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DEVELOPMENT OF SUPERIOR LIQUID COOLANTS CCF-1

Final Technical Report, September 1, 1978—December 31, 1979

By
Robert M. Hodges

December 31, 1979

Work Performed Under Contract No. EM-78-C-04-4296

Dow Corning Corporation
Midland, Michigan

U.S. Department of Energy

Solar Energy

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FINAL TECHNICAL REPORT

DOE CONTRACT NUMBER EM-78-C-04-4296

DEVELOPMENT OF SUPERIOR LIQUID COOLANTS CCF-1

REPORT PERIOD
1 September 1978 - 31 December 1979

December 31, 1979

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ABSTRACT

A comprehensive study of four representative commercially available heat transfer fluids being used in solar systems was undertaken to establish the most cost effective fluid over the life of the system. Criteria for making the assessment were the relative results of fluid toxicity tests, fire hazards tests, collector stagnation tests and physical property comparison data of various fluids. The specific fluids evaluated were Dow Corning® Syltherm™ 444 silicone, Uniroyal PAO-LV polyalphaolefin hydrocarbon, Union Carbide Prestone II® ethylene glycol/water solution and Dow Chemical Ambitrol NTC® propylene glycol/water solution. Although there is no essential difference in the installed cost when comparing solar systems based on each of these fluids, there is a very large cost difference between the systems when life cycle costing is performed on the systems. The system representing propylene glycol/water is by far the most costly system followed by the system representing ethylene glycol/water due to possible failures and maintenance schedules. The Uniroyal PAO-LV polyalphaolefin system is the third most expensive system. The Syltherm™ 444 silicone system is the least expensive, offering little or no potential for catastrophic failure and does not require any fluid maintenance.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
I. DESCRIPTION OF PROJECT.	1
A. Introduction.	1
B. Objectives.	1
C. Scope	1
D. Tasks	1
II. PHYSICAL DATA TAKING.	3
A. Fluids.	3
B. Test Methods and Physical Data.	3
C. Low Temperature Fluid Viscosities	4
D. Dow Corning® Q2-1162 Heat Transfer Liquid.	4
III. TOXICITY TESTING.	15
A. FHSA Toxicological Testing.	15
B. Biological Oxygen Demand Testing.	16
IV. SOLAR COLLECTOR STAGNATION TESTING.	17
A. Objectives.	17
B. Test Loops.	18
C. Data Collection	20
D. Solar Collectors.	20
E. Collector Efficiency Testing.	24
F. Collector Stagnation - Fluids Analysis. . .	26
G. Absorber Plate Metals Corrosion Analysis. .	32

<u>Section</u>	<u>Page</u>
V. FLAMMABILITY TESTING.	35
A. Fire Hazards Tests.	35
B. Summary of Fire Hazards	35
C. Materials Compatibility Evaluation.	37
VI. ANALYSIS OF DATA.	40
A. Physical Data	40
B. Toxicological and BOD	41
C. Metals Corrosion.	41
D. Flammability and Materials Compatibility.	41
VII. COST EFFECTIVENESS.	43
A. System First Cost	43
B. Fluid Maintenance Costs	48
C. Catastrophic Incident Potential	53
D. Total Life Cycle Costs.	56
VIII. APPENDIX.	58
A. Toxicologic and BOD Reports	58
1. Uniroyal PAO-LV Polyalphaolefin.	58
2. Dow Corning® Q2-1162 Heat Transfer Liquid	61
3. Syltherm™ 444	64
4. Ethylene Glycol/Water.	67
5. Propylene Glycol/Water	70
6. Toxicologic Test Methods	73
B. NMSU Solar Collector Stagnation Data.	77
C. Metals Corrosion Analysis	91
D. Fire Hazards Testing Report	97

LIST OF FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
II-D-1	Density vs. Temperature, Q2-1162	8
II-D-2	Thermal Conductivity, Q2-1162	9
II-D-3	Heat Capacity, Q2-1162	10
II-D-4	Viscosity, Q2-1162	11
II-D-5	Heat Transfer Coefficient, Q2-1162	12
II-D-6	Pressure Drop vs. Flow Rate, Q2-1162	13
II-D-7	Thermal Degradation Loss, Q2-1162	14
IV-B-1	Stagnation Test Loop Schematic - NMSU	19
IV-D-1	Solar Collector Array - NMSU	23
IV-D-2	Solar Collector Array - NMSU Photograph	25

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
II-B-1	Physical Data	5
II-C-1	Low Temperature Fluid Viscosities	7
IV-D-1	Average Maximum Stagnation Temperature - °F	22
IV-F-1	Monthly Collector Stagnation Times - Hours	27
IV-F-2	Collector Stagnation - Fluids Analysis - Part A	30
IV-F-3	Collector Stagnation - Fluids Analysis - Part B	31
IV-G-1	Absorber Plate Radiographic Analysis	33
VII-A-1	System Components List by Item	45
VII-A-2	System Components List by Type	46
VII-A-3	System Cost Analysis	47
VII-A-4	Net Installed Customer Cost	49
VII-B-1	Projected Fluid Maintenance Costs	52
VII-C-1	Potential for Catastrophic Incident	54
VII-D-1	Total Estimated Life Cycle Costs	57

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Nick Angelotti and Bob Hughes of the Analytical Department Laboratories at Dow Corning performed most of the critical fluids analysis. Chuck Groh and Ben Franklin of the Biological Services Department Laboratories at Dow Corning performed the FHSA and BOD testing. Bill Stevens of the Physical Science Laboratory at New Mexico State University coordinated the solar collector stagnation testing program. Al Castillo and Dr. Ed Smith of Olin Corporation's Metals Research Laboratories in New Haven, Connecticut performed the absorber plate metals corrosion analysis. Jerry Cappel, Alan Denny and Dr. Jon Lipowitz of Dow Corning's Research Department were responsible for the difficult flammability testing. Dick Montgomery of Dow Corning's Market Development Department performed the cost effectiveness evaluation.

I. DESCRIPTION OF PROJECT

A. Introduction

The work performed under this contract is part of the national program for Research and Development in Solar Heating and Cooling.

The overall objective is to stimulate the advancement of an industrial, commercial and professional capability for producing and distributing various solar energy systems. It is contemplated that the demand on fossil fuel supplies will be reduced through the widespread use of solar energy (a) in heating and cooling of residential and commercial buildings, (b) for service and process hot water, and (c) for the thermal needs of agricultural and industrial processes.

B. Objectives

The specific objective of this work is to establish the most cost effective solar heat transfer fluid through a comprehensive study of the four most common fluids being used. Criteria for making the assessment will be the relative results of F.H.S.A. toxicological studies, fire hazards testing, thermal efficiency performances, corrosion studies, collector stagnation testing and physical property comparison data of various fluids.

C. Scope

Dow Corning Corporation has conducted a 15 month study to determine the cost effectiveness of SylthermTM 444, a silicone heat transfer liquid, as compared to representative samples of three other commonly used fluids. Contributing to cost effectiveness is the simplification of solar collector systems by the elimination of devices and premium metals used to protect against freezing, over-heating and corrosion. Cost effectiveness is evaluated from a variety of other data including stagnation performance in solar collectors.

Additionally, physical property and engineering data is presented for a new, experimental silicone fluid known as Dow Corning® Q2-1162 Heat Transfer Liquid.

D. Tasks

The studies undertaken for this contract were broadly categorized in the PRDA as A) Data Taking and B) Analysis and Cost Effectiveness Determination.

Each of these two categories is composed of several specific areas which were divided, for monitoring and reporting purposes, into the six specific tasks listed as follows:

Task A-1	Physical Data Taking
Task A-2	Toxicity Testing
Task A-3	Solar Collector Testing
Task A-4	Flammability Testing
Task B-1	Analysis of Data
Task B-2	Cost Effectiveness

II. PHYSICAL DATA TAKING

A. Fluids

This testing was done to provide initial, basic background information on a variety of commercially available heat transfer liquids. Complete physical property test data was obtained on two silicone heat transfer liquids, two glycol/water mixtures and one hydrocarbon heat transfer liquid as follows:

<u>Fluid Sample</u>	<u>Fluid Description</u>
A	Uniroyal PAO-LV Polyalphaolefin (Hydrocarbon)
B	Dow Corning® Q2-1162 Heat Transfer Liquid (Experimental Silicone)
C	Syltherm™ 444 Heat Transfer Liquid (Commercial Silicone)
D	Union Carbide Prestone II® Ethylene Glycol/Water, 50:50 mixture by weight
E	Dow Chemical Ambitrol NTC® Propylene Glycol/Water, 50:50 mixture by weight

The silicone fluids, their room temperature viscosities, and anticipated temperature use conditions are:

	<u>Viscosity</u>	<u>Use Conditions</u>	<u>Collector Type</u>
Syltherm™ 444	20 cs	400°F Unblanketed	Flat Plate
Dow Corning® Q2-1162 Heat Transfer Liquid	10 cs	750°F Blanketed	Concentrator

Dow Corning® Q2-1162 requires a blanket of nitrogen or other inert gas at use conditions.

B. Test Methods and Physical Data

All physical property testing was performed by the Analytical Services Department at Dow Corning Corporation with the exception of thermal conductivity analysis which was performed at the Thermal Research Laboratory at the Dow Chemical Company, Midland, Michigan.

Test methods identified by a CTM designation in Table II-B-1 refer to Dow Corning corporate test methods. These methods are based, when appropriate, on standard methods in ASTM or other compendia, but may not be exactly equivalent. Vapor pressure measurements were obtained by ASTM D323 as modified for operation at 400°F (204.4°C). Liquid thermal conductivity measurements were obtained using a hot wire method similar to that described by O.B. Cecil, R. H. Munch, Ind. Eng. Chem. 48, 437 (1956).

Table II-B-1 summarizes the results of this basic physical property testing.

C. Low Temperature Fluid Viscosities

Concerns regarding fluid pumpability as related to fluid viscosity at low temperatures led to the preparation of Table II-C-1 which shows low temperature viscosity measurements of SylthermTM 444, Uniroyal PAO-LV Polyalphaolefin and Brayco 888 HF Solar Collector Fluid. Brayco 888 HF is a hydrocarbon material from Bray Oil Company, Los Angeles, California and is similar to Uniroyal PAO-LV Polyalphaolefin.

D. Dow Corning® Q2-1162 Heat Transfer Liquid

Dow Corning has developed a new, experimental silicone fluid known as Dow Corning® Q2-1162 Heat Transfer Liquid (previously designated X2-1162 and also known as SylthermTM 800). This fluid is a unique high temperature heat transfer medium based upon the technology of very stable silicone polymers.

Studies of thermal performance of Dow Corning® Q2-1162 have been made and engineering data derived therefrom are provided as follows:

Density vs. Temperature	Figure II-D-1
Thermal Conductivity	Figure II-D-2
Heat Capacity	Figure II-D-3
Viscosity	Figure II-D-4
Heat Transfer Coefficient	Figure II-D-5
Pressure Drop vs. Flow Rate	Figure II-D-6

Additionally, Dow Corning® Q2-1162 Heat Transfer Liquid has been evaluated for its rate of thermal degradation at various temperatures less than 750°F and this data is provided in Figure II-D-7.

