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STUDY OF LUBRICANT CIRCULATION IN HVAC SYSTEMS

PRESENTED AT ASHRAE MATERIALS COMPATIBILITY SEMINAR

ACCEPTABILITY OF ALTERNATIVE REFRIGERANTS AND LUBRICANTS

HOSTED BY: TC3.2 (REFRIGERANT SYSTEM CHEMISTRY)
TC3.3 (CONTAMINANT CONTROL IN SYSTEMS)
TC3.4 (LUBRICATION)

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WORK PERFORMED BY UNITED TECHNOLOGIES RESEARCH CENTER

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United Technologies Research Center

DISCLAIMER

ABSTRACT

Introduction

Under the provisions of the Montreal Protocol, CFCs and HCFCs, the backbone refrigerants for the air conditioning and refrigeration industry products for the last five decades, are being phased out or their usage is being capped. Because of their deleterious effect on the global ozone layer, this phase out and production capping is starting in 1996.

The HVAC and refrigeration industry leaders are rapidly and aggressively moving away from the currently used CFC and HCFC refrigerants to new, non-ozone depleting HFC refrigerants across their extensive product lines. This massive undertaking requires careful assessment of the performance, operational capabilities, durability , and longtime reliability of their products. Among the more important considerations in the change towards HFC refrigerants is the selection of lubricants that provide the same or improved characteristics relative to the traditional mineral oils and alkylbenzene lubricants. The new synthetic lubricants, primarily polyolesters (POEs) are being chosen for use with HFCs because of their favorable stability, lubricity and miscibility characteristics. Because the POE lubricants are miscible with the new HFC refrigerants over a wide range of temperatures, they could provide similar lubricant characteristics to the old, familiar CFC and HCFC systems, which largely used mineral oils. However, each type of HVAC system utilizes different compressor types, configurations, piping arrangements and other features so that universal guidelines are difficult to apply.

Among the new HFC refrigerants that are being evaluated, are a substantial number of refrigerant blends as substitutes for HCFC-22 in residential building air conditioning and heat pump applications. Analytical predictions and system tests have indicated that there are certain performance, capacity, operational advantages and potential size and weight improvements with the use of HFC refrigerants and blends. However, these blends can introduce significant service and operational issues. These issues can take the form of long-term reliability in typical system installations. One such concern is associated with the oil return characteristics and potentially different mechanisms that might be observed with new HFC refrigerants and appropriate lubricants such as polyolesters (POEs). The POEs appear to have the correct lubricity and thermal and chemical stability to meet the challenges of today's high performance compressors, but what is largely unknown are the proper oil management techniques to ensure that oil return to the compressor is achieved and that the compressors, and thus overall system, will function reliably for at least fifteen years of operation.

A second issue is the potential use of low cost lubricants, such as mineral oils, even though they are immiscible with most HFC refrigerants. Mutual solubilities of the new HFC/POE pairs are very different from those of the CFC/HCFC refrigerant/mineral oil pairs they are intended to replace. Similarly, interfacial surface tension properties of conventional

refrigerant/lubricant pairs show differences when compared with the newer HFC/POE combinations. In actual operating systems, there are still many unanswered questions about the behavioral differences between the old and new refrigerant/lubricant pairs. Thus, the subject program, sponsored by ARTI (the Air Conditioning and Refrigeration Technology Institute) (using a DOE grant as part of the MCLR program), was aimed at studies designed to obtain fundamental data to better understand the oil return parameters for the new versus the old refrigerant/lubricant pairs. The data generated in this study will aid in the assessment of how the differences in the physical properties affect system reliability and oil return mechanisms.

Because of the high cost and operational considerations associated with the POEs, the component and system manufacturers are also interested in the possibility of using immiscible mixtures of HFCs and mineral oil or alkylbenzene lubricants in air conditioning/heating and refrigeration systems. A major impediment to this strategy is the uncertainty of the return to the compressor of the immiscible lubricant which still must have a high enough viscosity to effectively lubricate the compressor. Therefore, it is imperative that the fluid properties of immiscible refrigerant/lubricant mixtures and their impact on the system operation be well understood. The data that was generated in this study also helps determine whether immiscible refrigerant/lubricant mixtures might be successfully applied with HFCs.

United Technologies Research Center (UTRC) has recognized these problems and has taken specific actions to insure that lubricant circulation in systems can be measured and that there are techniques in place to improve the understanding of adequate lubricant return with miscible HFC/POEs and possibly immiscible mixtures of HFCs with mineral oils and alkylbenzene lubricants in air-conditioning and refrigeration (AC&R) systems. In particular, United Technologies Corporation (UTC) has developed and assembled the following background material for application to the present oil circulation study:

1) Detailed computer models have been developed and verified by experimental results that predict the solubilities and fractionation effects of various HFCs mixtures and POE lubricants. These models and data were developed in large part under an ARTI-sponsored UTRC program (MCLR Project No. 660-52300) and under corporate sponsorship;
2) A comprehensive model has been developed under ARTI sponsorship, which describes the concentration of lubricant and HFC blends in typical heat pump systems during startup, shutdown, and various modes of operation;
3) Actual oil circulation rate measurements were carried out at Carrier and included as part of the performance tests and data provided by Carrier under the Alternative Refrigerants Evaluation Program (AREP) Soft Optimization Program efforts on a split system 5-ton heat pump;
4) Accumulated knowledge and detailed installation information were provided by Carrier Residential personnel based on their installation of hundreds of thousands of heat pumps and air conditioners each year;

5) Several new techniques for measuring, *in situ*, oil concentration rates with HFCs immiscible/miscible lubricants were developed and tested at UTRC.

