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Evaluation of Solvent Loss from Vapor Degreaser Systems. Phases 2 and 3 Effect of Crosscurrent Air Velocity on Control System Performance

PEDCo-Environmental, Inc.
Cincinnati, OH

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EVALUATION OF SOLVENT LOSS FROM VAPOR DEGREASER SYSTEMS PHASES 2 AND 3
Effect of Crosscurrent Air Velocity on Control System Performance

by

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Phase 2
Contract No. 68-02-2535
Task No. 3

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Project Officer

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16. ABSTRACT

The U.S. Environmental Protection Agency evaluated available pollution reduction capabilities of vapor degreasers fitted with add-on control systems as supplied by degreaser manufacturers. The principal objectives of this project were to develop and implement an experimental program for assessing solvent loss from degreasing systems of various designs, and to report the test conditions, procedures, results, and conclusions in a form usable by air pollution agencies and industry.

Tests were performed from October 1978 to June 1980 to evaluate the effects of different variables on the rate of solvent loss from degreasers. The variables tested include the following degreaser control options and operating conditions: freeboard ratio, load cross-sectional area, refrigerated freeboard chiller, hoist speed, lip exhaust, crosscurrent air velocity, degreaser size, solvent type, and automatic cover.

Various relationships between the test variables are presented in the report. The factor most likely to ensure long periods of operation with minimum solvent loss, regardless of the mix of control options, is installation in an area where crosscurrent velocity can be minimized.

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Vapor degreasing systems	Degreasers	13H
Solvents, cleaners	Organic compounds	11K
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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the pollution related impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents the results of Phase II and III of an investigation into the control of air pollutant emissions from the vapor degreasing process. The study was performed to develop improved methods for operation and control of degreaser to reduce solvent emissions rates. The results are being used within the Agency's Office of Research and Development as part of a larger effort to develop improved technologies for reducing volitile organic compound discharges to the atmosphere from metal finishing industries. The findings will also be useful to other Agency components and industry in dealing with environmental control problems. The Nonferrous Metals and Minerals Brarch of the Energy Pollution Control Division should be contacted for additional information concerning this program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

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NOTE: If the above appendices are required, copies may be obtained by contacting:

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Cincinnati, OH 45268

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FIGURES (continued)

FIGURES (continued)

TABLES

TABLES (continued)

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This report was prepared for the Industrial Environmental Research Laboratory of the U. S. Environmental Protection Agency at Cincinnati, Ohio. It was conducted under contract to Centec Consultants Incorporated and PECDO Environmental, Inc. Mr. Charles H. Darvin was the project officer. The American Society for Testing Materials (ASTM) Committee D-26 on degreasing provided assistance in defining and formulating the test program. Centec Consultants Inc., and PEDCO Environmental, Inc., appreciates the direction and extensive review provided by industry and ASTM. Thanks are also extended to the companies which provided assistance and degreaser units for this test program. They include Autosonics Inc.; Baron-Blakeslee, Inc.; Branson Cleaning Equipment Company; Detrex Chemical Industries, Inc.; and many other degreaser system manufacturers and users.

Mr. Richard W. Gerstle served as PEDCO Project Director for Phase 2 and Mr. Robert D. Wilson, for Phase 3. Mr. Edmund S. Schindler was Project Manager.

SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) initiated a research program to evaluate the solvent loss reduction capabilities of various degreaser modifications, controls, and operating practices on open-top vapor degreasers. PEDCo Environmental, Inc., was contracted to carry out the research program. The American Society for Testing and Materials (ASTM) was asked to assist EPA in defining and formulating the test program and reviewing its progress. A special ASTM subcommittee of Committee D-26 on degreasers was established for this purpose.

The program began with the writing of a detailed test plan, which was submitted to EPA for technical review.* The plan provided details of tests, test location, types of solvents, variables and control modifications to be tested, parameters to be measured, and test procedures. The test plan was implemented after approval by EPA. The results of these tests, which are referred to as Phase 1, were presented in the report "Evaluation of Solvent Loss From Vapor Degreaser Systems."†

Phase 1 quantified the ability of a control device to reduce solvent loss from a job-shop-size degreaser at the ideal operating conditions suggested by the manufacturer and EPA. It also tested the effect of nonideal operating conditions on solvent loss, but did not evaluate the effectiveness of control devices operating at nonideal conditions. The test data showed, however, that a slight draft across the lip of the degreaser increased solvent loss dramatically. On the basis of this

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* PEDCo Environmental, Inc. Degreaser Systems Evaluation Test Plan. Prepared under EPA Contract No. 68-02-2535, Task No. 3. Cincinnati, Ohio, March 1978.

† PEDCo Environmental, Inc. Prepared under EPA Contract No. 68-02-2535, Task No. 3. Cincinnati, Ohio, October 1979.

increase, the EPA decided that control devices should be evaluated for the ability to control solvent loss at two cross-current air velocities: 0.67 m/s (132 ft/min) and 1.12 m/s (220 ft/min).

Phase 2 comprised the supplemental tests that were performed to supply this evaluation. Tests were also conducted to supplement the Phase 1 data about variations in hoist speed. The present report describes only the test conditions that differ from those of Phase 1. Because the background data, including test site, solvent, and degreaser descriptions, were the same as in Phase 1, the reader is referred to the first report for these data.

Section 2 of the present report describes Phase 2 test conditions, and Section 3 discusses Phase 2 test results. Section 4 presents Phase 2 conclusions and recommendations, which are based on relevant tests in Phase 1 as well as tests in Phase 2.

Some Phase 2 results were unusual. Although the refrigerated freeboard chiller (RFC) substantially reduced solvent loss when methylene chloride (MC) was used, it substantially increased solvent loss when 1,1,1-trichloroethane (TE) was used. Further, Phase 2 results indicated that changing the freeboard ratio (FR) reduced solvent loss only slightly, regardless of solvent. Phase 3 was conducted to verify these results and examine the interaction of air velocity, RFC, and FR.

Section 5 of this report describes the Phase 3 test conditions that differ from those of Phase 1, and Section 6 presents the results of Phase 3 tests. Section 7 provides Phase 3 conclusions and recommendations based on tests in Phase 3 and on relevant tests in Phases 1 and 2.

Actual test data are given in five appendixes. Appendix A presents the Phase 2 raw test data, including the successive degreaser weights as measured throughout each test and a statistical breakdown of the data. Appendix B summarizes data from individual Phase 2 tests according to the modifications and operating conditions used. Appendix C contains the Phase 3 raw test data, and Appendix D summarizes data from individual Phase 3 tests.

Although Phase 1 and 2 showed a direct relationship between solvent loss from a vapor degreaser and draft velocity across it, no definitive data were available on average draft velocities. Thus, the Nonferrous Metals and Minerals Branch of the Energy Pollution Control Division, with assistance from PEDCo Environmental, undertook a study to obtain such data. Appendix E discusses this study.

The equipment and instrumentation in these tests were calibrated in English units of measure. Although the data are given in this report in the International System of Units (SI) as well as in English units, the original measurements of solvent loss (and all calculations derived from them) were in English units. The reader is cautioned that data expressed in SI equivalents can differ slightly from the original data.

SECTION 2

PHASE 2 TEST CONDITIONS

The Phase 2 tests were designed to evaluate the effect on solvent loss of high crosscurrent air velocities across the lip of the degreaser. The tests measured the ability of selected control devices (i.e., modifications and operating conditions) to reduce solvent loss under these conditions. The system modifications and operating conditions that were tested in combination with the increased air velocity are as follows:

- Automatic lid
- Freeboard ratio
- Refrigerated freeboard chiller
- Solvent

A few tests were also conducted to measure the effect of different hoist speeds on solvent loss. These tests, which were unrelated to the evaluation of crosscurrent air velocities, were included to supplement specific test data from Phase 1.

The modifications and operating conditions are described in the following subsections. Only those that are significantly different from the Phase 1 tests are discussed in detail.

CROSSCURRENT AIR VELOCITY

Most of the tests in Phase 1 were run under conditions of calm air at the lip of the degreaser. "Calm air" was defined as an average velocity of 0.1 m/s (20 ft/min). For the Phase 2 tests, higher air velocities were created by installing two fans--one for each of the two degreasers--within the testroom.

Figure 1 shows the locations of the fans and air velocity measuring positions in relation to Degreaser B; the locations are the same for Degreaser A.

Each fan was 51 cm (20 in.) in diameter and had three motor settings: high, or 1700 m^3/s (2900 cfm); medium, or 1500 m^3/s (2550 cfm); and low, or about 1200 m^3/s (2000 cfm). It was mounted about 122 cm (48 in.) from the degreaser, the bottom of the fan being level with the degreaser lip. Air velocity measurements were made with a Kurz Model 444 hot-wire anemometer, NBS traceable calibration.

Two target air velocities were used in the tests: 0.67 m/s (132 ft/min) and 1.12 m/s (220 ft/min). Before each test, air velocity measurements were taken at six equally spaced points on a line running 10 cm (4 in.) above the upwind lip of the degreaser. Velocities were changed by adjusting the fan speed or obstructing portions of the front or back of the fan with tape.

During the test, air velocity measurements were taken at 23 positions on each degreaser. Because only one anemometer was available, each measurement was taken separately. First, an air velocity profile lying within 5 percent of the target velocity was achieved at the 10-cm level. The probe was then mounted for 15 minutes in the probe stand for each of positions 1 through 6 at the 10-cm level. The sequence of positions was randomly selected. Air velocity at each of the other 17 positions was measured for 1 minute during each 6-hour test segment. The output of the velocity probe was recorded throughout the test.

The probe is very sensitive to turbulence, as shown in Figure 2. The velocity response curve was fitted to a polynomial equation as follows:

$$V = 0.268\ X^2 + 1.648 \qquad 10 < V < 600 \text{ ft/min}$$

where V = velocity (ft/min)

X = percent of chart

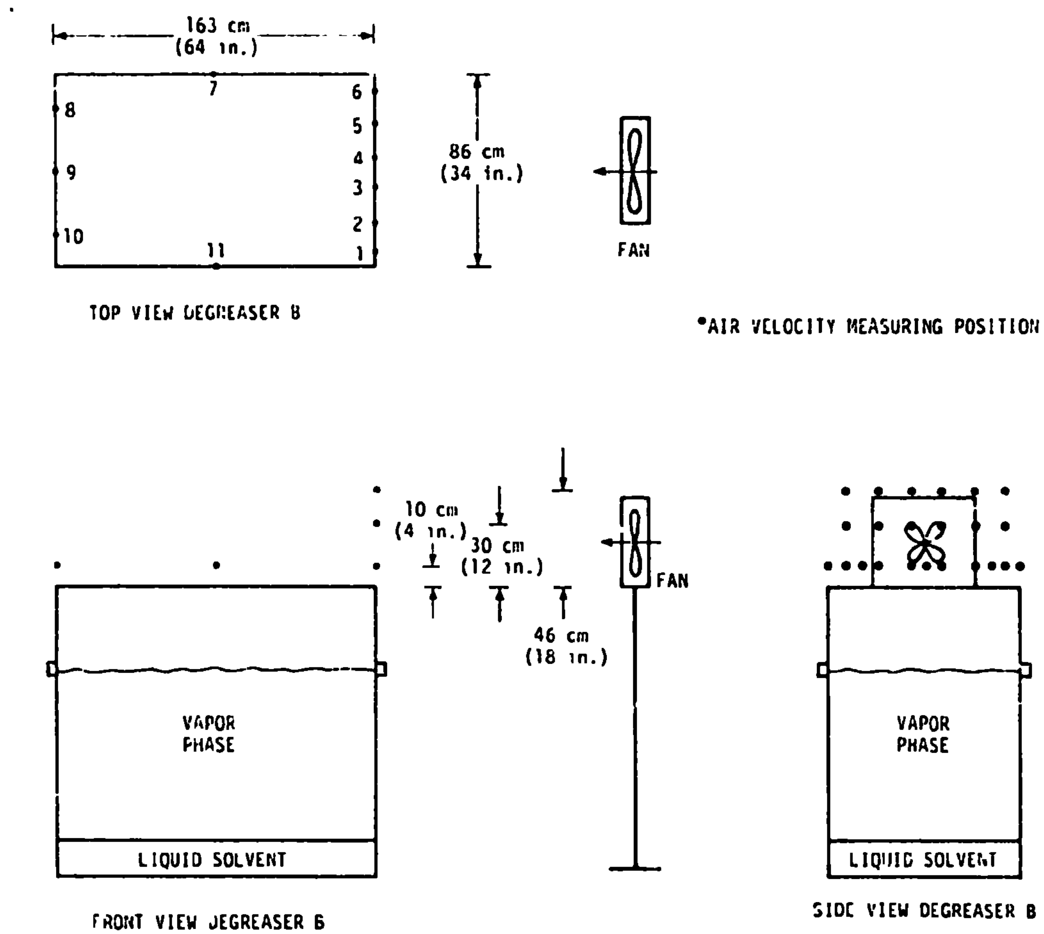


Figure 1. Location of fan and air velocity measuring positions in relation to Degreaser B during Phase 2.

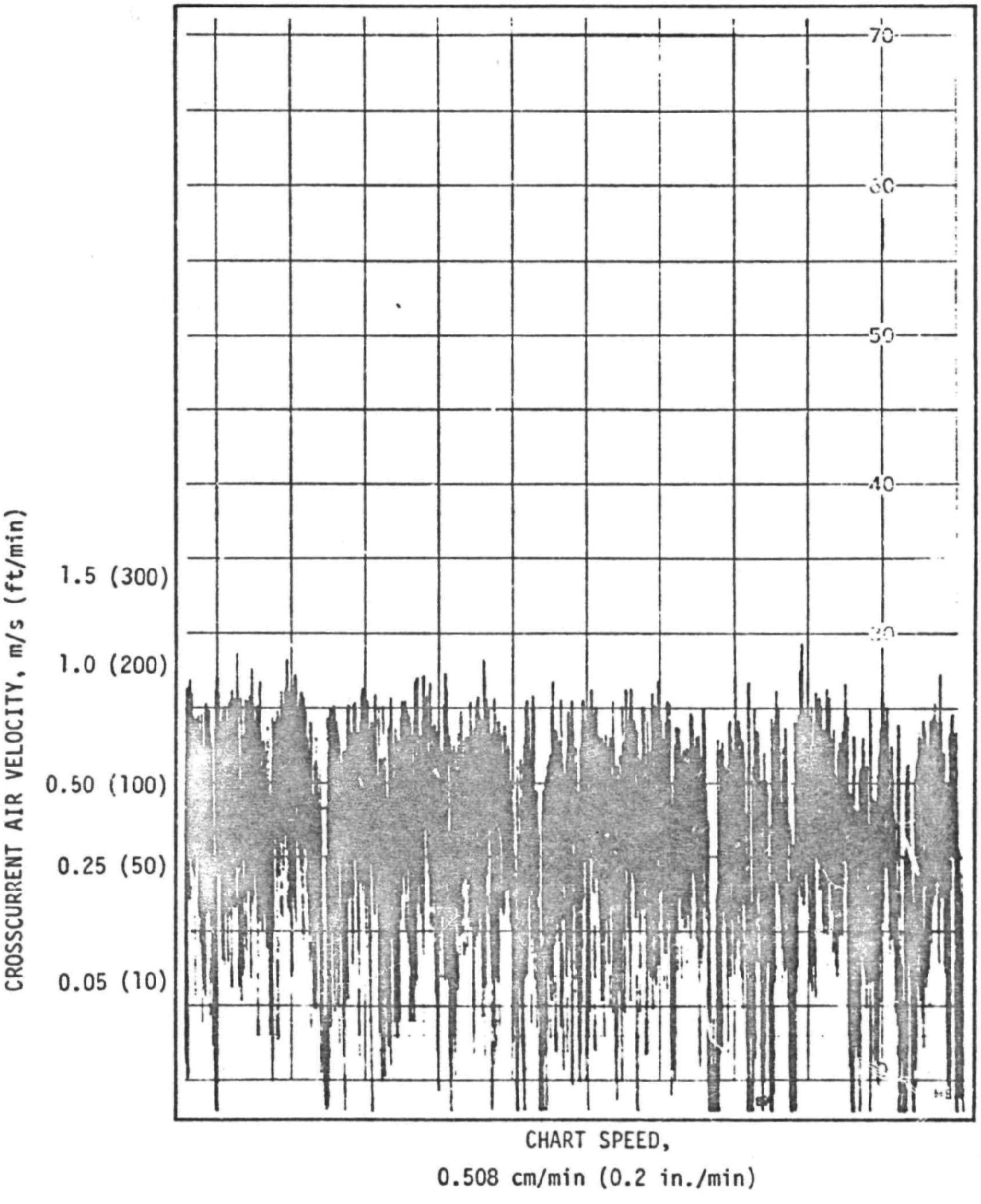


Figure 2. Sample output of the anemometer during Phase 2.

During actual testing the anemometer chart was read visually, and the readings were not integrated over the time period. The portion of the chart presented in Figure 2 shows air velocity fluctuations from 0 to 1.08 m/s (0 to 212 ft/min); 0.406 m/s (80 ft/min) was the visual average of the portion of the chart presented in Figure 2.

Table 1 lists the average velocity readings for each test at positions 1 through 6 [at 10 cm (4 in.), 30.5 cm (12 in.), and 46 cm (18 in.) above the degreaser lip] and at positions 7 through 11 [at 10 cm (4 in.) above the degreaser lip].

AUTOMATIC LID

A biparting lid designed for Degreaser A closed automatically whenever the load was removed from the degreaser. Lid controls were integrated into the timer controls for the hoist system. The lid remained totally closed for 98 out of 391 seconds, or 25 percent of the time required for each load cycle. This figure excludes closing and opening times of 20 seconds each.

The lid was installed so that the top closed at a level that would be considered 55 percent FR. Baffles were added to increase the FR to 75 percent. The lid could not be installed directly on top of a 75 percent FR collar modification because the motor housings were located on the ends of the lid and would obstruct airflow. This would be inconsistent with the intent to test the lid on a degreaser with a 75 percent FR. The motor housing extended up to a level that would be considered 92 percent FR. Although the housing would not act as a 92 percent FR, its exact effect could not be quantified and was thus not correlated with other tests in the series. The motor housings were removed, and the lid was installed directly on the 50 percent FR degreaser; the baffles were added to increase FR to 75 percent.

TABLE 1. AVERAGE VELOCITY READINGS TAKEN DURING EACH PHASE 2 TEST

Test No.	Degreaser	Target velocity, m/s	Average velocity of positions 1 through 6, m/s			Average velocity at 10 cm above lip, m/s		
			At 10 cm above lip	At 30 cm above lip	At 46 cm above lip	Average for positions 7 through 9	At position 10	At position 11
101	A	0.67	0.60	0.39	0.20			
	B	0.67	0.69	0.41	0.23			
102	A	1.12	0.99	0.67	0.27			
	B	1.12	1.14	0.66	0.30			
103	A	0.67	0.36	0.34	0 09	0.09	0.20	0.03
	B	0.67	0.77	0.94	0.61	0.11	0.15	0.05
104	A	1.12	0.69	0.51	0.28	0.11	0.10	0 05
	B	1.12	0.91	0.96	0 45	0.32	0 36	0.08
105	A	0.67	0.69	0.33	0.23			
	B	0.67	0.68	0.49	0.30			
106	A	1.12	1.03	0.67	NA			
	B	1.12	0.92	1 46	1.06			
107	A	0.67	0.70	0.20	0.07	0.10	0.19	0.29
	B	0 67	0.57	1.19	0.94	0.27	0.29	0.11
108	A	1.12	1.03	0.66	0.47	0.33	0.41	0 26
	B	1.12	1.12	0.34	0.10	0.16	0.19	0.37
109	A	Calm	Calm					
	B	Calm	Calm					
110	A	0.67	0.45	0.22	0.11		0.10	0.05
	B	Calm	Calm					
111	A	1.12	1.17	0.58	0.36	0.27	0.41	0.41
	B	1.12						
112	A	0.67	0.51	0.20	0.07	0.05	0.08	0.20
	B	Calm	Calm					
113	A	1.12	1.28	0.55	0.15	0.21	0.25	0.56
	B							

(continued)

TABLE 1 (continued)

Test No.	Degreaser	Target velocity, m/s	Average velocity of positions 1 through 6, m/s			Average velocity at 10 cm above, lip, m/s		
			At 10 cm above lip	At 30 cm above lip	At 46 cm above lip	Average for positions 7 through 9	At position 10	At position 11
114	A							
	B							
115	A							
	B							
116	A							
	B							
117	A	0.67	0.70	0.46	0.19	0.04	0.10	0.13
	B	0.67	0.78	0.60	0.33	0.10	0.20	0.15
118	A	1 12	1.05	0.30	0.09	0.29	0.27	0.29
		1.12	1.04	0.62	0.23	0.20	0 18	0.79
119	A	1.12	1.09	1.07	0.43	0.19	0.41	0.66
	B	1.12	1.21	0.96	0.17	0.57	0.51	0.79
120	A	0.67	0.52	0.94	0.58	0.05	0.05	0.51
	B	0.67	0.57	0.47	0.39	0.05	0.08	0.05
121	A	0.67	0.39	0.55	0.40	0.19	0.11	0.09
	B	0.67	0.89	0.76	0.34	0.21	0.29	0.29
122	A	1.12	0.90	0.84	0.40	0.30	0.25	0.15
	B	1.12	1.15	0.72	0.29	0.30	0 38	0 56
123	A	0.67	0.60	0.92	0.59	0.08	0.36	0.08
	B	0.67	0.50	0.68	0.41	0.05	0.03	0.03
124	A	1.12	1.06	1.22	1.00	0.12	0.47	0.30
	B	1.12	0 91	1.06	0.54	0.18	0.56	0.36
125	A	Calm	0.09	0.08	0.10			
	B	Calm	0.06	0.08	0.10			
126	A							
	B							

(continued)

TABLE 1 (continued)

Test no.	Degreaser	Target velocity, m/s	Average velocity of positions 1 through 6, m/s: At 10 cm above lip	At 30 cm above lip	At 46 cm above lip	Average velocity at 10 cm above lip, m/s: Average for positions 7 through 9	At position 10	At position 11
127	A	Calm	0.12	0.13	0.14	0.10	0.04	0.06
	B	Calm	0.09	0.12	0.10	0.09	0.08	0.03
128	A							
	B							
129	A	Calm	0.09	0.09	0.67	0.10	0.07	0.04
	B	Calm	0.06	0.10	0.10	0.09	0.18	0.10
130	A	0.67	0.74	0.18	0.03	0.03	0.18	0.46
	B	0.67	0.54	0.97	0.47	0.22	0.25	0.05
131	A	Calm	0.13			0.05	0.05	0.05
	B	Calm	0.05	0.06	0.06	0.06	0.10	0.05
132	A							
	B							
133	A							
	B							
134	A							
	B							
135	A	Calm						
	B	Calm						

TABLE 1a. AVERAGE VELOCITY READINGS TAKEN DURING EACH PHASE 2 TEST (English Units)