PHYSICAL DATA

Table II-B-1

	TEST METHOD	UNIROYAL PAO-LV	Q2-1162	SYLTHERMTM 444	PRESTONE II® WATER	AMBITROL NTC® WATER
Flash Point	CTM0021A	266°±5°F (130°C)	320°±5°F (160°C)	465°±10°F (240.5°C)	No Flash	No Flash
Fire Point	CTM0052	350°±5°F (176.7°C)	413°±10°F (211.7°C)	622°±10°F (327.8°C)	No fire - Boils @ 220°F	No fire - Boils @ 220°F
Viscosity	CTM0004					
77°F (25°C)		19.00cs±.40	10.2cs±.20	19.7cs±.40	3.08cs±.06	4.92cs±.10
140°F (60°C)		6.63cs±.12	6.03cs±.12	11.2cs±.20	1.47cs±.05	1.89cs±.05
210°F (98.9°C)		2.95cs±.05	3.58cs±.05	6.61cs±.05	0.74cs±.05	1.24cs±.05
Thermal Conductivity	Hot Wire Method	(K, cal cm ⁻¹ sec ⁻¹ °C ⁻¹ ±2%)				
25°C		3.38x10 ⁻⁴	3.29x10 ⁻⁴	3.49x10 ⁻⁴	9.285x10 ⁻⁴	8.590x10 ⁻⁴
40°C		3.32x10 ⁻⁴	3.33x10 ⁻⁴	3.43x10 ⁻⁴	9.490x10 ⁻⁴	8.790x10 ⁻⁴
60°C		3.23x10 ⁻⁴	3.14x10 ⁻⁴	3.36x10 ⁻⁴	9.750x10 ⁻⁴	9.025x10 ⁻⁴
80°C		3.14x10 ⁻⁴	3.05x10 ⁻⁴	3.29x10 ⁻⁴	9.970x10 ⁻⁴	9.215x10 ⁻⁴
100°C		3.10x10 ⁻⁴	2.97x10 ⁻⁴	3.22x10 ⁻⁴	10.120x10 ⁻⁴	9.330x10 ⁻⁴
Specific Gravity	CTM001A (±.005)					
77°F (25°C)		0.809	0.938	0.953	1.069	1.047
140°F (60°C)		0.786	0.906	0.921	1.050	1.024
210°F (98.9°C)		0.764	0.872	0.888	1.024	0.995
Pour Point	CTM0133	-112°F (-80°C)	<-148°F (<-100°C)	-94°F (-70°C)	-27.4°F (-33°C)	-58°F (-50°C)

Table II-B-1. Physical Data

PHYSICAL DATA

Table II-B-1 (con't)

	TEST METHOD	UNIROYAL PAO-LV	<u>Q2-1162</u>	<u>SYLTHERMTM 444</u>	PRESTONE II® WATER	AMBITROL NTC® WATER
Coefficient of Expansion	CTM0782X (Temp. Range = 25-98.9°C) 6.31x10 ⁻⁴ °C ⁻¹		9.44x10 ⁻⁴ °C ⁻¹	9.28x10 ⁻⁴ °C ⁻¹	6.33x10 ⁻⁴ °C ⁻¹	7.35x10 ⁻⁴ °C ⁻¹
Vapor Pressure	ASTM D323					
psig @ 400°F (204.4°C)		< 0.4	< 0.4	< 0.4	205±15	205±15
mmHG @ 400°F		<20.69	20.69	20.69	10,600±775	10,600±775
Specific Heat	CTM544 C _p , BTU/pound - °F (Cal/gm - °C)					
77°F (25°C)		0.52±0.01	0.37±0.01	0.38±0.01	0.88±0.02	0.90±0.02
140°F (60°C)		0.55±0.01	0.39±0.01	0.40±0.01	0.90±0.02	0.92±0.02
210°F (98.9°C)		0.57±0.01	0.41±0.01	0.41±0.01	a	a

a Unable to determine specific heat without either a mass change or pressure change.

Table II-B-1. Physical Data (con't)

LOW TEMPERATURE FLUID VISCOSITIES

<u>Fluid</u>	<u>Viscosity</u>		
	<u>77°F</u>	<u>32°F</u>	<u>0°F</u>
Syltherm TM 444	20 cs ± .4	38 cs ± .8	72 cs ± 1
Uniroyal PAO-LV Polyalphaolefin	19 cs ± .4	60 cs ± 1	202 cs ± 4
Brayco 888 HF	40 cs ± .8	143 cs ± 3	488 cs ± 10

Table II-C-1. Low Temperature Fluid Viscosities

DOW CORNING® Q2-1162

Figure II-D-1. Density vs. Temperature, Q2-1162

DOW CORNING® Q2-1162

Figure II-D-2. Thermal Conductivity, Q2-1162

DOW CORNING® Q2-1162

HEAT CAPACITY

Figure II-D-3. Heat Capacity, Q2-1162

Figure II-D-4. Viscosity, Q2-1162

**LIQUID HEAT TRANSFER COEFFICIENT FOR
DOW CORNING® Q2-1162 H.T.L. INSIDE PIPES AND TUBES
(Turbulent Flow)**

Figure II-D-5. Heat Transfer Coefficient, Q2-1162

**PRESSURE DROP vs FLOW RATE
OF DOW CORNING® Q2-1162 H.T.L.
IN SCHEDULE 40 PIPE**

Figure II-D-6. Pressure Drop vs. Flow Rate, Q2-1162

DOW CORNING® Q2-1162
THERMAL DEGRADATION LOSSES

Figure II-D-7. Thermal Degradation Losses, Q2-1162

III. TOXICITY TESTING

A. FHSA Toxicological Testing

This testing was performed by the Health and Environmental Services Department at Dow Corning Corporation, Midland, Michigan. Assessments were made of household consumer hazards when tested according to methods promulgated by the Consumer Product Safety Commission in compliance with the Federal Hazardous Substances Act (FHSA) regulations.

Acute toxicity studies were conducted on the following fluids:

<u>Fluid Sample</u>	<u>Fluid Description</u>
A	Uniroyal PAO-LV Polyalphaolefin
B	Dow Corning® Q2-1162 Heat Transfer Liquid
C	Syltherm™ 444 Heat Transfer Liquid
D	Union Carbide Prestone II® Ethylene Glycol/Water 50:50 mixture by weight
E	Dow Chemical Ambitrol NTC® Propylene Glycol/Water 50:50 mixture by weight

The results of these studies, for all of these fluids, conducted in compliance with FHSA regulations are as follows:

<u>Test Conducted</u>	<u>Classification</u>
Acute Oral Toxicity	Not toxic and not highly toxic; LD ₅₀ > 15.4 gm/kg body weight.
Acute Dermal Toxicity	Not toxic and not highly toxic; LD ₅₀ > 2.0 gm/kg body weight.
Eye Irritation	Not an eye irritant
Skin Irritation	Not a skin irritant

Complete toxicological testing information is provided in Appendix A.

B. Biological Oxygen Demand Testing

A HACH Manometric BOD Apparatus, Model 2173 was used to determine the biological oxygen demand of each test fluid. Fresh secondary effluent from the City of Midland Waste Treatment Plant was used as seed in these tests. Test fluids were dispersed into the test vessels at a concentration of 1250 parts per million. Each concentration was run in triplicate for a total of five days. A five-day BOD on a glucose/glutamic acid standard was conducted concurrently. Results are reported as the ratio of parts of oxygen consumed per parts of test chemical as follows:

<u>Fluid Sample</u>	<u>Biological Oxygen Demand</u>
Uniroyal PAO-LV Polyalphaolefin	0.19 ± 0.09
Dow Corning® Q2-1162	No measurable demand
SylthermTM 444	No measurable demand
Ethylene Glycol/Water 50:50 mixture by weight	0.55 ± 0.01
Propylene Glycol/Water 50:50 mixture by weight	0.55 ± 0.01

The five day BOD of the glucose/glutamic acid standard solution was within acceptable limits for this procedure.

Biological Oxygen Demand tests were done as part of the FHSA testing and the results are provided as part of Appendix A.

IV. SOLAR COLLECTOR STAGNATION TESTING

A. Objectives

Solar collector stagnation testing was performed by the Physical Science Laboratory (PSL) at New Mexico State University (NMSU), Las Cruces, New Mexico on the following four heat transfer fluids.

<u>Test Loop</u>	<u>Fluid Description</u>
1	SylthermTM 444
2	Uniroyal PAO-LV Polyalphaolefin
3	Prestone II® Ethylene Glycol/NMSU Tap Water, 50:50 mixture by weight
4	Ambitrol NTC® Propylene Glycol/NMSU Tap Water, 50:50 mixture by weight

New Mexico State University was chosen for this project because their test facility is located in an area which has one of the highest annual solar insolation exposures in the United States. From previous experience it was estimated that a stagnation temperature of greater than 300°F could be achieved for approximately four to five hours on an average clear day. Consequently, the time necessary to complete the testing at elevated stagnation temperatures (in the desired 300°F to 375°F range) was relatively short.

The solar collector stagnation testing project objectives were identified as follows:

1. Evaluate the relative performance of these four heat transfer fluids in solar collectors by performing solar collector efficiency tests at PSL in conformance with the National Bureau of Standards proposed procedure NBSIR 74-635.
2. Determine the long term effects of elevated stagnation temperatures on these fluids in a multi-metal solar collector array by periodically removing and analyzing fluid samples.
3. Determine the effects these fluids have on solar collector metals by performing a metallurgical analysis of the absorber plates at the termination of the stagnation testing.

B. Test Loop Construction

Four separate closed loops were fabricated at PSL, each loop consisting of two flat plate solar collectors (one collector with a copper absorber and one collector with an aluminum absorber), pump, solenoid valve, brass expansion tank, pressure relief valve, sediment bowl and flowmeter, all interconnected with copper pipe. Ancillary items in each loop included a thermometer well, pressure taps and a fluid sampling valve. A test loop schematic diagram is provided in Figure IV-B-1.

The solenoid valve provided a positive shutoff to prevent thermosiphon fluid flow which would lower stagnation temperatures. A 24-hour timer opened this solenoid valve and started a Grundfos UP 26-64-F circulating pump in each loop for 15 minutes each morning to thoroughly mix the fluids. During this daily pumping period, fluid flow rates and fluid temperatures were recorded to give an indication of any scale build-up or other restrictions in the fluid channels. Glass sediment bowls served to trap any heavier precipitates or loose scale which was also visually observed at regular internals. Brass expansion tanks were sized to accommodate fluid expansion without loss of liquid or vapor, and to limit pressure build-up to values well below the collector design value. Grundfos UP 26-64-F variable head circulation pumps were used, each fitted with ethylene/propylene rubber seals with the exception of the pump used in Test Loop #2. It was necessary to replace this pump with another Grundfos UP 26-64-F containing Viton® seals in place of EP rubber seals because the Uniroyal PAO-LV Polyalphaolefin fluid deteriorated the EP rubber seals severely enough to cause pump leakage.

All soldered pipe joints in these test loops were fabricated by a qualified technician experienced in air conditioning techniques using 95/5 tin/antimony solder throughout. Prior to fluid filling, each loop was pressure tested for leaks with nitrogen to 100 psi, held at that pressure for at least 48 hours, and any system leaks repaired at that time. Throughout the life of the test, no leaks were encountered in any soldered joints.

Additionally, each test loop contained approximately 75 threaded pipe joints. Approximately 50 of these joints in each loop, which were furthest from the collectors, were sealed using Loctite® Pipe Sealant with Teflon (Loctite Corporation, Part No. 59231). The remaining 25 joints in each loop, which were nearest to the collectors, were sealed using Dow Corning® 730 Fluorosilicone Sealant. Prior to Loctite® seal application, all thread surfaces were thoroughly cleaned and sprayed with Locquic® Primer N (Loctite Corporation, Catalog No. 764-56). Prior to Dow Corning® 730 application, all thread surfaces were thoroughly cleaned and brushed with Dow Corning® 1200 Primer. Throughout the life of the test,

STAGNATION TEST LOOP SCHEMATIC - NMSU

1. RELIEF VALVE: 20 psi-oil, 100 psi ET.GLY/H₂O

24501
PSL/NMSU
3 JAN 78

Figure IV-B-1. Stagnation Test Loop Schematic - NMSU

only one of these threaded joints out of a total of 300 threaded joints developed a slight leak. This one leak was in a Loctite® sealed joint in Loop #1 which contained Syltherm™ 444 and the leak did not become evident until after eight months into the test.