This program was aimed at understanding refrigerant/lubricant circulation issues, developing test data and approximate models that can predict operating regimes where good oil management can be assured. A dynamic test facility was constructed and used to examine oil return under varying system operating conditions. The development of industry guidelines for system reliability in using the new refrigerant blends was a goal of this program. To validate the guidelines, techniques and predictions, this dynamic.test facility was used to obtain data to compare to the analytical predictions.

Program Approach and Scope

The overall program approach undertaken to meet this objective was : 1) to identify poor oil return scenarios and, therefore, the worst case oil return parameters for conventional residential HVAC systems using HCFC-22 and mineral oils, in terms of compressor, suction and exhaust line vapor velocity, and refrigerant viscosity requirements, 2) design and instrument a test apparatus that simulates such conditions, as well as those that might be achieved with HFC and POE mixtures and HFCs and mineral oils, 3) conduct tests with the range of baseline refrigerants and lubricant mixtures to provide experimental data, and 4) prepare, present and interpret the test data to provide an expanded understanding of the phenomena required for good oil circulation in split-system heat pump systems.

To convert this general approach into the program specifics, three major tasks were defined and pursued. These are described briefly below and in greater detail in the report body as Task 1, Task 2, and Task 3. The report prepared for ARTI as part of the MCLR Project Number 665-53100 is described in Volumes I and II, "Study of Lubricant Circulation in the HVAC Systems," Oct. 1996, from the same authors as this publication

Task 1 consisted of gathering and reviewing available lubricant oil/refrigerant and oil return data. Within Task 1, an improved understanding of the lubricant circulation mechanism in refrigeration and HVAC systems was developed, along with a summary of the industry standard procedures and limitations on vapor velocity, viscosity and miscibility of the refrigerant/lubricant mixture. This included a review of the ASHRAE design guidelines, as well as discussions with system designers and manufacturers. In the second part of this task, we reviewed the available data for refrigerants and lubricants and selected representative POE and mineral oil lubricants that covered the range of viscosity and miscibility anticipated in HVAC systems.

Task 2 consisted of the design, fabrication, installation, and instrumentation, and then experimental efforts in the dynamic test facility. The Task 1 data was used to design and build a dynamic test facility in which both good and poor oil management regimes could be experimentally explored so that broad on-line visual and instrumentation observations of oil return could be simulated. Instrumentation for proper observation and on-line oil measurements were screened, designed and installed. A series of tests with the various HCFC, HFC and POE and mineral oil combinations were prepared and extensive data gathered.

Task 3 consisted of data collection, analysis, results, review and formulation of the program conclusions. More than fifty test runs were actually conducted in the dynamic test facility, reviewed and assessed for consistency. Broad as well as very specific conclusions and results were recorded. Much of the data is based on visual observations of poor oil return scenarios. Finally, broad guidelines as to acceptable flow velocities for “good” and “poor” oil management are provided for use by HVAC industry designers, manufacturers and installers.

The information presented in this publication note generally follows the three task effort described in Volume I of the referenced report. Volume II contains all of the detailed test data obtained during the program.

The material presented in this publication only highlights and summarizes the extensive information developed in the ARTI program. They are presented in approximately the same order as in the report. The authors urge readers to obtain the formal reports for all of the details and complete information.

Thank you.

OVERVIEW

- PROGRAM BACKGROUND, OBJECTIVE, AND SCOPE
- TEST MATRIX, DYNAMIC SYSTEM LAYOUT
- SPECIAL INSTRUMENTATION AND PROCEDURES
- TYPICAL RESULTS AND SAMPLE DATA
- CONCLUSIONS
- SUMMARY

PROGRAM

BACKGROUND

- HFC REFRIGERANT SUBSTITUTES ARE NEEDED TO REPLACE HCFC'S
- CIRCULATION BEHAVIOR OF NEW HFC REFRIGERANTS/LUBRICANTS COMBINATIONS HAS NOT BEEN CHARACTERIZED

OBJECTIVE

- CONDUCT EXPERIMENTAL AND ANALYTICAL EFFORTS TO DETERMINE LUBRICANT CIRCULATION CHARACTERISTICS WITH HFC/POE PAIRS AND HFC/MINERAL OIL PAIRS
- PROVIDE GUIDELINES FOR LUBRICANT CIRCULATION BEHAVIOR IN HVAC SYSTEMS

PROGRAM

SCOPE

- DESIGN AND BUILD A DYNAMIC TEST FACILITY, INCLUDING ON-LINE OIL MEASUREMENT

- FOCUS ON EFFECTS OF VAPOR VELOCITY, REFRIGERANT/LUBRICANT VISCOSITY, SYSTEM FEATURES AND EQUIPMENT TYPE

- EVALUATE R407C BLENDS WITH MO AND POE'S IN RESIDENTIAL CENTRAL SYSTEM DURING HEATING/COOLING MODES

PROGRAM SCOPE

<u>GATHER AND REVIEW EXISTING DATA</u> -

- DEVELOP A MORE THOROUGH UNDERSTANDING OF LUBRICANT CIRCULATION MECHANISMS
- ROLE OF KEY PARAMETERS SUCH AS REFRIGERANT/OIL MISCIBILITY, SOLUBILITY, VISCOSITY AND SURFACE TENSION
- DEVELOPMENT OF PARAMETER LIMITS FOR VISCOSITY, FLOW VELOCITY
- INDUSTRY PRACTICES AND DESIGN APPROACH IN SS HP'S AS AN EXAMPLE

PROGRAM SCOPE (CONTINUED)

