17
hi		3563.40	3597.77	3519.27	3176.25
Cond Water Velocity	Fps	9.37	9.40	9.37	8.03
Re		81918.85	82814.71	81708.85	70490.23
Pr		5.14	5.09	5.15	5.11
R		11.31	11.32	11.31	11.16
F		-5.37	-5.37	-5.37	-5.33
hi		4082.86	4103.29	4078.09	3649.39
Curve fit for motor efficiency					
A1		8.80E-01	8.80E-01	8.80E-01	8.80E-01
A2		1.49E-03	1.49E-03	1.49E-03	1.49E-03
A3		-1.09E-05	-1.09E-05	-1.09E-05	-1.09E-05
A4		2.91E-08	2.91E-08	2.91E-08	2.91E-08
A5		-2.57E-11	-2.57E-11	-2.57E-11	-2.57E-11
KW (input)		151.62	173.04	136.38	134.10
Hp (estimated assuming eff of .933)		188.86	215.54	169.88	167.04
Motor efficiency		0.938	0.933	0.941	0.942
Curve fit for motor RPM					
A1		3.60E+03	3.60E+03	3.60E+03	3.60E+03
A2		-2.30E-01	-2.30E-01	-2.30E-01	-2.30E-01
A3		8.10E-05	8.10E-05	8.10E-05	8.10E-05
A4		-9.47E-07	-9.47E-07	-9.47E-07	-9.47E-07
A5		8.88E-10	8.88E-10	8.88E-10	8.88E-10
Motor RPM		3554.178	3546.592	3559.345	3560.102

Medium Impellers - Imperial

1	EVAP WATER FLOWMETER DELTA P	PSID	17.20	17.59	16.62	12.31
3	ENT EVAP WATER TEMP LOC 1	Deg F	53.09	53.97	52.79	53.93
4	ENT EVAP WATER TEMP LOC 2	Deg F	53.04	53.93	52.74	53.88
5	LVG EVAP WATER TEMP LOC 1	Deg F	44.04	44.07	44.07	44.06
6	LVG EVAP WATER TEMP LOC 2	Deg F	44.02	44.04	44.03	44.03
15	COND WATER FLOWMETER DELTA P	PSID	25.04	25.20	25.01	18.40
17	ENT COND WATER TEMP LOC 1	Deg F	85.01	85.04	85.03	85.07
18	ENT COND WATER TEMP LOC 2	Deg F	85.02	85.10	85.06	85.09
19	LVG COND WATER TEMP LOC 1	Deg F	94.37	95.43	93.82	95.00
20	LVG COND WATER TEMP LOC 2	Deg F	94.37	95.45	93.84	95.03
50	ABOVE EVAP DISTRIB TEMP - SUPPLY	Deg F	38.99	37.73	38.25	41.78
51	ABOVE EVAP DISTRIB TEMP - MIDDLE	Deg F	36.74	38.90	37.93	39.02
52	ABOVE EVAP DISTRIB TEMP - RETURN	Deg F	36.99	39.99	38.09	40.34
61	EVAP SHELL STATIC PRESS - AVERAGE	PSIA	6.04	5.23	5.62	5.64
215	ENT 2nd IMPELLER TOTAL PRESS #1	PSIA	10.09	8.85	9.43	9.50
216	ENT 2nd IMPELLER TOTAL PRESS #2	PSIA	10.14	8.93	9.50	9.56
218	ENT 2nd IMP SHROUD STATIC PRESS #1	PSIA	9.64	8.20	9.09	9.17
315	ENT 3rd IMPELLER TOTAL PRESS #1	PSIA	15.76	14.05	13.74	13.91
316	ENT 3rd IMPELLER TOTAL PRESS #2	PSIA	16.21	14.58	15.49	15.65
318	ENT 3rd IMP SHROUD STATIC PRESS #1	PSIA	15.52	13.64	14.81	15.05
431	COND SHELL STATIC PRESS - AVERAGE	PSIA	24.33	22.33	23.53	23.82
440	REFRIGERANT LVG COND TEMP	Deg F	100.77	103.01	99.31	100.25
484	HIGH PRESS ECONOMIZER STATIC PRESS	PSIA	15.96	14.32	15.35	15.51
485	HIGH PRESS ECONOMIZER TEMP	Deg F	78.49	80.44	79.05	79.65
486	LOW PRESS ECONONOMIZER STATIC PRESS	PSIA	10.06	8.92	9.53	9.59
487	LOW PRESS ECONOMIZER TEMP	Deg F	55.80	58.46	57.72	57.96
530	ENT EVAP ORIFICE ASS'Y PRESS	PSIA	7.87	7.50	7.45	7.44
531	ENT EVAP ORIFICE ASS'Y TEMP	Deg F	55.72	58.80	57.65	57.90
532	LVG EVAP ORIFICE ASS'Y PRESS	PSIA	10.08	9.06	9.55	9.59
533	LVG EVAP ORIFICE ASS'Y TEMP	Deg F	44.64	50.94	47.43	47.44
534	ENT COND ORIFICE ASS'Y PRESS	PSIA	24.29	22.50	23.52	23.79
535	ENT COND ORIFICE ASS'Y TEMP	Deg F	101.51	103.91	100.27	100.94
536	LVG COND ORIFICE ASS'Y PRESS	PSIA	18.37	17.17	17.73	17.84
537	LVG COND ORIFICE ASS'Y TEMP	Deg F	86.31	90.77	86.48	86.86
560	ATMOSPHERIC PRESS	PSIA	14.38	14.50	14.39	14.37
580	MOTOR VOLTAGE - AB	Volts	3.850	3.880	3.922	3.901
581	MOTOR VOLTAGE - AC	Volts	3.858	3.884	3.931	3.908
582	MOTOR VOLTAGE - CB	Volts	3.840	3.874	3.908	3.889
583	MOTOR CURRENT - A	Volts	2.115	2.383	1.899	1.873
584	MOTOR CURRENT - B	Volts	2.187	2.482	1.971	1.938
585	MOTOR CURRENT - C	Volts	2.067	2.294	1.854	1.833
586	MOTOR POWER - PHASE 1	Volts	0.941	1.108	0.824	0.808
587	MOTOR POWER - PHASE 3	Volts	1.586	1.776	1.449	1.427
595	TC CARD #1 CHECK (LVG COND TEMP)	Deg F	94.38	95.38	93.75	94.97
601	MAXIMUM MOTOR TEMPERATURE	Deg F	130.50	150.2	111.50	110.00
605	1st STAGE VANE SETTING	Degrees	90.00	90	90.00	90.00
607	3rd STAGE VANE SETTING	Degrees	68.00	68	68.00	68.00
608	UNIT HOUR METER READING	Hr	453.40	470.2	487.50	500.50
609	UNIT START COUNTER READING		124	128	131	133
610	CURRENT REFRIGERANT CHARGE	Lbm	360	360	360	360
700	TIME (HOURS)	HOURS	0.00	1.3509	1.18	0.00
701	ENERGY BALANCE	%	-1.38	-1.2	-1.29	-0.63
702	EVAP CAPACITY	Tons	187.90	208.1	178.20	173.50
703	EVAP WATER FLOWRATE	GPM	497.80	503.5	489.40	421.20
704	COND WATER FLOWRATE	GPM	602.20	604.1	601.80	516.20