The test loops were not cleaned or flushed with anything after assembly or before heat transfer fluid filling because the possibility of contaminating test fluids with residual cleaning material was considered too great to justify a soap and water or solvent cleaning operation.

C. Data Collection

An Esterline-Angus Data System PD2064 data logger with a Techtran Industries Model 8400 Data cassette tape recorder was used to monitor and record all data at pre-set intervals during the test periods (daylight hours). This data includes thermocouple measurements on the collector absorber surfaces, temperatures in the inlet and outlet thermometer wells, collector differential pressure, flow as measured by a venturi flow meter with differential pressure transducer, solar insolation, ambient temperature, wind velocity, expansion tank temperature and system gauge pressure.

All data recorded on tape cassettes was periodically dumped through the existing PSL collector test facility - computer interface and stored in a computer file for processing and print out of information such as accumulated time at various temperature levels. Existing PSL programs were available to compute collector efficiencies.

While most of the operation and data taking was automatic, a daily visual check was made on regular work days to check for leaks, proper operation of automatic systems and data logger, and any system sediment accumulation. After each approximately 200 hours of operation above 325°F in the copper collectors, a fluid sample was removed from each loop and shipped to Dow Corning for analysis.

D. Solar Collectors

The eight flat plate solar collectors used for this study were fabricated for Dow Corning Corporation by PPG Industries, Inc., Pittsburgh, Pennsylvania. Four of these collectors contained aluminum SOLAR-BOND® absorber plates and four contained copper SOLAR-BOND® absorber plates, all of which were supplied by Olin Brass, East Alton, Illinois.

Although the fluid channel designs were the same for all of the aluminum absorbers, these were a different fluid channel configuration than all of the copper absorbers. This difference in fluid channel design should not have had any effect on average maximum stagnation temperatures.

The aluminum absorber surfaces were coated with an anodized selective surface material of unknown composition by Alcoa, Pittsburgh, Pennsylvania and were light brown in color. The copper absorbers were coated with a black chrome over nickel selective surface material by Olympic Solar Plating Corporation, Canton, Ohio and were nearly black in color. Initial optical properties of the two absorber surfaces were determined by PPG as follows:

<u>Absorber Surface</u>	<u>α</u> <u>Absorptivity</u>	<u>ϵ</u> <u>Emissivity</u>
Aluminum - Anodized Coating	0.88	0.34
Copper - Black Chrome over Nickel	0.95	0.10

Because of the absorptivity and emissivity differences between the aluminum and copper surfaces noted above, Table IV-D-1 shows notably higher average maximum collector stagnation temperatures for the copper absorbers than for the aluminum absorbers. During some months, the average maximum stagnation temperatures were more than 100°F higher in the copper collectors than were the aluminum collectors.

Double glazed collectors were originally specified from PPG for this work, but unfortunately, the collectors that arrived at NMSU were all only single glazed and could not be conveniently or quickly modified to double glazing within the time constraints of this contract. Table IV-D-1 shows that average maximum temperatures for the better copper collectors were in the 335-365°F range and the aluminum collectors were in the 235-275°F range.

PPG estimates based on previous experience indicated that the solar collector stagnation temperatures being recorded (350°F average in the copper collectors) were about what would be expected based on the absorptivity, emissivity, single glazing and solar insolation (330 BTU/HR/FT²) conditions encountered. PPG also estimated that, had these collectors been double glazed, the stagnation temperatures of the copper unit could have been raised by possibly 60°F and those of the aluminum units by possibly 45-50°F.

Additionally, several of the collector glazings were improperly sealed around the glass/frame joint, one collector had a large amount of dirt inside the collector, one had a large amount of moisture condensate inside the collector, and four absorber plates buckled so severely during stagnation that the plates touched the glass covers. Figure IV-D-1 is a diagram showing the mounting position of the solar collectors on the PSL Building roof at NMSU as seen looking from the sun and these additional collector problems are identified.

AVERAGE MAXIMUM STAGNATION TEMPERATURES - °F

<u>Month</u>	SYLTHERMTM 444 LOOP #1		UNIROYAL PAO-LV LOOP #2		PRESTONE II®/WATER LOOP #3		AMBITROL NTC®/WATER LOOP #4	
	<u>Aluminum</u>	<u>Copper</u>	<u>Aluminum</u>	<u>Copper</u>	<u>Aluminum</u>	<u>Copper</u>	<u>Aluminum</u>	<u>Copper</u>
November	98.1	68.1	-	-	-	-	-	-
December	174.2	209.8	209.9	277.9	-	-	-	-
January	221.5	288.8	227.6	262.9	-	-	-	-
February	246.4	344.7	250.6	345.8	236.6	354.6	243.7	321.3
March	244.9	335.1	249.6	336.1	238.9	345.6	248.0	348.9
April	266.7	345.3	270.7	344.3	256.0	352.9	266.7	364.6
May	264.1	342.3	268.7	355.4	253.7	348.3	264.5	355.8
June	266.6	344.9	271.5	343.1	256.7	351.3	272.8	359.6
July	268.3	344.6	272.9	341.3	252.4	348.2	277.8	359.1
August	262.3	340.9	267.2	337.2	252.0	345.6	277.5	354.7
September	254.7	330.5	259.1	328.0	239.7	333.8	265.8	344.3
October	268.2	357.8	273.2	354.4	245.2	369.1	281.2	378.0
November	249.1	337.6	253.9	333.7	229.4	346.2	261.8	356.7

Table IV-D-1. Average Maximum Stagnation Temperatures - °F

SOLAR COLLECTOR ARRAY - NMSU

- Loop #1 Aluminum - Absorber plate buckled
- Loop #1 Aluminum - Hot spot on glazing
- Loop #1 Aluminum - Glazing poorly sealed
- Loop #1 Copper - O.K.
- Loop #2 Aluminum - Dust and dirt inside collector
- Loop #2 Copper - Moisture condensate inside collector
- Loop #3 Aluminum - Absorber plate buckled, touching glass
- Loop #3 Aluminum - Very hot spot on glazing
- Loop #3 Aluminum - Glazing poorly sealed
- Loop #3 Copper - O.K.
- Loop #4 Aluminum - Absorber plate buckled
- Loop #4 Aluminum - Hot spot on glazing
- Loop #4 Copper - Absorber plate buckled
- Loop #4 Copper - Hot spot on glazing

Figure IV-D-1. Solar Collector Array - NMSU

The poorly sealed collectors were patched using a butyl rubber sealant similar to that used at the PPG factory to seal the glazings. Problems with the dirt soiled collector and the collector with the moisture condensate inside were not considered serious enough to justify tampering with the collectors in order to correct the difficulties.

The absorber plate buckling problem required a unique, although only partial solution. This problem was considered serious because of the potential for thermal shock glass breakage caused by the hot spots in the center of the glazings where the absorber plates came very close to, or in some cases, touched the glass. In an attempt to reduce or eliminate these hot spots without dismantling the collectors, holes were drilled through the sides of each collector panel approximately at the collector middle. Then, 3/8 inch glass reinforced nylon rods were inserted through the holes between the glass and absorber plate to prevent close or intimate contact between the glass and metal surfaces. This action considerably reduced the glazing hot spots without creating any other problems. For the sake of consistency and uniformity, nylon rods were eventually inserted into all of the solar collectors. Figure IV-D-2 is a photograph of the collector array which clearly shows these nylon rods in position.

E. Collector Efficiency Testing

Initial collector efficiency determinations were made using NBS proposed procedure NBSIR 74-635. The collectors were south facing, fixed angle, and were not azimuth tracking. Efficiencies were run on Loop #1 collectors after re-sealing the butyl rubber defects, but before the absorber plate buckling and glazing hot spot problems were discovered and somewhat corrected. Subsequent collector efficiency determinations on these two collectors could not be accurately reproduced, even after insertion of the nylon spacer rods into the collector panels. Furthermore, reproducible efficiency determinations could not be achieved on either collector in Loop #2.

It was originally planned that after each 250 hours at stagnation conditions, a collector efficiency test would be performed and reported to Dow Corning. However, due to the numerous problems encountered with these collectors, especially the absorber plate buckling and glazing hot spot problem, it was decided that the 250 hour interval and final efficiency testing of these collectors would be ludicrous.

SOLAR COLLECTOR ARRAY - NMSU

25

Figure IV-D-2. Solar Collector Array - NMSU Photograph

F. Collector Stagnation - Fluids Analysis

The collector test loops were filled, initial unaged fluid samples taken, stagnation begun, and subsequent fluid samples taken on the following dates:

	Syltherm TM 444	Uniroyal PAO-LV	Prestone II/ Water	Ambitrol NTC®/Water
<u>Fluid Sample</u>	<u>Loop 1</u>	<u>Loop 2</u>	<u>Loop 3</u>	<u>Loop 4</u>
Loops filled	10/20/78	12/11/78	1/03/79	1/25/79
Initial Samples Taken	11/20/78	1/30/79	1/30/79	1/30/79
Stagnation Begun	11/28/79	12/12/78	1/30/79	1/31/79
200 Hour Samples	4/16/79	4/16/79	5/11/79	5/11/79
400 Hour Samples	7/05/79	7/05/79	7/05/79	7/05/79
600 Hour Samples	9/25/79	9/25/79	9/05/79	8/24/79
Final	11/07/79	11/07/79	11/07/79	11/07/79

Two separate four ounce samples of fluid were taken from each loop in fresh, clean polyethylene bottles. Thus, two separate, but identical batches of fluid samples were sent to Dow Corning on two different dates to insure against sample loss, spillage or breakage.

Stagnation times discussed in this study refer to those times recorded which were above 325°F in the copper (Cu) collectors, unless otherwise stated.

Table IV-F-1 shows total monthly stagnation times accumulated for temperatures greater than 225°F in the aluminum (Al) collectors and temperatures greater than 325°F in the copper (Cu) collectors. Total stagnation times above these temperatures for the entire stagnation test period are summarized as follows:

<u>Loop No.</u>	<u>Al Hours > 225°F</u>	<u>Cu Hours > 325°F</u>
1	1266.25	754.25
2	1324.50	726.75
3	1059.25	808.75
4	1228.00	868.25

MONTHLY COLLECTOR STAGNATION TIMES - HOURS

<u>Month</u>	<u>SYLTHERMTM 444</u> <u>LOOP #1</u>		<u>UNIROYAL PAO-LV</u> <u>LOOP #2</u>		<u>PRESTONE II@/WATER</u> <u>LOOP #3</u>		<u>AMBITROL NTC@/WATER</u> <u>LOOP #4</u>	
	<u>Aluminum</u> <u>> 225°F</u>	<u>Copper</u> <u>> 325°F</u>	<u>Aluminum</u> <u>> 225°F</u>	<u>Copper</u> <u>> 325°F</u>	<u>Aluminum</u> <u>> 225°F</u>	<u>Copper</u> <u>> 325°F</u>	<u>Aluminum</u> <u>> 225°F</u>	<u>Copper</u> <u>> 325°F</u>
December	40.75	0	29.50	11.25	0	0	0	0
January	44.00	3.25	53.00	3.25	0	0	0	0
February	73.25	59.00	82.50	58.00	50.50	65.50	74.75	23.25
March	98.75	71.25	110.25	69.75	77.00	84.00	108.00	89.00
April	138.50	82.75	145.00	80.00	123.75	88.75	137.75	106.00
May	136.25	76.75	141.50	74.75	122.50	80.50	126.75	92.00
June	158.00	91.75	162.25	86.00	149.00	97.50	154.25	111.75
July	139.75	84.25	144.00	77.75	130.00	86.00	144.75	99.50
August	138.75	81.25	143.50	74.50	127.25	85.50	150.50	98.00
September	133.50	81.25	139.25	75.25	124.50	83.00	147.75	100.25
October	142.75	107.00	150.50	101.50	134.50	118.75	158.75	127.75
November	22.00	15.75	23.25	14.75	20.25	19.25	24.75	20.75
TOTALS	1266.25	754.25	1324.50	726.75	1059.25	808.75	1228.00	868.25

Table IV-F-1. Monthly Collector Stagnation Times - Hours

Appendix B is a complete computer listing from New Mexico State University showing daily and monthly stagnation times in hours along with daily peak temperatures and monthly average maximum stagnation temperatures for each test loop.