Test No	Degreaser	Target velocity, ft/min	Average velocity of positions 1 through 6, ft/min: At 4 in. above lip	At 12 in. above lip	At 18 in. above lip	Average velocity at 4 in. above lip, ft/min: Average for positions 7 through 9	At position 10	At position 11
101	A	132	119	76.9	38 61			
	B	132	135	40 8	45.22			
102	A	220	195	131.7	53.33			
	B	220	224	130	60.0			
103	A	132	69.6	66	18	18.33	40	5
	B	132	151	186	121	21 67	30	10
104	A	220	135	100	[illegible]	20.83	20	10
	B	220	180	188	89	63 33	70	15
105	A	132	136	65 8	45			
	B	132	134	95 8	58.3			
106	A	220	203	132	NA			
	B	220	181	287	208			
107	A	132	138	40	14	20.0	36.67	56.67
	B	132	113	234	186	52.22	56.67	21.67
108	A	220	202	129	93	65	80	51.67
	B	220	221	66	19	32	38 33	72
109	A	Calm	Calm					
	B	Calm	Calm					
110	A	132	88	43.5	22		20	10
	B	Calm	Calm					
111	A	220	230	115	71	52.5	80	80
	B	220						
112	A	132	100	38.5	13	10	15	40
	B	Calm	Calm					
113	A	220	252	108	29	42.22	50	110
	B							

(continued)

TABLE 1a (continued)

Test No	Degreaser	Target velocity, ft/min	Average velocity of positions 1 through 6, ft/min			Average velocity at 4 in. above lip, ft/min		
			At 4 in above lip	At [illegible] in. above lip	At 18 in. above lip	Average for positions 7 through 9	At position 10	At position 11
114	A							
	B							
115	A							
	B							
116	A							
	B							
117	A	132	138	90.8	37.5	7.33	20	25
	B	132	154	117.5	65	20	40	30
118	A	220	206	59.2	17.2	56.67	52.5	57.5
	B	220	204	142.9	45.4	40.0	35	170
119	A	220	214	210	85	36.67	80	130
	B	220	239	186	32.5	111.67	100	155
120	A	132	102	184.5	115	9.67	10	100
	B	132	112	91.7	77.5	10	15	10
121	A	132	76.4	107.5	79.2	36.67	22.5	17.5
	B	132	176	149	66.3	41.67	57.5	57.5
122	A	220	178	66	79	60	50	30
	B	220	227	142.15	58	60	75	110
123	A	132	130	162	117	15	70	15
	B	132	98.6	134.6	60	9	5	5
124	A	220	209	241	197	22.83	92.5	60
	B	220	180	208	106	35	110	70
125	A	Calm	18.33	16	20.33			
	B	Calm	11.67	16	20			
126	A							
	B							

(continued)

TABLE 1a (continued)

Test No	Degrease	Target velocity, ft/min	Average velocity of positions 1 through 6, ft/min			Average velocity at 4 in. above lip, ft/min		
			At 4 in above lip	At 12 in above lip	At 16 in. above lip	Average for positions 7 through 9	At position 10	At position 11
127	A	[illegible]lm	22 67	25 83	27.83	19.33	8	12
	B	Calm	17 83	23.5	18 [illegible]	16.67	16	5
128	A							
	B							
129	A	Calm	17 5	18	11 67	20	14	8
	B	Calm	12.17	19	19	18	35	20
130	A	132	145	35 8	6.5	5.67	35	90
	B	132	107	191 6	93 3	43.33	50	10
131	A	Calm	26			10	8	10
	B	Calm	9.5	11	11.33	11	19	10
132	A							
	B							
133	A							
	B							
134	A							
	B							
135	A	Calm						
	B	Calm						

FREEBOARD RATIO

Freeboard ratio is the fraction (or percentage) that results when degreaser wall height (above the vapor line) is divided by the width of the degreaser top opening. In Phase 2, FR was tested at 75 and 125 percent only.

REFRIGERATED FREEBOARD CHILLER

Two RFC designs were tested in Phase 2: RFC I, with a refrigerant temperature range of 1° to 2°C (34° to 36°F), and RFC II, with a range of -29° to -40°C (-20° to -40°F). The third RFC design that was tested in Phase 1--RFC II at a range of -23° to -32°C (-9° to -26°F)--was not tested in this phase.

SOLVENT

As in Phase 1, the two solvents tested in Phase 2 were TE and MC.

HOIST SPEED

In Phase 1, the hoist speeds tested were 0.04 m/s (8 ft/min) and 0.08 m/s (16 ft/min). In Phase 2, the hoist speed tested was 0.055 m/s (11 ft/min), which is the maximum speed suggested by manufacturers.

Pullies were used to increase the speed to 0.162 m/s (32 ft/min), then to reduce it by one-third to 0.055 m/s.

SECTION 3

PHASE 2 TEST RESULTS

METHOD OF ANALYSIS

The test program was conducted under a factorial design, wherein each variable is at a different and distinct level. In this case, air velocity was tested at the three levels: calm; 0.67 m/s (132 ft/min); and 1.12 m/s (220 ft/min). The calm air velocity tests were selected from Phase 1. The RFC was operated at two levels (off and on), FR was at two levels (75 and 125 percent), and two solvents were chosen (TE and MC). Replication of each test on a second degreaser was not considered a variable in the factorial design.

Analysis of variance with tests of significance is the typical method of evaluating the results. This analysis tells us, based on mean values and standard deviation, whether the difference in mean values between two levels of a variable is caused by something other than chance. Further, it tells us the probability of error in accepting a difference as significant when it is in fact caused by chance. The analysis of variance also indicates the interaction of the variables. For example, as a variable changes from one level to the next it changes the other variables in one of two ways: by the magnitude or by the direction of the change.

An initial screening of the data showed some factors that limit the value of an analysis of variance. A factorial design using analysis of variance requires a random testing sequence for the purpose of limiting the effect of variables beyond our control. A good example of variables beyond our control can be seen in tests that are separated by a long time span. In this case, a bias is introduced because the tests at the end of the period may be operated by different personnel than the tests at the beginning. A random test sequence limits the effect on the data base of these uncontrollable variables.

Several overriding constraints, however, caused us to select a test sequence that was not totally random. Solvent changes required at least 3 to 4 days: the degreasers had to be drained, dried, boiled out with water and sodium carbonate or bicarbonate, drained and dried again, and filled with new solvent. Because of the large effort involved in changing the solvent on a random basis, it was decided to operate the tests in two sets, each with a different solvent. This test method limits the comparison of the two solvents in terms of absolute values of solvent loss, but does not limit the comparison of the effects of the other variables on each solvent.

Another constraint was the use of calm air tests from Phase 1, which was separated by many months from Phase 2. This bias was acceptably reduced by rerunning three Phase 1 tests at the beginning of Phase 2.

A third constraint was the discovery, shortly after Phase 2 testing started, that RFC II was defective. Consequently, tests using the RFC's were postponed until the unit was repaired, and the testing of other variables continued. The possibility of a time bias was recognized, but testing had to stop for 1 month while the chiller was repaired. An additional test without the RFC's was added near the end of the tests to flag any bias problems resulting from this change in schedule.

Another requirement of a factorial design is the setting of variables at levels that are consistent from one test to the next. The measured airflow over the degreaser at 10 cm did not meet this requirement. Before each test, the windspeed at the downwind lip of the degreaser was set within $\pm$ 5 percent of the two velocities (either 0.67 m/s or 1.12 m/s). This tolerance would normally be sufficient to meet the requirement of a factorial design. During the test, however, continuous measurements of velocity taken at the 10-cm level showed average velocities that were sometimes quite different from the average obtained at the beginning of the test. The differences were great enough to prevent this requirement of the factorial design from being met.

Tables 2 through 7 and Figures 3 through 15 present the test results. Appropriate comparisons with Phase 1 data have been included.

EFFECT OF CROSSCURRENT AIR VELOCITY

Tests on operating degreasers using TE and MC showed a direct relationship between air velocity at the lip and solvent loss rate. As the velocity increased the solvent loss increased, and the rate of increase in solvent loss increased with increasing air velocity. Three different air velocities were used in tests of an operating degreaser with RFC off, load area of 50 percent, hoist speed of 0.04 m/s (8 ft/min), FR of 75 percent, and using TE. When compared with the base case,* solvent loss decreased by a range of 7 to 25 percent at calm air; increased by 2 to 13 percent at 0.67 m/s (132 ft/min): and increased by 65 to 144 percent at 1.12 m/s (220 ft/min) (Figure 3). At 125 percent FR (and all other conditions the same), a similar effect was observed in relation to the base case (Figure 3). Changes in solvent loss ranged from a decrease of 4 percent to an increase of 31 percent at calm air, an increase of 64 to

* Base case: Degreaser with 50 percent FR and operating under conditions of calm air (0.1 m/s, 20 ft/min).

TABLE 2. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE

Test conditions[a]								Solvent loss data									
								Degreaser A					Degreaser B				
										Decrease (Increase) from base case					Decrease (Increase) from base case		
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	kg/h	%		Measured air velocity at lip, m/s	kg/h	kg/h	%	
1	b	✓	✓	✓		50	0.1		1.04					1.00			
3	c	✓	✓	✓		75	0.1		0.97	0.07	7.0			0.75	0.25	24.5	
101	101	✓	✓	✓		75	0.67	0.59	1.181	(0.141)	(13.2)		0.69	1.015	(0.015)	(1.73)	
102	102	✓	✓	✓		75	1.12	1.17	2.551	(1.511)	(144)		1.14	1.651	(0.651)	(65.4)	
109	d	✓	✓	✓		125	0.1		1.363	(0.323)	(30.6)			0.955	0.045	4.27	
105	e	✓	✓	✓		125	0.67	0.705	1.846	(0.806)	(77.0)		0.776	1.640	(0.640)	(64.4)	
106	106	✓	✓	✓		125	1.12	1.03	1.964	(0.924)	(88.3)		0.92	1.265	(0.265)	(22.8)	

[a] Hoist speed of 0.04 m/s and a load area of 50 percent unless otherwise indicated.
[b] Time-weighted average of weight loss of Tests 1, 6, 7, 8 and 89, from Phase 1.
[c] Time-weighted average of Tests 22, 43, 84, 87 and 90, weight loss only from Phase 1.
[d] Time-weighted average of Tests 109, 127 and 129; weight loss and air velocity at lip only.
[e] Time-weighted average of Tests 105 and 130; weight loss and air velocity at lip only.

TABLE 2a. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE (English Units)

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	lb/h	%	Measured air velocity at lip, ft/min	lb/h	lb/h	%
1	b	✓	✓	✓		50	20		2.30				2.20		
3	c	✓	✓	✓		75	20		2.14	0.16	7.0		1.66	0 54	24.5
101	101	✓	✓	✓		75	132	119	2.604	(0.304)	(13.2)	135	2 238	(0.038)	(1.73)
102	102	✓	✓	✓		75	220	195	5 623	(3.323)	(144)	224	3.639	(1 439)	(65.4)
109	d	✓	✓	✓		125	20		3.004	(0 705)	(30.7)		2.106	0.094	4.27
105	e	✓	✓	✓		125	132	139	4 072	(1.772)	(77 0)	153	3 618	(1.418)	(64.5)
106	106	✓	✓	✓		125	220	203	4.330	(2.030)	(88.3)	181	2.789	(0.589)	(26.8)

[a] Hoist speed of 8 ft/min and a load area of 50 percent unless otherwise indicated.
[b] Time-weighted average of weight loss of Tests 1, 6, 7, 8, and 89, from Phase 1.
[c] Time-weighted average of Tests 22, 43, 84, 87, and 90, weight loss only from Phase 1.
[d] Time-weighted average of Tests 109, 127, and 129, weight loss and air velocity at lip only.
[e] Time-weighted average of Tests 105 and 130, weight loss and air velocity at lip only.

TABLE 3. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE WITH RFC ON

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	kg/h	%	Measured air velocity at lip, m/s	kg/h	kg/h	%
1	b	✓	✓	✓		50	0.1		1.04				1.00		
3	c	✓	✓	✓		75	0.1		0.97	0.07	7.0		0.75	0.25	24.5
16	d	✓	✓	✓	✓	50	0.1		0.99	0.05	5.2		0.92	0.08	7.7
17	e	✓	✓	✓	✓	75	0.1		0.96	0.08	8.3		0.82	0.18	18.2
103	103	✓	✓	✓	✓	75	0.67	0.35	1.838	(0.798)	(76.7)	0.766	2.277	(1.277)	(128)
104	104	✓	✓	✓	✓	75	1.12	0.68	2.964	(1.924)	(184)	0.876	2.598	(1.598)	(160)
18[f]	30	✓	✓	✓	✓	125	0.1		0.68	0.36	34.8		0.53	0.47	47.3
107	107	✓	✓	✓	✓	125	0.67	0.70	1.736	(0.696)	(66.4)	0.57	2.061	(1.061)	(107)
108	108	✓	✓	✓	✓	125	1.12	1.02	4.172	(3.132)	(300)	1.12	1.685	(0.685)	(68.9)

[a] Hoist speed of 0.04 m/s and a load area of 50 percent unless otherwise indicated.

[b] Time-weighted average (TWA) of weight loss of Tests 1, 6, 7, 8, and 89 from Phase 1.

[c] TWA of Tests 22, 43, 84, 87, and 90, weight loss only, from Phase 1.

[d] TWA of weight loss of Tests 11, 14, 19, 25, 34, and 88 for Degreaser A; 19, 25, and 34 for Degreaser B, from Phase 1.

[e] TWA of weight loss of Tests 18 and 86 for Degreaser A; Test 18 for Degreaser B, from Phase 1.

[f] Test data from Phase 1.

TABLE 3a. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE WITH RFC ON (English Units)

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	lb/h	%	Measured air velocity at lip, ft/min	lb/h	lb/h	%
1	b	✓	✓	✓		50	20		2.30				2.20		
13	c	✓	✓	✓		75	20		2.14	0.16	7.0		1.66	0.54	24.5
16	d	✓	✓	✓	✓	50	20		2.18	0.12	5.2		2.03	0.17	7.7
17	e	✓	✓	✓	✓	75	20		2.11	0.19	8.3		1.80	0.40	18.2
103	103	✓	✓	✓	✓	75	132	69.6	4.051	(1.751)	(76.1)	151	5.019	(2.819)	(128)
104	104	✓	✓	✓	✓	75	220	135	6.536	(4.236)	(184)	180	5.727	(3.527)	(160)
18[f]	30	✓	✓	✓	✓	125	20		1.50	0.80	34.8		1.16	1.04	47.3
107	107	✓	✓	✓	✓	125	132	138	3.827	(1.527)	(66.4)	113	4.543	(2.343)	(107)
108	108	✓	✓	✓	✓	125	220	202	9.197	(6.897)	(300)	221	3.715	(1.515)	(68.9)

[a] Hoist speed of 8 ft/min and a load area of 50 percent unless otherwise indicated.

[b] Time-weighted average (TWA) of weight loss of Tests 1, 6, 7, 8, and 89, from Phase 1.

[c] TWA of weight loss of Tests 22, 43, 84, 87, and 90, from Phase 1.

[d] TWA of weight loss of Tests 11, 14, 19, 25, 34, and 88 for Degreaser A; 19, 25, and 34 for Degreaser B, from Phase 1.

[e] TWA of weight loss of Tests 18 and 86 for Degreaser A; test 18 for Degreaser B, from Phase 1.

[f] Test data from Phase 1.

TABLE 4. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING METHYLENE CHLORIDE WITH RFC OFF

Test conditions[a]								Solvent loss data									
								Degreaser A				Degreaser B					
										Decrease (Increase) from base case				Decrease (Increase) from base case			
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	kg/h	%	Measured air velocity at lip, m/s	kg/h	kg/h	%
34[b]	37	✓	✓	✓		50	0.1		0.78				1.05		
35[b]	74	✓	✓	✓		75	0.1		0.61	0.17	21.6		0.87	0.18	17.2
117	117	✓	✓	✓		75	0.67	0.70	3.001	(2.22)	(287)	0.78	1.444	(0.39)	(37.2)
118	118	✓	✓	✓		75	1.12	1.05	5.767	(4.98)	(644)	1.04	2.377	(2.26)	(126)
36[b]	41	✓	✓	✓		125	0.1		0.59	0.19	24.6		0.78	0.27	26.3
120	120	✓	✓	✓		125	0.67	0.52	1.889	(1.11)	(144)	0.57	1.234	(0.18)	(17.2)
119	119	✓	✓	✓		125	1.12	1.09	3.634	(2.854)	(369)	1.21	4.077	(3 027)	(288)

[a] Hoist speed of 0.04 m/s and a load area of 50 percent unless otherwise indicated.
[b] Test results from Phase 1.

TABLE 4a. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING METHYLENE CHLORIDE WITH RFC OFF (English Units)

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	Decrease (Increase) from base case, lb/h	Decrease (Increase) from base case, %	Measured air velocity at lip, ft/min	lb/h	Decrease (Increase) from base case, lb/h	Decrease (Increase) from base case, %
34[b]	37	✓	✓	✓		50	20		1.71				2.32		
35[b]	74	✓	✓	✓		75	20		1.34	0.37	21.6		1.92	0.40	17.2
117	117	✓	✓	✓		75	132	138	6.616	(4.906)	(287)	154	3.183	(0.863)	(37.2)
118	118	✓	✓	✓		75	220	206	12.715	(11.005)	(644)	204	5.241	(2.921)	(126)
36[b]	41	✓	✓	✓		125	20		1.29	0.42	24.6		1.71	0.61	26.3
120	120	✓	✓	✓		125	132	102	4.164	(2.454)	(144)	112	2.720	(0.40)	(17.2)
119	119	✓	✓	✓		125	220	214	8.012	(6.302)	(369)	239	8.990	(6.670)	(288)

[a] Hoist speed of 8 ft/min and a load area of 50 percent unless otherwise indicated.

[b] Test results from Phase 1.

TABLE 5. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING METHYLENE CHLORIDE WITH RFC ON

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	Decrease (Increase) from base case, kg/h	Decrease (Increase) from base case, %	Measured air velocity at lip, m/s	kg/h	Decrease (Increase) from base case, kg/h	Decrease (Increase) from base case, %
34[b]	37	✓	✓	✓		50	0.1		0.78				1.05		
35[h]	74	✓	✓	✓		75	0.1		0.61	0.17	21.6		0.87	0.18	17.2
43[b]	38	✓	✓	✓	✓	50	0.1		0.88	(0.10)	(13.5)		0.89	0.16	15.5
44[b]	75	✓	✓	✓	✓	75	0.1		0.73	0.05	6.4		0.59	0.46	44.0
121	121	✓	✓	✓	✓	75	0.67	0.387	1.515	(0.74)	(95.3)	0.894	1.575	(0.525)	(49.7)
122	122	✓	✓	✓	✓	75	1.12	0.97	2.582	(1.80)	(233)	1.157	1.849	(0.799)	(75.7)
36[b]	41	✓	✓	✓		125	0.1		0.59	0.19	24.5		0.78	0.27	26.3
45[b]	42	✓	✓	✓	✓	125	0.1		0.59	0.19	24.6		0.41	0.64	61.2
123	123	✓	✓	✓	✓	125	0.67	0.66	1.607	(0.83)	(107)	0.50	0.806	0.244	23.4
124	124	✓	✓	✓	✓	125	1.12	1.06	2.649	(1.87)	(241)	0.919	1.217	(0.167)	(15.6)

[a] Hoist speed of 0.04 m/s and a load area of 50 percent unless otherwise indicated.

[h] Test results from Phase 1.

TABLE 5a. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING METHYLENE CHLORIDE WITH RFC ON (English Units)

Test conditions[a]								Solvent loss data								
								Degreaser A				Degreaser B				
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	Decrease (Increase) from base case, lb/h	Decrease (Increase) from base case, %	Measured air velocity at lip, ft/min	lb/h	Decrease (Increase) from base case, lb/h	Decrease (Increase) from base case, %
34[b]	37	✓	✓	✓		50	20		1.71				2.32		
35[b]	74	✓	✓	✓		75	20		1.34	0.37	21.6		1.92	0.40	17.2
43[b]	38	✓	✓	✓	✓	50	20		1.94	(0.23)	(13.5)		1.96	0.36	15.5
47[b]	75	✓	✓	✓	✓	75	20		1.60	0.11	6.4		1.30	1.02	44.0
121	121	✓	✓	✓	✓	75	132	76.4	3.339	(1.629)	(95.3)	176	3.472	(1.152)	(49.7)
122	122	✓	✓	✓	✓	75	220	178	5.692	(3.982)	(233)	227	4.[illegible]7	(1.757)	(75.7)
36[b]	41	✓	✓	✓		125	20		1.29	0.42	24.6		1.71	0.61	26.3
45[b]	42	✓	✓	✓	✓	125	20		1.29	0.42	24.6		0.90	1.42	61.2
123	123	✓	✓	✓	✓	125	132	130	3.543	(1.833)	(107)	98.6	1.777	0.543	(23.4)
124	124	✓	✓	✓	✓	125	220	209	5.639	(4.129)	(241)	180	2.682	(0.362)	(15.6)

[a] Hoist speed of 8 ft/min and a load area of 50 percent unless otherwise indicated.

[b] Test results from Phase 1.

TABLE 6. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE WITH POWERED LID OPERATING

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	Decrease (Increase) from base case, kg/h	Decrease (Increase) from base case, %	Measured air velocity at lip, m/s	kg/h	Decrease (Increase) from base case, kg/h	Decrease (Increase) from base case, %
1	b	✓	✓	✓		50	0.1		1.04						
3	c	✓	✓	✓		75	0.1		0.97	0.07	7.0				
112[d]	112	✓	✓	✓		75	0.67	0.5[illegible]7	1.628	(0.588)	(56.0)				
113[d]	113	✓	✓	✓		75	1.12	1.27	4.001	(2.961)	(284)				
110[d]	110	✓	✓	✓	✓	75	0.67	0.446	1.785	(0.745)	(71.[illegible])				
111[d]	111	✓	✓	✓	✓	75	1.12	1.17	3.413	(2.373)	(227)				

[a] Hoist speed of 0.04 m/s and a load area of 50 percent unless otherwise indicated.
[b] Time-weighted average of weight loss of Tests 1, 6, 7, 8 and 89, from Phase 1.
[c] Time-weighted average of Tests 22, 43, 84, 87 and 90, weight loss only, from Phase 1.
[d] Automatic powered lid totally closed [illegible]3/391 seconds of cycle.

TABLE 6a. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE WITH POWERED LID OPERATING (English Units)

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	lb/h	%	Measured air velocity at lip, ft/min	lb/h	lb/h	%
1	b	✓	✓	✓		50	20		2.30						
3	c	✓	✓	✓		75	20		2.14	0.16	7.0				
112[d]	112	✓	✓	✓		75	132	100	3.589	(1.289)	(56.0)				
113[d]	113	✓	✓	✓		75	220	252	8.821	(6.521)	(284)				
110[d]	110	✓	✓	✓	✓	75	132	88	3.935	(1.635)	(71.1)				
111[d]	111	✓	✓	✓	✓	75	220	230	7.524	(5.224)	(227)				

[a] Hoist speed of 8 ft/min and a load area of 50 percent unless otherwise indicated.