DESIGN AND BUILD DYNAMIC TEST FACILITY WITH UNIQUE INSTRUMENTATION -

- CRITICAL PARAMETERS OF FLOW VELOCITY AND VISCOSITY
- TESTS IN COOLING AND HEATING MODES
- TESTS WITH IN-SITU OIL CONCENTRATION MEASUREMENTS, ABILITY TO CHANGE OIL CONCENTRATION
- COMBINATION OF VISUAL BEHAVIOR AND MEASUREMENTS USED TO DEFINE OIL RETURN, DATA COLLECTION, ANALYSIS AND RESULTS REVIEW
- TEST MATRIX (RESULTS ANALYSIS AND CONCLUSION0

Table 1.3 Refrigerant/Lubricant Miscibility Data

Refrigerant/Lubricant Pair	T(lower consolute)
R-22/Suniso 3GS	-4°C at 20 wt% oil
R-22/Suniso 1GS	-10°C at 20 wt% oil
R-407C/Castrol SW32 (low visc., high misc.)	< -50°C at 10 wt% oil
R-407C/ICI RL32S (low visc., low misc.)	-5°C at 10 wt% oil
R-407C/Castrol SW68 (high visc., high misc.)	-30°C at 10 wt% oil
R-407C/ICI RL68S (high visc., low misc.)	-3°C at 10 wt% oil
R-407C / Suniso 1GS and 3GS	immiscible

Table 2.1 Dynamic Test Facility Features and Operating Range

	Cooling Mode	Heating Mode
(1) - Minimum Vapor Ranges, ft/min (temperature dependent)	350	200
(2) - Maximum Lubrication Viscosity cSt (at least)	650	650
(3) - Achieve Low Temperature IEC Operation T_{sat} with Reduced Fan Flow or Blocked Fan	45°F (32°F)	10°F (0 to 10°F)
Visual Observations of • Oil Return Mechanism in Vapor Lines • Compressor Oil Sump Level and Change of Level (use of remote TV camera and on-line display)	Compressor Suction Lines Both	Compressor Discharge Lines Both
On Line Measurement • Liquid/Lubricant Concentration in System, 0% to 5 to 10% • Include Provisions for Metering in Excess Lubricant, if desired • All Pressure, Temperature, Flow Rates, and, as needed, Refrigerant Composition		

SPECIAL INSTRUMENTATION FOR TEST

- UV OIL METER - CALIBRATED FOR ALL PARTIALLY MISCIBLE REFRIGERANT/OIL COMBINATIONS. THIS WILL ALSO BE USED TO OBTAIN A "QUALITATIVE" MEASUREMENT OF IMMISCIBLE COMBINATIONS.
- TV CAMERA - TO DISPLAY COMPRESSOR OIL SUMP LEVEL IN ORDER TO DETERMINE IF OIL IS RETURNING TO SUMP
- OIL INJECTION FLOWMETER - USED TO DETERMINE THE OIL INJECTION FLOW RATES. OIL IS INJECTED DIRECTLY INTO SCROLL WRAPS.
- VISUAL OBSERVATIONS AT MANIFOLD LOCATIONS.