Initially, the fluid samples were free of sediment, precipitate and foreign material and had the following appearance:

<u>Loop</u>	<u>Fluid</u>	<u>Appearance</u>
1	SylthermTM 444	Crystal clear liquid
2	Uniroyal PAO-LV	Crystal clear liquid
3	Prestone II®/ Water	Bright, "fluorescent" yellow, clear liquid
4	Ambitrol NTC®/ Water	Dark blue, clear liquid

Loop #1 SylthermTM 444 stayed crystal clear and free of particulate material throughout the test. Loop #2 Polyalpha-olefin acquired a slight brownish tinge after 200 hours of stagnation and remained this color for the duration of the test without getting any darker in color and remained free of particulate material. Loop #3 Prestone II®/Water remained yellow, clouded only very slightly and remained free of particulate material. Loop #4 Ambitrol NTC®/Water had changed from a dark blue to a dark tan color after only 200 hours of stagnation and small amounts of particulate matter in the sediment bowl was noted at that time. After further stagnation, the Ambitrol NTC®/Water fluid became only slightly darker, but the quantity of particulate material greatly increased.

System pressures in Loops #1 and #2 never exceeded 10 psig during the stagnation testing and Loop #3 never exceeded 20 psig. Loop #4, however, began a pressure buildup during July, 1979 after approximately 500 hours of stagnation, finally reading 90 psig on 8-2-79 after 525 hours of stagnation. This pressure suddenly and mysteriously subsided to less than 5 psig on 8-9-79 after 556 hours stagnation. A sample of the residual gas was taken from Loop #4 after this dramatic pressure loss and sent to Dow Corning for analysis. Results indicated that the gas sample was predominantly water vapor.

As will be seen later, the sudden loss of pressure in Loop #4 Ambitrol NTC®/Water was due to catastrophic corrosion failure of the aluminum absorber which created a perforation through the absorber wall, thus allowing the heat transfer fluid to escape.

All fluid samples from the test loops at NMSU were analyzed at Dow Corning for fluid physical properties as follows:

<u>Test</u>	<u>Method</u>
Refractive Index	CTM0002
Pensky-Martens Closed Cup Flash Point	CTM0021A
Viscosity @ 77°F (25°C)	CTM0004
Acid Number for Syltherm TM 444 & Uniroyal PAO-LV	CTM0051
pH for Prestone II®/Water & Ambitrol NTC®/Water	CTM0007
Metals - Atomic Emission Spectroscopy	CTM0368

Table IV-F-2 shows refractive index, closed cup flash, viscosity and metals analysis for all stagnation fluid samples. Table IV-F-3 shows acid number values for the non-aqueous SylthermTM 444 and Uniroyal PAO-LV Polyalphaolefin fluids and pH values for the aqueous Prestone II®/Water and Ambitrol NTC®/Water fluids.

The relatively low closed cup flash points observed for the glycol/water fluids taken from the collector test loops initiated some additional testing of these samples to substantiate Dow Corning's results and to help determine the probable cause for these flash points. 200 hour stagnation samples of the Prestone II®/Water and Ambitrol NTC®/Water fluids were sent to Union Carbide Corporation, Tarrytown Technical Center in Tarrytown, New York for analysis and 400 hour stagnation samples of the Prestone II®/Water and Ambitrol NTC®/Water fluids were sent to The Dow Chemical Company in Midland, Michigan for analysis.

The samples sent to Union Carbide were in the original four ounce polyethylene bottles as received from New Mexico State and contained only about 1/4 ounce of liquid. Union Carbide's testing consisted of a head space gas chromatographic analysis of the gas in the sample bottles between the liquid surface and the bottle cap. This analysis showed that both samples contain small amounts of aliphatic alcohols as follows:

Approximate Weight Percent Alcohols

	<u>Prestone II®/Water</u>	<u>Ambitrol NTC®/Water</u>
Methanol	0.0056	0.0055
Ethanol	0.0006	0.0007
Isopropanol	0.0096	0.0081
n-Propanol	0.224	0.0027

COLLECTOR STAGNATION - FLUIDS ANALYSIS - PART A				
	REFRACTIVE INDEX	VISCOSITY @ 77°F	CLOSED CUP FLASH POINT °F	METALS PPM
<u>SylthermTM 444</u>				
Unaged	1.4014 ± .0002	19.0 cs ± .4	472 ± 10	Al-2.2
200 Hours	1.4014 ± .0002	19.0 cs ± .4	422 ± 10	Nil
400 Hours	1.4010 ± .0002	19.0 cs ± .4	370 ± 10	Nil
600 Hours	1.4014 ± .0002	18.7 cs ± .4	325 ± 10	Nil
754 Hours	1.4011 ± .0002	18.9 cs ± .4	327 ± 10	Nil
<u>Uniroyal PAO</u>				
Unaged	1.4508 ± .0002	19.0 cs ± .4	275 ± 5	Nil
200 Hours	1.4505 ± .0002	20.0 cs ± .4	272 ± 5	Nil
400 Hours	1.4499 ± .0002	19.0 cs ± .4	270 ± 5	Al ~16
600 Hours	1.4506 ± .0002	18.5 cs ± .4	270 ± 5	Nil
727 Hours	1.4508 ± .0002	18.6 cs ± .4	265 ± 5	Nil
<u>Prestone II®/Water</u>				
Unaged	1.3816 ± .0002	3.0 cs ± .1	149 ± 5	Ca ~20, P >200, Al ~10 Na >200
200 Hours	1.3816 ± .0002	3.0 cs ± .1	146 ± 5	P >200, Na >200
400 Hours	1.3811 ± .0002	3.1 cs ± .1	145 ± 5	Al ~10, P >200, Na >200
600 Hours	1.3822 ± .0002	3.1 cs ± .1	147 ± 5	Al ~5, P >200, Na >200
809 Hours	1.3823 ± .0002	3.1 cs ± .1	138 ± 5	Al <5, P >200, Na >200
<u>Ambitrol NTC®/Water</u>				
Unaged	1.3877 ± .0002	5.0 cs ± .1	124 ± 5	Al ~30, P >400, Sn ~20
200 Hours	1.3879 ± .0002	5.0 cs ± .1	142 ± 5	P>400, Na Tr <100
400 Hours	1.3873 ± .0002	4.9 cs ± .1	144 ± 5	Al ~150, P >400, Cu ~100
600 Hours	1.3737 ± .0002	3.2 cs ± .1	136 ± 5	Sn 7.3, P >200, Al 19
868 Hours	1.3884 ± .0002	5.1 cs ± .1	131 ± 5	Al 200, Sb <5, Cu 6.4 P >200, Sn 140

Table IV-F-2. Collector Stagnation - Fluids Analysis - Part A

COLLECTOR STAGNATION - FLUIDS ANALYSIS - PART B

		BCP ACID NUMBER	pH AT 75°F
<u>SylthermTM 444</u>			
Unaged	N.D.	$<0.005 \pm 0.001$	
200 Hours	N.D.	$<0.005 \pm 0.001$	
400 Hours	Trace	$\sim 0.005 \pm 0.001$	
600 Hours		0.006 ± 0.001	
754 Hours		0.006 ± 0.001	
<u>Prestone II®/Water</u>			
Unaged			9.27 ± 0.1
200 Hours			8.79 ± 0.1
400 Hours			8.70 ± 0.1
600 Hours			8.70 ± 0.1
809 Hours			8.90 ± 0.1
<u>Uniroyal PAO-LV</u>			
Unaged		0.015 ± 0.001	
200 Hours		0.025 ± 0.001	
400 Hours		0.035 ± 0.001	
600 Hours		0.006 ± 0.001	
727 Hours		0.006 ± 0.001	
<u>Ambitrol NTC®/Water</u>			
Unaged			8.77 ± 0.1
200 Hours			8.68 ± 0.1
400 Hours			8.72 ± 0.1
600 Hours			9.70 ± 0.1
868 Hours			11.00 ± 0.1

Table IV-F-3. Collector Stagnation - Fluids Analysis - Part B

Union Carbide does not believe there is sufficient alcohol present to account for the reported closed cup flash points of 147°F for the Prestone II®/Water sample and 123°F for the Ambitrol NTC®/Water sample. It must be noted, however, that the particular samples tested by Union Carbide had been un-capped and exposed to atmospheric air on several occasions before the chromatographic analysis was done and that in all likelihood, these samples contained less than representative amounts of volatile alcohols and other volatile components.

The Dow Chemical Company gas chromatography mass spectrometric analysis confirmed only the presence of propyl alcohol at less than 100 parts per million, or less than 0.01% in the Prestone II®/Water sample.

G. Absorber Plate Metals Corrosion Analysis

At the termination of the stagnation testing on 11/7/79, the absorber plates were immediately removed from the solar collector panels and stenciled on the backs using white paint to indicate loop numbers, collector numbers, fluid outlets, absorber metals and areas where glazing hot spots were observed. Without flushing or other cleaning of the fluid channels, the absorber plates were shipped via air freight to Olin Corporation, Metals Research Laboratories, New Haven, Connecticut for metals corrosion analysis.

After arrival at Olin, the absorber plates were flushed clean of residual heat transfer fluid using the appropriate cleaning solutions, thoroughly dried, and analyzed for internal corrosion using the metallography methods as follows:

- Radiography
- Visual Examination
- SEM - Scanning Electron Microscope

Radiography consisted of the X ray photography of six critical areas of each absorber plate, concentrating on the header sections, in an attempt to locate and identify anomalies. If no anomalies are identified on these X ray photographs, no further examination is necessary.

The visual examination entailed the observation of questionable areas of the absorber plates as shown on the X ray photographs both before and after cutting open these sections to look for evidence of local attack, corrosion, pitting, etc.

The scanning electron microscope was then used to further study the type and extent of any anomalies previously identified.

Table IV-G-1 shows the results of the radiographic analysis. Only the aluminum and copper absorber plates from the Ambitrol NTC® propylene glycol/water system showed evidence of corrosion.

ABSORBER PLATE RADIOGRAPHIC ANALYSIS

<u>Fluid System</u>	<u>Aluminum Absorber</u>	<u>Copper Absorber</u>
SylthermTM 444 Silicone	No anomalies observed	No anomalies observed
Uniroyal PAO-LV Polyalphaolefin	No anomalies observed	No anomalies observed
Prestone II®/Water (Ethylene glycol/water)	No anomalies observed	No anomalies observed
Ambitrol NTC®/Water (Propylene glycol/water)	Inlet and outlet areas pitted and corroded-deposits	Questionable deposits

Table IV-G-1. Absorber Plate Radiographic Analysis

Visual examination and SEM analysis of the aluminum absorber from the Ambitrol NTC® propylene glycol/water system showed that crevice corrosion and pitting corrosion had caused the perforations through the metal walls. The copper absorber plate from the Ambitrol NTC® propylene glycol/water system, although not corroded or pitted, did show evidence of several areas where foreign material had deposited onto the copper.

A summary of this metals corrosion study done by Olin Corporation is included as Appendix C.