[b] Time-weighted average of weight loss of Tests 1, 6, 7, 8, and 89, from Phase 1.

[c] Time-weighted average of Tests 42, 43, 84, 87, and 90, weight loss only, from Phase 1.

[d] Automatic powered lid totally closed 98/391 seconds of cycle.

TABLE 7. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS WITH HOIST SPEED OF 0.055 m/s (11 ft/min)

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Hoist speed, m/s	kg/h	Decrease (Increase) from base case, kg/h	Decrease (Increase) from base case, %	Hoist speed, m/s	kg/h	Decrease (Increase) from base case, kg/h	Decrease (Increase) from base case, %
1	b	✓	✓	✓		50	0.1					0.04	1.00		
3	c	✓	✓	✓		75	0.1					0.04	0.75	0.25	24.5
125	110	✓	✓	✓		75	0.1					0.055	0.909	0.091	8.95
11[d]	33	✓	✓	✓		75	0.1					0.08	0.84	0.16	15.9
109	109	✓	✓	✓		125	0.1	0.04	1.363	(0.323)	(30.7)	0.04	0.955	0.045	4.27
126	112	✓	✓	✓		125						0.055	0.733	0.267	26.5

[a] Load area of 50 percent unless otherwise indicated.

[b] Time-weighted average of weight loss of Tests 1, 6, 7, 8, and 89, from Phase 1.

[c] Time-weighted average of Tests 22, 43, 84, 87, and 90, weight loss only, from Phase 1.

[d] Test results from Phase 1.

TABLE 7a. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 2 FOR OPERATING DEGREASERS WITH HOIST SPEED OF 0.055 m/s (11 ft/min) (English Units)

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Hoist speed, ft/min	lb/h	lb/h	%	Hoist speed, ft/min	lb/h	lb/h	%
1	b	✓	✓	✓		50	20					8	2.20		
3	c	✓	✓	✓		75	20					8	1.66	0.54	24.5
125	110	✓	✓	✓		75	20					11	2.003	0.197	8.95
11[d]	33	✓	✓	✓		75	20					16	1.85	0.35	15.9
109	109	✓	✓	✓		125	20	8	3.004	0.705	30.7	8	2.106	0.094	4.27
126	112	✓	✓	✓		125	20					11	1.617	0.583	26.5

[a] Load area of 50 percent unless otherwise indicated.

[b] Time-weighted average of weight loss of Tests 1, 6, 7, 8, and 89, from Phase 1.

[c] Time-weighted average of Tests 22, 43, 84, 87, and 90, weight loss only, from Phase 1.

[d] Test results from Phase 1.

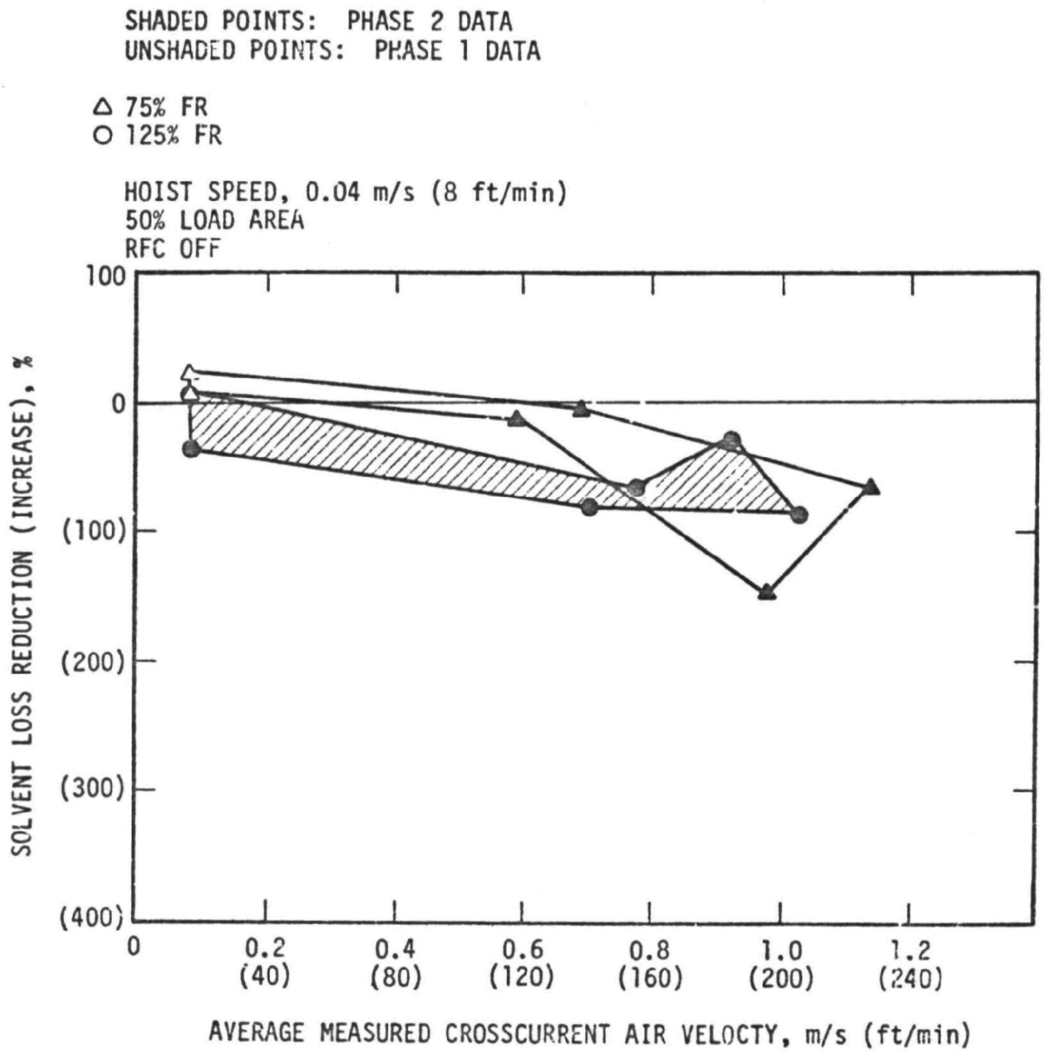


Figure 3. Effect of high crosscurrent air velocity on solvent loss from an operating degreaser using 1,1,1-trichloroethane.

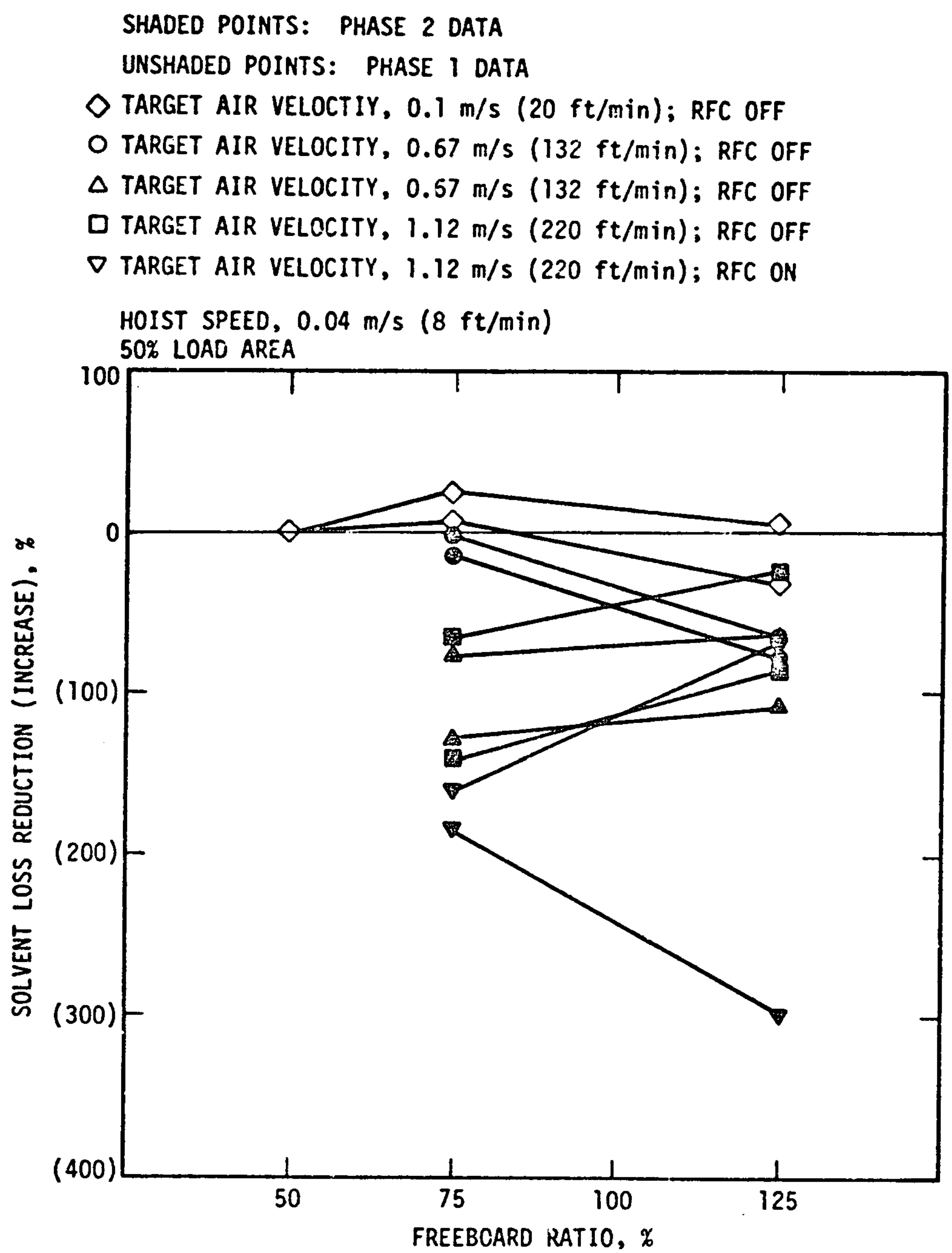


Figure 4. Effect of freeboard ratio on solvent loss from an operating degreaser using 1,1,1-trichloroethane at different target air velocities.

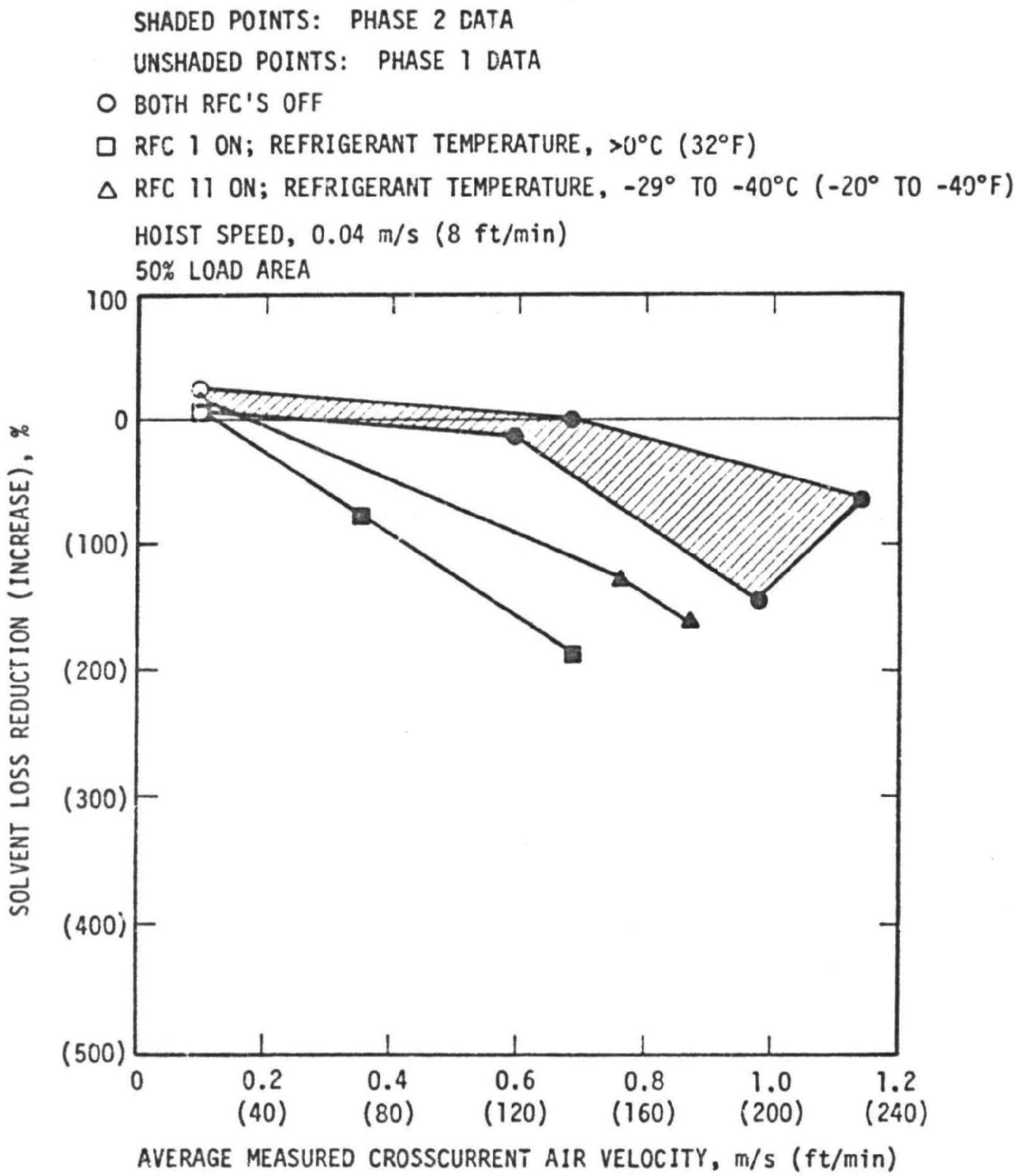


Figure 5. Effect of refrigerated freeboard chiller on solvent loss from an operating degreaser using 1,1,1-trichloroethane at 75 percent freeboard ratio.

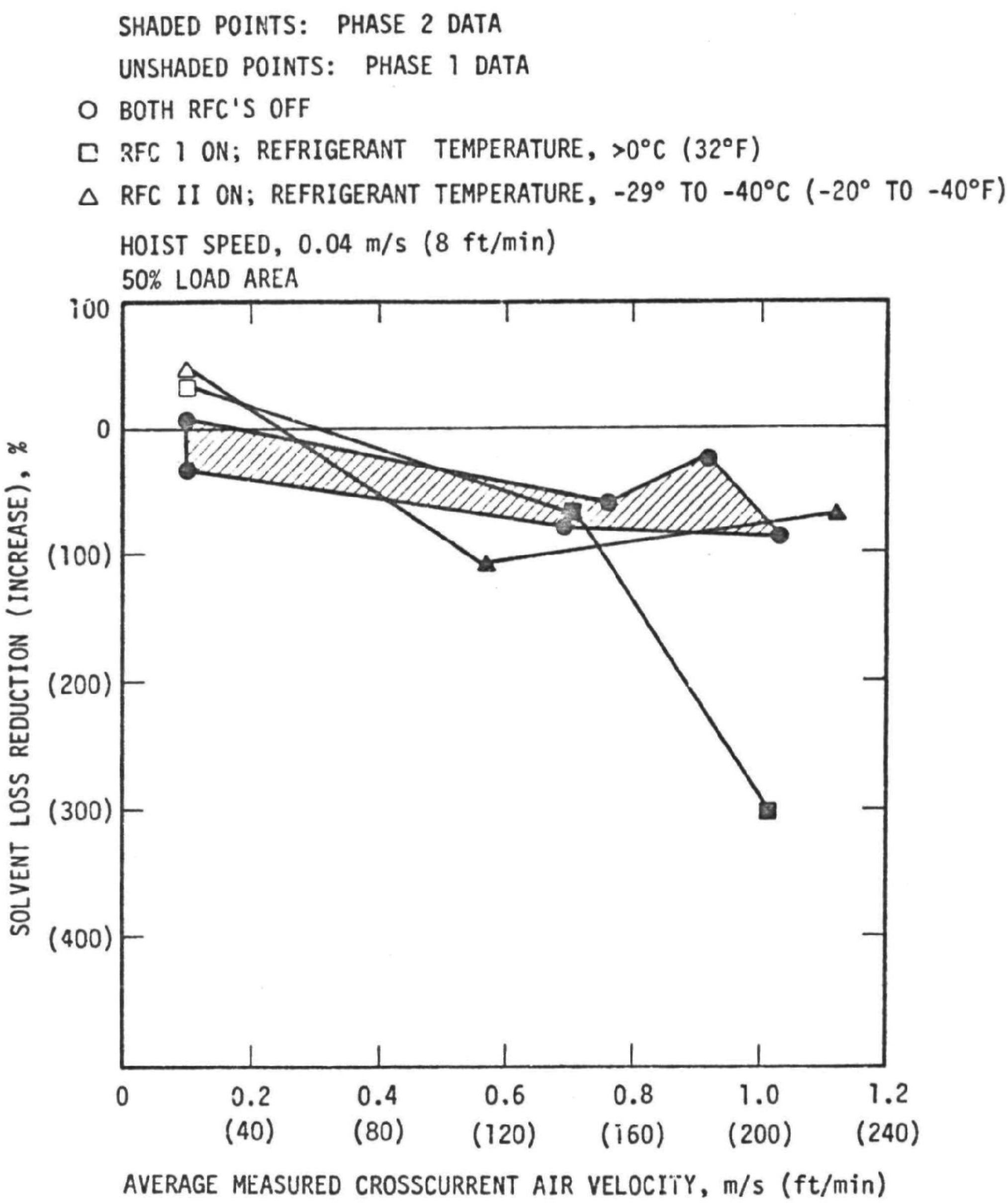


Figure 6. Effect of refrigerated freeboard chiller on solvent loss from an operating degreaser using 1,1,1-trichloroethane at 125 percent freeboard ratio.

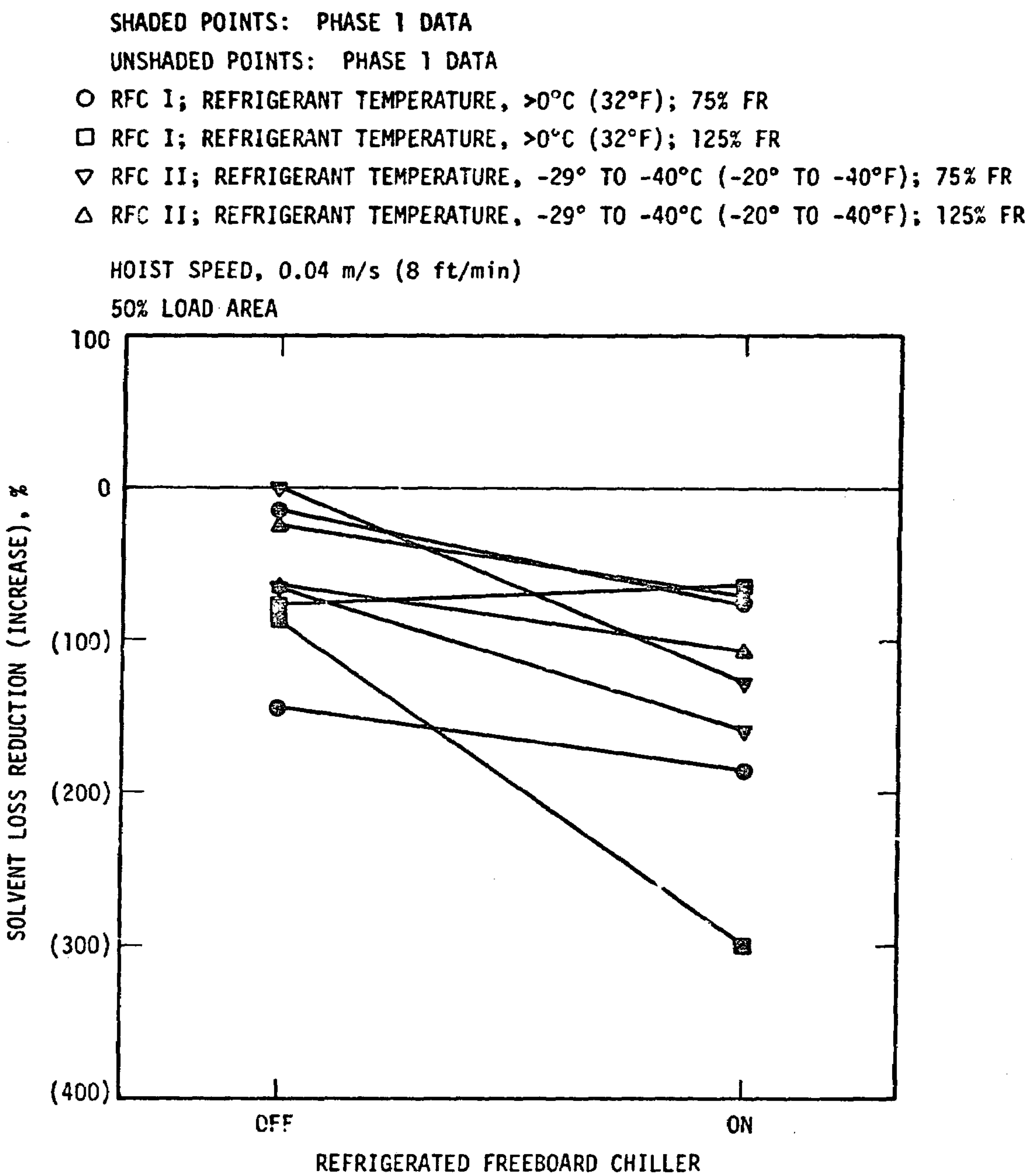


Figure 7. Effect of refrigerated freeboard chiller on solvent loss from an operating degreaser using 1,1,1-trichloroethane at high crosscurrent air velocities.