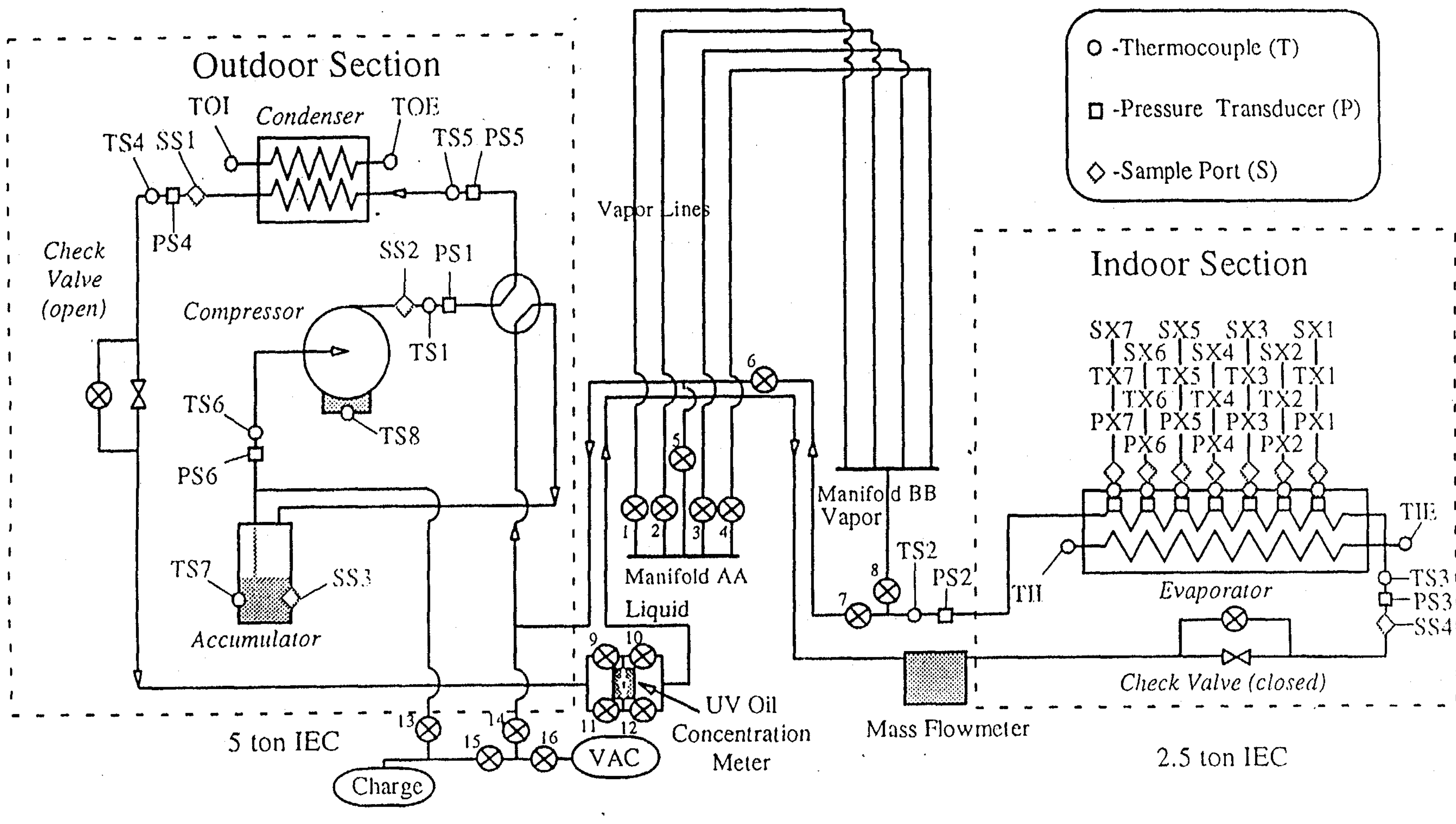


Figure 2.1. Oil Circulation Program Dynamic Test Facility - Cooling Mode

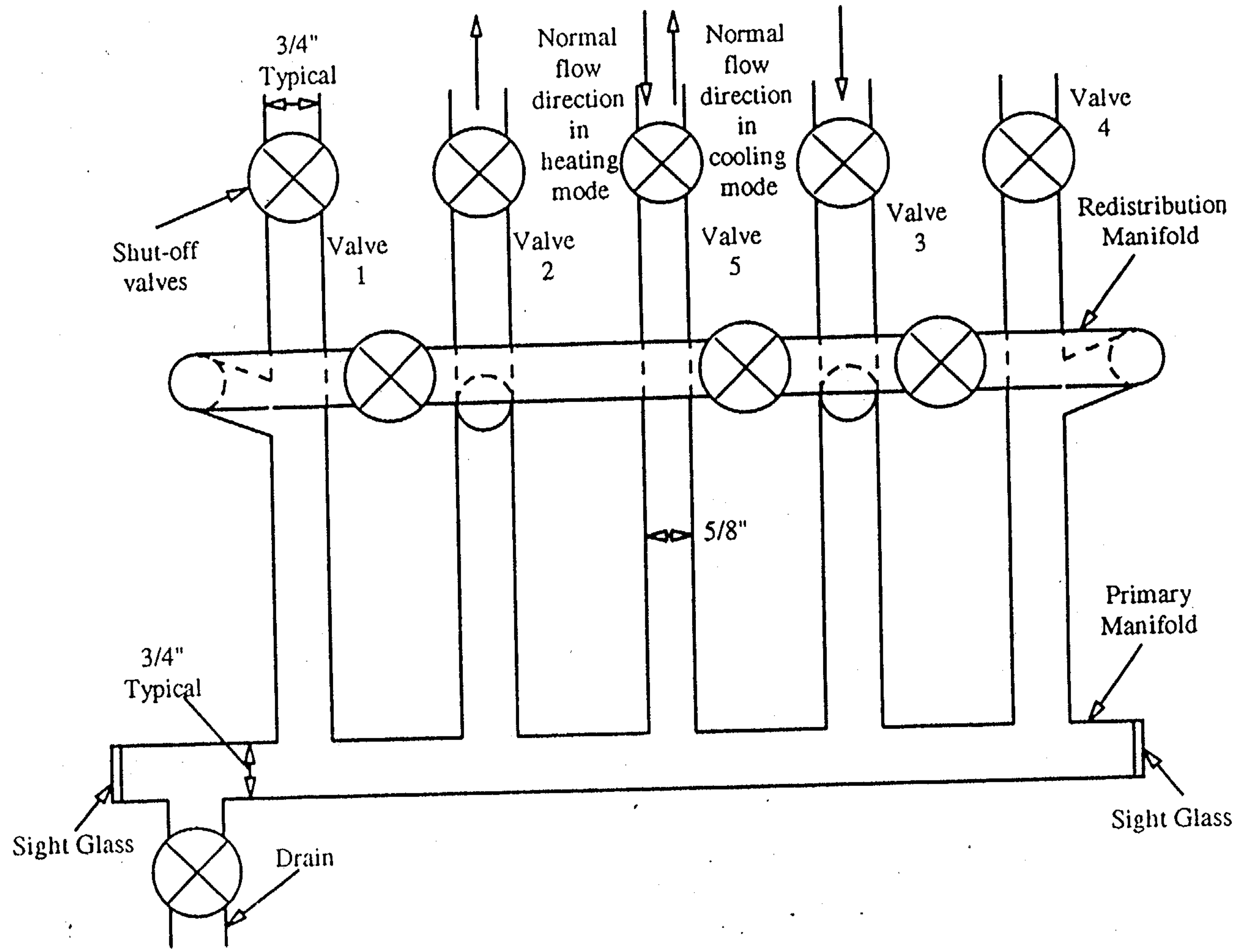


Figure 2.4. Outdoor Unit Vapor Manifold (AA)