V. FLAMMABILITY TESTING

A. Fire Hazard Tests

Five solar heat transfer fluids were tested to compare their fire hazard characteristics. Fluids tested included two silicones, two glycols and a synthetic hydrocarbon described as follows:

<u>Fluid Sample</u>	<u>Description</u>
A	Uniroyal PAO-LV Polyalphaolefin (hydrocarbon)
B	Dow Corning® Q2-1162 Heat Transfer Liquid (Experimental Silicone)
C	Syltherm™ 444 Heat Transfer Liquid (Commercial Silicone)
D	Union Carbide Prestone II® Ethylene Glycol, concentrated, undiluted
E	Dow Chemical Ambitrol NTC® Propylene Glycol, concentrated, undiluted

Small scale tests were run to determine ignition properties, heats of combustion, relative fire size, smoke density, and fire behavior of construction materials saturated with fluid.

Large scale pool tests were performed to determine convective and radiant heat release trends, extent of burning, and ease of extinguishment. Fire hazard characteristics obtained from large scale tests are expected to be suggestive of what would be found during an actual pool fire situation.

B. Summary of Fire Hazards

The tests performed in this study indicate the relative rankings in the various fire hazards criteria as follows:

1. Ease of Ignition

Ambitrol NTC® > Prestone II® > DC® Q2-1162 > Syltherm™ 444

2. Small Scale Fire Intensities

PAO-LV > Ambitrol NTC® > Prestone II® > DC® Q2-1162 > Syltherm™ 444

3. Rate of Heat Release

PAO-LV > Ambitrol NTC® > DC® Q2-1162 > Prestone II® > SylthermTM 444

4. Smoke Density (D_s)

Smoldering Condition Maximum Smoke Density

PAO-LV > DC® Q2-1162 > Ambitrol NTC® > Prestone II® > SylthermTM 444

Smoldering, $D_s = 16$ (Chamber Visibility - 10 feet)

Ambitrol NTC® > Prestone II® > PAO-LV > DC® Q2-1162 > SylthermTM 444

Flaming Condition Maximum Smoke Density

DC® Q2-1162 > SylthermTM 444 > PAO-LV > Ambitrol NTC® ~ Prestone II®

Flaming, $D_s = 16$ (Chamber Visibility - 10 feet)

DC® Q2-1162 > PAO-LV > SylthermTM 444 > Ambitrol NTC® ~ Prestone II®

5. Ease of Extinguishment

Prestone II® > Ambitrol NTC® > SylthermTM 444 > DC® Q2-1162 > PAO-LV

The silicones have the highest thermal and oxidative stability and the best resistance to ignition. Large pool fires indicate that the silicones and the ethylene glycol have the lowest total heat release and lowest rates of heat release. The silicones are moderate in ease of extinguishment relative to the organics tested. Release of amorphous silica during burning conditions causes the silicones to perform rather poorly in the NBS smoke chamber tests. However, silicones perform well under smoldering conditions.

Significant fire hazard properties are summarized in Tables 14 and 16 of the fire testing report which is Appendix D of this report.

Videotapes of the large scale pool burns and extinguishment tests referred to in Appendix D are on file at Dow Corning Corporation.

C. Materials Compatibility Evaluation

In conjunction with the flammability testing performed by the Research Laboratories at Dow Corning, the Technical Service and Development Laboratories evaluated the five heat transfer fluids to determine what effects these fluids have on common residential building materials. These building materials are the same as those used in the small scale fire hazards testing to determine the fire behavior of various construction materials saturated with fluids.

Separate eight ounce french square bottles were filled approximately two thirds full with each heat transfer fluid identified as follows:

<u>Fluid Sample</u>	<u>Fluid Description</u>
A	Uniroyal PAO-LV Polyalphaolefin (Hydrocarbon)
B	Dow Corning® Q2-1162 Heat Transfer Liquid (Experimental Silicone)
C	Syltherm™ 444 Heat Transfer Liquid (Commercial Silicone)
D	Union Carbide Prestone II® Ethylene Glycol/Water, 50:50 mixture by weight
E	Dow Chemical Ambitrol NTC® Propylene Glycol/Water, 50:50 mixture by weight

The building materials are identified and described as follows:

<u>Material Sample</u>	<u>Material Description</u>
1	Plywood Sheet - 1/4 inch, 3 ply
2	Wood Paneling - 3/16 inch, 3 ply finished one side
3	Composition Ceiling Tile - 1/2 inch, with a white finish on one side
4	Asphalt Roof Shingle - 1/8 inch, crushed rock one side
5	Fiberglas Ceiling Panel - 1/2 inch, white coating on one side
6	Vinyl Floor Tile - 1/6 inch

Additional lumber and ceiling building materials were evaluated in place of any rug materials simply because a carpet sample representative of what would typically be found in residential construction could not be identified due to the many different varieties, styles and weaves of carpet materials available.

Individual samples of each building material measuring one half inch wide by five inches long were placed in the separate fluid sample bottles. The bottles were then tightly capped and allowed to sit undisturbed without shaking or agitating.

Initially, all samples were unaffected by the fluids with the exception of sample A-4, the Uniroyal PAO-LV/Asphalt shingle. This shingle sample was slightly dissolved, and slightly discolored the polyalphaolefin to a brown color.

After one day of immersion in the fluids, all material samples were unaffected with the exception of sample A-4 as noted above.

After one week of immersion in the fluids, the following observations were made:

<u>Sample</u>	<u>Description</u>
A-4	Uniroyal PAO-LV/Asphalt Shingle - more shingle dissolving, more dark color to the fluid
D-4	Prestone II® Ethylene Glycol: Water/Asphalt Shingle - Shingle not dissolving, but softening and bending
E-4	Ambitrol NTC® Propylene Glycol: Water/Asphalt Shingle - Shingle not dissolving, but softening and bending

After two weeks of material immersion in the fluids, the following, final observations were made:

<u>Sample</u>	<u>Description</u>
A-4	Uniroyal PAO-LV/Asphalt Shingle - Slightly more shingle dissolving, slightly more dark color to the fluid
D-1	Prestone II® Ethylene Glycol:Water/Plywood Sheet - Badly darkening plywood, fluid color turned from yellow to amber
D-2	Prestone II® Ethylene Glycol:Water/Wood Paneling - Badly darkening panel to almost black

- D-4 Prestone II® Ethylene Glycol:Water/Asphalt Shingle -
not dissolving, but softening and bending
- E-1 Ambitrol NTC® Propylene Glycol:Water/Plywood Sheet -
Badly darkening plywood, fluid color turned from blue
to green
- E-2 Ambitrol NTC® Propylene Glycol:Water/Wood Paneling -
Badly darkening paneling to almost black
- E-3 Ambitrol NTC® Propylene Glycol:Water/Ceiling Tile -
Fluid color turned from blue to dark green, tile
unchanged
- E-4 Ambitrol NTC® Propylene Glycol:Water/Asphalt Shingle -
Shingle not dissolving, but softening and bending

The two silicone fluids did not adversely affect any of the building materials at any time during this evaluation. Also, the silicone fluids were not discolored, clouded or in any way affected by any of the building materials.

VI. ANALYSIS OF DATA

A. Physical Data

Closed cup flash points observed for Prestone II®/Water and Ambitrol NTC®/Water fluids taken from the test loops at New Mexico State University were in a dangerously low range for the intended solar application. Closed cup flash points for the Uniroyal PAO-LV Polyalphaolefin fluid were relatively low initially and remained low throughout the stagnation period. Syltherm™ 444 had by far the highest closed cup flash point initially as well as at the end of the stagnation test, but did drift lower with increasing stagnation time. However, no increase in system pressure was ever observed, indicating that any volatile materials present did not increase fluid vapor pressure.

Initial low temperature viscosities of Uniroyal PAO-LV Polyalphaolefin were nearly three times higher than those of Syltherm™ 444. Both of the glycol/water fluids have very acceptable low temperature viscosities, however, their pour points are much higher than the silicone or polyalphaolefin fluids. None of the fluids showed any appreciable viscosity change during the stagnation period with the exception of the Ambitrol NTC®/ Water fluid which did drop in viscosity at the approximate time of the aluminum absorber plate failure due to corrosion.

The relatively high vapor pressures of glycol/water fluids are of concern because this property will require some special design considerations which must be taken into account for a pressure system. Syltherm™ 444 and Uniroyal PAO-LV Polyalphaolefin vapor pressures are very low and therefore create no pressure concerns. However, precautions must be taken in system design to allow adequate space for silicone and polyalphaolefin thermal expansion.

Refractive index properties were not affected by thermal stagnation for any of the four fluids over the life of the test.

Acid numbers for Syltherm™ 444 and Uniroyal PAO-LV Polyalphaolefin remained essentially unchanged over the life of the stagnation test.

The pH of Prestone II®/Water fluid was essentially unchanged over the life of the test, but the Ambitrol NTC®/Water fluid showed catastrophic changes in pH at approximately the time of the aluminum absorber plate catastrophic corrosion failure.

Fluids metals analysis showed no metals present in either the Syltherm™ 444 or Uniroyal PAO-LV Polyalphaolefin. The Prestone II®/Water fluid did contain small amounts (5-10 ppm) of aluminum during thermal stagnation. The Ambitrol NTC®/Water

fluid contained substantial amounts of both aluminum and copper during the stagnation period, indicative of a metals corrosion process taking place. Additionally, the Ambitrol NTC®/Water fluid on final analysis contained a fairly large amount of tin and a small amount of antimony.

B. Toxicological and BOD

Results of Dow Corning's toxicological testing for all fluids showed that none of these fluids are toxic or highly toxic with regard to acute oral and acute dermal toxicity according to FHSA classification. Additionally, according to FSHA classification, none of these fluids so tested can be classified as eye or skin irritants.

The biological oxygen demand was unfavorably high for the Prestone II®/Water and Ambitrol NTC®/Water solutions, next highest for Uniroyal PAO-LV Polyalphaolefin and very favorably low (not measurable) for Syltherm™ 444.

C. Metals Corrosion

Analysis of solar collector absorber plates after stagnation should show no signs of internal metal corrosion in any of the absorbers which contained Syltherm™ 444 silicone, Uniroyal PAO-LV Polyalphaolefin or Prestone II® ethylene glycol/water. The aluminum absorber which contained Ambitrol NTC® propylene glycol/water showed evidence of metal pitting and crevice corrosion that eventually caused perforations through the metal. The copper absorber in the Ambitrol NTC® propylene glycol/water system did not show signs of corrosion, but did show several areas where foreign material had deposited. This analysis indicates that, of the four heat transfer fluids studied, only the Ambitrol NTC® propylene glycol/water fluid is unacceptable for mixed metal solar systems.

D. Flammability and Materials Compatibility

No one fluid can be recommended as safest with respect to all fire hazard characteristics under all conditions of use. The glycol/water mixtures show the lowest degree of fire hazard. However, in a spill or rupture condition during use, water would be expected to evaporate from hot fluid leaving a concentrated glycol. Under these conditions, Syltherm™ 444 silicone exhibits the best overall fire safety performance.

In choosing a fluid for a solar heat transfer application, the particular location of the equipment must be considered and all applicable fire hazard characteristics must be weighed with respect to the intended use and potential modes of failure and ignition.

With regard to materials compatibility, Ambitrol NTC®/Water followed closely by Prestone II®/Water fluids were determined to be the most damaging to common building materials primarily due to staining, discoloring and warping. Uniroyal PAO-LV was found to be damaging to common asphalt shingles because of its dissolving effect on asphalt. SylthermTM 444 was determined to be essentially non-damaging to all building materials tested because SylthermTM 444 did not color, discolor, corrode, warp or dissolve any building material.