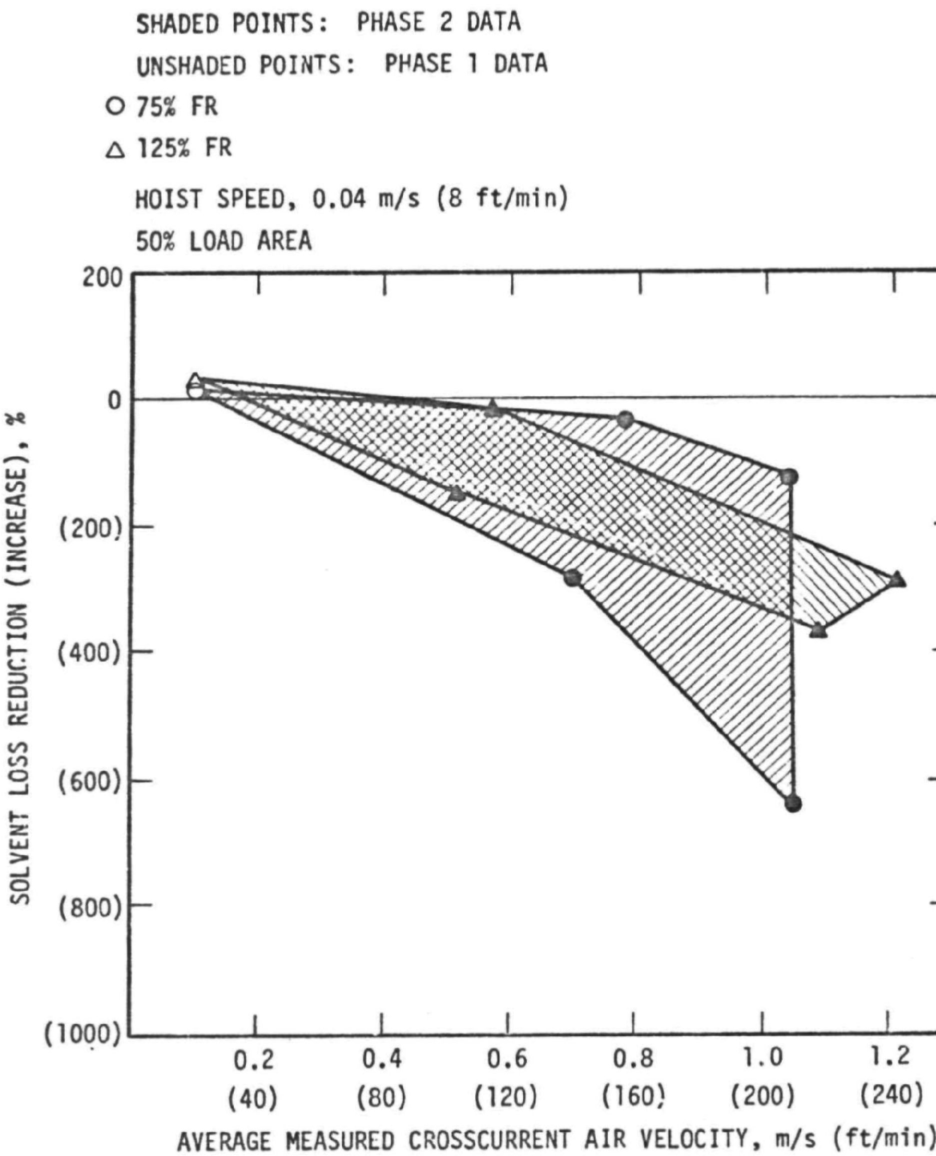


Figure 8. Effect of high crosscurrent air velocity on solvent loss from an operating degreaser using methylene chloride.

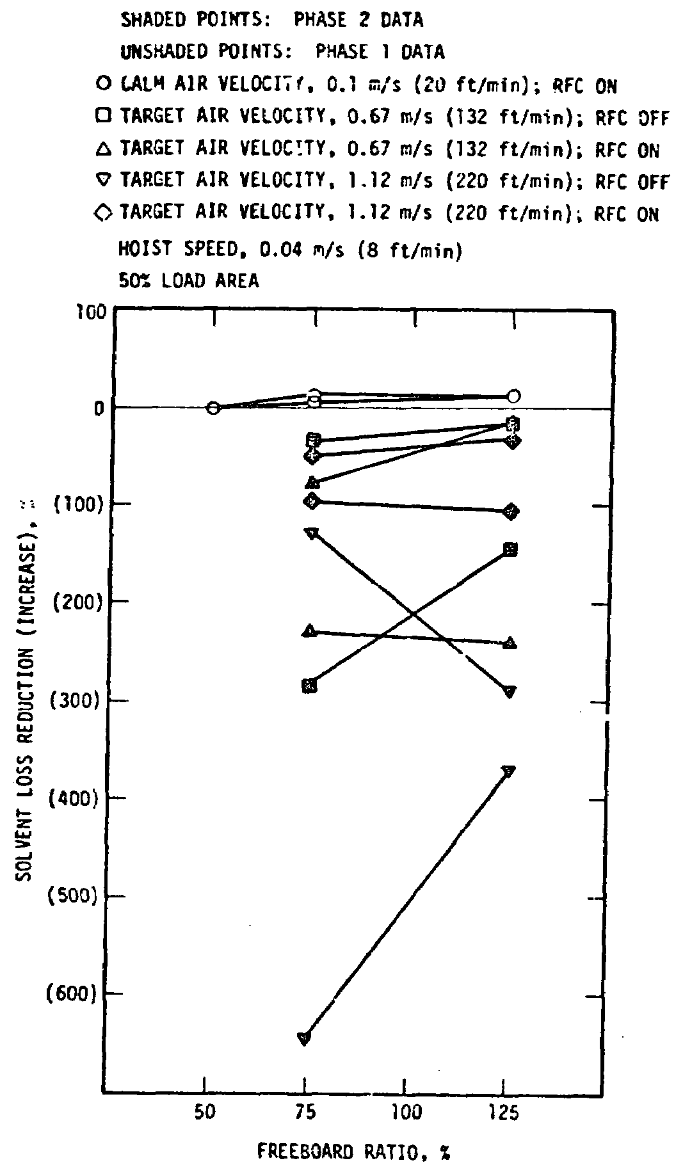


Figure 9. Effect of freeboard ratio on solvent loss from an operating degreaser using methylene chloride.

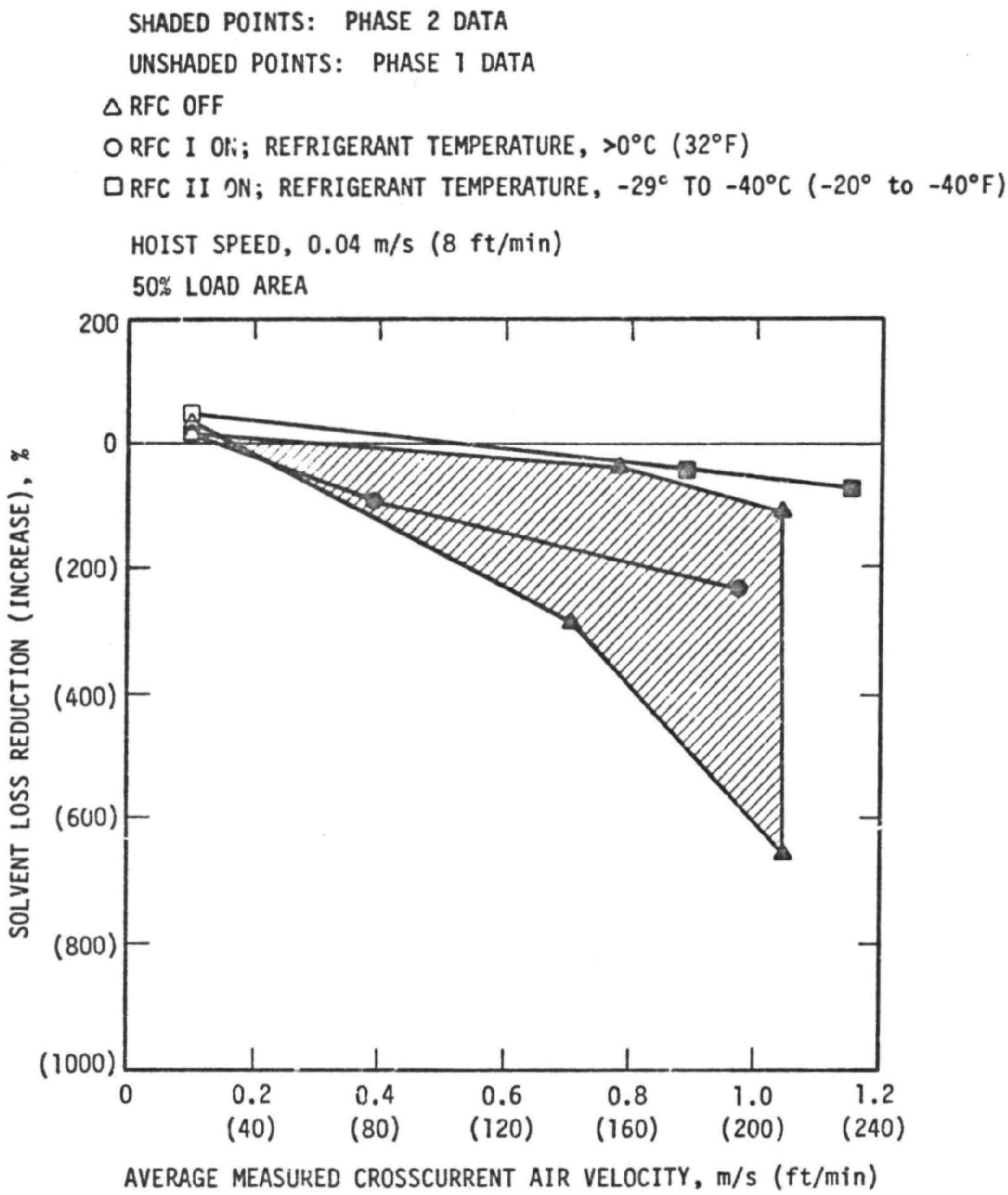


Figure 10. Effect of refrigerated freeboard chiller on solvent loss from an operating degreaser using methylene chloride at 75 percent freeboard ratio.

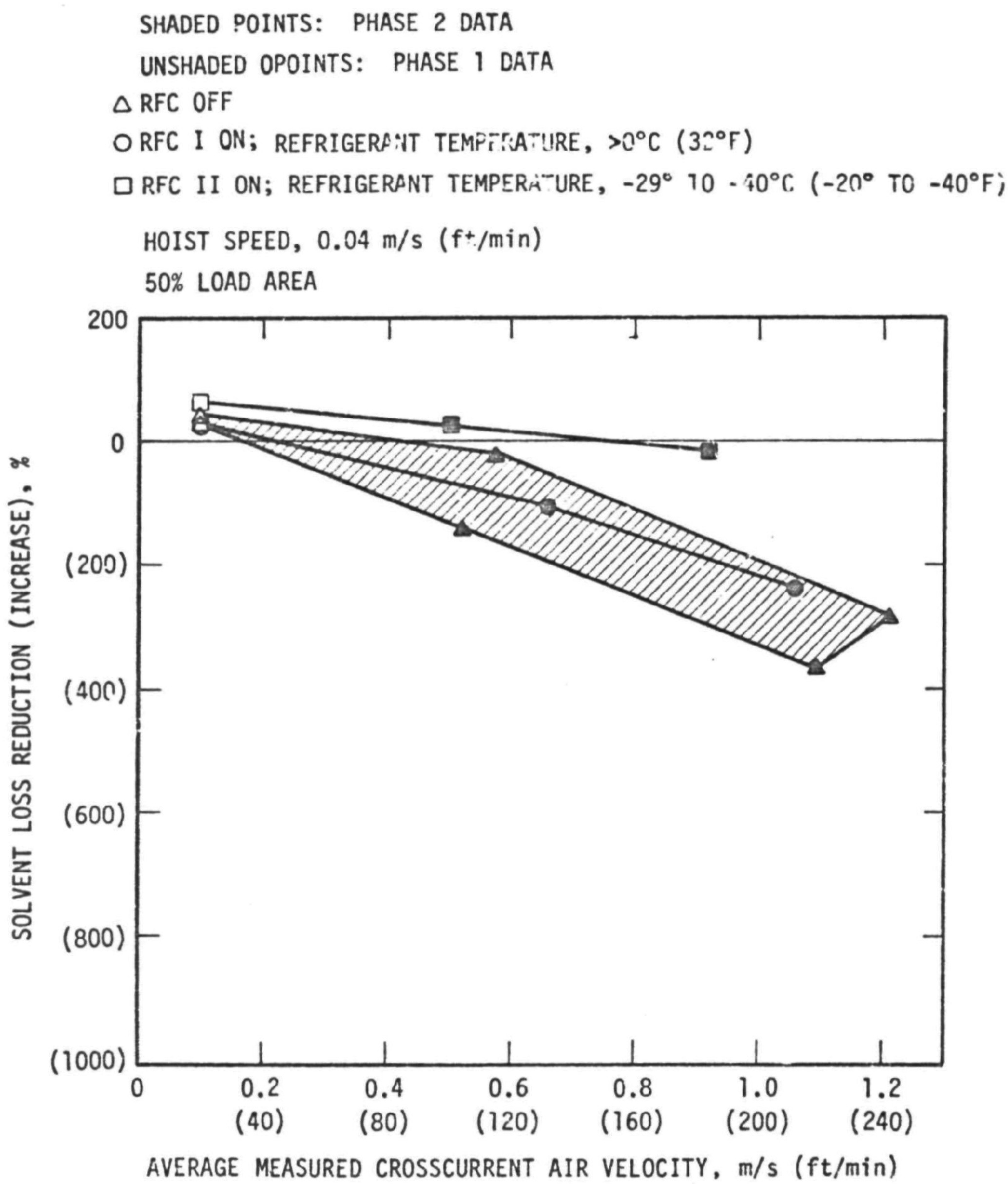


Figure 11. Effect of refrigerated freeboard chiller on solvent loss from an operating degreaser using methylene chloride at 125 percent freeboard ratio.

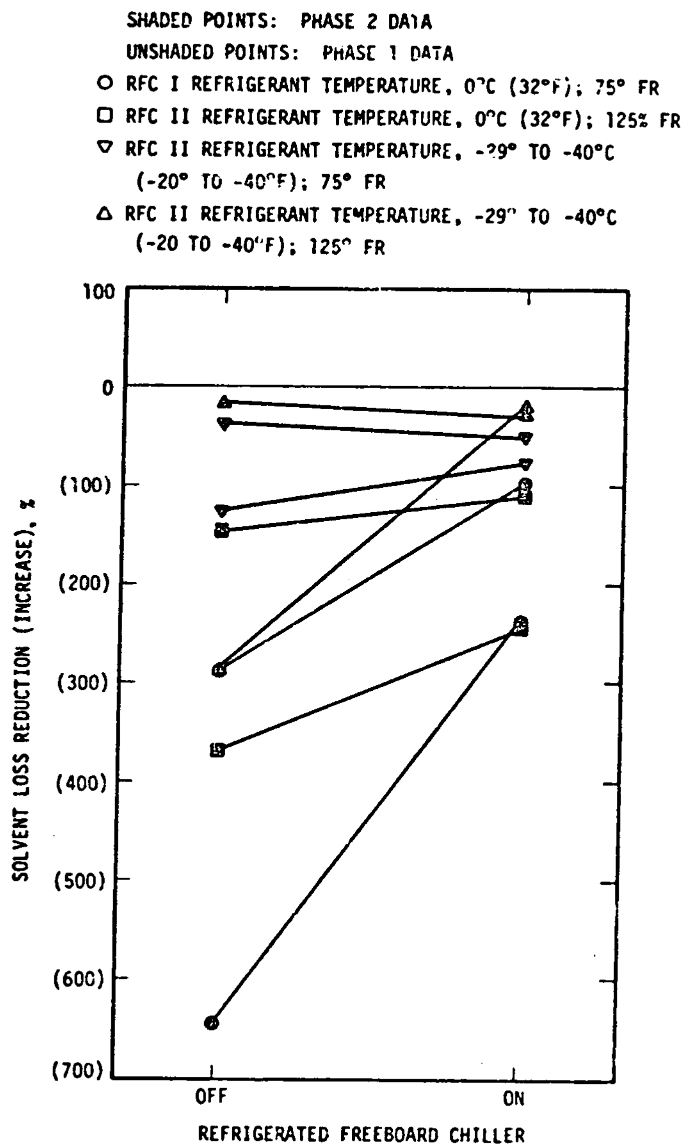


Figure 12. Effect of refrigerated freeboard chiller on solvent loss from an operating degreaser using methylene chloride at high crosscurrent air velocities.

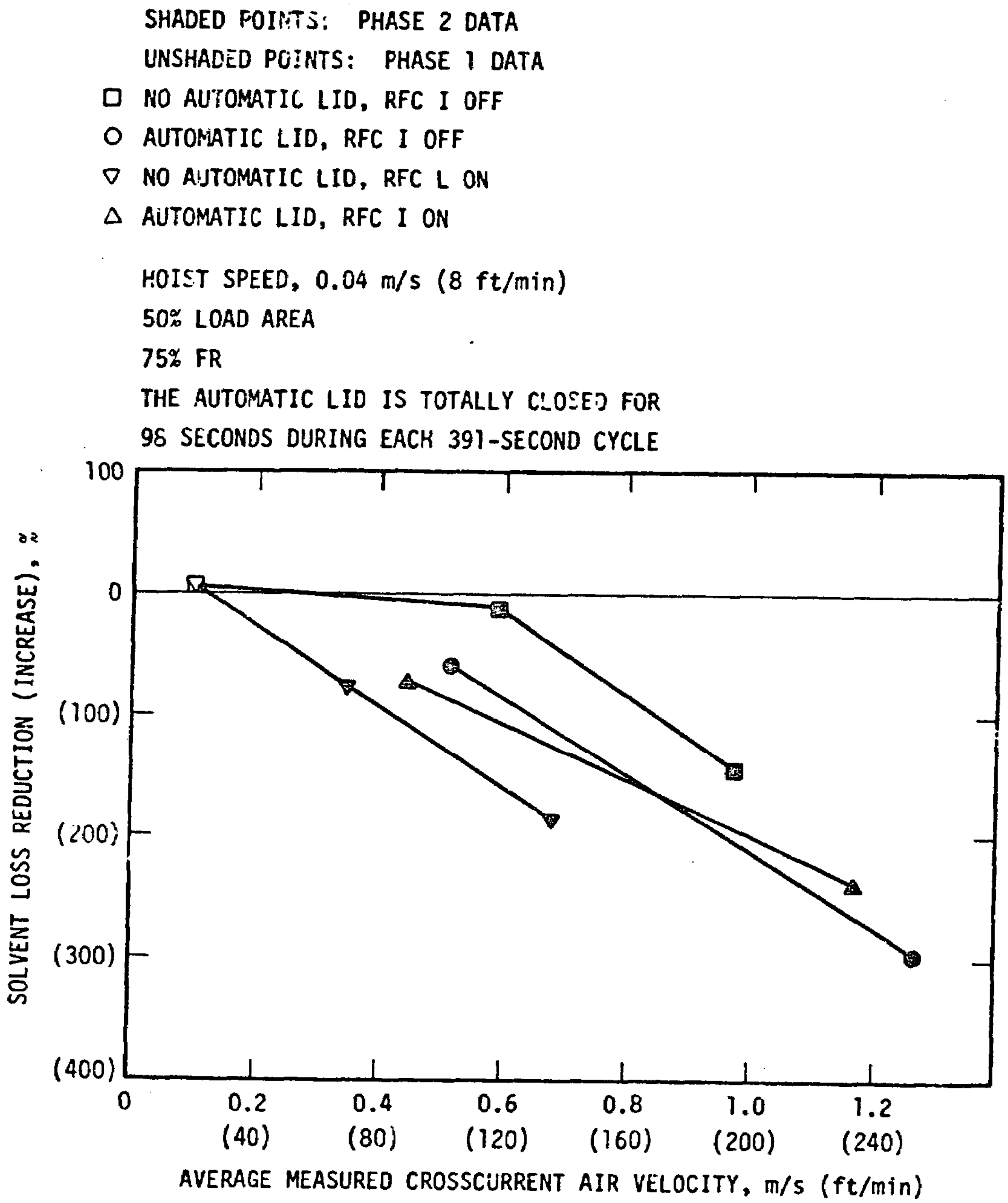


Figure 13. Effect of automatic lid on solvent loss from an operating degreaser using 1,1,1-trichloroethane.

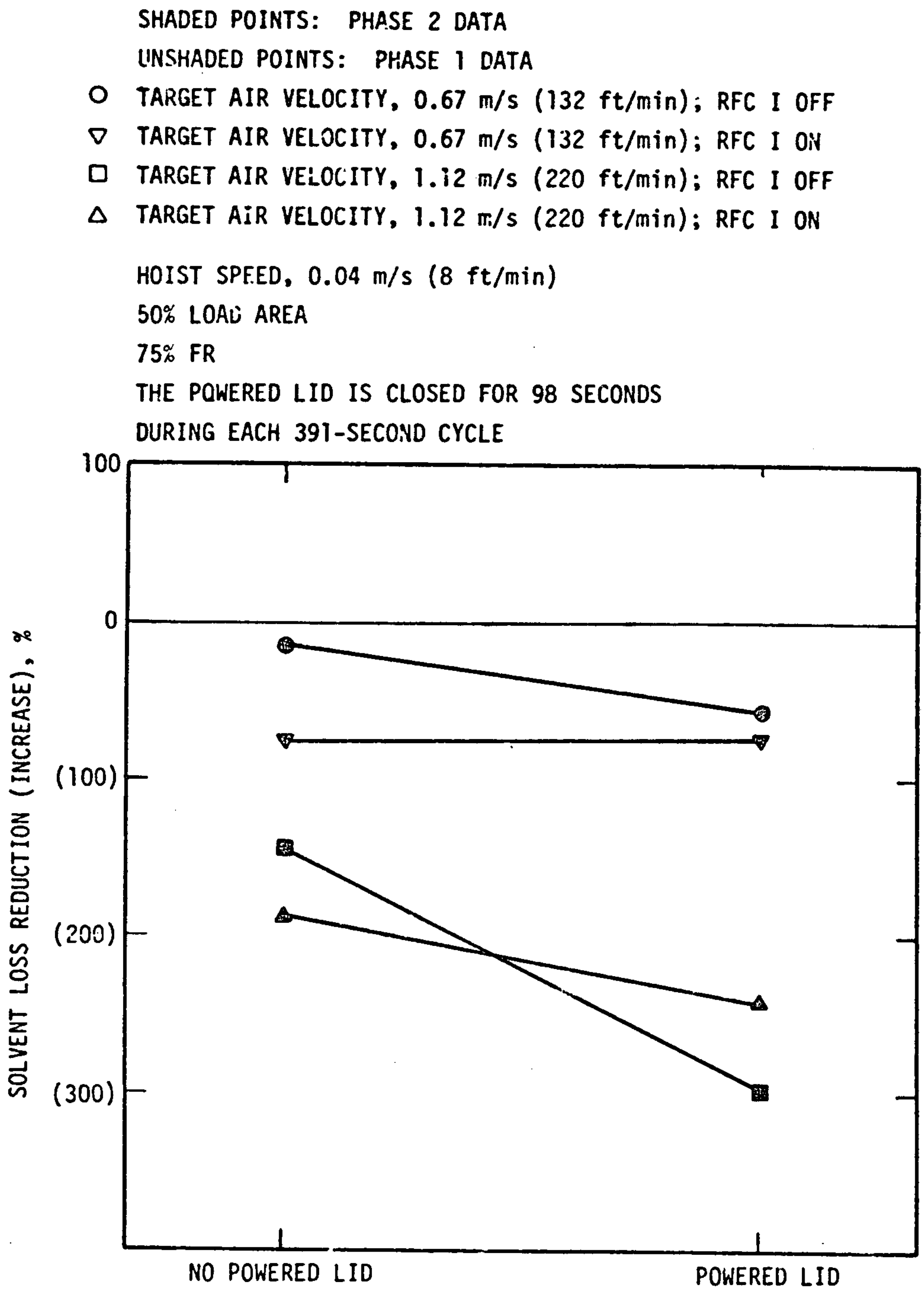


Figure 14. Effect of automatic lid on solvent loss from an operating degreaser using 1,1,1-trichloroethane at high crosscurrent air velocities.