Medium Impellers - Imperial

710	AVE ENT EVAP WATER TEMP	Deg F	53.06	53.95	52.77	53.91
711	AVE LVG EVAP WATER TEMP	Deg F	44.03	44.05	44.05	44.05
712	AVE ENT COND WATER TEMP	Deg F	85.02	85.07	85.05	85.06
713	AVE LVG COND WATER TEMP	Deg F	94.37	95.44	93.83	95.02
715	MOTOR VOLTAGE - AB	Volts	462.00	465.6	470.60	468.10
716	MOTOR VOLTAGE - AC	Volts	463.00	466.1	471.70	469.00
717	MOTOR VOLTAGE - CB	Volts	460.80	464.9	469.00	466.70
718	MOTOR CURRENT - A	Amps	211.50	238.3	189.90	187.30
719	MOTOR CURRENT - B	Amps	218.70	248.2	197.10	193.80
720	MOTOR CURRENT - C	Amps	206.70	229.4	185.40	183.30
721	UNIT POWER	KW	151.62	173.04	136.38	134.10
722	AVERAGE VOLTAGE	Volts	461.90	465.5	470.40	467.90
723	AVERAGE CURRENT	Amps	212.30	238.63	190.80	188.13
725	KW/TON	KW/Ton	0.81	0.83	0.77	0.77
730	EVAP DELTA T	Deg F	9.03	9.89	8.72	9.85
731	COND DELTA T	Deg F	9.35	10.37	8.79	9.93
735	EVAP WATER FLOWRATE	Lbm/min	4154.40	4201.2	4083.80	3514.50
736	COND WATER FLOWRATE	Lbm/min	5006.30	5022.3	5003.30	4291.50
740	EVAP CAPACITY	Btu/min	37580.30	41616.9	35634.40	34691.60
741	COND CAPACITY	Btu/min	46724.80	51959.8	43851.60	42536.60
743	EVAP SAT'N TEMP (BASED ON ID #61)	Deg F	33.50	35.73	35.79	35.93
744	COND SAT'N TEMP (BASED ON ID #431)	Deg F	102.08	103.9	101.52	102.16
750	RUNNING TIME	Hr	124.50	141.3	158.60	171.60
751	STARTS		29	33	36	38
752	EVAP APPROACH TEMP	Deg F	10.50	8.3	8.30	8.10
753	COND APPROACH TEMP	Deg F	7.70	8.5	7.70	7.10
800	EVAP AVG H2O TEMP	Deg F	48.55	49	48.41	48.98
801	EVAP WATER DENSITY	Lbm/Ft3	62.43	62.4311	62.43	62.43
802	EVAP H2O VISCOSITY(LBM/SEC-FT)	Lbm/Sec-l	0.000893	0.000887	0.000895	0.000887
803	EVAP H2O SPECIFIC HEAT (Cp)	Btu/lbm-F	1.0012	1.0010	1.0012	1.0010
804	EVAP H2O CON(K) (BTU/HR-FT-F)		0.3385	0.3387	0.3384	0.3387
810	COND AVG H2O TEMP	Deg F	89.69	90.25	89.44	90.05
811	COND WATER DENSITY	Lbm/Ft3	62.14	62.13	62.14	62.13
812	COND H2O VISCOSITY(LBM/SEC-FT)	Lbm/Sec-l	0.000513	0.000509	0.000514	0.000511
813	COND H2O SPECIFIC HEAT (Cp)	Btu/lbm-F	0.9977	0.9977	0.9977	0.9977
814	COND H2O CON(K) (BTU/HR-FT-F)		0.3588	0.3591	0.3587	0.3590
815	ITD/DELTA T		2.17	1.84	1.95	1.82
850	RTD DIFFERENCE CHECK - ECWT	Deg F	-0.01	-0.06	-0.03	-0.02
851	RTD DIFFERENCE CHECK - LCWT	Deg F	0.00	-0.02	-0.02	-0.03
852	RTD DIFFERENCE CHECK - EEWT	Deg F	0.05	0.04	0.05	0.05
853	RTD DIFFERENCE CHECK - LEWT	Deg F	0.02	0.03	0.04	0.03
870	TC/RTD CARD #1 CHECK (#19-#595)	Deg F	-0.01	0.05	0.07	0.03

Small Impellers - Imperial

1	EVAP WATER FLOWMETER DELTA P	PSID	16.77	16.79	14.45		
3	ENT EVAP WATER TEMP LOC 1	Deg F	47.17	46.97	54.09		
4	ENT EVAP WATER TEMP LOC 2	Deg F	47.10	46.87	54.03		
5	LVG EVAP WATER TEMP LOC 1	Deg F	44.04	44.03	44.04		
6	LVG EVAP WATER TEMP LOC 2	Deg F	44.00	43.98	44.00		
15	COND WATER FLOWMETER DELTA P	PSID	25.45	25.43	22.15		
17	ENT COND WATER TEMP LOC 1	Deg F	90.03	93.00	85.03		
18	ENT COND WATER TEMP LOC 2	Deg F	90.06	93.02	85.04		
19	LVG COND WATER TEMP LOC 1	Deg F	93.40	96.20	95.11		
20	LVG COND WATER TEMP LOC 2	Deg F	93.43	96.20	95.11		
50	ABOVE EVAP DISTRIB TEMP - SUPPLY	Deg F	42.59	42.75	38.38		
51	ABOVE EVAP DISTRIB TEMP - MIDDLE	Deg F	42.93	43.13	39.00		
52	ABOVE EVAP DISTRIB TEMP - RETURN	Deg F	43.87	44.10	40.07		
61	EVAP SHELL STATIC PRESS - AVERAGE	PSIA	5.90	5.92	5.30		
215	ENT 2nd IMPELLER TOTAL PRESS #1	PSIA	7.55	7.89	8.75		
216	ENT 2nd IMPELLER TOTAL PRESS #2	PSIA	7.71	8.05	8.81		
218	ENT 2nd IMP SHROUD STATIC PRESS #1	PSIA	7.47	7.82	8.21		
315	ENT 3rd IMPELLER TOTAL PRESS #1	PSIA	10.55	11.25	12.78		
316	ENT 3rd IMPELLER TOTAL PRESS #2	PSIA	11.71	12.49	14.12		
318	ENT 3rd IMP SHROUD STATIC PRESS #1	PSIA	12.24	12.97	13.23		
431	COND SHELL STATIC PRESS - AVERAGE	PSIA	18.87	19.93	21.75		
440	REFRIGERANT LVG COND TEMP	Deg F	94.60	97.37	102.28		
484	HIGH PRESS ECONOMIZER STATIC PRESS	PSIA	13.01	13.63	13.87		
485	HIGH PRESS ECONOMIZER TEMP	Deg F	75.86	78.08	78.98		
486	LOW PRESS ECONONOMIZER STATIC PRESS	PSIA	7.53	7.87	8.78		
487	LOW PRESS ECONOMIZER TEMP	Deg F	51.02	52.91	57.82		
530	ENT EVAP ORIFICE ASS'Y PRESS	PSIA	6.52	6.63	7.31		
531	ENT EVAP ORIFICE ASS'Y TEMP	Deg F	50.67	52.53	57.93		
532	LVG EVAP ORIFICE ASS'Y PRESS	PSIA	7.51	7.83	8.91		
533	LVG EVAP ORIFICE ASS'Y TEMP	Deg F	44.63	45.28	49.67		
534	ENT COND ORIFICE ASS'Y PRESS	PSIA	18.83	19.82	21.88		
535	ENT COND ORIFICE ASS'Y TEMP	Deg F	94.96	97.63	102.76		
536	LVG COND ORIFICE ASS'Y PRESS	PSIA	14.18	14.81	16.62		
537	LVG COND ORIFICE ASS'Y TEMP	Deg F	80.25	82.40	89.08		
560	ATMOSPHERIC PRESS	PSIA	14.33	14.32	14.31		
580	MOTOR VOLTAGE - AB	Volts	3.872	3.861	3.879		
581	MOTOR VOLTAGE - AC	Volts	3.875	3.869	3.882		
582	MOTOR VOLTAGE - CB	Volts	3.862	3.857	3.870		
583	MOTOR CURRENT - A	Volts	1.076	1.077	2.096		
584	MOTOR CURRENT - B	Volts	1.158	1.158	2.188		
585	MOTOR CURRENT - C	Volts	1.069	1.078	2.033		
586	MOTOR POWER - PHASE 1	Volts	0.330	0.329	0.943		
587	MOTOR POWER - PHASE 3	Volts	0.806	0.813	1.575		
595	TC CARD #1 CHECK (LVG COND TEMP)	Deg F	93.41	96.30	95.10		
601	MAXIMUM MOTOR TEMPERATURE	Deg F	78.50	80.50	130.50		
605	1st STAGE VANE SETTING	Degrees	10.00	10.00	90.00		
607	3rd STAGE VANE SETTING	Degrees	19.00	19.00	68.00		
608	UNIT HOUR METER READING	Hr	517.40	518.10	519.00		
609	UNIT START COUNTER READING		135	135	135		
610	CURRENT REFRIGERANT CHARGE	Lbm	360	360	360		
700	TIME (HOURS)	HOURS	411.01	411.61	412.38		
701	ENERGY BALANCE	%	-2.22	-1.35	-1.21		
702	EVAP CAPACITY	Tons	64.00	59.90	191.40		
703	EVAP WATER FLOWRATE	GPM	491.50	491.80	456.30		
704	COND WATER FLOWRATE	GPM	607.40	607.40	566.40		