VII. COST EFFECTIVENESS

A. System First Cost

The system first cost is defined as the total cost of that system as installed and ready to operate. Although a cost analysis could be performed for each of the many types of existing systems, a well known and successful domestic hot water system was chosen for this financial analysis. The general configuration of the system was established from the HUD document Installation Guidelines for Solar Domestic Hot Water Systems, April, 1979.

Changes in the system's components were made for each of the four fluids evaluated in order to take maximum advantage of the fluid properties shown in Table II-B-1, and to guard against premature failure of the system and fluid according to these fluid properties. A discussion of these changes and the reasons for them are detailed below.

1. Ambitrol NTC® Propylene Glycol/Water System

A getter was added to insure against any corrosion failures of the collectors. This has been standard practice in systems containing aluminum absorber plates to prevent metal wastage and fluid degradation and is recommended for copper systems as well. A single wall heat exchanger was utilized due to the low order of toxicity determined for Ambitrol NTC® propylene glycol/water fluid. A stainless steel pump is required to prevent corrosion of the pump body and pump impeller over the life of the system.

2. Prestone II® Ethylene Glycol/Water System

A getter column was also added to this system. Although there is less of a need for it in this system than in the Ambitrol NTC® propylene glycol/water system, its presence is still strongly indicated. A double wall heat exchanger was utilized due to the toxic nature of the fluid as warned by the glycol manufacturer. Again, a stainless steel pump was designed into the system as per the manufacturer's recommendations.

3. Uniroyal PAO-LV Polyalphaolefin System

Organic heat transfer fluids have lower specific heat values than glycol/water mixtures. Therefore, in order to keep the temperature differential across the collector within acceptable limits, the flow rate of the polyalphaolefin heat transfer fluid must be increased. Doing this results in higher pressure drops unless the pipe size is increased. Experience has shown that moving from 1/2 inch pipe to 3/4 inch pipe in a system of this type will alleviate this problem. Also, a larger circulating pump is required to move more fluid and because no water is present, a carbon steel pump can be utilized at a cost savings. The larger pump size is required

also to overcome the extremely high viscosity exhibited by this fluid at temperatures less than 20°F. Because this is a hydrocarbon fluid, a double wall heat exchanger was designed into the system.

4. Syltherm™ 444 Silicone System

Larger piping and a larger horsepower pump are required for the same reasons as for the polyalphaolefin system. Again, a carbon steel pump can be utilized. The pressure relief valve can be eliminated because the Syltherm™ silicone fluid exhibits negligible vapor pressure at the temperatures encountered in flat plate collector systems. Also, the air eliminator may be omitted from the system because the fluid is not affected by atmospheric oxygen at the temperatures anticipated. A single wall heat exchanger is satisfactory for this system due to the low order of toxicity of the silicone fluid.

Table VII-A-1 lists the number of components in each system and Table VII-A-2 lists the general specifications for these parts. Table VII-A-3 shows the November, 1979 recommended contractor trade price for each of these components as obtained from the manufacturers via telephone on that date. In a few instances, for some minor components, it was necessary to estimate prices from retail catalogs. Any discrepancies between the estimated prices and actual prices is very minor. The prices indicated generally include a 30 percent markup from the wholesaler cost. The manufacturers would not reveal their exact markups for competitive reasons.

The aqueous systems require approximately three gallons of a 50:50 mixture of a glycol/water, or 1.5 gallons of concentrated, undiluted glycol. The polyalphaolefin and silicone systems require 3.5 gallons of concentrated, undiluted fluid, due to the larger system pipe diameters specified for these fluids. From this information, the heat transfer fluid costs were established as follows:

<u>Fluid</u>	<u>Quantity</u>	<u>Dollars/Gal.</u>	<u>Fluid Cost</u>
Ambitrol NTC®	1.5 gal.	6	\$ 9
Prestone II®	1.5 gal.	3	\$ 4
Uniroyal PAO-LV	3.5 gal.	8	\$28
Syltherm™ 444	3.5 gal.	28	\$98

The total materials cost listed on Table VII-A-3 shows that, if the properties of the fluids are considered in the design of the system, there is little difference in the total components cost for the complete system.

SYSTEM COMPONENTS LIST BY ITEM

Part Name	Ambitrol NTC® Propylene Glycol	Prestone II® Ethylene Glycol	Uniroyal PAO-LV Fluid	Syltherm™ 444 Silicone Fluid
Collectors	3	3	3	3
Water Heater	1	1	1	1
Preheater Tank	1	1	1	1
Circulator Pump	1	1	1	1
Differential Controller	1	1	1	1
Air Vents	2	2	2	1
Pressure Gauge	1	1	1	1
Pressure Relief Valve	1	1	1	0
Check Valve	1	1	1	1
Globe Valve	1	1	1	1
Strainer	1	1	1	0
Getter	1	1	0	0
Air Eliminator	1	1	1	0
Expansion Tank	1	1	1	1
Boiler Drains	4	4	4	4
Gate Valves	5	5	5	5
Thermometer Wells	2	2	2	2
Mixing Valve	1	1	1	1
T-P Relief Valve	2	2	2	2
Thermometers	2	2	2	2
Piping (ft)	100	100	100	100
Heat Transfer Fluid (gal)	3	3	3.5	3.5
Total No. of Parts*	33	33	32	28

*Excludes gallons of heat transfer fluid and pipe and fittings

Table VII-A-1. System Components List by Item

SYSTEM COMPONENTS LIST BY TYPE

<u>Part Name</u>	<u>Ambitrol NTC® Propylene Glycol</u>	<u>Prestone II® Ethylene Glycol</u>	<u>Uniroyal PAO-LV Polyalphaolefin</u>	<u>Syltherm™ 444 Silicone</u>
Collectors	S.G./S.S./Glass Copper absorber	S.G./S.S./Glass Copper absorber	S.G./S.S./Glass Copper absorber	S.G./S.S./Glass Copper absorber
Water Heater	Gas/40 gal/glass	Gas/40 gal/glass	Gas/40 gal/glass	Gas/40 gal/glass
Preheater Tank (heat exchanger)	120 gal/stone sw 20 ft.	120 gal/stone sw 20 ft.	120 gal/stone sw 20 ft.	120 gal/stone sw 20 ft.
Circulator Pump	1/20th hp	1/20th hp	1/12th hp	1/12th hp
Differential Controller	Standard	Standard	Standard	Standard
Air Vents	Amtrol 701	Amtrol 701	Amtrol 701	Amtrol 701
Pressure Gauge	Marsh J0046	Marsh J0046	Marsh J0046	Marsh J0046
Pressure Relief Valve	Standard	Standard	Standard	None
Check Valve	Standard	Standard	Standard	Standard
Globe Valve	Standard	Standard	Standard	Standard
Strainer	Standard	Standard	Standard	None
Getter	Standard	Standard	None	None
Air Eliminator	Extrol	Extrol	Extrol	None
Expansion Tank	Extrol	Extrol	Extrol	Bladderless
Boiler Drain Valve	Standard	Standard	Standard	Standard
Gate Valves	Standard	Standard	Standard	Standard
Thermometer Wells	Standard	Standard	Standard	Standard
Mixing Valve	Standard	Standard	Standard	Standard
T-P Relief Valve	Standard	Standard	Standard	Standard
Thermometers	Standard	Standard	Standard	Standard
Piping & Fittings	1/2"	1/2"	3/4"	3/4"
Heat Transfer Fluid	Ambitrol NTC®	Prestone II®	Uniroyal PAO-LV	Syltherm™ 444

S.G. = Single glazed; S.S. = Selective surface; sw = Single wall; dw = Double wall

Table VII-A-2. System Components List by Type

SYSTEM COST ANALYSIS

<u>Part</u>	<u>Ambitrol NTC® Propylene Glycol</u>	<u>Prestone II® Ethylene Glycol</u>	<u>Uniroyal PAO-LV Polyalphaolefin</u>	<u>Syltherm™ 444 Silicone</u>
Collectors	\$ 990.00	\$ 990.00	\$ 990.00	\$ 990.00
Water Heater	109.00	109.00	109.00	109.00
Preheater Tank	450.00	479.95	479.95	449.45
Circulator Pump	188.00	188.00	120.00	120.00
Differential Controller	79.35	79.35	79.35	79.35
Air Vents	25.42	25.42	25.42	12.71
Pressure Gauge	8.00	8.00	8.00	8.00
Pressure Relief Valve	12.32	12.32	12.32	---
Check Valve	11.30	11.30	13.75	13.75
Flow Control Valve	4.10	4.10	6.50	6.50
Strainer	12.00	12.00	18.80	---
47 Getter	29.10	29.10	---	---
Air Eliminator	17.08	17.08	17.08	---
Expansion Tank	15.61	15.61	15.61	15.61
Boiler Drain Valves	8.24	8.24	8.24	8.24
Gate Valves	43.55	43.55	45.00	45.00
Thermometer Wells	10.00	10.00	10.00	10.00
Thermometers	10.50	10.50	10.50	10.50
Mixing Valve	13.48	13.48	13.48	13.48
T-P Relief Valve	24.64	24.64	24.64	24.64
Piping and Fittings**	97.60	97.60	133.00	133.00
Heat Transfer Fluid	9.00	4.50	28.00	98.00
Total Materials Cost	\$2,168.29	\$2,193.74	\$2,168.64	\$2,147.23

**Based on 20 mixed fittings and 100 ft. of pipe

Table VII-A-3. System Cost Analysis

The labor cost to install a system of this type varies depending on the geographical location, unionization, and wage scales. For the purposes of this analysis, it was assumed that the skilled craftsman cost is \$10.00 per hour gross for all systems, that it would take two men three days to install the system and that the elimination of five parts in the silicone system would save one man hour of installation time. These estimates were made after talking with a plumber in Ann Arbor, Michigan, a solar installer in Detroit, Michigan, and two solar equipment manufacturers, one in Big Rapids, Michigan, and one in Mystic, Connecticut. The time in hours estimated to complete an installation and the labor cost based on the above criteria are as follows:

<u>System</u>	<u>Hours</u>	<u>Cost</u>
Ambitrol NTC®	48	\$480
Prestone II®	48	\$480
Uniroyal PAO-LV	48	\$480
Syltherm™ 444	47	\$470

The profits desired by the contractor for his services also vary depending on a number of market factors. For the purpose of this analysis, a 25 percent profit margin and a ten percent overhead cost on the total contractor cost was utilized.

The tax credits available for the customers also vary with geographic location. Therefore, only the federal tax credit was used in this financial analysis. All systems are built in a manner that qualified them for the federal tax credit.

Table VII-A-4 shows the final installed cost to the customer for each system based on the criteria selected above. There is no essential difference in installed cost when standard markups and overheads are applied equally to all systems.

B. Fluid Maintenance Costs

The cost of solar heat transfer fluid maintenance must be carefully considered in the system life cost analysis. For example, test data has shown that the Ambitrol NTC® propylene glycol/ water and Prestone II® ethylene glycol/water fluids exhibit a useful life less than the 25 year system design life. The testing also indicates that if proper fluid maintenance is not performed before the fluids reach their end point, the life of the system can be drastically reduced due to premature failure.

Such fluid testing was done under the severe conditions of accelerated collector stagnation. The number of hours of stagnation will vary greatly from system to system and is a

NET INSTALLED CUSTOMER COST
(Rounded to Whole Dollars)

<u>Item</u>	<u>Ambitrol NTC® System</u>	<u>Prestone II® System</u>	<u>Uniroyal PAO-LV System</u>	<u>Syltherm™ 444 System</u>
Materials	2168	2194	2169	2147
Labor	480	480	480	470
Overhead (10% of M&L)	265	267	265	262
Profit Margin (33% of M&L)	874	882	874	864
Total Sale Price	3787	3823	3788	3743
Less Tax Credit*	957	965	958	949
Net Cost	2830	2858	2830	2794

*30% of first \$2,000 of total sale price + 20% of balance

Table VII-A-4. Net Installed Customer Cost

function of end-use, geographical location, and dwelling occupancy. For the purposes of this analysis, it was estimated that over the course of a year, a system of this type would stagnate an average of 100 hours per year or four hours per day for 25 days. This figure is debatable, but definitely on the conservative side for most locations.