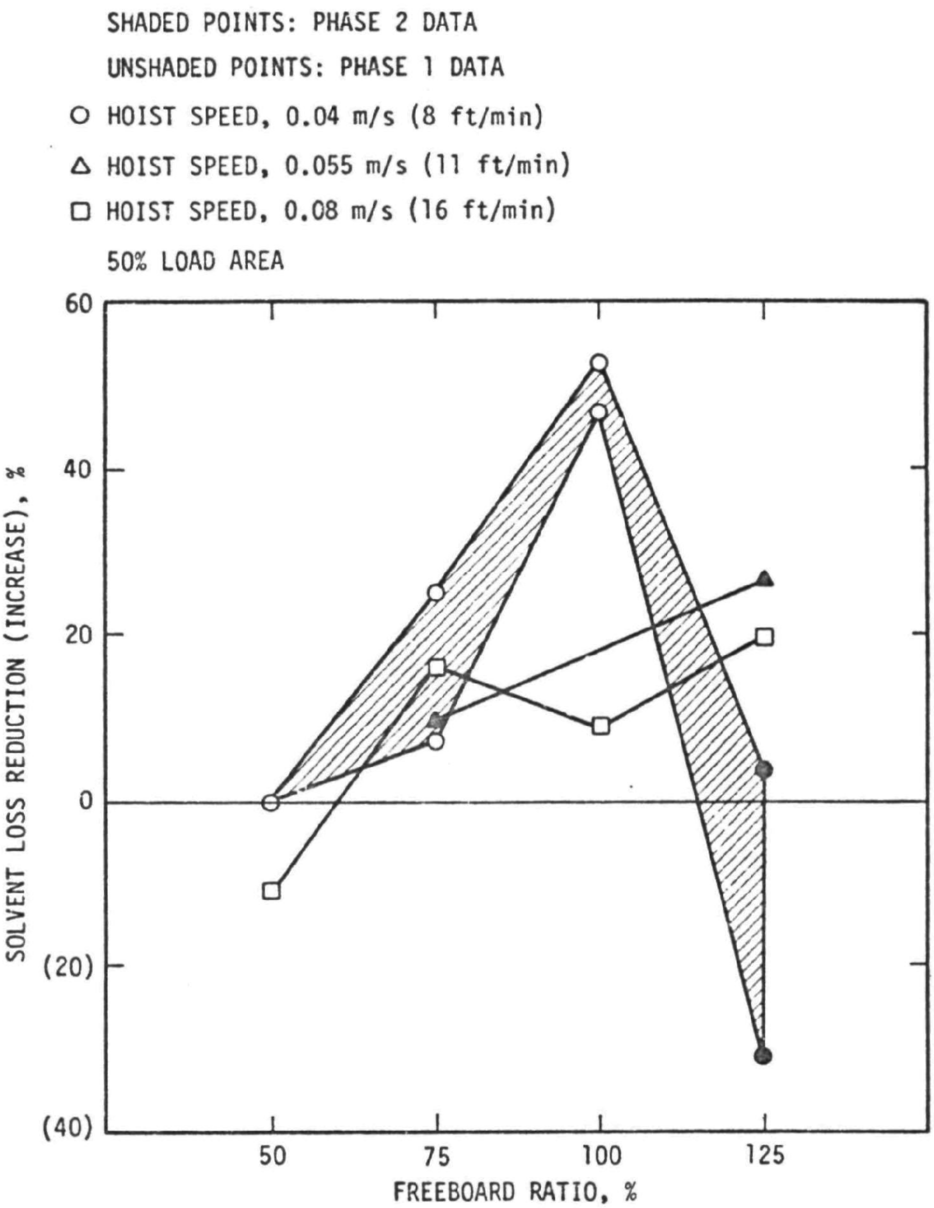


Figure 15. Effect of hoist speed on solvent loss from an operating degreaser using 1,1,1-trichloroethane.

77 percent at 0.67 m/s (132 ft/min), and an increase of 27 to 88 percent at 1.12 m/s (220 ft/min). A similar trend was indicated when the RFC was turned on (Figure 5 and 6).

When MC was used as the solvent, the trend was the same as when TE was used (Figure 8). Compared with the base case, solvent loss at 75 percent FR decreased by 17 to 22 percent at calm air; increased by 37 to 287 percent at 0.67 m/s (132 ft/min); and increased by 126 to 644 percent at 1.12 m/s (220 ft/min). A similar effect was observed at 125 percent FR. Solvent loss decreased by 25 to 26 percent at calm air; increased by 17 to 144 percent at 0.67 m/s (132 ft/min); and increased by 288 to 319 percent at 1.12 m/s (220 ft/min). A similar trend was indicated when the RFC was turned on (Figures 10 and 11).

When all the data are averaged together (i.e., air velocity sets grouped with an equal number of each level of the other variables), a simple relationship can be developed between air velocity and solvent loss, as shown in Table 8.

TABLE 8 RELATIONSHIP BETWEEN AIR VELOCITY AND SOLVENT LOSS IN PHASE 2

Velocity			Mean solvent loss, kg/h (lb/h)	Increase (decrease) from base case, %
Low:	0.1 m/s	(20 ft/min)	0.76 (1.68)	(25)
Medium:	0.67 m/s	(132 ft/min)	1.66 (3.67)	63
High:	1.12 m/s	(220 ft/min)	2.69 (5.92)	163

When an operating degreaser using TE had an automatic lid installed at 75 percent FR and all other conditions remained the same, results still showed an increase in solvent loss as air velocity increased (Figure 13).

EFFECT OF FREEBOARD RATIO

Figures 4 and 9 present the data on the relationship of FR primarily, but also air velocity and RFC, to solvent loss. The figures present the results of tests on an operating degreaser using TE and MC respectively at primarily two different freeboard heights.

An operating degreaser with 125 percent FR, RFC off, load area of 50 percent, hoist speed of 0.04 m/s (8 ft/min), and using TE showed a slight decrease in solvent loss when compared with the same degreaser at 75 percent FR. At calm air and 75 percent FR, solvent loss ranged from 7 to 25 percent below the base case; at calm air and 125 percent FR, solvent loss increased to a range of 4 percent below to 31 percent above the base case. At 0.67 m/s (132 ft/min) and 75 percent FR, solvent loss ranged from 2 to 13 percent above the base case; at 0.67 m/s and 125 percent FR, solvent loss increased to a range of 64 to 77 percent above the base case. At 1.12 m/s (220 ft/min) and 75 percent FR, solvent loss ranged from 65 to 144 percent above the base case; at 1.12 m/s and 125 percent FR, solvent loss decreased to a range of 27 to 88 percent above the base case. In summary, at calm air solvent loss increased as FR increased from 75 to 125 percent; at 0.67 m/s solvent loss increased as the FR increased from 75 to 125 percent; while at 1.12 m/s solvent loss decreased substantially as FR increased from 75 to 125 percent.

When the RFC was turned on (and all other conditions remained the same), the effect of changing the FR from 75 to 125 percent was similar; however, at 0.67 m/s (132 ft/min) solvent loss increased when the FR was changed from 75 to 125 percent, and at 1.12 m/s (220 ft/min) it increased for one degreaser and decreased for the other. There was a slight tendency for the solvent loss rate to decrease as the FR increased from 75 to 125 percent at three different air velocities and TE solvent.

Similarly, when MC was used the solvent loss also tended to decrease as the FR was increased from 75 to 125 percent (all other conditions remaining the same) (Figure 9). When the RFC was off, at calm air and 75 percent FR, solvent loss ranged from 17 to 22 percent below the base case; at calm air and 125 FR, solvent loss decreased to a range of 25 to 26 percent below the base case. At 0.67 m/s (132 ft/min) and 75 percent FR, solvent loss ranged from 37 to 287 percent above the base case; at 0.67 m/s and 125 percent FR, solvent loss decreased to a range of 17 to 144 percent above the base case. At 1.12 m/s (220 ft/min), solvent loss on one degreaser increased from 126 to 288 percent above the base case as FR was increased from 75 to 125 percent; solvent loss from the other degreaser decreased from 644 to 369 percent above the base case as FR was increased from 75 to 125 percent. When the RFC was turned on and all other conditions were the same, the effect on the trend in solvent loss of changing FR from 75 to 125 percent remained essentially the same.

EFFECT OF REFRIGERATED FREEBOARD CHILLER

Figures 7 and 12 present the data in a form that accentuates the effect of the RFC. The data show that when TE was used as the solvent the RFC definitely increased solvent loss (Figure 7); when MC was used as the solvent, the RFC definitely decreased solvent loss (Figure 12). This interaction is very unusual and was totally unexpected. The data were examined thoroughly to determine the cause of this phenomenon, and two possible explanations can be forwarded: either the RFC actually increased solvent loss when TE was used or the time lag between the tests with and without the RFC was sufficient to introduce a bias into the results. If the tests had been run in random sequence, the bias could have been minimized.

Test 130 was run for the purpose of confirming either of the above explanations. This test was a repeat of Test 105, but was run directly after Test 107 without changing the fan position. Solvent loss increased dramatically from Test 107, RFC on, to Test 105, RFC off, indicating that the RFC reduced the rate of solvent loss. Because Test 130 did not confirm the theory that the RFC increased solvent loss with solvent TE, comparisons of tests using TE and with RFC off or on cannot be made. When MC is used as the solvent, it can be concluded that the RFC does reduce solvent loss. We suggest, because of questions about the effect of the RFC with one solvent, that the effect of the RFC be verified on both solvents.

EFFECT OF AUTOMATIC LID

Figures 13 and 14 present the results of tests comparing (against the base case) solvent loss from an operating degreaser with and without automatic lid, and also comparing the interaction of the lid with an RFC. Unfortunately, the results appear to be influenced by the same time bias that influenced the RFC results. The tests with and without the automatic lid and the RFC off were separated by a couple of months. These tests showed that an automatic lid increased solvent loss substantially, which was contrary to the expected results. It is very likely that some variable beyond our control changed between the test with and that without the automatic lid, and consequently no conclusions can be drawn from this series of tests.

The tests conducted with RFC on were sufficiently close in time to keep this bias at a minimum. As shown in Figure 14, when an automatic lid was used on an operating degreaser with RFC on and an air velocity of 0.67 m/s (132 ft/min), a slight decrease in solvent loss occurred when compared with a similar degreaser with no automatic lid. When the automatic lid was used and the air velocity was 1.12 m/s (220 ft/min), a slight increase in solvent loss occurred when compared with a similar degreaser with no automatic lid. The conclusion is that the automatic lid adds no additional control capability if an RFC is already operating on the degreaser.

RESULTS OF TESTS OF HOIST SPEED

In Phase 2, additional tests were included to increase information about the effect of hoist speed on solvent loss. Three tests were contemplated, but because of equipment problems only two of the tests could be run. The new data are plotted in Figure 15 alongside the data from Phase 1 (see Figure 14 in the earlier report); only the new data, however, are given in Table 7 (except for the base case). Also shown in Table 7 and Figure 15 are new data from test group 109 at 125 percent FR and 0.04-m/s (8-ft/min) hoist speed. These data replace those for test group 31, Phase 1, which were questionable because the cooling water to the load was not turned on during the test.

The results confirm those reported in Phase 1: As hoist speed is increased, solvent loss also increases. Except for the data at 75 percent FR and hoist speed of 0.08 m/s (16 ft/min) and at 125 percent and 0.04 m/s (8 ft/min), solvent loss was higher (when compared with the base case) at 0.055 m/s (11 ft/min) than at 0.04 m/s, and higher at 0.08 m/s than at 0.055 m/s.

Figure 9 shows the new data at 125 percent FR and hoist speed of 0.04 m/s (8 ft/min). The data show an increase in solvent loss as the FR is increased beyond 100 percent. This anomaly cannot be explained. Because the test was repeated twice on both degreasers with essentially the same results, the difference cannot be attributed to chance.

SECTION 4

PHASE 2 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

High Crosscurrent Air Velocity

When crosscurrent air velocity across the lip of the degreaser is increased above calm air velocities, solvent loss from an operating degreaser increases above the base case (50 percent FR, 0.04 m/s or 8 ft/min hoist speed, and 50 percent load area) for either solvent. Further, as the average air velocity across the lip of the degreaser increases to higher levels, the proportional increase in solvent loss is greater.

Freeboard Ratio at High Crosscurrent Air Velocity

When crosscurrent air velocities are increased, there is only a slight decrease in solvent loss as the FR is increased from 75 to 125 percent with either solvent tested. This conclusion is in agreement with Phase I testing, which indicated decreasing savings as FR was increased beyond 100 percent.

Freeboard Ratio at Calm Air Velocity

Under calm air conditions, solvent loss appears to increase as FR is increased from 100 to 125 percent when TE is used as the solvent and when the RFC is off. When MC is used, however, solvent loss decreases when the FR is increased to 125 percent. This conclusion contradicts Phase I results, and should be verified.

Refrigerated Freeboard Chiller at High Crosscurrent Air Velocity

With MC solvent, the degreasers using different RFC designs showed substantial reductions in solvent loss at both high crosscurrent air velocities when the RFC was operated. With TE solvent, the degreasers using different RFC designs generally showed substantial increases in solvent loss at high air velocities when the RFC was operated. Because of this unexpected result, an additional test was conducted; it did not verify the initial results. Replication of this series of tests will help in identifying the factors involved in this unusual set of results.

Automatic Lid at High Crosscurrent Air Velocity

The automatic lid was tested only with TE, and conclusions can only be drawn about its effect on this solvent. The lid shows a slight decrease in solvent loss when the RFC is used and an increase in solvent loss when the RFC is not used, when compared with a degreaser operating under the same conditions but without the lid. This conclusion is contradictory and should also be verified through additional tests.

Hoist Speed at Calm Air Velocity

An intermediate hoist speed of 0.055 m/s (11 ft/min) was tested for comparison with previously tested speeds of 0.04 m/s (8 ft/min) and 0.08 m/s (16 ft/min). As was expected, the results showed that the 0.055-m/s speed results in greater solvent loss than the 0.04-m/s speed and less solvent loss than the 0.08-m/s speed.

RECOMMENDATIONS

Based on the above conclusions, we recommend that additional testing be conducted to verify the effect on solvent loss of the refrigerated freeboard chiller and the automatic lid, and to verify the increase in solvent loss when the freeboard ratio is increased from 100 to 125 percent with solvent TE and calm air conditions. Further, we recommend additional testing of high crosscurrent air velocity at freeboard ratios of 50 and 100 percent to assess the ability of increased FR as a control technique under this condition.

SECTION 5

PHASE 3 TEST CONDITIONS

The Phase 3 tests were designed to study the relationship between air velocity and solvent loss control obtainable by use of FR, RFC, and automatic lid. The aim was to use factorial analysis for distinguishing significant trends from nonsignificant ones. Combining data from Phases 1, 2, and 3 made such factorial analysis possible.

The first three Phase 3 tests showed that the baseline rate of solvent loss from operating Degreasers A and B with TE had changed. Although replacement of the primary condenser coil in Degreaser A brought the operation back into design specifications, it did not restore the previous baseline rate. Because of the baseline shift, raw data from Phases 1 and 2 cannot be combined with raw data from Phase 3 in a rigorous statistical analysis.

The first task in Phase 3 was to solve earlier problems in air velocity measurement. Then four types of laboratory tests were run: with TE, MC, no solvent, and smoke. As discussed in Appendix E, a survey of seven industrial plants was also conducted.

AIR VELOCITY MEASUREMENT SYSTEM

An improved air velocity system was developed for Phase 3 to overcome problems in the previous system design. These problems included:

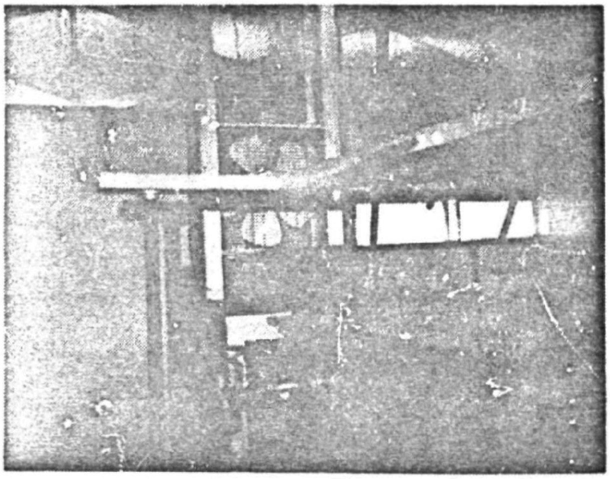
- Inability to achieve the same air velocity from test to test
- Inability to maintain constant air velocity during a test

- Accelerated instrument degradation caused by excessive handling
- Turbulence

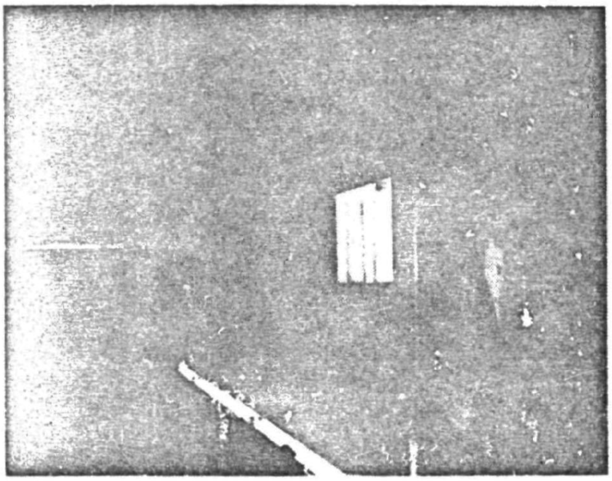
Figure 16 shows the design of the fan stands during the Phase 3 tests, and Figure 17 is a block diagram of the electronic equipment used to measure and integrate the data generated by the air velocity probes. The fan stand design allowed the relationship between the air velocity probes, fan, and degreaser lip to be reproduced consistently and the fan and probe to be raised or lowered easily, as required by changes in the degreaser freeboard.

A constant-voltage transformer was used to control the voltage supplied to the fans and thus minimize the fluctuations in fan blade velocity. Cycling of electric motors and heaters and changes in utility system voltage tend to cause such fluctuations. A separate variable transformer was included for each fan, so that slight differences in fan motor design could be overcome by adjusting the voltage. Thus, air flow characteristics could be made very similar for each degreaser.

The electronic signal from the air velocity probe was fed into a signal multiplier and then into an integrator, and the integrator output was totaled by electromechanical counters. Because budget considerations precluded simultaneous integration of all six signals, only two signals (one from each degreaser) were integrated at the same time. Data from two probes were recorded during each load cycle, which lasted 6.5 minutes. Thus, a complete set of data from all six probes was recorded every 19.5 minutes. All available data on air velocity were recorded each hour, and the accuracy of the air velocity probes was checked before each test.



FRONT VIEW OF FAN FOR DEGREASER B



SIDE VIEW OF FANS FOR DEGREASER A AND B

Figure 16. Fan stands during Phase 3.

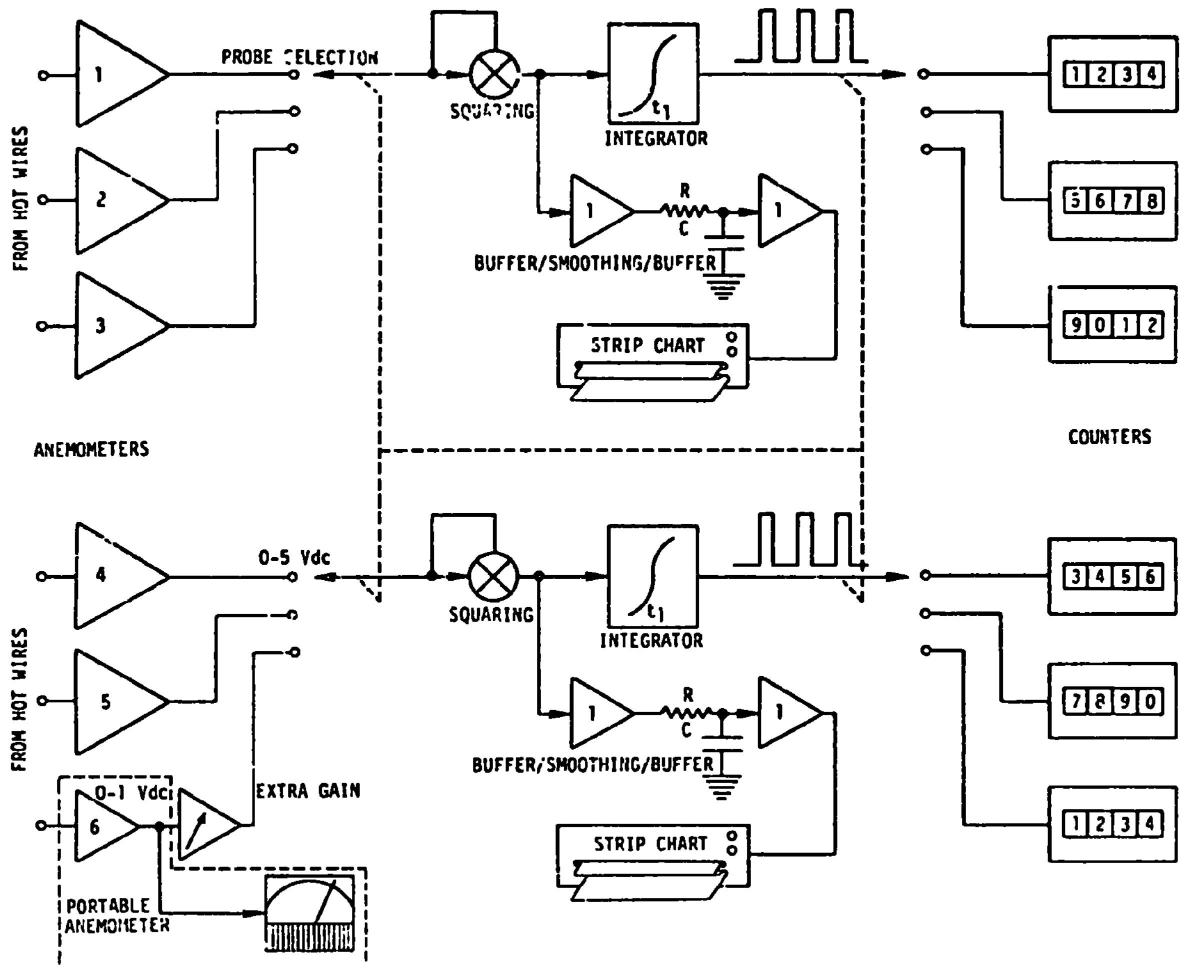


Figure 17. Diagram of electronic equipment used to measure air velocity at the degreaser lip and integrate data during Phase 3.