Small Impellers - Imperial

710	AVE ENT EVAP WATER TEMP	Deg F	47.14	46.92	54.06		
711	AVE LVG EVAP WATER TEMP	Deg F	44.02	44.01	44.02		
712	AVE ENT COND WATER TEMP	Deg F	90.05	93.01	85.03		
713	AVE LVG COND WATER TEMP	Deg F	93.42	96.20	95.11		
715	MOTOR VOLTAGE - AB	Volts	464.60	463.30	465.50		
716	MOTOR VOLTAGE - AC	Volts	465.00	464.30	465.80		
717	MOTOR VOLTAGE - CB	Volts	463.40	462.80	464.40		
718	MOTOR CURRENT - A	Amps	107.60	107.70	209.60		
719	MOTOR CURRENT - B	Amps	115.80	115.80	218.80		
720	MOTOR CURRENT - C	Amps	106.90	107.80	203.40		
721	UNIT POWER	KW	68.16	68.51	151.08		
722	AVERAGE VOLTAGE	Volts	464.30	463.50	465.20		
723	AVERAGE CURRENT	Amps	110.10	110.43	210.60		
725	KW/TON	KW/Ton	1.05	1.14	0.79		
730	EVAP DELTA T	Deg F	3.12	2.91	10.04		
731	COND DELTA T	Deg F	3.37	3.19	10.08		
735	EVAP WATER FLOWRATE	Lbm/min	4102.20	4104.70	3807.80		
736	COND WATER FLOWRATE	Lbm/min	5045.40	5042.30	4708.50		
740	EVAP CAPACITY	Btu/min	12802.70	11988.40	38272.40		
741	COND CAPACITY	Btu/min	16963.30	16047.50	47327.50		
743	EVAP SAT'N TEMP (BASED ON ID #61)	Deg F	40.68	40.82	36.27		
744	COND SAT'N TEMP (BASED ON ID #431)	Deg F	94.93	97.79	102.48		
750	RUNNING TIME	Hr	188.50	189.20	190.10		
751	STARTS		40.00	40.00	40.00		
752	EVAP APPROACH TEMP	Deg F	3.30	3.20	7.80		
753	COND APPROACH TEMP	Deg F	1.50	1.60	7.40		
800	EVAP AVG H2O TEMP	Deg F	45.58	45.47	49.04		
801	EVAP WATER DENSITY	Lbm/Ft3	62.44	62.44	62.43		
802	EVAP H2O VISCOSITY(LBM/SEC-FT)	Lbm/Sec-(	0.000936	0.000938	0.000886		
803	EVAP H2O SPECIFIC HEAT (Cp)	Btu/lbm-F	1.0019	1.0019	1.0010		
804	EVAP H2O CON(K) (BTU/HR-FT-F)		0.3368	0.3368	0.3388		
810	COND AVG H2O TEMP	Deg F	91.73	94.61	90.07		
811	COND WATER DENSITY	Lbm/Ft3	62.11	62.08	62.13		
812	COND H2O VISCOSITY(LBM/SEC-FT)	Lbm/Sec-(	0.000500	0.000485	0.000511		
813	COND H2O SPECIFIC HEAT (Cp)	Btu/lbm-F	0.9977	0.9977	0.9977		
814	COND H2O CON(K) (BTU/HR-FT-F)		0.3597	0.3610	0.3590		
815	ITD/DELTA T		2.07	2.09	1.77		
850	RTD DIFFERENCE CHECK - ECWT	Deg F	-0.03	-0.02	-0.01		
851	RTD DIFFERENCE CHECK - LCWT	Deg F	-0.03	0.00	0.00		
852	RTD DIFFERENCE CHECK - EEWT	Deg F	0.07	0.10	0.06		
853	RTD DIFFERENCE CHECK - LEWT	Deg F	0.04	0.05	0.04		
870	TC/RTD CARD #1 CHECK (#19-#595)	Deg F	-0.01	-0.10	0.01		

Small Impellers - Imperial

LTO 23127 Note: Impeller diameters are 24.0/24.0/24.0		Full Load Performance Comparison at 44/85	
Run Number		208	232
			ARI
Refrigerant		123	123
Oil		Solest 68	Solest 68
1st Stage Guide Vane Setting	Degrees	90	90
Capacity	Tons	192.40	191.40
Power	KW	151.02	151.08
KW/Ton	KW/Ton	0.785	0.789
TOE	Deg F	44.02	44.02
TIC	Deg F	84.98	85.03
Energy Balance	%	-1.25	-1.21
TIE	Deg F	53.43	54.06
TOE	Deg F	44.02	44.02
GPME	GPM	490.00	456.30
TIC	Deg F	84.98	85.03
TOC	Deg F	94.45	95.11
GPMC	GPM	605.70	566.40
Evap Sat Press	Psia	5.32	5.30
Sat Temp	Deg F	36.43	36.27
Approach	Deg F	7.60	7.80
LMTD	Deg F	11.67	12.08
ITD/Delta T		1.81	1.77
Q/Ao	B/hr-ft2	13997.83	13923.14
Uo	B/hr ft2 F	1199.53	1152.33
ho'	B/hr ft2 F	1975.61	1907.71
Cond Sat Press	Psia	21.64	21.75
Sat Temp	Deg F	102.20	102.48
Approach	Deg F	7.80	7.40
Refrigerant Leaving Temp	Deg F	101.85	102.28
LMTD	Deg F	11.86	11.69
Q/Ao	B/hr-ft2	13837.25	13773.34
Uo	B/hr ft2 F	1166.56	1177.73
ho'	B/hr ft2 F	1737.43	1807.24
Cond Sat Temp	Deg F	102.20	102.48
Evap Sat Temp	Deg F	36.43	36.27
Estimated Motor Efficiency (1)		0.938	0.938
Estimated Motor RPM (1)		3554	3554
Compressor Suction CFM (2)	CFM	3450	3446
Isentropic KW/T (2)		0.524	0.528
Adiabatic Efficiency (3)		0.668	0.669
Q/N (4)		0.971	0.970

(1) From motor curves at measured power input
(2) Cycle calculation using evap and cond sat, motor efficiency, and equal head split
(3) Ratio of isentropic and test KW/T
(4) CFM from cycle calculation / estimated motor RPM
(5) Heat transfer coefficient calculations use bulk fluid properties

Small Impellers - Imperial

Evap Water Velocity	Fps	9.53	8.88
Re		48201.11	45138.78
Pr		9.48	9.42
R		10.78	10.72
F		-5.22	-5.20
hi	B/hr ft2 F	3526.87	3361.25
Cond Water Velocity	Fps	9.43	8.81
Re		82394.44	77345.09
Pr		5.14	5.11
R		11.32	11.26
F		-5.37	-5.36
hi		4100.76	3905.21
Curve fit for motor efficiency			
A1		8.80E-01	8.80E-01
A2		1.49E-03	1.49E-03
A3		-1.09E-05	-1.09E-05
A4		2.91E-08	2.91E-08
A5		-2.57E-11	-2.57E-11
KW (input)		151.02	151.08
Hp (estimated assuming eff of .933)		188.11	188.19
Motor efficiency		0.938	0.938
Curve fit for motor RPM			
A1		3.60E+03	3.60E+03
A2		-2.30E-01	-2.30E-01
A3		8.10E-05	8.10E-05
A4		-9.47E-07	-9.47E-07
A5		8.88E-10	8.88E-10
Motor RPM		3554.385	3554.365

Small Impellers - Imperial

1	EVAP WATER FLOWMETER DELTA P	PSID	16.66	14.45			
3	ENT EVAP WATER TEMP LOC 1	Deg F	53.44	54.09			
4	ENT EVAP WATER TEMP LOC 2	Deg F	53.41	54.03			
5	LVG EVAP WATER TEMP LOC 1	Deg F	44.04	44.04			
6	LVG EVAP WATER TEMP LOC 2	Deg F	44.01	44.00			
15	COND WATER FLOWMETER DELTA P	PSID	25.33	22.15			
17	ENT COND WATER TEMP LOC 1	Deg F	84.98	85.03			
18	ENT COND WATER TEMP LOC 2	Deg F	84.99	85.04			
19	LVG COND WATER TEMP LOC 1	Deg F	94.45	95.11			
20	LVG COND WATER TEMP LOC 2	Deg F	94.45	95.11			
50	ABOVE EVAP DISTRIB TEMP - SUPPLY	Deg F	40.20	38.38			
51	ABOVE EVAP DISTRIB TEMP - MIDDLE	Deg F	39.09	39.00			
52	ABOVE EVAP DISTRIB TEMP - RETURN	Deg F	39.68	40.07			
61	EVAP SHELL STATIC PRESS - AVERAGE	PSIA	5.32	5.30			
215	ENT 2nd IMPELLER TOTAL PRESS #1	PSIA	8.77	8.75			
216	ENT 2nd IMPELLER TOTAL PRESS #2	PSIA	8.85	8.81			
218	ENT 2nd IMP SHROUD STATIC PRESS #1	PSIA	8.24	8.21			
315	ENT 3rd IMPELLER TOTAL PRESS #1	PSIA	12.93	12.78			
316	ENT 3rd IMPELLER TOTAL PRESS #2	PSIA	14.05	14.12			
318	ENT 3rd IMP SHROUD STATIC PRESS #1	PSIA	13.26	13.23			
431	COND SHELL STATIC PRESS - AVERAGE	PSIA	21.64	21.75			
440	REFRIGERANT LVG COND TEMP	Deg F	101.85	102.28			
484	HIGH PRESS ECONOMIZER STATIC PRESS	PSIA	13.90	13.87			
485	HIGH PRESS ECONOMIZER TEMP	Deg F	79.08	78.98			
486	LOW PRESS ECONONOMIZER STATIC PRESS	PSIA	8.83	8.78			
487	LOW PRESS ECONOMIZER TEMP	Deg F	58.01	57.82			
530	ENT EVAP ORIFICE ASS'Y PRESS	PSIA	7.29	7.31			
531	ENT EVAP ORIFICE ASS'Y TEMP	Deg F	58.14	57.93			
532	LVG EVAP ORIFICE ASS'Y PRESS	PSIA	8.93	8.91			
533	LVG EVAP ORIFICE ASS'Y TEMP	Deg F	49.74	49.67			
534	ENT COND ORIFICE ASS'Y PRESS	PSIA	21.78	21.88			
535	ENT COND ORIFICE ASS'Y TEMP	Deg F	102.34	102.76			
536	LVG COND ORIFICE ASS'Y PRESS	PSIA	16.43	16.62			
537	LVG COND ORIFICE ASS'Y TEMP	Deg F	88.71	89.08			
560	ATMOSPHERIC PRESS	PSIA	14.41	14.31			
580	MOTOR VOLTAGE - AB	Volts	3.831	3.879			
581	MOTOR VOLTAGE - AC	Volts	3.833	3.882			
582	MOTOR VOLTAGE - CB	Volts	3.823	3.870			
583	MOTOR CURRENT - A	Volts	2.109	2.096			
584	MOTOR CURRENT - B	Volts	2.203	2.188			
585	MOTOR CURRENT - C	Volts	2.040	2.033			
586	MOTOR POWER - PHASE 1	Volts	0.959	0.943			
587	MOTOR POWER - PHASE 3	Volts	1.558	1.575			
595	TC CARD #1 CHECK (LVG COND TEMP)	Deg F	94.46	95.10			
601	MAXIMUM MOTOR TEMPERATURE	Deg F	131.50	130.50			
605	1st STAGE VANE SETTING	Degrees	90.00	90.00			
607	3rd STAGE VANE SETTING	Degrees	68.00	68.00			
608	UNIT HOUR METER READING	Hr	506.20	519.00			
609	UNIT START COUNTER READING		134	135			
610	CURRENT REFRIGERANT CHARGE	Lbm	360	360			
700	TIME (HOURS)	HOURS	384.16	412.38			
701	ENERGY BALANCE	%	-1.25	-1.21			
702	EVAP CAPACITY	Tons	192.40	191.40			
703	EVAP WATER FLOWRATE	GPM	490.00	456.30			
704	COND WATER FLOWRATE	GPM	605.70	566.40			