The assumption was made that all fluids could be made to work satisfactorily if their shortcomings were properly designed for. One exception is the Ambitrol NTC® propylene glycol/water fluid which is definitely unacceptable for any mixed metal system which is not subjected to biyearly maintenance over the entire system life. The projected maintenance schedule adapted for the four fluids is as follows:

<u>System</u>	<u>Maintenance Time Period</u>
Ambitrol NTC®	2 years
Prestone II®	3 years
Uniroyal PAO-LV	10 years
SylthermTM 444	None

The propylene glycol/water maintenance schedule above is typically advised by most solar equipment manufacturers. Fluid testing indicates that more frequent changing is indicated under high stagnation conditions to protect the solar system.

The ethylene glycol/water maintenance schedule is one year longer than typically recommended by most solar manufacturers and a leading ethylene glycol producer. The stagnation testing showed that the life of Prestone II® ethylene glycol/water is better than the two year maintenance schedules presently being used. For the purpose of this cost analysis, a three year maintenance schedule was used for Prestone II®.

There is no recommended life data available for polyalpha-olefin fluids in solar systems. Because it is a hydrocarbon fluid that is being stagnated above its distillation point, some buildup of high boiling, high molecular weight materials is expected which may affect the heat transfer properties of the fluid. Five year maintenance plans would be indicated in areas of high stagnation, however, a ten year plan most likely would be suitable under average conditions.

Solar collector stagnation testing, laboratory testing and many years of previous field experience have shown that the life of the SylthermTM 444 silicone fluid will exceed the 25 year solar system design life that was chosen for this analysis and that no silicone fluid maintenance is required.

The cost of fluid maintenance is a function of labor and materials. Although the material costs are relatively low, the cost of labor required to change the fluid is relatively high. Fluid maintenance is definitely a professional job, particularly in a residential installation.

While the amount of labor required for fluid changing will vary, it is unlikely that any professional service company would accept the responsibility of performing the task for less than the cost of one half of a day or four hours labor. If the labor is calculated at \$10.00 per hour and no allowance is made for overhead or profit, then a minimum figure which compares favorably with appliance home service calls for any major appliance is seen. Therefore, an estimate of \$40.00 for this service, plus the cost of the fluid, is used in this analysis. All costs are in 1979 dollars and are tabulated in Table VII-B-1.

PROJECTED FLUID MAINTENANCE COSTS
(Rounded to Whole Dollars)

<u>Year</u>	<u>Ambitrol NTC® PG</u>	<u>Prestone II® EG</u>	<u>Uniroyal PAO-LV PAO</u>	<u>Syltherm™ 444 Silicone</u>
2	49			
3		44		
4	49			
5				
6	49	44		
7				
8	49			
9		44		
10	49		52	
11				
12	49	44		
13				
14	49			
15		44		
16	49			
17				
18	49	44		
19				
20	49		52	
21		44		
22	49			
23				
24	49	44		
25	25	15	26	
	<u>613</u>	<u>367</u>	<u>130</u>	<u>0</u> (prorated life)

Table VII-B-1. Projected Fluid Maintenance Costs

C. Catastrophic Incident Potential

The potential for a catastrophic failure incident due to fluid failure was examined. A catastrophic incident was defined as a failure that resulted in enough damage to the system or the building on which it is mounted to shut down its operation and require professional repair. Seven catastrophic modes of failure were defined as non-circulation, fire, corrosion, explosion, boil-out, pressure rupture and building damage.

1. Non-Circulation. If the fluid viscosity reaches 200 centistokes at zero degrees Fahrenheit, the potential for non-circulation with premature pump failure was deemed to exist.
2. Fire. If the aged fluid had a flash point lower than the top operating temperature of the loop, calculated as 165°F, the potential for a fire was deemed to exist.
3. Corrosion. If the aged fluid contained over 50 parts per million of metals or if the absorber plates exhibited physical damage at the conclusion of the test, the potential for corrosion was deemed to exist.
4. Explosion. If the degradation of the fluid resulted in the formation of flammable gases in the system, the potential for an explosion was deemed to exist.
5. Boil-out. If the vapor pressure of the fluid exceeded 75 psig at 350°F stagnation temperature, the potential of fluid boil-out was deemed to exist.
6. Pressure Rupture. If the vapor pressure of the fluid exceeded 150 psig at 350°F, the potential for pressure rupture was deemed to exist.
7. Building Damage. If the material was damaging to building materials and finishes at operating temperatures (165°F), the potential for building damage was deemed to exist.

Based upon the data collected, the potential for catastrophic incident was deemed to be as shown in Table VII-C-1.

POTENTIAL FOR CATASTROPHIC INCIDENT

<u>Mode</u>	<u>Ambitrol NTC® System</u>	<u>Prestone II® System</u>	<u>Uniroyal PAO-LV System</u>	<u>Syltherm™ 444 System</u>
Non-Circulation			X	
Fire	X	X	X	
Corrosion	X			
Explosion	X	X		
Boil-Out	X	X		
Rupture	X	X		
Building Damage	X	X	X	
Total No. Modes	6	5	3	0

Table VII-C-1. Potential for Catastrophic Incident

Data which would substantiate the number of catastrophic incidents based on field experience is sketchy and questionable because the system designs are usually unknown, thus making a failure rate for the number of incidences impossible to establish. Therefore, failure rates were estimated at 1/4 of one percent per year per existing failure mode, a very low rate and one that appears to have been exceeded to date.

Assuming a 25 year design life and the above failure incident rates, the estimated number of catastrophic failures over 25 years due to failure of the heat transfer fluid in number of failures per one hundred installed systems is as follows:

<u>System Fluid</u>	<u>Number Of Failures</u>
Ambitrol NTC®	37.50
Prestone II®	31.25
Uniroyal PAO-LV	18.75
Syltherm™ 444	0

It is not possible to calculate the cost of a catastrophic incident when the failure modes are so far ranging. For example, explosion and fire can cause negligible damage or extensive damage. Corrosion can appear in any metal part of the fluid passages and can be confined to piping or can be extensive enough to require the repair of a heat exchanger or collector. Similar differences can exist for all failure modes.

Therefore, the cost of a catastrophic failure was estimated at four hours of professional labor plus \$50.00 worth of materials which assumes that no major components or building material damage occurred. A minimal labor rate of \$10.00 per hour was used for the services of a professional craftsman. The total cost of an incident, therefore, calculates as a minimum of \$90.00.

The cost of incidents per system was then calculated as follows:

$$\frac{(\$90.00)(\text{Number of Failures})}{100 \text{ Systems}}$$

The results of these calculations are as follows:

<u>System Fluid</u>	<u>Cost Per System</u>
Ambitrol NTC®	\$33.75
Prestone II®	\$28.13
Uniroyal PAO-LV	\$16.88
Syltherm™ 444	-

A pump, heat exchanger, tank, or collector failure would add from \$150.00 to \$330.00 to the \$90.00 minimum cost. The probability of a major component failure cannot be estimated with any accuracy and is therefore excluded from this discussion.

D. Total Life Cycle Costs

The total life cycle costs associated with fluid choice in 1979 dollars has been shown to be a function of first cost, maintenance cost and catastrophic incident potential. Table VII-D-1 tabulates these estimated life cycle costs.

The Ambitrol NTC®/water system is by far the most costly system and prone to the most possible failures over its life followed by the Prestone II®/water system due to the maintenance schedule plus the failure modes.

The Uniroyal PAO-LV polyalphaolefin system is a very satisfactory system provided that adequate consideration is given to the low temperature viscosity problem and to the fire hazard potential, both of which would increase costs slightly over those shown in this financial analysis. And also, that field experience does not prove to result in lower efficiency due to the buildup of carbonaceous materials with time.

The Syltherm™ 444 silicone system is the least expensive, offers little or no potential for catastrophic failure, and does not require any fluid maintenance.

TOTAL ESTIMATED LIFE CYCLE COSTS
(Rounded to Whole Dollars)

<u>Item</u>	<u>Ambitrol NTC® System</u>	<u>Prestone II® System</u>	<u>Uniroyal PAO-LV System</u>	<u>Syltherm™ 444 System</u>
Installed Cost (Net)	2830	2858	2830	2794
Fluid Maintenance Cost	613	367	130	0
Catastrophic Incident Potential	34	28	17	0
Total Life Cycle Costs (25 Years)	3477	3253	2977	2794
% Increase Over Silicone System	24	16	6	-

Table VII-D-1. Total Estimated Life Cycle Costs

VIII. APPENDIX

A. Toxicologic and BOD Reports

1. Uniroyal PAO-LV Polyalphaolefin

DOW CORNING CORPORATION HEALTH & ENVIROMENTAL SERVICES DEPARTMENT

ACUTE TOXICOLOGIC PROPERTIES AND 5-DAY BIOLOGICAL OXYGEN DEMAND OF UNIROYAL PAO-LV POLYALPHAOLEFIN

A sample of Uniroyal PAO-LV was submitted to the Biological Services Department for an assessment of acute toxicologic properties and evaluation of household consumer hazards when tested according to the Consumer Product Safety Commission in compliance with the Federal Hazardous Substances Act (FHSA) regulations. This colorless liquid is commercially available as a lubricant base and may be used as hydraulic, electrical and solar heat transfer fluids.

Uniroyal PAO-LV is essentially non-toxic when ingested on an acute basis by laboratory rats ($LD_{50} > 15.4$ gm/kg body weight) and is not absorbed through the skin in acutely toxic amounts ($LD_{50} > 2.0$ gm/kg body weight).

Direct eye contact with Uniroyal PAO-LV should not result in irritation. According to FHSA guidelines, this material is not an eye irritant.

Application of this liquid to skin produced a very slight amount of redness. Under current FHSA regulations, Uniroyal PAO-LV is not a primary skin irritant.

Presentation of Data

Acute Oral Toxicity of Uniroyal PAO-LV in Rats

<u>Sex</u>	<u>Dose(gm/kg)</u>	<u>No. Dead/No. Dosed</u>
M	15.4	0/5
F	15.4	0/5

Acute Dermal Toxicity of Uniroyal PAO-LV in Rabbits

<u>Condition of Skin</u>	<u>Dose (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
Abraded	2.0	0/3
Intact	2.0	0/3

Eye Irritation Potential of Uniroyal PAO-LV in Rabbits

	<u>Period After Exposure</u>	<u>Animal No.</u>					
		<u>D-6</u>	<u>B-9</u>	<u>C-5</u>	<u>C-7</u>	<u>C-9</u>	<u>C-10</u>
Cornea	24 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea	48 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	72 hrs.	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	7 days	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Comments

Not an eye irritant.

Skin Irritation Potential of Uniroyal PAO-LV in Rabbits

<u>Parameter</u>	<u>Reading Interval (Hours)</u>	<u>Mean Value</u>
Erythema & Eschar Formation:		
Intact skin	24	0.2
Intact skin	72	0.0
Abraded skin	24	0.0
Abraded skin	72	<u>0.0</u>
	Subtotal	0.2
Edema Formation:		
Intact skin	24	0.0
Intact skin	72	0.0
Abraded skin	24	0.0
Abraded skin	72	<u>0.0</u>
	Subtotal	0.0
	TOTAL	0.2

PRIMARY IRRITATION SCORE: 0.05

Comments:

Not a skin irritant.