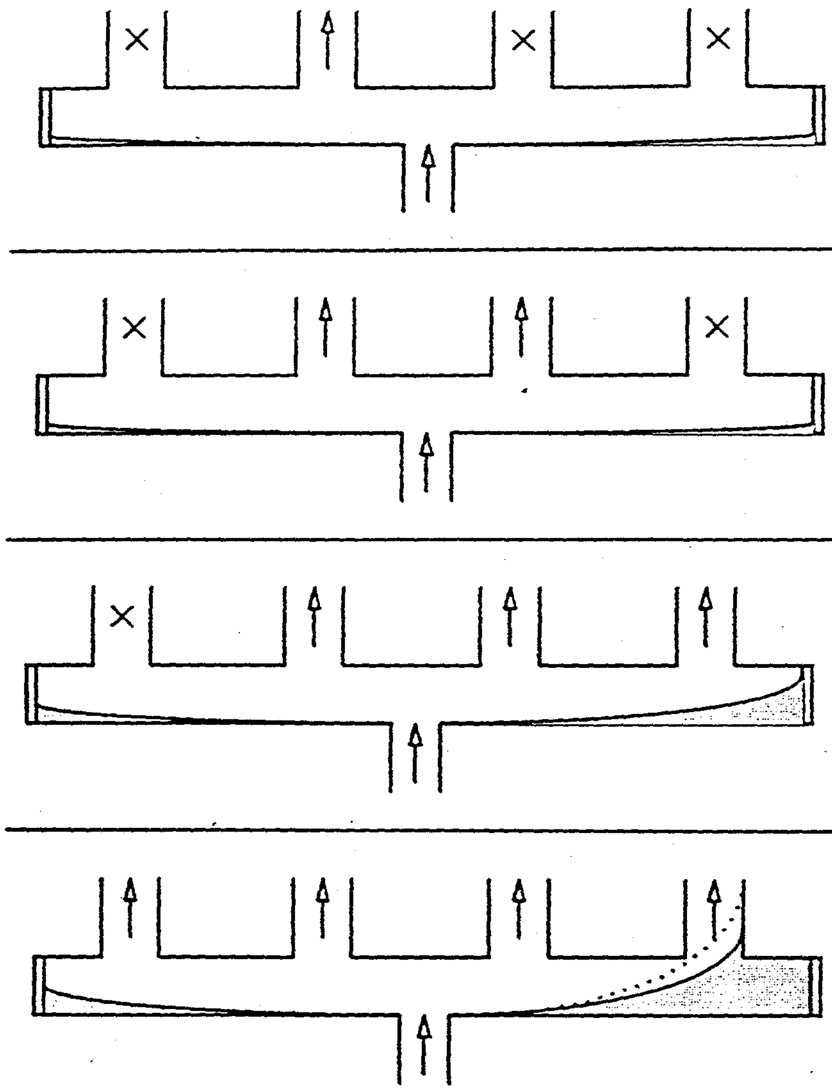


Figure 2.6a
(1 vapor line open)

Figure 2.6b
(2 vapor lines open)

Figure 2.6c
(3 vapor lines open)

Figure 2.6d
(4 vapor lines open)

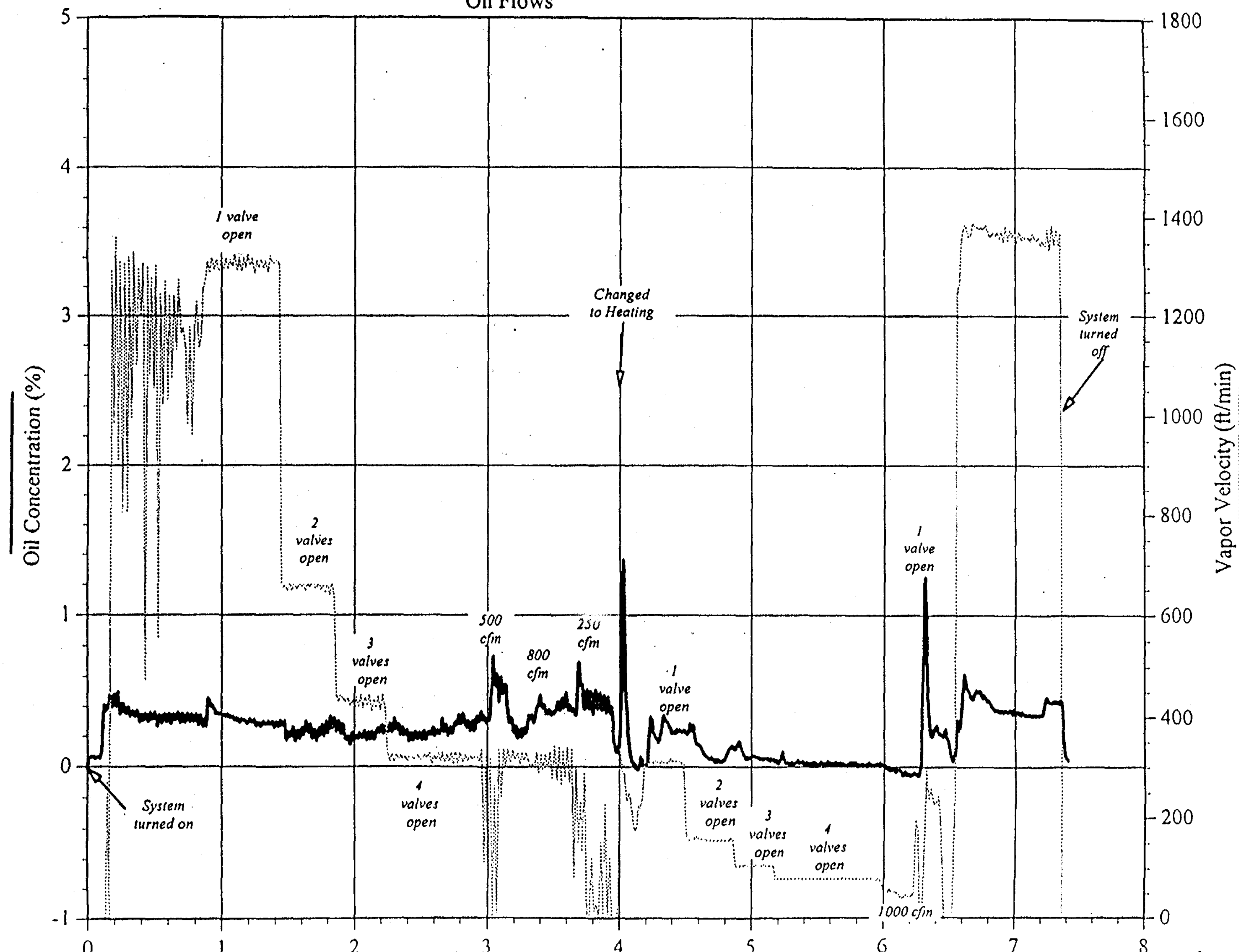
Figure 2.6. Typical Manifold Flooding Behavior