Small Impellers - Imperial

710	AVE ENT EVAP WATER TEMP	Deg F	53.43	54.06			
711	AVE LVG EVAP WATER TEMP	Deg F	44.02	44.02			
712	AVE ENT COND WATER TEMP	Deg F	84.98	85.03			
713	AVE LVG COND WATER TEMP	Deg F	94.45	95.11			
715	MOTOR VOLTAGE - AB	Volts	459.70	465.50			
716	MOTOR VOLTAGE - AC	Volts	460.00	465.80			
717	MOTOR VOLTAGE - CB	Volts	458.80	464.40			
718	MOTOR CURRENT - A	Amps	210.90	209.60			
719	MOTOR CURRENT - B	Amps	220.30	218.80			
720	MOTOR CURRENT - C	Amps	204.00	203.40			
721	UNIT POWER	KW	151.02	151.08			
722	AVERAGE VOLTAGE	Volts	459.50	465.20			
723	AVERAGE CURRENT	Amps	211.73	210.60			
725	KW/TON	KW/Ton	0.78	0.79			
730	EVAP DELTA T	Deg F	9.39	10.04			
731	COND DELTA T	Deg F	9.47	10.08			
735	EVAP WATER FLOWRATE	Lbm/min	4088.60	3807.80			
736	COND WATER FLOWRATE	Lbm/min	5035.20	4708.50			
740	EVAP CAPACITY	Btu/min	38477.70	38272.40			
741	COND CAPACITY	Btu/min	47547.10	47327.50			
743	EVAP SAT'N TEMP (BASED ON ID #61)	Deg F	36.43	36.27			
744	COND SAT'N TEMP (BASED ON ID #431)	Deg F	102.20	102.48			
750	RUNNING TIME	Hr	177.30	190.10			
751	STARTS		39.00	40.00			
752	EVAP APPROACH TEMP	Deg F	7.60	7.80			
753	COND APPROACH TEMP	Deg F	7.80	7.40			
800	EVAP AVG H2O TEMP	Deg F	48.73	49.04			
801	EVAP WATER DENSITY	Lbm/Ft3	62.43	62.43			
802	EVAP H2O VISCOSITY(LBM/SEC-FT)	Lbm/Sec-I	0.000891	0.000886			
803	EVAP H2O SPECIFIC HEAT (Cp)	Btu/lbm-F	1.0012	1.0010			
804	EVAP H2O CON(K) (BTU/HR-FT-F)		0.3386	0.3388			
810	COND AVG H2O TEMP	Deg F	89.72	90.07			
811	COND WATER DENSITY	Lbm/Ft3	62.13	62.13			
812	COND H2O VISCOSITY(LBM/SEC-FT)	Lbm/Sec-I	0.000513	0.000511			
813	COND H2O SPECIFIC HEAT (Cp)	Btu/lbm-F	0.9977	0.9977			
814	COND H2O CON(K) (BTU/HR-FT-F)		0.3588	0.3590			
815	ITD/DELTA T		1.81	1.77			
850	RTD DIFFERENCE CHECK - ECWT	Deg F	-0.01	-0.01			
851	RTD DIFFERENCE CHECK - LCWT	Deg F	0.00	0.00			
852	RTD DIFFERENCE CHECK - EEWT	Deg F	0.03	0.06			
853	RTD DIFFERENCE CHECK - LEWT	Deg F	0.03	0.04			
870	TC/RTD CARD #1 CHECK (#19-#595)	Deg F	-0.01	0.01			

Large Impellers - Metric

LTO 23127	**Note: Impeller diameters are 660/660/660 mm**					
	Run Number		20	42	64	93
	Refrigerant		11	11	123	245ca
	Oil		Trane 22	Solest 68	Solest 68	Solest 68
	1st Stage Guide Vane Setting	Degrees	90	90	90	90
	Capacity	KW	838.9	814.3	796.0	725.0
	Power	KW	198.0	193.0	199.3	164.5
	Coefficient of Performance (COP)		4.237	4.220	3.994	4.408
	Evaporator Leaving Water Temperature	Deg C	6.67	6.67	6.69	6.66
	Condenser Entering Water Temperature	Deg C	29.43	29.43	29.56	29.43
	Energy Balance	%	-0.73	-0.65	-0.90	-0.92
	Evaporator Entering Water Temperature	Deg C	13.26	13.08	12.87	12.13
	Evaporator Leaving Water Temperature	Deg C	6.67	6.67	6.69	6.66
	Evaporator Water Flow Rate	L/S	30.41	30.29	30.76	31.67
	Condenser Entering Water Temperature	Deg C	29.43	29.43	29.56	29.43
	Condenser Leaving Water Temperature	Deg C	36.06	35.81	35.84	35.05
	Condenser Water Flow Rate	L/S	37.84	38.14	38.34	38.27
	Evap Sat Press	kPa	44.33	43.64	35.65	37.78
	Sat Temp	Deg C	2.32	1.94	1.82	1.54
	Approach	Deg C	4.33	4.72	4.89	5.11
	LMTD	Deg C	7.14	7.48	7.54	7.52
	ITD/Delta T		1.66	1.74	1.79	1.94
	Q/Ao	kW/m2	54.76	53.15	51.95	47.31
	Uo	kW/m2 C	7.67	7.11	6.89	6.29
	ho'	kW/m2 C	13.83	12.13	11.42	9.78
	Cond Sat Press	kPa	180.23	178.85	161.96	168.78
	Sat Temp	Deg C	41.23	40.98	41.49	39.78
	Approach	Deg C	5.17	5.17	5.67	4.72
	Refrigerant Leaving Temp	Deg C	40.52	40.35	40.74	38.59
	LMTD	Deg C	8.03	7.94	8.40	7.18
	Q/Ao	kW/m2	54.46	52.87	52.33	46.78
	Uo	kW/m2 C	6.78	6.66	6.23	6.51
	ho'	kW/m2 C	10.24	9.93	8.99	9.61
	Cond Sat Temp	Deg C	41.23	40.98	41.49	39.78
	Evap Sat Temp	Deg C	2.32	1.94	1.82	1.54
	Estimated Motor Efficiency (1)		0.93	0.93	0.93	0.93
	Estimated Motor Rev/Sec (1)		58.95	58.99	58.95	59.16
	Compressor Suction Flow Rate (2)	m3/sec	1.762	1.734	1.982	1.673
	Isentropic COP (2)		6.234	6.212	6.062	6.347
	Adiabatic Efficiency (3)		0.680	0.682	0.659	0.693
	Q/N - m3/rev (4)		0.0299	0.0294	0.0336	0.0283
(1) From motor curves at measured power input						
(2) Cycle calculation using evap and cond sat, motor efficiency,						
and equal head split						
(3) Ratio of test and isentropic COP						
(4) CFM from cycle calculation / estimated motor RPM						
(5) Heat transfer coefficient calculations use bulk fluid properties						