LABORATORY TESTS WITH 1,1,1-TRICHLOROETHANE

Phase 3 laboratory tests began with Tests 136, 137, and 138, which were run to determine whether baseline performance with TE had shifted. After the detection of such a shift, Tests 151, 152, and 153 were performed to obtain additional data on the new baseline rate of solvent loss. Test 156 was run at the same conditions as Test 152 to document the effect of a new primary condenser in Degreaser A on solvent loss rate. As part of the shakedown of equipment associated with fans and air velocity measurement, Tests 154 and 155 were conducted. Other Phase 3 tests with TE included one (Test 138) at 125 percent FR and calm airflow with the RCF off to verify unusual data from Phases 1 and 2 (i.e., results indicating that under some conditions degreaser operation at 125 percent FR can cause more solvent loss than operation at 100, 75, and possibly even 50 percent FR) and one (Test 136) to determine the effect of two different ambient temperatures on solvent loss. In addition, Tests 139 through 145 were run to measure the solvent loss control obtainable by use of FR, RFC, and automatic lid at high air velocity (0.67 m/s or 132 ft/min).

LABORATORY TESTS WITH METHYLENE CHLORIDE

Laboratory tests with MC included two (Tests 146 and 158) to verify the repeatability of laboratory results and four (Tests 147 through 150) to determine the solvent loss control obtainable by use of FR and RFC at high air velocity (0.67 m/s or 132 ft/min).

LABORATORY TEST WITHOUT SOLVENT

Test 159 was run without solvent in either degreaser, but with primary cooling water on, RFC off, and heat off. Previous tests had shown unusual weight gains (0.5 to 1 kg or 1 to 2 lb) that lasted 1 or 2 hours, although they disappeared by the end of each test. Changes in cooling water pressure were believed to cause these gains.

LABORATORY TESTS WITH SMOKE

Tests were performed with smoke to gain information about the airflow characteristics of each degreaser. This information was used for modification of the airflow system to correct any serious imbalances between the two degreasers. Smoke tests were also used to investigate degreaser operation at the conditions that produced unusual Phase 2 results with TE (i.e., 125 percent FR and calm airflow).

FIELD TESTS

Airflow was measured over degreasers at seven industrial plants to gain information about field conditions versus laboratory conditions and give the EPA an appropriate basis for regulations.

SECTION 6

PHASE 3 TEST RESULTS

LABORATORY TESTS WITH 1,1,1-TRICHLOROETHANE

Baseline Performance

At the beginning of Phase 3, three tests with TE from Phases 1 and 2 were selected for repitition to determine whether baseline degreaser performance had changed. These were the 50, 100, and 125 percent FR tests with RFC off at a calm airflow, hoist speed of 0.04 m/s (8 ft/min), and load area of 50 percent. The test at 50 percent FR indicated that solvent loss from the operation of Degreaser A had increased significantly. Although solvent loss from Degreaser B had also increased, the increase was not sufficient to cause concern to the manufacturer of that unit. An additional test at 75 percent FR was run to obtain data about new baseline performance at all four FR's previously tested. Table 9 summarizes baseline solvent loss data from Phases 1, 2, and 3, and Figure 18 depicts the results of Phase 3 baseline performance tests and comparable earlier tests.

When called in to examine Degreaser A, the manufacturer noticed that the primary condenser was not performing up to specifications and required replacement. After replacement, another test was run at 75 percent FR to observe the effect of the new condenser. The vapor line dropped 20.3 cm (8 in.) to the design position, but solvent loss changed only slightly, as shown in Figure 18.

The most important result of the baseline performance tests was that FR acted in a similar fashion on both degreasers in Phases 1, 2, and 3. Additional freeboard effectively controlled

TABLE 9. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1, 2, AND 3 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE AT CALM AIR VELOCITY

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. freeboard chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	kg/h	%	Measured air velocity at lip, m/s	kg/h	kg/h	%
1	b	✓	✓	✓		50	0.1	0.1	1.04			0.1	1.00		
3	c	✓	✓	✓		75	0.1	0.1	0.97	0.073	6.96	0.1	0.75	0.25	24.5
4[d]	23	✓	✓	✓		100	0.1	0.1	0.55	0.49	47.0	0.1	0.47	0.53	53.2
109[e]	109	✓	✓	✓		125	0.1	0.1	1.36	(0.32)	(30.6)	0.1	0.96	0.043	4.27
151	151	✓	✓	✓		50	0.1	0.1	1.58	(0.21)	(51.3)	0.1	1.16	(0.16)	(16.3)
152	152	✓	✓	✓		75	0.1	0.1	1.25	(0.19)	(20.0)	0.1	0.96	0.037	3.68
137	137	✓	✓	✓		100	0.1	0.1	1.30	(0.26)	(24.6)	0.1	0.76	0.24	24.0
138	138	✓	✓	✓		125	0.1	0.1	1.17	(0.13)	(12.2)	0.1	1.00	(0.0059)	(0.59)
156[f]	156	✓	✓	✓		75	0.1	0.1	1.23	(0.19)	(17.96)	0.1	0.87	0.13	12.9

[a] Hoist speed of 0.1 m/s and load area of 50 percent unless otherwise indicated.

[b] Time-weighted average of weight loss during Tests 1, 6, 7, 8, and 89, from Phase 1.

[c] Time-weighted average of weight loss during Tests 22, 43, 84, 87, and 90, from Phase 1.

[d] Phase 1 test.

[e] Phase 2 test.

[f] Repeat of Test 152 after replacement of primary condenser coil on Degreaser A.

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TABLE 9a. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1, 2, AND 3 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE AT CALM AIR VELOCITY

Test conditions[a]								Solvent loss data								
								Degreaser A				Degreaser B				
										Decrease (Increase) from base case				Decrease (Increase) from base case		
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	lb/h	%	Measured air velocity at lip, ft/min	lb/h	lb/h	%	
1	b	✓	✓	✓		50	20	20	2.30			20	2.20			
3	c	✓	✓	✓		75	20	20	2.14	0.16	6.96	20	1.66	0.54	24.5	
4[d]	23	✓	✓	✓		100	20	20	1.22	1.08	47.0	20	1.03	1.17	53.2	
109[e]	109	✓	✓	✓		125	20	20	3.004	(0.704)	(30.6)	20	2.106	0.094	4.27	
151	151	✓	✓	✓		50	20	20	3.480	(1.18)	(51.3)	20	2.559	(0.359)	(16.3)	
152	152	✓	✓	✓		75	20	20	2.760	(0.46)	(20.0)	20	2.119	0.061	3.68	
137	137	✓	✓	✓		100	20	20	2.866	(0.566)	(24.6)	20	1.672	0.528	24.0	
138	138	✓	✓	✓		125	20	20	2.581	(0.281)	(12.2)	20	2.213	(0.013)	(0.59)	
156[f]	156	✓	✓	✓		75	20	20	2.713	(0.413)	(17.96)	20	1.917	0.283	12.9	

[a] Hoist speed of 8 ft/min and load area of 50 percent unless otherwise indicated.

[b] Time-weighted average of weight loss during Tests 1, 6, 7, 8, and 89, from Phase 1.

[c] Time-weighted average of weight loss during Tests 22, 43, 84, and 90, from Phase 1.

[d] Phase 1 test.

[e] Phase 2 test.

[f] Repeat of Test 152 after replacement of primary condenser coil on Degreaser A.

solvent loss from new and used degreasers; although the baseline rate of solvent loss shifted, the relative effect of increasing FR did not change.

Effect of High Crosscurrent Air Velocity

Phase 3 tests at high crosscurrent air velocity (0.67 m/s or 132 ft/min) increased solvent loss above the rate at calm airflow by roughly the same amounts as Phase 2 tests at 0.67-m/s air velocity. A 32 to 42 percent increase above the baseline rate for Phase 3 was found at 50 percent FR; a 17 to 21 percent increase, at 75 percent FR; and an 18 to 35 percent increase, at 100 percent FR. Table 10 summarizes Phase 3 data on solvent loss from operating degreasers using TE at calm and high air velocities, and Figure 19 depicts the effect of high air velocity on solvent loss during Phase 3.

Effect of Freeboard Ratio

Figure 20 shows the effect of 50, 75, and 100 percent FR on solvent loss at different target air velocities during Phase 3; baseline conditions in this phase were 50 percent FR and calm airflow. As indicated by Figure 20, solvent loss at 50 percent FR and 0.67-m/s (132-ft/min) air velocity was 32 to 42 percent. At 75 percent FR and 0.67-m/s air velocity, the additional freeboard almost totally controlled the average increase caused by the higher air velocity; solvent loss was only 0 to 3 percent, which amounted to a control effect of 32 to 39 percent. At 100 percent FR and 0.67-m/s air velocity, solvent load ranged from a 4 percent decrease to a 36 percent increase; the control effect was thus 3 to 36 percent.

Effect of Refrigerated Freeboard Chiller

As in Phase 2, two types of refrigerated freeboard chiller were used: RFC I, which operated at a refrigerant temperature greater than 0°C (32°F), and RFC II, which operated at a refrigerant temperature of -29° to -40°C (-20° to -40°F). Figure 21 shows the results of Phase 3 TE tests with these RFC's.

TABLE 10. SUMMARY OF SOLENT LOSS DATA FROM PHASE 3 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE AT CALM AND HIGH AIR VELOCITIES

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	kg/h	%	Measured air velocity at lip, m/s	kg/h	kg/h	%
152	151	✓	✓	✓		50	0.1	0.1	1.580			0.1	1.162		
152	152	✓	✓	✓		75	0.1	0.1	1.253	0.327	20.7	0.1	0.962	0.200	17.2
137	137	✓	✓	✓		100	0.1	0.1	1.298	0.279	17.64	0.1	0.759	0.403	34.7
138	138	✓	✓	✓		125	0.1	0.1	1.172	0.408	25.8	0.1	1.005	0.157	13.5
142	142	✓	✓	✓		50	0.67	0.65	2.239	(0.659)	(41.70)	0.70	1.539	(0.377)	(32.5)
145	145	✓	✓	✓		75	0.67	0.70	1.628	(0.049)	(3.07)	0.69	1.158	0.004	0.35
141	141	✓	✓	✓		100	0.67	0.68	2.152	(0.572)	(36 2)	0.67	1.109	0.053	4.57
144	144	✓	✓	✓	✓	50	0.67	0.74	1.517	0.0627	3.97	0.76	1.844	(0 682)	(58.7)
140	140	✓	✓	✓	✓	15	0.67	0.71	1.267	0.313	19.8	0.65	1.091	0.071	6.14
139	139	✓	✓	✓	✓	100	0.67	0.65	1.241	0 337	21.4	0.65	0.952	0.210	18.1
143	143	b	✓	✓		75	0.67	0.68	0.781	0.799	50.6	0.69			

[a] Hoist speed of 0.1 m/sec and load area of 50 percent unless otherwise indicated.

[b] Automatic lid.

TABLE 10a. SUMMARY OF SOLVENT LOSS DATA FROM PHASE 3 FOR OPERATING DEGREASERS USING 1,1,1-TRICHLOROETHANE AT CALM AND HIGH AIR VELOCITIES

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	lb/h	%	Measured air velocity at lip, ft/min	lb/h	lb/h	%
151	151	✓	✓	✓		50	20	20	3.480			20	2.559		
152	152	✓	✓	✓		75	20	20	2.760	0.720	20.7	20	2.119	0.44	17.2
137	137	✓	✓	✓		100	20	20	2.866	0.614	17.64	20	1.672	0 887	34.7
138	138	✓	✓	✓		125	20	20	2.581	0.899	25.8	20	2.213	0.346	13.5
142	142	✓	✓	✓		50	132	128	4.931	(1.451)	(41.70)	138	3.390	(0.831)	(32.5)
145	145	✓	✓	✓		75	132	138	3.587	(0.107)	(3.07)	136	2.550	(0.009)	(0.35)
141	141	✓	✓	✓		100	132	134	4.739	(1.259)	(36.2)	132	2.442	0.117	4.57
144	144	✓	✓	✓	✓	50	132	145	3.342	0.138	3.97	147	4.061	(1.502)	(58.7)
140	140	✓	✓	✓	✓	75	132	140	2.79	0.69	19.8	127	2.402	0.157	6.14
139	139	✓	✓	✓	✓	100	132	128	2.734	0.746	21.4	129	2.096	0.463	18.1
143R	143	b	✓	✓		75	132	134	1.720	1.760	50.6				

[a] Hoist speed of 8 ft/min and load area of 50 percent unless otherwise indicated.

[b] Automatic lid.

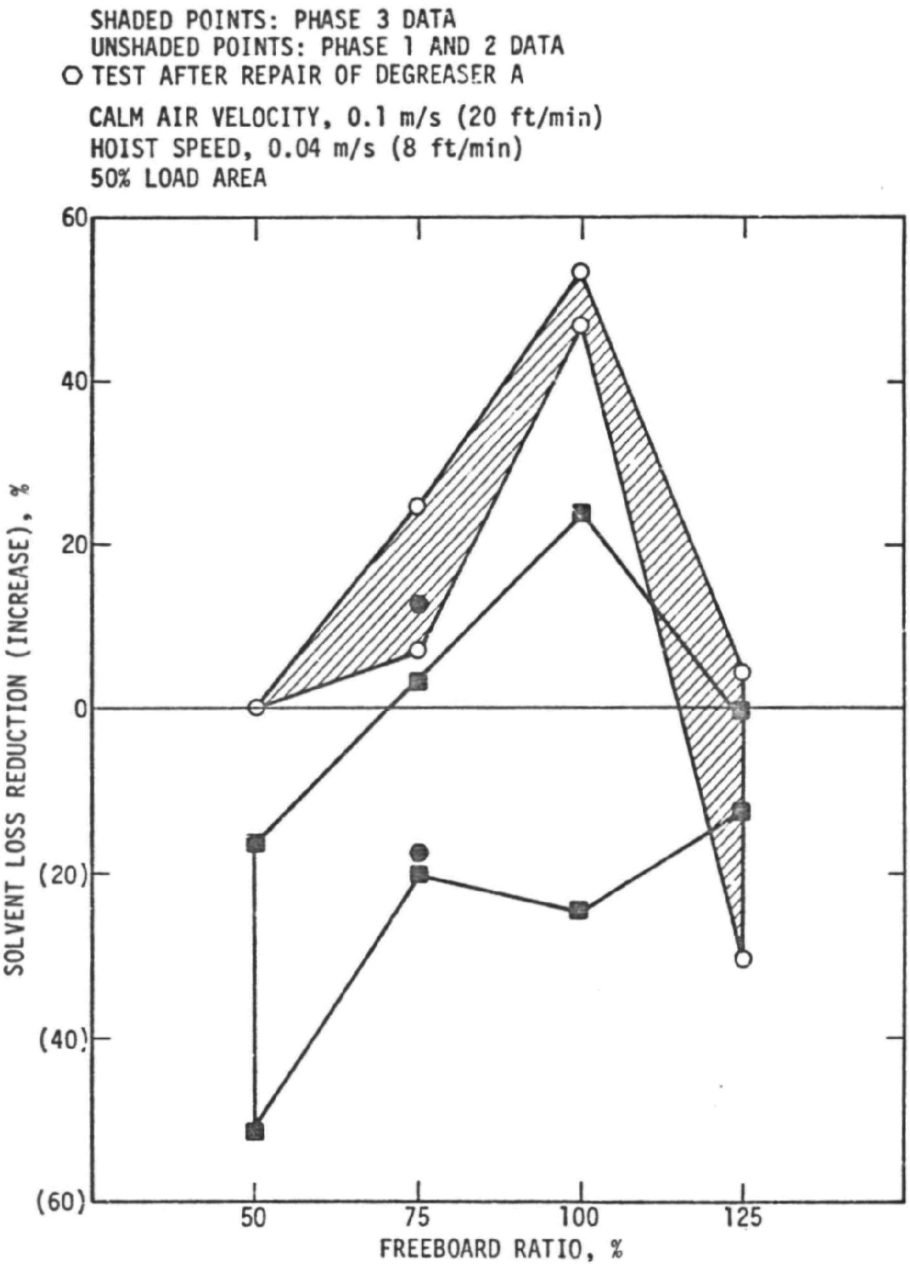

Figure 18. Effect of freeboard ratio on solvent loss from an an operating degreaser using 1,1,1-trichloroethane during Phases 1, 2, and 3.

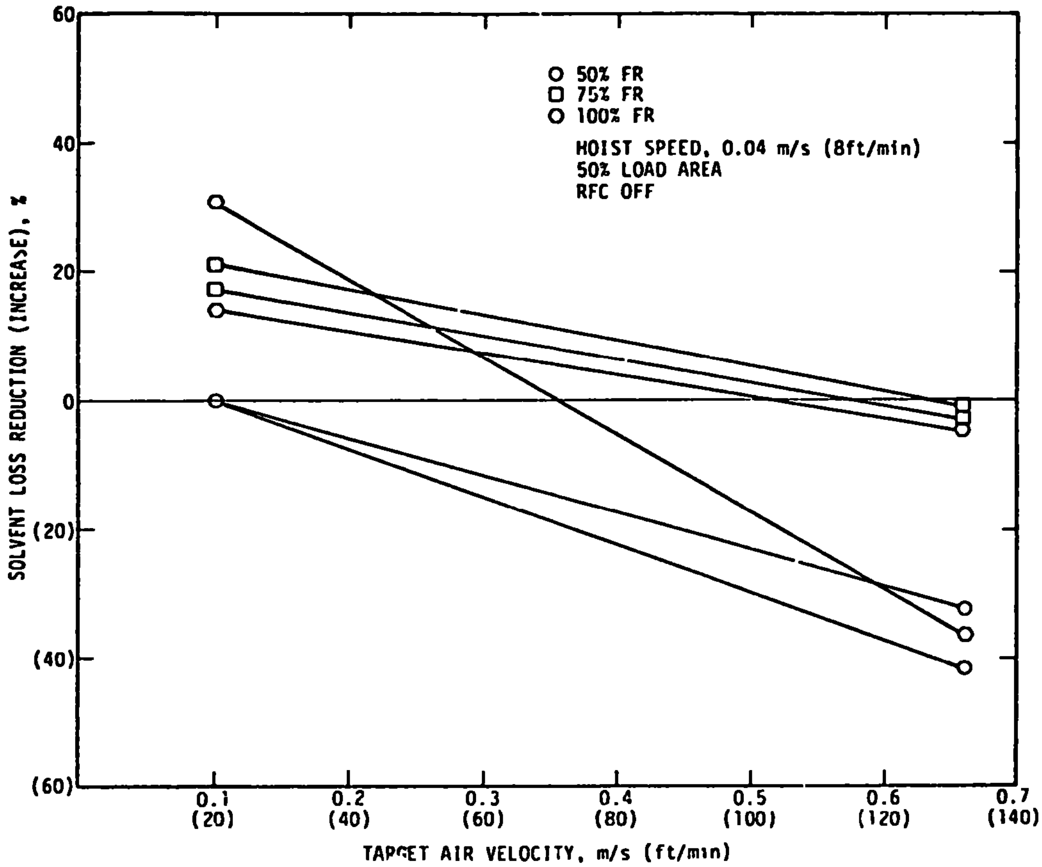

Figure 19. Effect of high crosscurrent air velocity on loss from an operating degreaser using 1,1,1-trichloroethane during Phase 3.

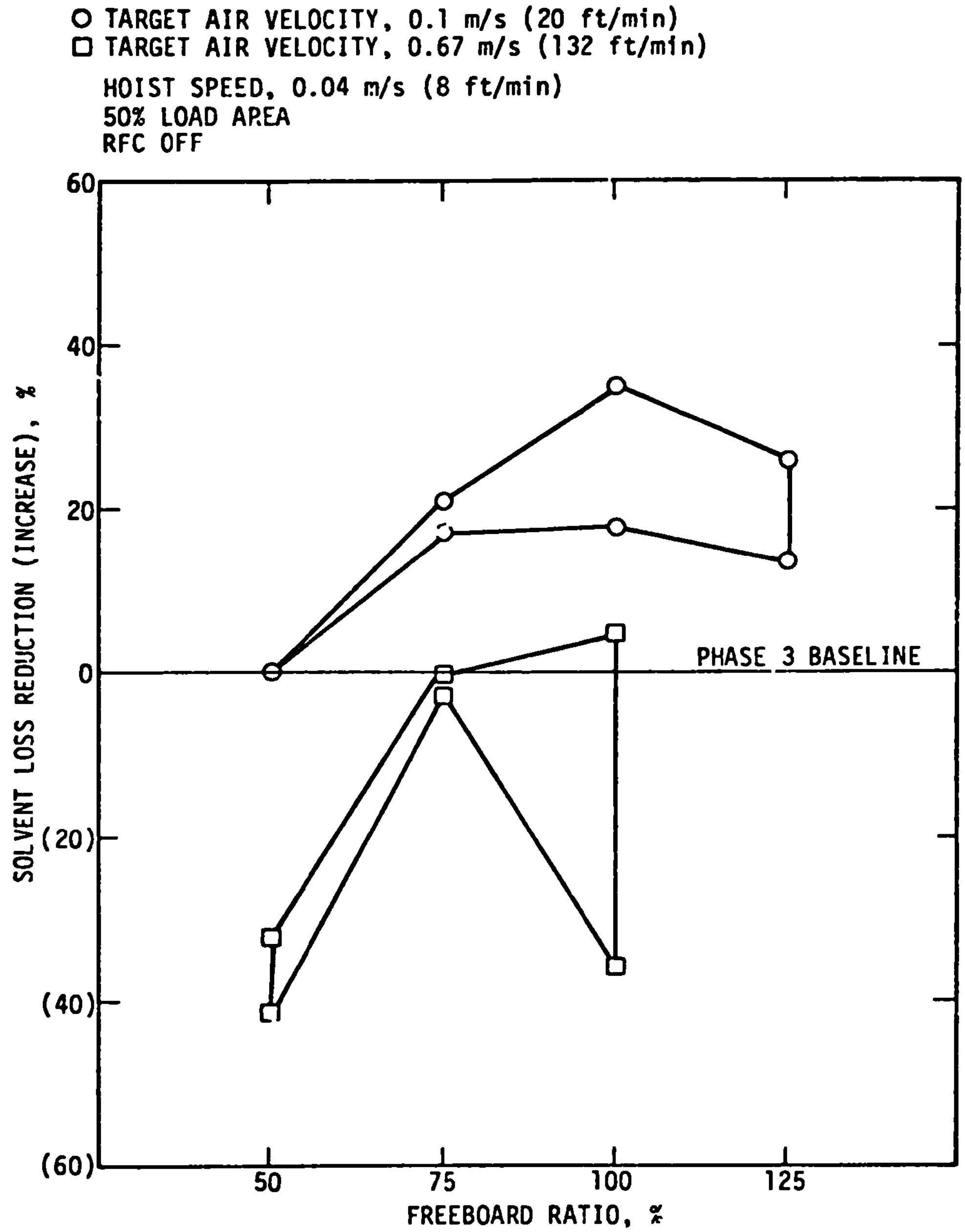

Figure 20. Effect of freeboard ratio on solvent loss from an operating degreaser using 1,1,1-trichloroethane at different target air velocities during Phase 3.