ARTI Heat Pump R22-Suniso 3GS Oil Circulation Tests (35&36)

SLO 2/23/96

Cooling & Heating Modes - No Oil Injection

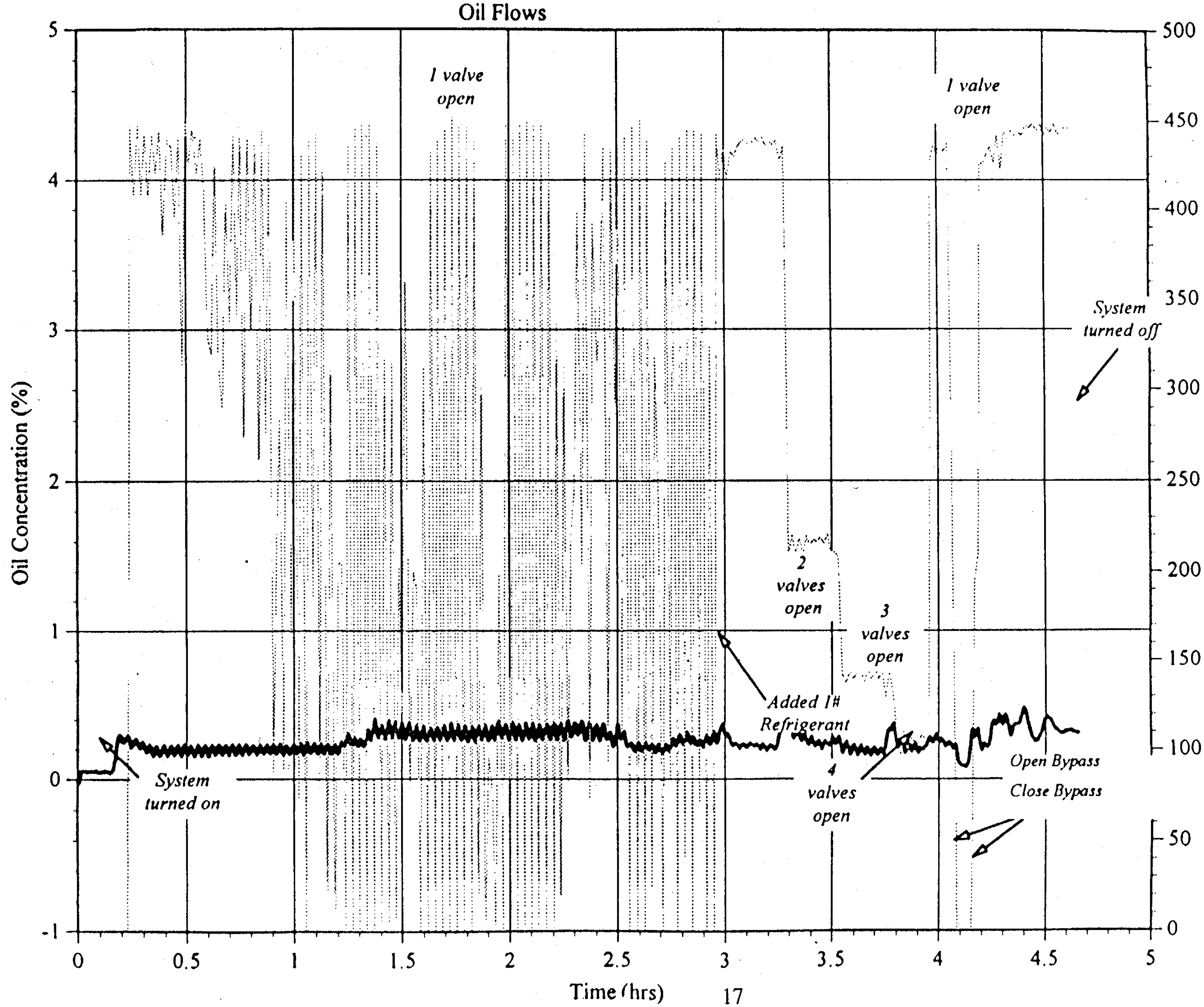
Oil Flows



ARTI Heat Pump R407c-Sunico 3GS Oil Circulation Test (2/9/96)