Large Impellers - Metric

Evap Water Velocity	M/Sec	2.86	2.85	2.89	2.98
Re		48324	48035	48608	49538
Pr		9.28	9.31	9.34	9.45
R		10.79	10.78	10.79	10.81
F		-5.22	-5.22	-5.22	-5.23
hi	KW/m2 C	19.89	19.83	20.02	20.37
Cond Water Velocity	M/Sec	2.84	2.87	2.88	2.88
Re		82689	83185	83776	82835
Pr		5.06	5.07	5.06	5.11
R		11.32	11.33	11.34	11.32
F		-5.37	-5.38	-5.38	-5.37
hi	KW/m2 C	23.21	23.33	23.44	23.34
Curve fit for motor efficiency					
A1		0.880	0.880	0.880	0.880
A2		0.001	0.001	0.001	0.001
A3		0.000	0.000	0.000	0.000
A4		0.000	0.000	0.000	0.000
A5		0.000	0.000	0.000	0.000
KW (input)		198.00	192.96	199.32	164.46
Hp (estimated assuming eff of .933)		246.63	240.35	248.28	204.85
Motor efficiency		0.928	0.929	0.928	0.935
Curve fit for motor RPM					
A1		3600.026	3600.026	3600.026	3600.026
A2		-0.230	-0.230	-0.230	-0.230
A3		0.000	0.000	0.000	0.000
A4		0.000	0.000	0.000	0.000
A5		0.000	0.000	0.000	0.000
Motor Rev/Sec		58.95	58.99	58.95	59.16

Large Impellers - Metric

Data as received from Laboratory						
ID	Description	Units				
1	EVAP WATER FLOWMETER DELTA P	kPa	111.1	110.2	113.7	120.5
3	ENT EVAP WATER TEMP LOC 1	Deg C	13.25	13.07	12.86	12.11
4	ENT EVAP WATER TEMP LOC 2	Deg C	13.27	13.09	12.88	12.14
5	LVG EVAP WATER TEMP LOC 1	Deg C	6.67	6.67	6.69	6.67
6	LVG EVAP WATER TEMP LOC 2	Deg C	6.67	6.66	6.68	6.66
15	COND WATER FLOWMETER DELTA P	kPa	171.2	174.0	175.7	175.2
17	ENT COND WATER TEMP LOC 1	Deg C	29.43	29.43	29.57	29.43
18	ENT COND WATER TEMP LOC 2	Deg C	29.43	29.42	29.54	29.42
19	LVG COND WATER TEMP LOC 1	Deg C	36.06	35.81	35.85	35.06
20	LVG COND WATER TEMP LOC 2	Deg C	36.06	35.81	35.84	35.04
50	ABOVE EVAP DISTRIB TEMP - SUPPLY	Deg C	4.08	4.34	4.79	3.14
51	ABOVE EVAP DISTRIB TEMP - MIDDLE	Deg C	3.47	2.55	3.34	2.91
52	ABOVE EVAP DISTRIB TEMP - RETURN	Deg C	3.52	3.80	3.61	3.83
61	EVAP SHELL STATIC PRESS - AVERAGE	kPa	44.3	43.6	35.6	37.8
215	ENT 2nd IMPELLER TOTAL PRESS #1	kPa	74.5	73.6	61.4	64.5
216	ENT 2nd IMPELLER TOTAL PRESS #2	kPa	74.8	73.9	61.8	64.9
218	ENT 2nd IMP SHROUD STATIC PRESS #1	kPa	69.6	68.9	55.8	61.2
315	ENT 3rd IMPELLER TOTAL PRESS #1	kPa	126.9	123.4	106.4	181.9
316	ENT 3rd IMPELLER TOTAL PRESS #2	kPa	120.3	119.1	100.8	105.8
318	ENT 3rd IMP SHROUD STATIC PRESS #1	kPa	112.2	111.1	94.1	100.6
431	COND SHELL STATIC PRESS - AVERAGE	kPa	180.2	178.8	162.0	168.8
440	REFRIGERANT LVG COND TEMP	Deg C	40.52	40.35	40.74	38.59
484	HIGH PRESS ECONOMIZER STATIC PRESS	kPa	117.1	116.0	100.7	106.0
485	HIGH PRESS ECONOMIZER TEMP	Deg C	27.67	27.38	27.51	26.42
486	LOW PRESS ECONONOMIZER STATIC PRESS	kPa	74.3	73.6	62.5	65.6
487	LOW PRESS ECONOMIZER TEMP	Deg C	15.11	14.76	14.99	14.31
530	ENT EVAP ORIFICE ASS'Y PRESS	kPa	74.8	73.9	64.7	66.2
531	ENT EVAP ORIFICE ASS'Y TEMP	Deg C	15.15	14.79	15.20	14.32
532	LVG EVAP ORIFICE ASS'Y PRESS	kPa	61.3	60.3	53.0	52.7
533	LVG EVAP ORIFICE ASS'Y TEMP	Deg C	10.32	9.63	11.32	9.10
534	ENT COND ORIFICE ASS'Y PRESS	kPa	178.7	176.8	160.6	166.7
535	ENT COND ORIFICE ASS'Y TEMP	Deg C	40.54	40.28	40.79	38.80
536	LVG COND ORIFICE ASS'Y PRESS	kPa	135.8	133.8	124.7	125.1
537	LVG COND ORIFICE ASS'Y TEMP	Deg C	32.64	32.30	33.77	31.33
560	ATMOSPHERIC PRESS	kPa	98.6	99.7	99.3	98.9
580	MOTOR VOLTAGE - AB	Volts	3.864	3.861	3.887	3.900
581	MOTOR VOLTAGE - AC	Volts	3.888	3.883	3.902	3.902
582	MOTOR VOLTAGE - CB	Volts	3.865	3.866	3.886	3.884
583	MOTOR CURRENT - A	Volts	2.686	2.612	2.707	2.277
584	MOTOR CURRENT - B	Volts	2.810	2.743	2.831	2.348
585	MOTOR CURRENT - C	Volts	2.667	2.616	2.650	2.190
586	MOTOR POWER - PHASE 1	Volts	1.240	1.200	1.259	1.038
587	MOTOR POWER - PHASE 3	Volts	2.060	2.016	2.063	1.703
595	TC CARD #1 CHECK (LVG COND TEMP)	Deg C	36.07	35.83	35.67	35.06
601	MAXIMUM MOTOR TEMPERATURE	Deg C	84.17	80.83	83.61	54.72
605	1st STAGE VANE SETTING	Degrees	90	90	90	90
607	3rd STAGE VANE SETTING	Degrees	68	68	68	68
608	UNIT HOUR METER READING	Hr	350	391	403	420
609	UNIT START COUNTER READING		98	109	112	115
610	CURRENT REFRIGERANT CHARGE	Kg	163.3	163.3	163.3	163.7
700	TIME (HOURS)	HOURS	360	1	0	0
701	ENERGY BALANCE	%	-0.73	-0.65	-0.90	-0.92

Large Impellers - Metric

702	EVAP CAPACITY	KW	838.9	814.3	796.0	725.0
703	EVAP WATER FLOWRATE	L/S	30.41	30.29	30.76	31.67
704	COND WATER FLOWRATE	L/S	37.84	38.14	38.34	38.27
710	AVE ENT EVAP WATER TEMP	Deg C	13.26	13.08	12.87	12.13
711	AVE LVG EVAP WATER TEMP	Deg C	6.67	6.67	6.69	6.66
712	AVE ENT COND WATER TEMP	Deg C	29.43	29.43	29.56	29.43
713	AVE LVG COND WATER TEMP	Deg C	36.06	35.81	35.84	35.05
715	MOTOR VOLTAGE - AB	Volts	464	463	466	468
716	MOTOR VOLTAGE - AC	Volts	467	466	468	468
717	MOTOR VOLTAGE - CB	Volts	464	464	466	466
718	MOTOR CURRENT - A	Amps	269	261	271	228
719	MOTOR CURRENT - B	Amps	281	274	283	235
720	MOTOR CURRENT - C	Amps	267	262	265	219
721	UNIT POWER	KW	198	193	199	164
722	AVERAGE VOLTAGE	Volts	465	464	467	467
723	AVERAGE CURRENT	Amps	272	266	273	227
725	Coefficient of Performance		4.237	4.220	3.994	4.408
730	EVAP DELTA T	Deg C	6.59	6.42	6.18	5.47
731	COND DELTA T	Deg C	6.63	6.38	6.28	5.63
735	EVAP WATER FLOWRATE	Kg/Sec	30.39	30.28	30.75	31.66
736	COND WATER FLOWRATE	Kg/Sec	37.69	37.99	38.19	38.13
740	EVAP CAPACITY	KW	839.03	814.43	795.95	724.91
741	COND CAPACITY	KW	1043.11	1012.70	1002.38	896.02
743	EVAP SAT'N TEMP (BASED ON ID #61)	Deg C	2.32	1.94	1.82	1.54
744	COND SAT'N TEMP (BASED ON ID #431)	Deg C	41.23	40.98	41.49	39.78
750	RUNNING TIME	Hr	21	62	75	91
751	STARTS		3	14	17	20
752	EVAP APPROACH TEMP	Deg C	4.33	4.72	4.89	5.11
753	COND APPROACH TEMP	Deg C	5.17	5.17	5.67	4.72
800	EVAP AVG H2O TEMP	Deg C	9.96	9.88	9.78	9.39
801	EVAP WATER DENSITY	Kg/M3	1000.5	1000.5	1000.5	1000.5
802	EVAP H2O VISCOSITY	cp	1.301	1.304	1.308	1.321
803	EVAP H2O SPECIFIC HEAT (Cp)	Kj/Kg C	4.190	4.190	4.191	4.191
804	EVAP H2O CON(K)	W/M C	0.587	0.587	0.587	0.586
810	COND AVG H2O TEMP	Deg C	32.74	32.62	32.71	32.24
811	COND WATER DENSITY	Kg/M3	995.5	995.5	995.5	995.7
812	COND H2O VISCOSITY	cp	0.753	0.754	0.753	0.760
813	COND H2O SPECIFIC HEAT (Cp)	Kj/Kg C	4.177	4.177	4.177	4.177
814	COND H2O CON(K)	W/M C	0.622	0.622	0.622	0.621
815	ITD/DELTA T		1.66	1.74	1.79	1.94
850	RTD DIFFERENCE CHECK - ECWT	Deg C	0.006	0.006	0.028	0.017
851	RTD DIFFERENCE CHECK - LCWT	Deg C	0.006	0.006	0.011	0.017
852	RTD DIFFERENCE CHECK - EEWT	Deg C	-0.017	-0.022	-0.022	-0.028
853	RTD DIFFERENCE CHECK - LEWT	Deg C	0.006	0.006	0.011	0.011
870	TC/RTD CARD #1 CHECK (#19-#595)	Deg C	-0.011	-0.017	0.183	0.000