As indicated by Figure 21, use of RFC I on a degreaser operating at 50 percent FR and 0.67-m/s (132-ft/min) air velocity can totally control the increased solvent loss caused by the higher air velocity. In fact, RFC I decreased solvent loss to 4 percent less than the Phase 3 baseline value; i.e., it produced a 46 percent control effect. When used on a degreaser operating at 75 percent FR and 0.67-m/s air velocity, RFC I decreased solvent loss to 20 percent less than the Phase 3 baseline value; this was a 23 percent incremental control effect not attributable to FR. Use of RFC I on a degreaser operating at 100 percent FR and 0.67-m/s air velocity decreased solvent loss to 21 percent less than the Phase 3 baseline value; this equaled a 57 percent incremental control effect not attributable to FR.

Although RFC II increased solvent loss at 50 percent FR, it reduced solvent loss at the higher FR's. Figure 21 shows that use of RFC II on a degreaser operating at 50 percent FR and 0.67 m/s (132 ft/min) air velocity increased solvent loss to 59 percent above the Phase 3 baseline value; this was 27 percent more solvent loss than occurred at the high draft velocity without RFC II. When used in a degreaser operating at 75 percent FR and draft air velocity of 0.67 m/s, RFC II decreased solvent loss to 6 percent less than the baseline value; this constituted a 6 percent incremental control effect not attributable to FR. Use of RFC II on a degreaser operating at 100 percent FR and draft air velocity of 0.67 m/s decreased solvent loss rate to 18 percent less than the baseline value; thus, the incremental control effect not attributable to FR was 13 percent.

Effect of Automatic Lid

The automatic lid tested in Phase 2 was tested again in Phase 3, but was operated differently. In Phase 2 the lid was closed only when the load was not being cleaned or moved up or

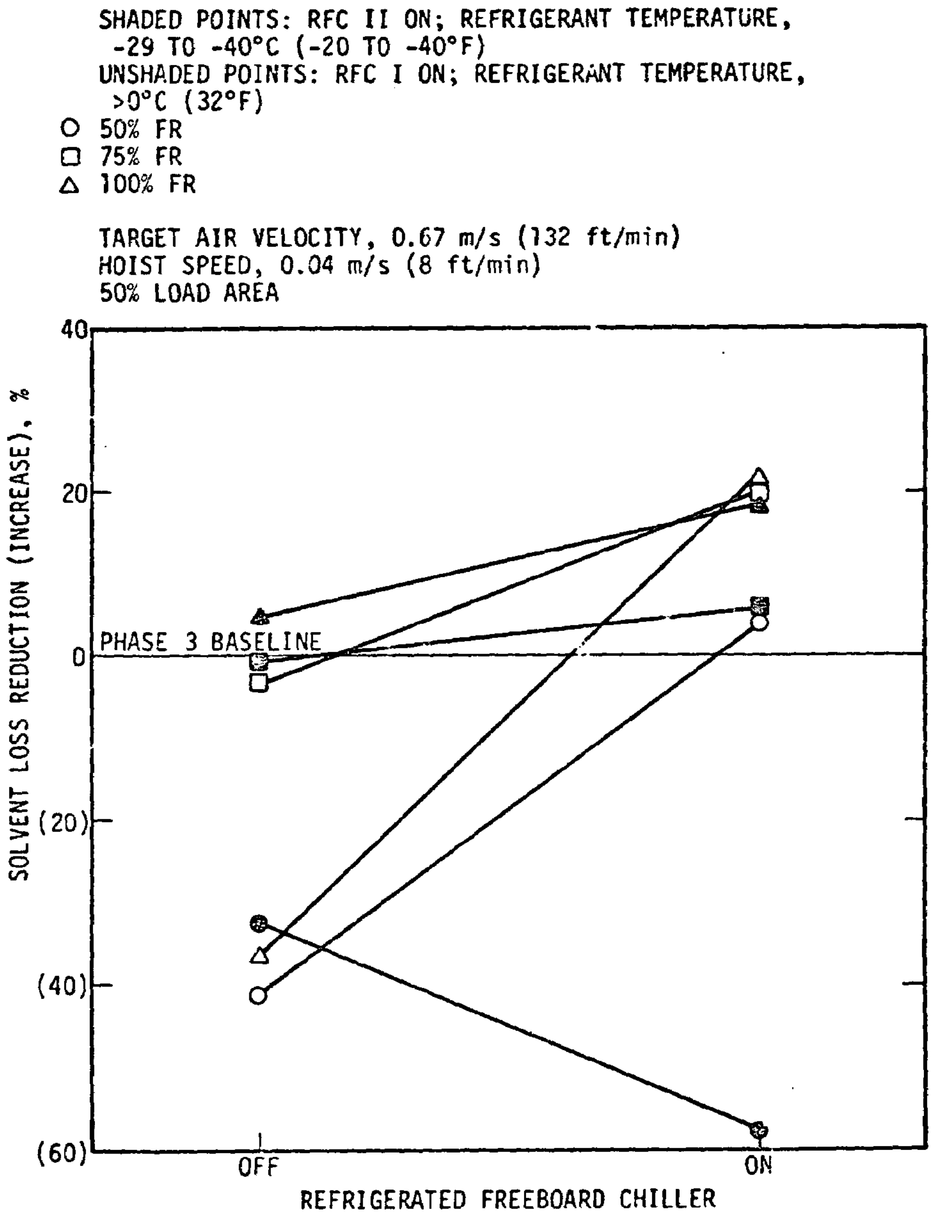

Figure 21. Effect of refrigerated freeboard chiller on solvent loss from an operating degreaser during 1,1,1-trichloroethane at a target air velocity of 0.67 m/s (132 ft/min) during Phase 3.

down (about 25 percent of the time). In Phase 3 the lid was also closed when the load was being cleaned, but not when it was being moved up or down (70 percent of the time). The lid was tested at 75 percent FR and a draft air velocity of 0.67 m/s (132 ft/min). Figure 22 shows that the lid decreased solvent loss to 50 percent less than the baseline value; this was a 53 percent incremental control effect not attributable to FR. The effects of FR and RFC are also presented on Figure 22 to allow comparison of the different means of control.

Effect of Ambient Temperature

Figure 23 presents the results of Phase 3 tests to determine the effect of ambient temperature on the rate of solvent loss from Degreasers A and B. The ambient temperature was measured separately near each degreaser at the end of every hour of testing. Hours of rapid temperature change were excluded from the data base. The linear regression fit of the data shows that an ambient temperature increase of 0.7° to 4.3°C (4.9° to 7.7°F) reduced solvent loss by 0.45 kg/h (1.0 lb/h). The use of a linear regression fit, however, should not be construed to suggest that the relationship between ambient temperature and solvent loss rate is linear; we expect that experimentation over a larger temperature scale would show a nonlinear relationship.

The buoyancy of gas inside the freeboard area compared with the buoyancy of ambient air outside the degreaser is probably the controlling factor. As the buoyancy of air inside the tank increases, air moving out of the degreaser increases in velocity and takes with it solvent vapors.

Phase 3 data should probably not be used to correct or adjust previous data to room temperature, especially data from tests run with different control systems or operational procedures. The best course would be to reject tests run at an ambient temperature other than 21°C (70°F).

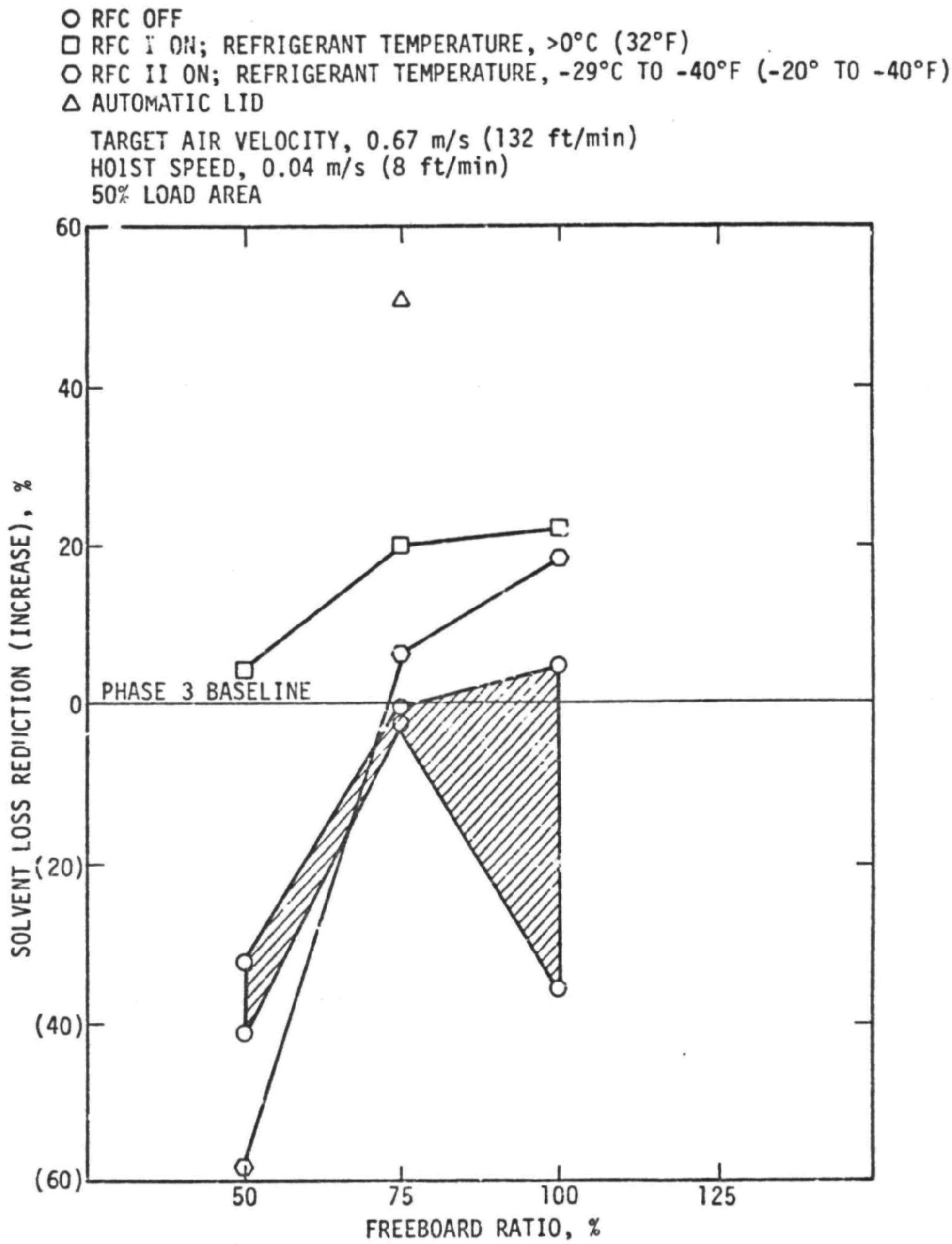

Figure 22. Effect of automatic lid, freeboard ratio, and refrigerated freeboard chiller on solvent loss from an operating degreaser using 1,1,1-trichloroethane at a target air velocity of 0.67 m/s (132 ft/min) during Phase 3.

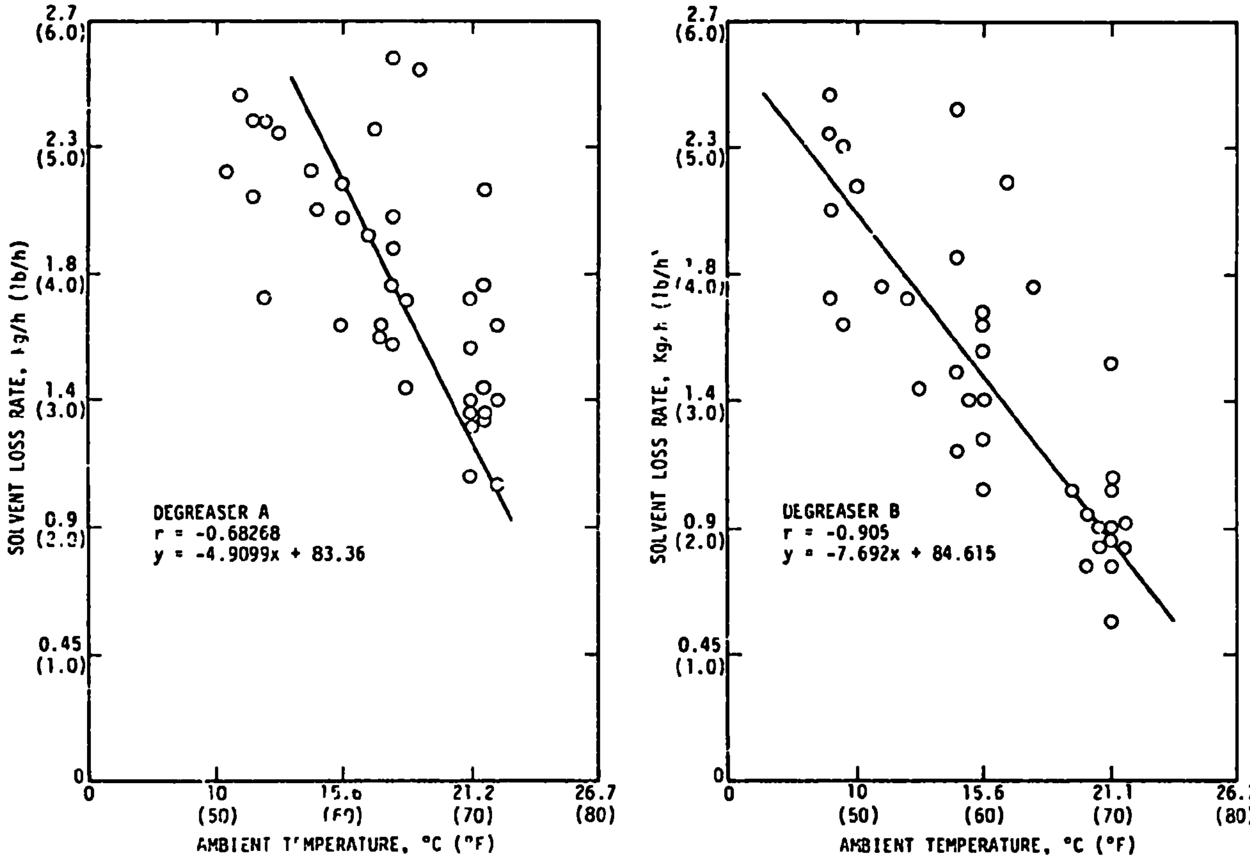

Figure 23. Effect of ambient temperature on rate of solvent loss from Degreasers A and B during Test 136.

Other Tests

Tests 154 and 155 were run sequentially at the same fan speed setting (about 1.32 m/s or 260 ft/min). They showed that either RFC can reduce solvent loss at high crosscurrent air velocities and that other variables affect the measured air velocity. The use of an RFC reduced measured air velocity from about 1.32 m/s (260 ft/min) to 1.11 m/s (220 ft/min). Early in the testing program, it was recognized that turning on the degreaser altered the measured air velocity by 10 to 20 percent, and the test procedure was subsequently changed to accommodate this phenomenon by adjusting the fan speed after the degreaser had warmed up. Passing the load basket through the lip area reduced the average velocity in one test to 0.42 m/s (84 ft/min) from 0.67 m/s (132 ft/min) at the initial fan speed setting. The ambient temperature control system malfunctioned near the end of one test and allowed the temperature to increase about 27°C (80°F); a significant increase was noticed in the recorded air velocity.

Figure 24 presents the results of Test 157, which concerned only Degreaser B. Four randomly selected air velocities were tested with the RFC on (after a 3-hour stabilization period); then the same air velocities were tested in random order with the RFC off (after a 1-hour stabilization period). Each point on the figure represents the solvent loss rate during 1 hour of testing. As Figure 24 indicates, the RFC controlled solvent loss at crosscurrent velocities up to 1.02 m/s (200 ft/min), but not at higher velocities. Figure 24 also shows that above 1.02 m/s (200 ft/min) the solvent loss rate increased rapidly, possibly with the square of the velocity. Because the data were taken every hour, they cannot be accepted with the same confidence as data taken over longer intervals, although the correlation with data from extended tests is better than would be expected.

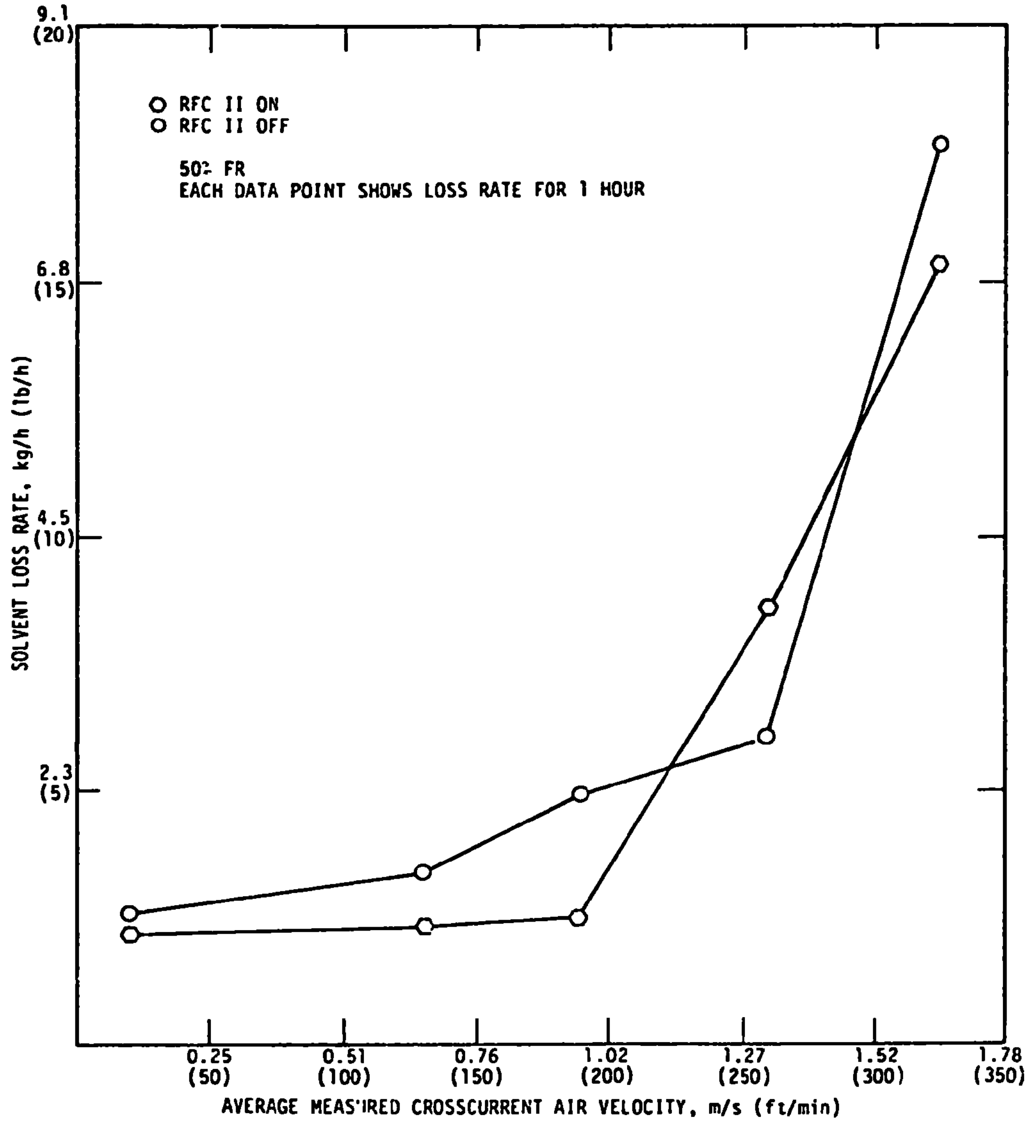

Figure 24. Results of Test 157.

LABORATORY TESTS WITH METHYLENE CHLORIDE

Baseline Performance

Phase 1 tests of an operating degreaser using methylene chloride at calm airflow and 75 and 125 percent FR were repeated during Phase 3 to determine whether baseline performance had changed. Table 11 summarizes baseline solvent loss data from Phases 1 and 3, and Figure 25 presents the results of comparable Phase 1 and 3 baseline tests. The data indicate no significant shift in performance between the two phases.

Effect of High Crosscurrent Air Velocity

Phase 3 tests of operating degreasers using methylene chloride at high crosscurrent air velocity (0.67 m/s or 132 ft/min) increased solvent loss above the rate at calm airflow by slightly less than comparable Phase 2 tests. A 60 to 64 percent increase in solvent loss above the baseline rate was found at 75 percent FR, and a 17 to 26 percent increase was estimated at 100 percent FR. Solvent loss at 100 percent FR and calm airflow was not tested. The estimated increase at 100 percent FR resulted from straight-line interpolation between data at 75 and 125 percent FR. Table 12 summarizes Phase 3 data on solvent loss from operating degreasers using MC at calm and high air velocities.

Effect of Freeboard Ratio

Figure 26 shows the effect of 75 and 100 percent FR on solvent loss. At 75 percent FR and 0.67-m/s (132-ft/min) air velocity, solvent loss was 60 to 64 percent more than the baseline value. At 100 percent FR and 0.67-m/s air velocity, however, solvent loss was 10 to 28 percent more than the baseline value. This indicates that the change from 75 to 100 percent FR caused a net reduction in solvent loss rate of 36 to 50 percent.