Cooling Mode - No Oil Injection

SLO 2/28/96



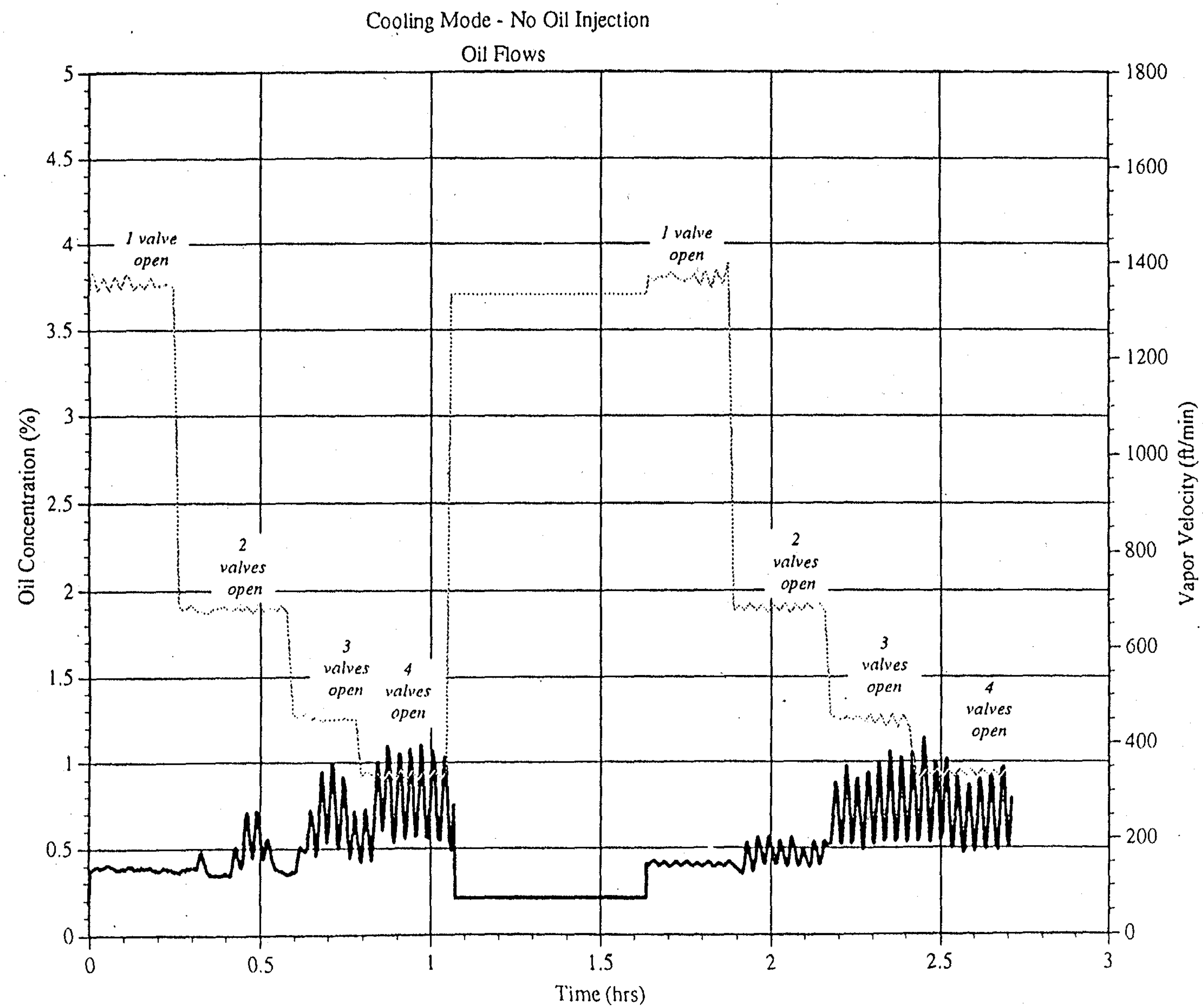


Figure 3.4. Heat Pump R407C - Castrol SW68 Oil Circulation Tests (15 & 16)

Table 3.4. Summary of Oil Return Problems for Refrigerant and Lubricant Combinations

Bold face type shows first indicator of oil return problem

Operating Mode	*Nominal Oil Circulation Rate (%) from UV*	*First Indication of Oil Return Problem*			*Potential Cause of Oil Return Problem*	
		Manifold Flooding	*Oil Sump Level*	*UV Oil Meter Reading*	*Low Vapor Velocity*	*Low Saturat. Temp.*
R22 /	3GS					
Cooling	.3	**1/2 FAN FLOW**	STEADY	STEADY	< 315 FT/MIN	
Cooling + oil inj.	.8	**4 OPEN**	STEADY	STEADY	330 FT/MIN	
Heating	.3	**3 OPEN**	STEADY	STEADY	108 FT/MIN	
Heating + oil inj.	.8	1 OPEN	**DROPPING**	STEADY		5^0 F
R407C/	3GS					
Cooling	N/A	**4 OPEN**	STEADY	STEADY	280 FT/MIN	
Cooling + oil inj.	N/A	1 OPEN	**DROPPING**	STEADY		40^0 F
Heating	N/A	**3 OPEN**	STEADY	STEADY	79 FT/MIN	
Heating + oil inj.	N/A	1 OPEN	**DROPPING**	STEADY		5^0 F
R407C/	1GS					
Cooling	N/A	**4 OPEN**	STEADY	STEADY	330 FT/MIN	
Cooling + oil inj.	N/A	N/A	N/A	N/A		
Heating	N/A	**3 OPEN**	STEADY	STEADY	82 FT/MIN	
Heating + oil inj.	N/A	N/A	N/A	N/A		
R407C/	SW32					
Cooling	.8	3 OPEN	STEADY	UNSTEADY	455 FT/MIN	
Cooling + oil inj.	3.5	**4 OPEN**	STEADY	STEADY	330 FT/MIN	
Heating	.8	**4 OPEN**	STEADY	STEADY	70 FT.MIN	
Heating + oil inj.	6.0	**2 OPEN**	STEADY	STEADY	142 FT/MIN	
R407C/	SW68					
Cooling	.45	3 OPEN	STEADY	UNSTEADY	445 FT/MIN	
Cooling + oil inj.	3.5	**4 OPEN**	DROPPING	UNSTEADY	305 FT/MIN	
Heating	.5	**4 OPEN**	STEADY	STEADY	67 FT/MIN	
Heating + oil inj.	3.5	**1 OPEN**	STEADY	STEADY	290 FT/MIN	
R407C/	32S					
Cooling	3.5	3 OPEN	STEADY	UNSTEADY	455 FT/MIN	
Cooling + oi inj.	4.25	**4 OPEN**	STEADY	STEADY	330 FT/MIN	
Heating	3.5	3 OPEN	STEADY	STEADY	95 FT/MIN	
Heating + oil inj.	N/A	N/A	N/A	N/A		