Medium Impellers - Metric

LTO 23127 Note: Impeller diameters are 635/635/622 mm					
Run Number		121	154	185	204
Refrigerant		11	123	245ca	245ca
Oil		Solest 68	Solest 68	Solest 68	Solest 68
1st Stage Guide Vane Setting	Degrees	90	90	90	90
Capacity	KW	660.7	731.7	626.5	610.0
Power	KW	151.6	173.0	136.4	134.1
Coefficient of Performance (COP)		4.357	4.228	4.594	4.549
Evaporator Leaving Water Temperature	Deg C	6.68	6.69	6.69	6.69
Condenser Entering Water Temperature	Deg C	29.46	29.48	29.47	29.49
Energy Balance	%	-1.38	-1.20	-1.29	-0.63
Evaporator Entering Water Temperature	Deg C	11.7	12.2	11.5	12.2
Evaporator Leaving Water Temperature	Deg C	6.68	6.69	6.69	6.69
Evaporator Water Flow Rate	L/s	31.4	31.8	30.9	26.6
Condenser Entering Water Temperature	Deg C	29.46	29.48	29.47	29.49
Condenser Leaving Water Temperature	Deg C	34.65	35.24	34.35	35.01
Condenser Water Flow Rate	L/s	38.0	38.1	38.0	32.6
Evap Sat Press	kPa	41.64	36.06	38.75	38.89
Sat Temp	Deg C	0.83	2.07	2.11	2.18
Approach	Deg C	5.83	4.61	4.61	4.50
LMTD	Deg C	8.10	7.02	6.72	6.89
ITD/Delta T		2.17	1.84	1.95	1.82
Q/Ao	kW/m2	43.12	47.75	40.88	39.80
Uo	kW/m2 C	5.32	6.81	6.08	5.78
ho'	kW/m2 C	7.65	11.06	9.38	9.17
Cond Sat Press	kPa	167.75	153.96	162.23	164.23
Sat Temp	Deg C	38.93	39.94	38.62	38.98
Approach	Deg C	4.28	4.72	4.28	3.94
Refrigerant Leaving Temp	Deg C	38.21	39.45	37.39	37.92
LMTD	Deg C	6.54	7.20	6.40	6.33
Q/Ao	kW/m2	42.89	47.69	40.25	39.04
Uo	kW/m2 C	6.56	6.62	6.28	6.17
ho'	kW/m2 C	9.74	9.86	9.15	9.40
Cond Sat Temp	Deg C	38.93	39.94	38.62	38.98
Evap Sat Temp	Deg C	0.83	2.07	2.11	2.18
Estimated Motor Efficiency (1)		0.94	0.93	0.94	0.94
Estimated Motor Rev/sec (1)		59.24	59.11	59.32	59.34
Compressor Suction Flow Rate (2)	m3/sec	1.462	1.795	1.407	1.366
Isentropic COP (2)		0.55	0.55	0.52	0.53
Adiabatic Efficiency (3)		0.68	0.66	0.68	0.68
Q/N - m3/rev (4)		0.87	1.07	0.84	0.81
(1) From motor curves at measured power input					
(2) Cycle calculation using evap and cond sat, motor efficiency,					
and equal head split					
(3) Ratio of isentropic and test KW/T					
(4) CFM from cycle calculation / estimated motor RPM					
(5) Heat transfer coefficient calculations use bulk fluid properties					

Medium Impellers - Metric

Evap Water Velocity	M/s	2.95	2.99	2.90	2.50
Re		48859	49752	47928	41620
Pr		9.5	9.4	9.5	9.4
R		10.8	10.8	10.8	10.6
F		-5.2	-5.2	-5.2	-5.2
hi	kW/m2 C	20.23	20.42	19.98	18.03
Cond Water Velocity	Fps	9	9	9	8
Re		81919	82815	81709	70490
Pr		5.1	5.1	5.1	5.1
R		11.3	11.3	11.3	11.2
F		-5.4	-5.4	-5.4	-5.3
hi	kW/m2 C	23.18	23.29	23.15	20.72
Curve fit for motor efficiency					
A1		0.88	0.88	0.88	0.88
A2		0.0015	0.0015	0.0015	0.0015
A3		-0.00001	-0.00001	-0.00001	-0.00001
A4		0.00000	0.00000	0.00000	0.00000
A5		0.00000	0.00000	0.00000	0.00000
KW (input)		151.62	173.04	136.38	134.10
Hp (estimated assuming eff of .933)		188.86	215.54	169.88	167.04
Motor efficiency		0.94	0.93	0.94	0.94
Curve fit for motor RPM					
A1		3600	3600	3600	3600
A2		-0.230	-0.230	-0.230	-0.230
A3		0.00008	0.00008	0.00008	0.00008
A4		0.00000	0.00000	0.00000	0.00000
A5		0.00000	0.00000	0.00000	0.00000
Motor RPM		3554	3547	3559	3560