Effect of Refrigerated Freeboard Chiller

The refrigerated freeboard chillers tested were of two designs: RFC I, which operated at a refrigerant temperature

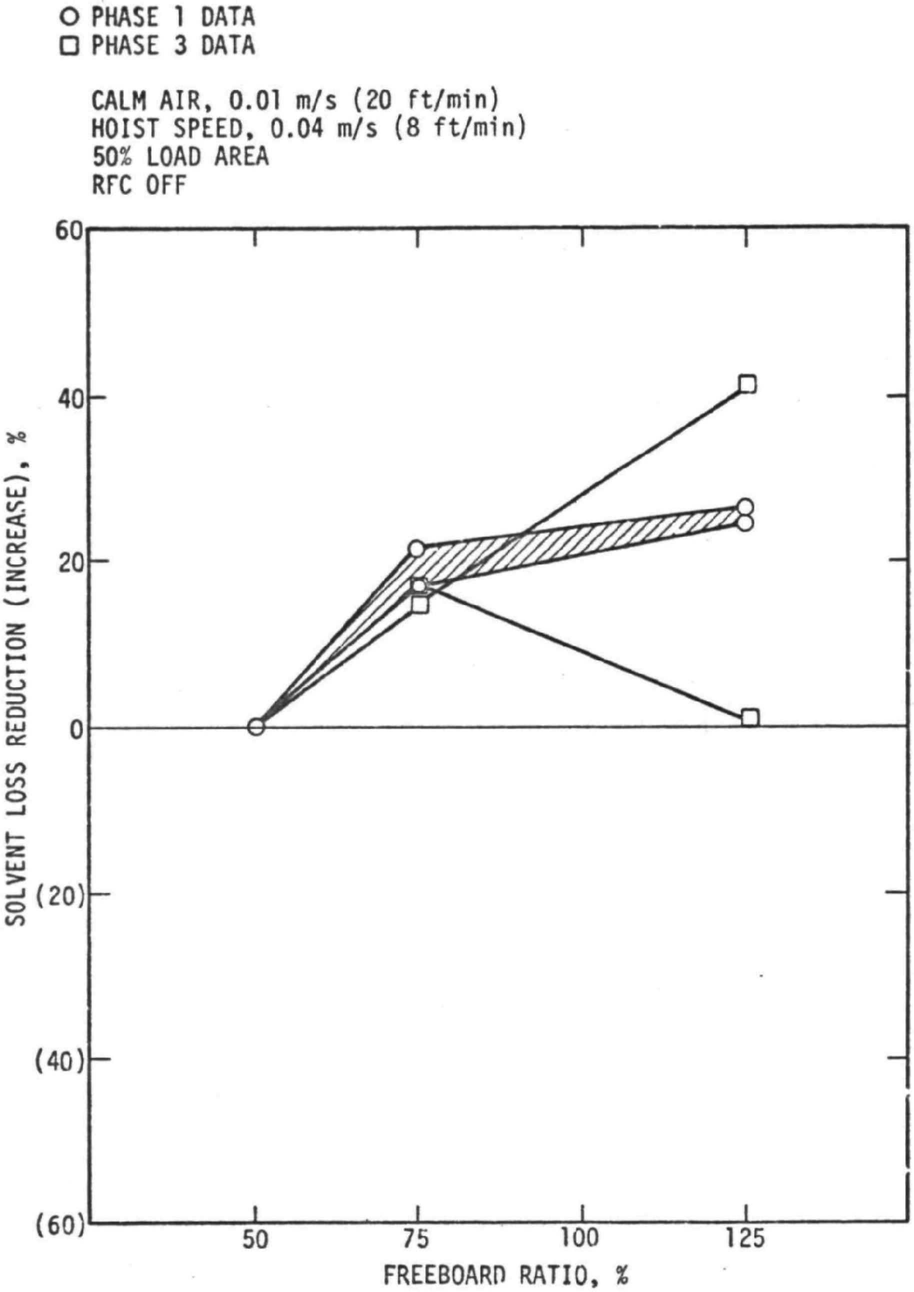

Figure 25. Effect of freeboard ratio on solvent loss from an operating degreaser using methylene chloride during Phases 1 and 3.

TABLE 11. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 3 FOR OPERATING DEGREASERS USING METHYLENE CHLORIDE AT CALM AIR VELOCITY

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	kg/h	%	Measured air velocity at lip, m/s	kg/h	kg/h	%
34[b]	37	✓	✓	✓		50	0.1	0.1	0.776			0.1	1.05		
35[b]	74	✓	✓	✓		75	0.1	0.1	0.608	0.168	21.6	0.1	0.87	0.18	17.2
36[b]	41	✓	✓	✓		125	0.1	0.1	0.586	0.191	24.6	0.1	0.78	0.28	26.3
158[c]	158	✓	✓	✓		75	0.1	0.1	0.644	0.133	17.1	0.1	0.90	0.156	14.8
146[c]	146	✓	✓	✓		125	0.1	0.1	0.779	(0.003)	(0.35)	0.1	0.62	0.431	40.9

[a] Hoist speed of 0.1 m/s and load area of 50 percent unless otherwise specified.

[b] Phase 1 test.

[c] Phase 3 test.

TABLE 11a. SUMMARY OF SOLVENT LOSS DATA FROM PHASES 1 AND 3 FOR OPERATING DEGREASERS USING METHYLENE CHLORIDE AT CALM AIR VELOCITY

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	lb/h	%	Measured air velocity at lip, ft/min	lb/h	lb/h	%
34[b]	37	✓	✓	✓		50	20	20	1.71			20	2.32		
35[b]	74	✓	✓	✓		75	20	20	1.34	0.37	21.6	20	1.92	0.40	17.2
36[b]	41	✓	✓	✓		125	20	20	1.29	0.42	24.6	20	1.71	0.61	26.3
158[c]	158	✓	✓	✓		75	20	20	1.418	0.292	17.1	20	1.976	0.344	14.8
146[c]	146	✓	✓	✓		125	20	20	1.716	(0.006)	(0.35)	20	1.371	0.949	40.9

[a] Hoist speed of 8 ft/min and load area of 50 percent unless otherwise specified.
[b] Phase 1 test.
[c] Phase 3 test

TABLE 12. SUMMARY OF SOLVENT LOSS DATA FROM PHASE 3 FOR OPERATING DEGREASERS USING METHYLENE CHLORIDE AT CALM AND HIGH AIR VELOCITIES

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, m/s	Measured air velocity at lip, m/s	kg/h	kg/h	%	Measured air velocity at lip, m/s	kg/h	kg/h	%
158	158	✓	✓	✓		75	0.1	0.1	0.644			0.1	0.897		
146	146	✓	✓	✓		125	0.1	0.1	0.779	(0.135)	(21.0)	0.1	0.622	0.275	30.6
150	150	✓	✓	✓		75	0.67	0.75	1.058	(0.415)	(64.4)	0.74	1.440	(0.543)	(60.5)
147	147	✓	✓	✓	✓	75	0.67	0.66	1.145	(0.502)	(77.9)	0.64	1.520	(0.623)	(69.5)
148	148	✓	✓	✓		100	0.67	0.65	0.711	(0.067)	(10.4)	0.71	1.145	(0.248)	(27.6)
149	149	✓	✓	✓	✓	100	0.67	0.71	0.732	(0.089)	(13.8)	0.56	0.769	0.126	14.1

[a] Hoist speed of 0.1 m/s and load area of 50 percent unless otherwise indicated.

TABLE 12a. SUMMARY OF SOLVENT LOSS DATA FROM PHASE 3 FOR OPERATING DEGREASERS USING METHYLENE CHLORIDE AT CALM AND HIGH AIR VELOCITIES

Test conditions[a]								Solvent loss data							
								Degreaser A				Degreaser B			
										Decrease (Increase) from base case				Decrease (Increase) from base case	
Test group No.	Test No.	Lid open	Solvent boiling	Primary condenser	Refrig. free-board chiller	Freeboard ratio, %	Target air velocity at lip, ft/min	Measured air velocity at lip, ft/min	lb/h	lb/h	%	Measured air velocity at lip, ft/min	lb/h	lb/h	%
158	158	✓	✓	✓		75	20	20	1.418			20	1.976		
146	146	✓	✓	✓		125	20	20	1.716	(0.298)	(21.0)	20	1.371	0.605	30.6
150	150	✓	✓	✓		75	132	148	2.331	(0.913)	(64.4)	146	3.172	(1.196)	(60.5)
147	147	✓	✓	✓	✓	75	132	130	2.523	(1.105)	(77.9)	126	3.349	(1.373)	(69.5)
148	148	✓	✓	✓		100	132	127	1.565	(0.147)	(10.4)	140	2.522	(0.546)	(27.6)
149	149	✓	✓	✓	✓	100	132	139	1.613	(0.195)	(13.8)	110	1.698	0.278	14.1

[a] Hoist speed of 8 ft/min and load area of 50 percent unless otherwise indicated.

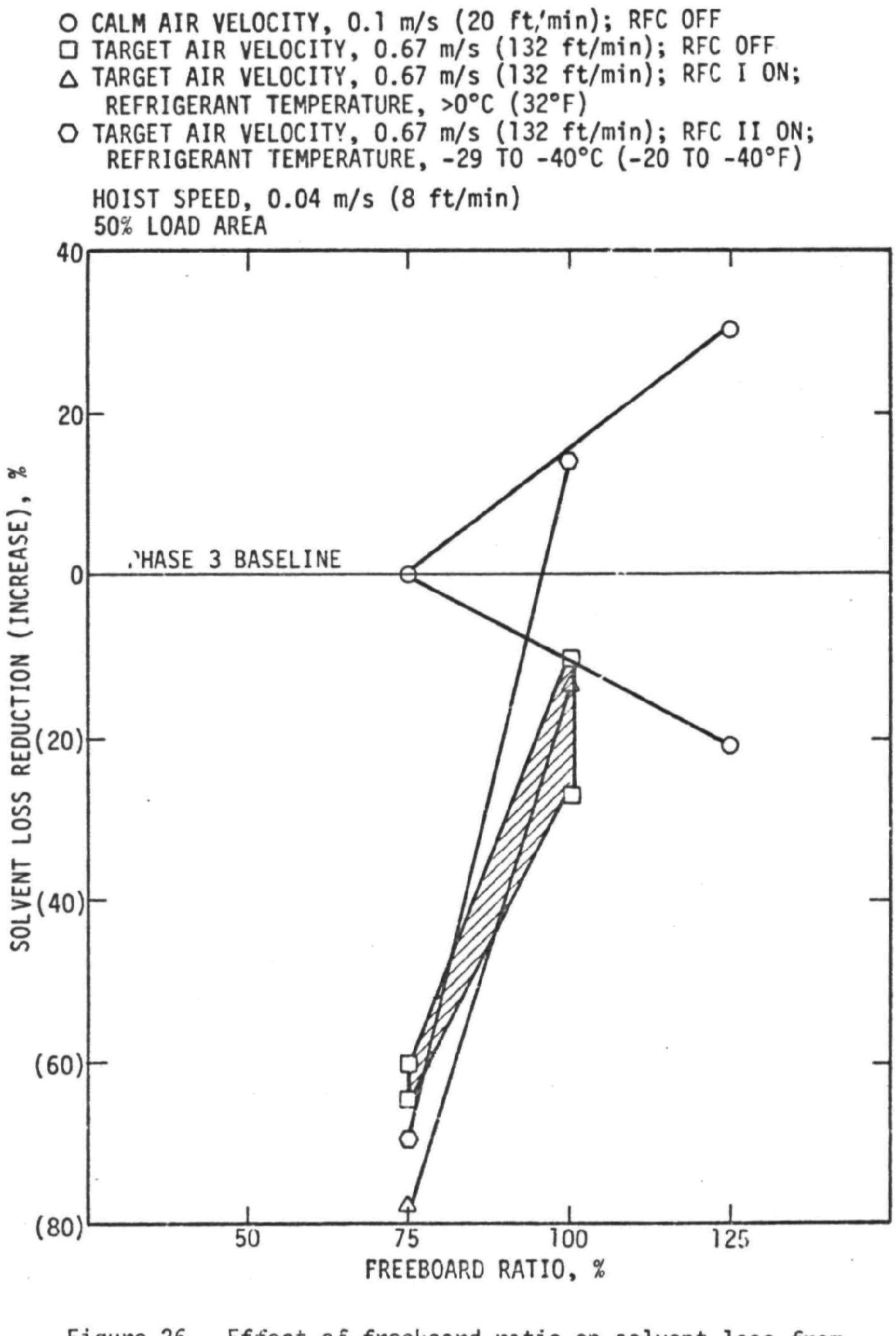

Figure 26. Effect of freeboard ratio on solvent loss from an operating degreaser using methylene chloride with refrigerated freeboard chiller during Phase 3.

greater than 0°C (32°F), and RFC II, which operated at a refrigerant temperature of -29° to 40°C (-20° to -40°F). Figure 27 depicts the results of Phase 3 MC tests with these RFC's.

As Figure 27 shows, use of RFC I on a degreaser operating at a target air velocity of 0.67 m/s (132 ft/min) increased solvent loss by 14 percent at 75 percent FR and by 4 percent at 100 FR. Use of RFC II increased solvent loss by 9 percent at 75 percent FR, but reduced solvent loss at 100 percent FR to 14 percent less than the baseline value; this was 42 percent incremental control effect at 100 percent FR.

LABORATORY TEST WITHOUT SOLVENT

Test 159 was designed to be run without solvent in either degreaser. The aim was to determine whether the variable flow rate of cooling water through the degreaser significantly affected data variability, especially whether it caused the unusual weight gains that sometimes appeared at one reading but disappeared by the end of the test. Before Test 159 was run, the cause of the weight gain was discovered, and corrections were made to the system. The unusual weight gains were attributed to flexible plumbing connections to the load. Weight was attached to the flexible hose to keep it in proper position for drainage of excess water from the load. Occasionally the weight or hose landed on the degreaser during the weighing portion of the cycle. This generally occurred at the same time as problems with the load entry or exit guides and disruption of the loading cycle. When the loading cycle was restarted, the problem with the hose was inadvertently corrected and thus was not detected at first.

A comparison of the test results using student's "t" statistical tests suggests that the weight loss indicated by the regression line is caused by chance at the 95 percent confidence level. A comparison of Syx, Sx, Sa, and Sc values (as defined in Appendix A) from Test 159 with values from other tests indicates that the variability of the data is similar. Similarity

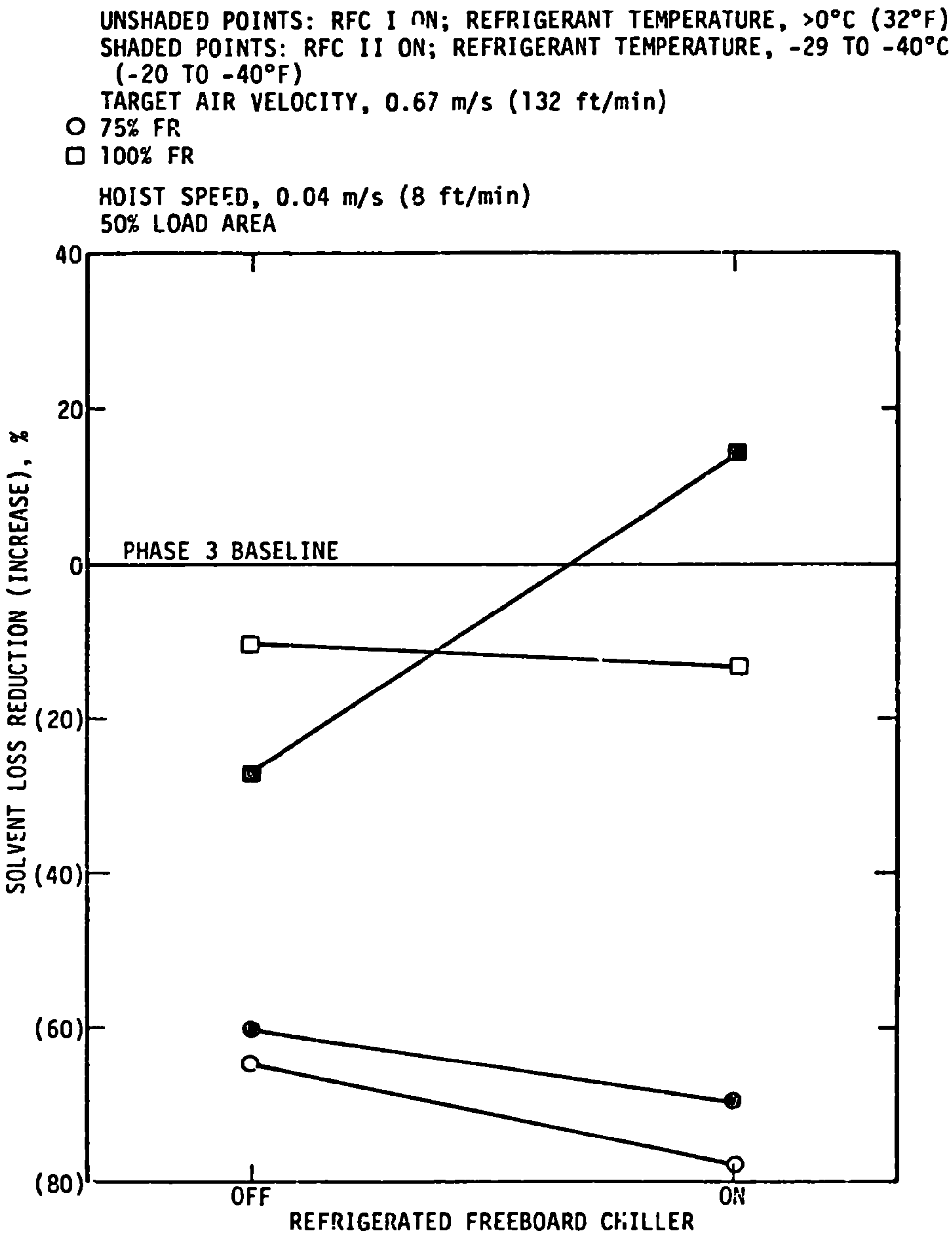

Figure 27. Effect of refrigerated freeboard chiller on solvent loss from an operating degreaser using methylene chloride at a target air velocity of 0.67 m/s (132 ft/min) during Phase 3.

in variability shows that the tests were run in the same manner, but that most of the variability resulted from some factor other than solvent loss.

LABORATORY TESTS WITH SMOKE

The smoke tests were intended to be visual indicators of velocity and turbulence in the degreaser tank. Although many attempts were made to get a clear photographic record of air velocity in the freeboard area while the degreaser contained boiling solvent, none was successful. The turbulence caused by the fan rapidly dispersed the smoke trace. There was some mixing of smoke down into the freeboard area, but it could not be quantified and had no apparent direction. A simulated degreaser and fan combination was set up in a nearby laboratory area. This equipment showed that the draft blowing over the leading lip aspirated air from just below the lip into the draft passing across the top. This air moving up the inside front wall set up a circular flow in the box as shown in Figure 28.

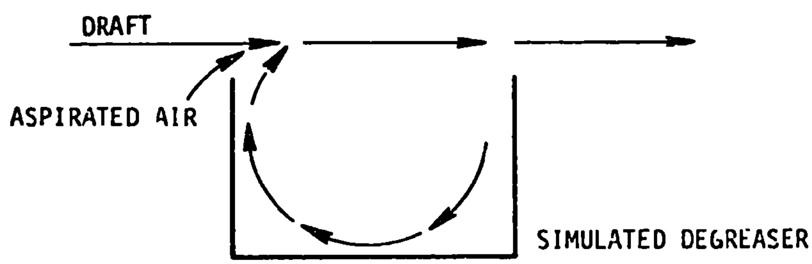

Figure 28. Turbulence created by a draft passing across the top of a simulated degreaser.

If similar flow exists in a degreaser, the solvent loss rate will be increased by higher air velocities.

FIELD TESTS

A field survey was conducted to determine air velocities near open-top vapor degreasers in industrial use. The aim was to put the laboratory results in proper perspective. As discussed in Appendix E, seven plants were studied in the Cincinnati area. They included two aircraft firms, three machinery manufacturers, one electrical equipment company, and one heavy equipment repair shop. The degreasers ranged from 0.55 m^2 (6 ft^2) to 3.9 m^2 (42 ft^2). The overall average air velocity found at the plants was 0.445 m/s (87.6 ft/min). Twenty-four 5-minute velocity readings were taken at each degreaser. Sixteen sampling places were on the long face of each degreaser, and eight places were on the short face. The readings were recorded on strip charts, and a 5-minute average was estimated. The range of 5-minute averages was from 0.35 to 0.568 m/s (69.4 to 112 ft/min) for all seven plants. The highest instantaneous peak velocity recorded was 3.04 m/s (600 ft/min); the lowest was 0 m/s. The overall average reflects the sum of the average velocity for each face divided by 14 (the number of faces measured).

SECTION 7

PHASE 3 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The use of sophisticated monitoring and control equipment in Phase 3 yielded data of sufficiently high quality to answer the questions raised in Phase 2. The conclusions presented below are based on data from Phases 1 and 2, as well as from Phase 3.

High Crosscurrent Air Velocity

When crosscurrent air velocity across the lip of the degreaser was increased to 0.67 m/s (132 ft/min), solvent loss increased to 40 percent more than the baseline value for both solvents. As the air velocity at the lip was increased further, solvent loss increased at a proportionately higher rate. As discussed in/Appendix E, crosscurrent air was found to be lower in velocity and much less turbulent at industrial plants in the Cincinnati area than in Phase 3 laboratory tests. Phase 1 tests, however, were run with crosscurrent air lower in velocity and less turbulent than that at the plants visited. Therefore, the range of laboratory conditions tested overlaps typical industrial conditions.

Freeboard Ratio at High Crosscurrent Air Velocities

As FR was increased from 50 to 125 percent at high crosscurrent air velocities, solvent loss decreased. Increasing FR from 50 to 75 percent reduced solvent loss by 40 percent with TE, and increasing FR from 75 to 100 percent reduced solvent loss by 20 percent with TE and 40 percent with MC. The two 40 percent reductions are significant.

Although increasing FR from 75 to 100 percent with TE reduced solvent loss, the reduction (20 percent) was only half that caused by increasing FR from 50 to 75 percent. Further, Phase 2 tests indicate that increasing FR from 75 to 125 percent reduces solvent loss very little. Thus, solvent loss reduction seems to decrease as FR is increased above 100 percent FR.

Refrigerated Freeboard Chiller at High Crosscurrent Air Velocity

Phase 3 tests with TE show that RFC I increased the control effect by 46, 23, and 21 percent at 50, 75, and 100 percent FR, respectively, and that RFC II increased the control effect by 27, 6, and 13 percent at the same FR's. These were increased above those attributable only to FR. Phase 3 tests with MC showed that no increase in control effect occurred with RFC I 75 or 100 percent FR or with RFC II at 75 percent FR; at 100 percent FR, however, RFC II increased the control effect by 42 percent. Again, this was an increase above that attributable to FR alone. Based on these tests and Phase 2 tests with MC, an increase in control effect of roughly 20 percent can be expected from an RFC of either design at the FR's and high air velocities tested.

Automatic Lid at High Crosscurrent Air Velocities

As in Phase 2, the automatic lid was tested only with TE, and conclusions can only be drawn about its effect on this solvent. Phase 3 testing showed that the use of this device reduced solvent loss by 53 percent.

RECOMMENDATIONS

The best solvent loss reduction technique is to lower air velocity at the lip of the degreaser. The position of the degreaser and the work flow to and from the degreaser, however, can severely limit the extent to which lowering of air velocity is possible. Other solvent loss reduction techniques include increasing FR and using an RFC and automatic lid. We recommend that these other techniques be considered equally effective means of reducing solvent loss for the degreaser sizes and air velocities found at industrial plants, and that they be accepted as only slightly less effective than lowering the airflow rate at the lip of the degreaser.