Table 3.5. Minimum Velocities Needed for Oil Return Problem

Refrigerant / Oil	*Oil Return Status*	*Cooling*			*Cooling Injection*			*Heating*			*Heating Injection*		
		Visual	*UV Meter*	*Model* [a]	*Visual*	*UV Meter*	*Model* [a]	*Visual*	*UV Meter*	*Model* [a]	*Visual*	*UV Meter*	*Model* [a]
R22	OK	315 (4)	315 (4)	-	430 (3)	*3	-	158 (2)	108 (3)	-	312 (1)	105 (3)	-
Suniso 3GS	Not OK	*1	*1	355	320 (4)	1325 (1)	377	108 (3)	80 (4)	245	154 (2)	78 (4)	250
R407C	OK	450 (3)	*2	-	675 (2)	*2	-	130 (2)	*2	-	262 (1)	*2	-
Suniso 3GS	Not OK	280 (4)	*2	375	435 (3)	*2	375	79 (3)	*2	234	115 (2)	*2	242
R407C	OK	450 (3)	*2	-	N/A	N/A	N/A	120 (2)	*2	-	N/A	N/A	N/A
Suniso 1GS	Not OK	330 (4)	*2	384	N/A	N/A	N/A	82 (3)	*2	253	N/A	N/A	N/A
R407C	OK	455 (3)	685 (2)	-	445 (3)	655 (2)	-	94 (3)	70 (4)	-	275 (1)	90 (3)	-
Castrol SW32	Not OK	340 (4)	455 (3)	375	330 (4)	330 (4)	388	70 (4)	60 (4+)	267	142 (2)	70 (4)	237
R407C	OK	450 (3)	685 (2)	-	430 (3)	*3	-	97 (3)	97 (3)	-	*3	95 (3)	-
Castrol SW68	Not OK	330 (4)	445 (3)	375	305 (4)	1370 (1)	378	67 (4)	50 (4+)	242	290 (1)	68 (4+)	245
R407C	OK	340 (4)	685 (2)	-	465 (3)	705 (2)	-	150 (2)	75 (4)	-	N/A	N/A	N/A
ICI RL32S	Not OK	*1	455 (3)	375	330 (4)	320 (4)	375	95 (3)	45 (4+)	240	N/A	N/A	N/A

a Based on ASHRAE guidelines (Ref. 3)
*1 - No Accurate Measurement of Velocity Available
*2 - Not Calibrated for Refrigerant - Lubricant Combination
*3 - No Upper Bound on Velocity Available
(n) - Number of Vapor Lines Open

MAJOR RESULTS

- DYNAMIC TEST FACILITY WAS DESIGNED, CONSTRUCTED, AND INSTRUMENTED TO SIMULATE OIL MANAGEMENT SCENARIOS THAT COULD PRODUCE ZERO OIL RETURN
- UNIQUE INSTRUMENTATION AND VISUAL OBSERVATIONS INCORPORATED FOR ON-LINE CONTINUOUS MEASUREMENT AND MONITORING OF OIL RETURN BEHAVIOR
- SIX COMBINATIONS OF REFRIGERANTS AND LUBRICANTS WERE TESTED TO REPRESENT A RANGE OF MISCIBILITIES
- MINIMUM FLOW VELOCITIES FOR GOOD OIL MANAGEMENT (NOTED BY VISUAL AND MEASUREMENT TECHNIQUES) WERE:

  <u>HEATING MODE</u>
    - 100 FT/MIN (LOW OIL CONCENTRATIONS OF 0.25 TO 0.50% BY WT)
    - 200 PT/MIN (HIGHER OIL CONCENTRATIONS)

  <u>COOLING MODE</u>
    - 350 TO 375 FT/MIN (APPROXIMATE THOSE IN ASHRAE GUIDELINES)
- MISCIBLE LUBRICANTS WITH HCFC-22 AND R407C HAVE ABOUT SAME VELOCITY LIMITS
- IMMISCIBLE LUBRICANTS WITH R407C HAVE <u>NO</u> WORSE EFFECTS

CONCLUSIONS AND RECOMMENDATIONS

- R407C (WITH 1GS OR 3GS) EXHIBITED GOOD OIL RETURN, I.E., IMMISCIBLE MIXTURES COULD OPERATE AT LOWER MINIMUM VELOCITIES THAN WITH MISCIBLE COMBINATIONS
- EXTREME OPERATING CONDITIONS (LOW SATURATION TEMPS) I.E., HIGH LUBRICANT VISCOSITY WERE NOT THOROUGHLY EXPLORED
- VISUAL OBSERVATIONS OF POOR OIL RETURN SITUATIONS ARE AS IMPORTANT AND RELIABLE AS ON-LINE MEASUREMENTS
- IMPROVEMENTS IN ON-LINE OIL MEASUREMENT TECHNIQUES WOULD BE VALUABLE
- OPPORTUNITIES FOR OIL TRAPPING/POOLING MAY EXIST IN BOTH INDOOR & OUTDOOR HEAT PUMP SECTIONS

CONCLUSIONS AND RECOMMENDATIONS (CONTINUED)

- INDUSTRY GUIDELINES FOR HCFC/CFC/LUBRICANTS APPEAR CONSERVATIVE
- ADDITIONAL TESTS AND INCREASED UNDERSTANDING OF HFC'S WITH MO, POE'S, AND AB IN OTHER SYSTEM REQUIRED
- BETTER UNDERSTANDING OF ROLE OF ALL PARAMETERS NEEDED
- LOWER TEMPERATURE OPERATION SUGGESTED TO FILL OUT MATRIX