Medium Impellers - Metric

1	EVAP WATER FLOWMETER DELTA P	kPa	118.59	121.28	114.59	84.87
3	ENT EVAP WATER TEMP LOC 1	Deg C	11.72	12.21	11.55	12.18
4	ENT EVAP WATER TEMP LOC 2	Deg C	11.69	12.18	11.52	12.16
5	LVG EVAP WATER TEMP LOC 1	Deg C	6.69	6.71	6.71	6.70
6	LVG EVAP WATER TEMP LOC 2	Deg C	6.68	6.69	6.68	6.68
15	COND WATER FLOWMETER DELTA P	kPa	172.64	173.75	172.44	126.86
17	ENT COND WATER TEMP LOC 1	Deg C	29.45	29.47	29.46	29.48
18	ENT COND WATER TEMP LOC 2	Deg C	29.46	29.50	29.48	29.49
19	LVG COND WATER TEMP LOC 1	Deg C	34.65	35.24	34.34	35.00
20	LVG COND WATER TEMP LOC 2	Deg C	34.65	35.25	34.36	35.02
50	ABOVE EVAP DISTRIB TEMP - SUPPLY	Deg C	3.88	3.18	3.47	5.43
51	ABOVE EVAP DISTRIB TEMP - MIDDLE	Deg C	2.63	3.83	3.29	3.90
52	ABOVE EVAP DISTRIB TEMP - RETURN	Deg C	2.77	4.44	3.38	4.63
61	EVAP SHELL STATIC PRESS - AVERAGE	kPa	41.64	36.06	38.75	38.89
215	ENT 2nd IMPELLER TOTAL PRESS #1	kPa	69.57	61.02	65.02	65.50
216	ENT 2nd IMPELLER TOTAL PRESS #2	kPa	69.91	61.57	65.50	65.91
218	ENT 2nd IMP SHROUD STATIC PRESS #1	kPa	66.47	56.54	62.67	63.22
315	ENT 3rd IMPELLER TOTAL PRESS #1	kPa	108.66	96.87	94.73	95.91
316	ENT 3rd IMPELLER TOTAL PRESS #2	kPa	111.76	100.53	106.80	107.90
318	ENT 3rd IMP SHROUD STATIC PRESS #1	kPa	107.01	94.04	102.11	103.77
431	COND SHELL STATIC PRESS - AVERAGE	kPa	167.75	153.96	162.23	164.23
440	REFRIGERANT LVG COND TEMP	Deg C	38.21	39.45	37.39	37.92
484	HIGH PRESS ECONOMIZER STATIC PRESS	kPa	110.04	98.73	105.83	106.94
485	HIGH PRESS ECONOMIZER TEMP	Deg C	25.83	26.91	26.14	26.47
486	LOW PRESS ECONONOMIZER STATIC PRESS	kPa	69.36	61.50	65.71	66.12
487	LOW PRESS ECONOMIZER TEMP	Deg C	13.22	14.70	14.29	14.42
530	ENT EVAP ORIFICE ASS'Y PRESS	kPa	54.26	51.71	51.37	51.30
531	ENT EVAP ORIFICE ASS'Y TEMP	Deg C	13.18	14.89	14.25	14.39
532	LVG EVAP ORIFICE ASS'Y PRESS	kPa	69.50	62.47	65.84	66.12
533	LVG EVAP ORIFICE ASS'Y TEMP	Deg C	7.02	10.52	8.57	8.58
534	ENT COND ORIFICE ASS'Y PRESS	kPa	167.47	155.13	162.16	164.03
535	ENT COND ORIFICE ASS'Y TEMP	Deg C	38.62	39.95	37.93	38.30
536	LVG COND ORIFICE ASS'Y PRESS	kPa	126.66	118.38	122.24	123.00
537	LVG COND ORIFICE ASS'Y TEMP	Deg C	30.17	32.65	30.27	30.48
560	ATMOSPHERIC PRESS	kPa	99.15	99.97	99.22	99.08
580	MOTOR VOLTAGE - AB	Volts	3.850	3.880	3.922	3.901
581	MOTOR VOLTAGE - AC	Volts	3.858	3.884	3.931	3.908
582	MOTOR VOLTAGE - CB	Volts	3.840	3.874	3.908	3.889
583	MOTOR CURRENT - A	Volts	2.115	2.383	1.899	1.873
584	MOTOR CURRENT - B	Volts	2.187	2.482	1.971	1.938
585	MOTOR CURRENT - C	Volts	2.067	2.294	1.854	1.833
586	MOTOR POWER - PHASE 1	Volts	0.941	1.108	0.824	0.808
587	MOTOR POWER - PHASE 3	Volts	1.586	1.776	1.449	1.427
595	TC CARD #1 CHECK (LVG COND TEMP)	Deg C	34.66	35.21	34.31	34.98
601	MAXIMUM MOTOR TEMPERATURE	Deg C	54.72	65.67	44.17	43.33
605	1st STAGE VANE SETTING	Degrees	90	90	90	90
607	3rd STAGE VANE SETTING	Degrees	68	68	68	68
608	UNIT HOUR METER READING	Hr	453	470	488	501
609	UNIT START COUNTER READING		124	128	131	133
610	CURRENT REFRIGERANT CHARGE	Kg	163.3	163.3	163.3	163.3
700	TIME (HOURS)	HOURS	0	1	1	0
701	ENERGY BALANCE	%	-1.38	-1.20	-1.29	-0.63
702	EVAP CAPACITY	KW	660.7	731.7	626.5	610.0
703	EVAP WATER FLOWRATE	L/s	31.4	31.8	30.9	26.6
704	COND WATER FLOWRATE	L/s	38.0	38.1	38.0	32.6

Medium Impellers - Metric

710	AVE ENT EVAP WATER TEMP	Deg C	11.70	12.19	11.54	12.17
711	AVE LVG EVAP WATER TEMP	Deg C	6.68	6.69	6.69	6.69
712	AVE ENT COND WATER TEMP	Deg C	29.46	29.48	29.47	29.49
713	AVE LVG COND WATER TEMP	Deg C	34.65	35.24	34.35	35.01
715	MOTOR VOLTAGE - AB	Volts	462	466	471	468
716	MOTOR VOLTAGE - AC	Volts	463	466	472	469
717	MOTOR VOLTAGE - CB	Volts	461	465	469	467
718	MOTOR CURRENT - A	Amps	212	238	190	187
719	MOTOR CURRENT - B	Amps	219	248	197	194
720	MOTOR CURRENT - C	Amps	207	229	185	183
721	UNIT POWER	KW	152	173	136	134
722	AVERAGE VOLTAGE	Volts	462	466	470	468
723	AVERAGE CURRENT	Amps	212	239	191	188
725	Coefficient of Performance (COP)		4.357	4.228	4.594	4.549
730	EVAP DELTA T	Deg C	5.02	5.49	4.84	5.47
731	COND DELTA T	Deg C	5.19	5.76	4.88	5.52
735	EVAP WATER FLOWRATE	Kg/sec	31.41	31.76	30.87	26.57
736	COND WATER FLOWRATE	Kg/sec	37.85	37.97	37.82	32.44
740	EVAP CAPACITY	KW	660.7	731.6	626.4	609.9
741	COND CAPACITY	KW	821.4	913.4	770.9	747.8
743	EVAP SAT'N TEMP (BASED ON ID #61)	Deg C	0.83	2.07	2.11	2.18
744	COND SAT'N TEMP (BASED ON ID #431)	Deg C	38.93	39.94	38.62	38.98
750	RUNNING TIME	Hr	125	141	159	172
751	STARTS		29	33	36	38
752	EVAP APPROACH TEMP	Deg C	5.83	4.61	4.61	4.50
753	COND APPROACH TEMP	Deg C	4.28	4.72	4.28	3.94
800	EVAP AVG H2O TEMP	Deg C	9.19	9.44	9.12	9.43
801	EVAP WATER DENSITY	Kg/M3	1001	1000	1001	1001
802	EVAP H2O VISCOSITY	cp	1.33	1.32	1.33	1.32
803	EVAP H2O SPECIFIC HEAT (Cp)	KJ/Kg C	4.19	4.19	4.19	4.19
804	EVAP H2O THERMAL CONDUCTIVITY	W/M C	0.586	0.586	0.586	0.586
810	COND AVG H2O TEMP	Deg C	32.05	32.36	31.91	32.25
811	COND WATER DENSITY	Kg/M3	996	996	996	996
812	COND H2O VISCOSITY	cp	0.76	0.76	0.76	0.76
813	COND H2O SPECIFIC HEAT (Cp)	KJ/Kg C	4.18	4.18	4.18	4.18
814	COND H2O THERMAL CONDUCTIVITY	W/M C	0.621	0.621	0.621	0.621
815	ITD/DELTA T		2.17	1.84	1.95	1.82
850	RTD DIFFERENCE CHECK - ECWT	Deg C	-0.01	-0.03	-0.02	-0.01
851	RTD DIFFERENCE CHECK - LCWT	Deg C	0.00	-0.01	-0.01	-0.02
852	RTD DIFFERENCE CHECK - EEWT	Deg C	0.03	0.02	0.03	0.03
853	RTD DIFFERENCE CHECK - LEWT	Deg C	0.01	0.02	0.02	0.02
870	TC/RTD CARD #1 CHECK (#19-#595)	Deg C	-0.01	0.03	0.04	0.02

LTO 23127 **Note: Impeller diameters are 610/610/610 mm**			
Run Number		208	232
Refrigerant		123	123
Oil		Solest 68	Solest 68
1st Stage Guide Vane Setting	Degrees	90	90
Capacity	KW	676.47	672.96
Power	KW	151.02	151.08
Coefficient of Performance (COP)		4.48	4.45
Evaporator Outlet Water Temperature	Deg C	6.68	6.68
Evaporator Inlet Water Temperature	Deg C	29.43	29.46
Energy Balance	%	-1.25	-1.21
Evaporator Inlet Water Temperature	Deg C	11.91	12.26
Evaporator Outlet Water Temperature	Deg C	6.68	6.68
Evaporator Water Temperature Flowrate	L/s	30.92	28.79
Condenser Inlet Water Temperature	Deg C	29.43	29.46
Condenser Outlet Water Temperature	Deg C	34.69	35.06
Condenser Water Temperature Flowrate	L/s	38.22	35.74
Evaporator Saturation Pressure	kPa	36.68	36.54
Saturation Temperature	Deg C	2.46	2.37
Approach	Deg C	4.22	4.33
Log Mean Temperature Difference	Deg C	6.48	6.71
ITD/Delta T		1.81	1.77
Q/Ao	kW/m2	44.15	43.91
Uo	kW/m2 C	6.81	6.54
ho'	kW/m2 C	11.22	10.83
Cond Sat Press	kPa	149.20	149.96
Sat Temp	Deg C	39.00	39.16
Approach	Deg C	4.33	4.11
Refrigerant Leaving Temp	Deg C	38.81	39.04
LMTD	Deg C	6.59	6.50
Q/Ao	kW/m2	43.64	43.44
Uo	kW/m2 C	6.62	6.69
ho'	kW/m2 C	9.86	10.26
Cond Sat Temp	Deg C	39.00	39.16
Evap Sat Temp	Deg C	2.46	2.37
Estimated Motor Efficiency (1)		0.94	0.94
Estimated Motor Rev/sec (1)	Rev/sec	59.24	59.24
Compressor Suction Flow Rate (2)	m3/sec	1.628	1.626
Isentropic COP (2)		6.710	6.659
Adiabatic Efficiency (3)		0.668	0.669
Q/N - m3/rev (4)		0.0275	0.0275
(1) From motor curves at measured power input			
(2) Cycle calculation using evap and cond sat, motor efficiency, and equal head split			
(3) Ratio of isentropic and test KW/T			
(4) CFM from cycle calculation / estimated motor RPM			
(5) Heat transfer coefficient calculations use bulk fluid properties			

Small Impellers - Metric

	Evap Water Velocity	m/s	2.91	2.71
	Re		48201.11	45138.78
	Pr		9.48	9.42
	R		10.78	10.72
	F		-5.22	-5.20
	hi	kW/m2 C	20.02	19.08
	Cond Water Velocity	m/s	2.87	2.69
	Re		82394.44	77345.09
	Pr		5.14	5.11
	R		11.32	11.26
	F		-5.37	-5.36
	hi	kW/m2 C	23.28	22.17
	Curve fit for motor efficiency			
	A1		0.88	0.88
	A2		0.00	0.00
	A3		0.00	0.00
	A4		0.00	0.00
	A5		0.00	0.00
	KW (input)		151.02	151.08
	Hp (estimated assuming eff of .933)		188.11	188.19
	Motor efficiency		0.94	0.94
	Curve fit for motor RPM			
	A1		3600.03	3600.03
	A2		-0.23	-0.23
	A3		0.00	0.00
	A4		0.00	0.00
	A5		0.00	0.00
	Motor Rev/sec		59.24	59.24

Small Impellers - Metric

1	EVAP WATER FLOWMETER DELTA P	kPa	114.87	99.63
3	ENT EVAP WATER TEMP LOC 1	Deg C	11.91	12.27
4	ENT EVAP WATER TEMP LOC 2	Deg C	11.89	12.24
5	LVG EVAP WATER TEMP LOC 1	Deg C	6.69	6.69
6	LVG EVAP WATER TEMP LOC 2	Deg C	6.67	6.67
15	COND WATER FLOWMETER DELTA P	kPa	174.64	152.72
17	ENT COND WATER TEMP LOC 1	Deg C	29.43	29.46
18	ENT COND WATER TEMP LOC 2	Deg C	29.44	29.47
19	LVG COND WATER TEMP LOC 1	Deg C	34.69	35.06
20	LVG COND WATER TEMP LOC 2	Deg C	34.69	35.06
50	ABOVE EVAP DISTRIB TEMP - SUPPLY	Deg C	4.56	3.54
51	ABOVE EVAP DISTRIB TEMP - MIDDLE	Deg C	3.94	3.89
52	ABOVE EVAP DISTRIB TEMP - RETURN	Deg C	4.27	4.48
61	EVAP SHELL STATIC PRESS - AVERAGE	kPa	36.68	36.54
215	ENT 2nd IMPELLER TOTAL PRESS #1	kPa	60.47	60.33
216	ENT 2nd IMPELLER TOTAL PRESS #2	kPa	61.02	60.74
218	ENT 2nd IMP SHROUD STATIC PRESS #1	kPa	56.81	56.61
315	ENT 3rd IMPELLER TOTAL PRESS #1	kPa	89.15	88.11
316	ENT 3rd IMPELLER TOTAL PRESS #2	kPa	96.87	97.35
318	ENT 3rd IMP SHROUD STATIC PRESS #1	kPa	91.42	91.22
431	COND SHELL STATIC PRESS - AVERAGE	kPa	149.20	149.96
440	REFRIGERANT LVG COND TEMP	Deg C	38.81	39.04
484	HIGH PRESS ECONOMIZER STATIC PRESS	kPa	95.84	95.63
485	HIGH PRESS ECONOMIZER TEMP	Deg C	26.16	26.10
486	LOW PRESS ECONONOMIZER STATIC PRESS	kPa	60.88	60.54
487	LOW PRESS ECONOMIZER TEMP	Deg C	14.45	14.34
530	ENT EVAP ORIFICE ASS'Y PRESS	kPa	50.26	50.40
531	ENT EVAP ORIFICE ASS'Y TEMP	Deg C	14.52	14.41
532	LVG EVAP ORIFICE ASS'Y PRESS	kPa	61.57	61.43
533	LVG EVAP ORIFICE ASS'Y TEMP	Deg C	9.86	9.82
534	ENT COND ORIFICE ASS'Y PRESS	kPa	150.17	150.86
535	ENT COND ORIFICE ASS'Y TEMP	Deg C	39.08	39.31
536	LVG COND ORIFICE ASS'Y PRESS	kPa	113.28	114.59
537	LVG COND ORIFICE ASS'Y TEMP	Deg C	31.51	31.71
560	ATMOSPHERIC PRESS	kPa	99.35	98.66
580	MOTOR VOLTAGE - AB	Volts	3.83	3.88
581	MOTOR VOLTAGE - AC	Volts	3.83	3.88
582	MOTOR VOLTAGE - CB	Volts	3.82	3.87
583	MOTOR CURRENT - A	Volts	2.11	2.10
584	MOTOR CURRENT - B	Volts	2.20	2.19
585	MOTOR CURRENT - C	Volts	2.04	2.03
586	MOTOR POWER - PHASE 1	Volts	0.96	0.94
587	MOTOR POWER - PHASE 3	Volts	1.56	1.58
595	TC CARD #1 CHECK (LVG COND TEMP)	Deg C	34.70	35.06
601	MAXIMUM MOTOR TEMPERATURE	Deg C	55.28	54.72
605	1st STAGE VANE SETTING	Degrees	90.00	90.00
607	3rd STAGE VANE SETTING	Degrees	68.00	68.00
608	UNIT HOUR METER READING	Hr	506.20	519.00
609	UNIT START COUNTER READING		134.00	135.00
610	CURRENT REFRIGERANT CHARGE	Kg	163.29	163.29
700	TIME (HOURS)	HOURS	384.16	412.38
701	ENERGY BALANCE	%	-1.25	-1.21
702	EVAP CAPACITY	KW	676.47	672.96
703	EVAP WATER FLOWRATE	L/s	30.92	28.79
704	COND WATER FLOWRATE	L/s	38.22	35.74

Small Impellers - Metric

710	AVE ENT EVAP WATER TEMP	Deg C	11.91	12.26
711	AVE LVG EVAP WATER TEMP	Deg C	6.68	6.68
712	AVE ENT COND WATER TEMP	Deg C	29.43	29.46
713	AVE LVG COND WATER TEMP	Deg C	34.69	35.06
715	MOTOR VOLTAGE - AB	Volts	459.70	465.50
716	MOTOR VOLTAGE - AC	Volts	460.00	465.80
717	MOTOR VOLTAGE - CB	Volts	458.80	464.40
718	MOTOR CURRENT - A	Amps	210.90	209.60
719	MOTOR CURRENT - B	Amps	220.30	218.80
720	MOTOR CURRENT - C	Amps	204.00	203.40
721	UNIT POWER	KW	151.02	151.08
722	AVERAGE VOLTAGE	Volts	459.50	465.20
723	AVERAGE CURRENT	Amps	211.73	210.60
725	Coefficient of Performance (COP)		4.48	4.45
730	EVAP DELTA T	Deg C	5.22	5.58
731	COND DELTA T	Deg C	5.26	5.60
735	EVAP WATER FLOWRATE	Kg/sec	30.91	28.79
736	COND WATER FLOWRATE	Kg/sec	38.07	35.60
740	EVAP CAPACITY	Kw	676.43	672.82
741	COND CAPACITY	Kw	835.87	832.01
743	EVAP SAT'N TEMP (BASED ON ID #61)	Deg C	2.46	2.37
744	COND SAT'N TEMP (BASED ON ID #431)	Deg C	39.00	39.16
750	RUNNING TIME	Hr	177.30	190.10
751	STARTS		39.00	40.00
752	EVAP APPROACH TEMP	Deg C	4.22	4.33
753	COND APPROACH TEMP	Deg C	4.33	4.11
800	EVAP AVG H2O TEMP	Deg C	9.29	9.47
801	EVAP WATER DENSITY	Kg/m3	1000.51	1000.50
802	EVAP H2O VISCOSITY	cp	1.33	1.32
803	EVAP H2O SPECIFIC HEAT (Cp)	Kj/Kg C	4.19	4.19
804	EVAP H2O THERMAL CONDUCTIVITY	KW/M C	0.0006	0.0006
810	COND AVG H2O TEMP	Deg C	32.07	32.26
811	COND WATER DENSITY	Kg/m3	995.75	995.69
812	COND H2O VISCOSITY	cp	0.76	0.76
813	COND H2O SPECIFIC HEAT (Cp)	Kj/Kg C	4.18	4.18
814	COND H2O THERMAL CONDUCTIVITY	KW/M C	0.0006	0.0006
815	ITD/DELTA T		1.81	1.77
850	RTD DIFFERENCE CHECK - ECWT	Deg C	-0.01	-0.01
851	RTD DIFFERENCE CHECK - LCWT	Deg C	0.00	0.00
852	RTD DIFFERENCE CHECK - EEWT	Deg C	0.02	0.03
853	RTD DIFFERENCE CHECK - LEWT	Deg C	0.02	0.02
870	TC/RTD CARD #1 CHECK (#19-#595)	Deg C	-0.01	0.01