SUMMARY

The results of the biological oxygen demand and acute toxicity tests conducted with Uniroyal PAO-LV in compliance with FHSA regulations are as follows:

<u>Test Conducted</u>	<u>Classification</u>
Acute Oral Toxicity	Not toxic and not highly toxic; LD ₅₀ >15.4 gm/kg body weight.
Acute Dermal Toxicity	Not toxic and not highly toxic; LD ₅₀ >2.0 gm/kg body weight.
Eye Irritation	Not an eye irritant.
Skin Irritation	Not a skin irritant.
Biological Oxygen Demand	0.19 ± 0.09

2. Dow Corning® Q2-1162 Heat Transfer Liquid

DOW CORNING CORPORATION HEALTH & ENVIRONMENTAL SERVICES DEPARTMENT

ACUTE TOXICOLOGIC PROPERTIES AND 5-DAY BIOLOGICAL OXYGEN DEMAND OF DOW CORNING® Q2-1162 HEAT TRANSFER FLUID

A sample of DOW CORNING® Q2-1162 Heat Transfer Fluid was received by the Biological Services Department for determination of Biological Oxygen Demand, assessment of acute toxicologic properties, and evaluation of household consumer hazards when tested according to methods promulgated by the Consumer Product Safety Commission in compliance with the Federal Hazardous Substances Act (FHSA) regulations. This straw colored liquid is intended for use in industrial heat transfer systems.

Dow Corning® Q2-1162 heat transfer fluid is essentially non-toxic when ingested on an acute basis by laboratory rats. ($LD_{50} > 15.4$ gm/kg body weight) and is not absorbed through the skin in acutely toxic amounts ($LD_{50} > 2.0$ gm/kg body weight).

Direct eye contact with Dow Corning® Q2-1162 heat transfer fluid should not result in irritation. According to current FHSA guidelines, this liquid is not an eye irritant.

A single application of Dow Corning® Q2-1162 heat transfer fluid should not produce irritation. When tested according to current FHSA regulations, this liquid is not a primary skin irritant.

Presentation of Data

Acute Oral Toxicity of Dow Corning® Q2-1162 Heat Transfer Fluid

<u>Sex</u>	<u>Dose (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
M	15.4	0/5
F	15.4	0/5

Acute Dermal Toxicity of Dow Corning® Q2-1162 Heat Transfer Fluid

<u>Condition of Skin</u>	<u>Dose (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
Abraded	2.0	0/3
Intact	2.0	0/3

Eye Irritation Potential of Dow Corning® Q2-1162 Heat Transfer
Fluid in Rabbits

	Period After Exposure	VALUES Animal No.					
		C-11	E-6	E-7	E-9	E-10	E-11
Cornea	24 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea	48 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	72 hrs.	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	7 days	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Comments

Not an eye irritant.

Skin Irritation Potential of Dow Corning® Q2-1162 Heat Transfer Fluid in Rabbits

<u>Parameter</u>	<u>Reading Interval (Hours)</u>	<u>Mean Score</u>
Erythema & Eschar Formation:		
Intact skin	24	0.0
Intact skin	72	0.0
Abraded skin	24	0.0
Abraded skin	72	0.0
Subtotal		0.0
Edema Formation:		
Intact skin	24	0.0
Intact skin	72	0.0
Abraded skin	24	0.0
Abraded skin	72	0.0
Subtotal		0.0
TOTAL		0.0

PRIMARY IRRITATION SCORE: 0.0

Comments:

Not a skin irritant.

SUMMARY

The results of the Biological Oxygen Demand and acute toxicity tests conducted on Dow Corning® Q2-1162 heat transfer fluid in compliance with FHSA regulations are as follows:

<u>Test Conducted</u>	<u>Classification</u>
Acute Oral Toxicity	Not toxic and not highly toxic; LD ₅₀ >15.4 gm/kg body weight.
Acute Dermal Toxicity	Not toxic and not highly toxic; LD ₅₀ >2.0 gm/kg body weight.
Eye Irritation	Not an eye irritant.
Skin Irritation	Not a skin irritant.
Biological Oxygen Demand	No measurable Biological Oxygen Demand

3. SylthermTM 444 Heat Transfer Liquid

DOW CORNING CORPORATION
HEALTH & ENVIRONMENTAL SERVICES DEPARTMENT

ACUTE TOXICOLOGIC PROPERTIES AND 5-DAY BIOLOGICAL OXYGEN DEMAND OF SYLTHERMTM® 444 HEAT TRANSFER LIQUID

A sample of SylthermTM 444 heat transfer liquid was submitted to the Biological Services Department for determination of acute toxicologic properties and evaluation of household consumer hazards when tested according to procedures prescribed by the Consumer Product Safety Commission in compliance with Federal Hazardous Substances Act (FHSA) regulations. This water-clear liquid is intended for use as a solar collector fluid.

SylthermTM 444 heat transfer liquid is essentially non-toxic when ingested on an acute basis by laboratory rats ($LD_{50} > 15.4$ gm/kg body weight) and is not absorbed through the skin in acutely toxic amounts ($LD_{50} > 2.0$ gm/kg body weight).

Direct eye contact with SylthermTM 444 heat transfer liquid may result in, at most, a very slight amount of irritation which is similar to a "windburn" effect. According to current FHSA definition, SylthermTM 444 heat transfer fluid is not an eye irritant.

Skin exposure to this liquid should not cause irritation. Under the condition of this test, SylthermTM 444 heat transfer liquid is not a skin irritant.

Presentation of Data

Acute Oral Toxicity of SylthermTM® 444 Heat Transfer Liquid

<u>Sex</u>	<u>Dose Level (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
M	15.4	0/5
F	15.4	0/5

Acute Dermal Toxicity of SylthermTM 444 Heat Transfer Liquid

<u>Condition of Skin</u>	<u>Dose (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
Abraded	2.0	0/3
Intact	2.0	0/3

Eye Irritation Potential of Syltherm™ 444 Heat Transfer Liquid
in Rabbits

	Period After Exposure	VALUES Animal Nos.					
		E-12	F-4	F-6	F-7	F-8	F-9
Cornea	24 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea	48 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	1
- chemosis		0	0	0	0	0	0

Cornea - before stain	72 hrs.	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	7 days	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Comments

Not an eye irritant

Primary Skin Irritation Potential of Syltherm™ 444 Heat Transfer Liquid in Rabbits

<u>Parameter</u>	<u>Reading Interval (Hours)</u>	<u>Mean Score</u>
Erythema & Eschar Formation:		
Intact skin	24	0.0
Intact skin	72	0.0
Abraded skin	24	0.0
Abraded skin	72	0.0
Subtotal		0.0
Edema Formation:		
Intact skin	24	0.0
Intact skin	72	0.0
Abraded skin	24	0.0
Abraded skin	72	0.0
Subtotal		0.0
TOTAL		0.0

PRIMARY IRRITATION SCORE: 0.0

Comments

Not a skin irritant.

SUMMARY

The results of the biological oxygen demand and acute toxicity tests conducted on Syltherm™ 444 heat transfer liquid in compliance with FHSA regulations are as follows:

<u>Test Conducted</u>	<u>Classification</u>
Acute Oral Toxicity	Not toxic and not highly toxic; LD ₅₀ >15.4 gm/kg body weight.
Acute Dermal Toxicity	Not toxic and not highly toxic; LD ₅₀ >2.0 gm/kg body weight.
Eye Irritation	Not an eye irritant.
Skin Irritation	Not a skin irritant.
Biological Oxygen Demand	No measurable biological oxygen demand

4. Ethylene Glycol/Water

DOW CORNING CORPORATION HEALTH & ENVIRONMENTAL SERVICES DEPARTMENT

ACUTE TOXICOLOGIC PROPERTIES AND 5-DAY BIOLOGICAL OXYGEN DEMAND OF ETHYLENE GLYCOL/WATER

A laboratory prepared sample of a 50:50 mixture (w/w) of ethylene glycol (Prestone II®) and water was submitted to the Biological Services Department for determination of acute toxicologic properties and household consumer hazards when tested according to procedures prescribed by the Consumer Product Safety Commission in compliance with Federal Hazardous Substances Act (FHSA) regulations. This cloudy, "fluorescent" lime-yellow liquid is commercially available as a heat transfer fluid.

Ethylene glycol/water (50:50 by weight) is essentially non-toxic when ingested on an acute basis by laboratory rats ($LD_{50} > 15.4$ gm/kg body weight) and is not absorbed through the skin in acutely toxic amounts ($LD_{50} > 2.0$ gm/kg body weight).

Direct eye contact with this material should not cause irritation. According to current FHSA guidelines, this material is not an eye irritant.

A single application of ethylene glycol/water (50:50 by weight) to skin may cause, at most, a very slight amount of redness. In accordance with FHSA definition, this liquid is not a skin irritant.

Presentation of Data

Acute Oral Toxicity of Ethylene Glycol/Water in Rats

<u>Sex</u>	<u>Dose (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
M	15.4	1/5
F	15.4	3/5

Comments

Under the conditions of this test, ethylene glycol/water appears to be slightly higher in oral toxicity among female test subjects.

Acute Dermal Toxicity of Ethylene Glycol/Water in Rabbits

<u>Condition of Skin</u>	<u>Dose (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
Intact	2.0	0/3
Abraded	2.0	0/3

Eye Irritation Potential of Ethylene Glycol/Water in Rabbits

	<u>Period After Exposure</u>	<u>VALUES</u>					
		<u>Animal Nos.</u>					
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
Cornea	24 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea	48 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	72 hrs.	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	7 days	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Comment

Not an eye irritant.

Skin Irritation Potential of Ethylene Glycol/Water in Rabbits

<u>Parameter</u>	<u>Reading Interval (Hours)</u>	<u>Mean Score</u>
Erythema & Eschar Formation:		
Intact skin	24	0.2
Intact skin	72	0.0
Abraded skin	24	0.2
Abraded skin	72	<u>0.0</u>
Subtotal		0.4
Edema Formation:		
Intact skin	24	0.0
Intact skin	72	0.0
Abraded skin	24	0.0
Abraded skin	72	<u>0.0</u>
Subtotal		0.0
TOTAL		0.4

PRIMARY IRRITATION SCORE: 0.1

SUMMARY

The results of the biological oxygen demand and acute toxicologic studies conducted with a 50:50 mixture of ethylene glycol/water in compliance with FHSA regulations are as follows:

<u>Test Conducted</u>	<u>Classification</u>
Acute Oral Toxicity	Not toxic and not highly toxic; LD ₅₀ >15.4 gm/kg body weight.
Acute Dermal Toxicity	Not toxic and not highly toxic; LD ₅₀ >2.0 gm/kg body weight.
Eye Irritation	Not an eye irritant.
Skin Irritation	Not a skin irritant.
Biological Oxygen Demand	0.55 ± 0.01

5. Propylene Glycol/Water

DOW CORNING CORPORATION HEALTH & ENVIRONMENTAL SERVICES DEPARTMENT

ACUTE TOXICOLOGIC PROPERTIES AND 5-DAY BIOLOGICAL OXYGEN DEMAND OF PROPYLENE GLYCOL/WATER

A laboratory prepared sample of a 50:50 mixture by weight of propylene glycol (Ambitol NTC®) and water was submitted to the Biological Services Department for determination of acute toxicologic properties and assessment of household consumer hazards when tested according to procedures prescribed by the Consumer Product Safety Commission in compliance with Federal Hazardous Substances Act (FHSA) regulations. This translucent, blue liquid is commercially available for use as a heat transfer fluid.

Propylene glycol/water (50:50 by weight) is essentially non-toxic when ingested on an acute basis by laboratory rats ($LD_{50} > 15.4$ gm/kg body weight and is not absorbed through the skin in acutely toxic amounts ($LD_{50} > 2.0$ gm/kg body weight).

Direct eye contact with this liquid should not cause irritation, therefore, according to current FHSA definition, this material is not an eye irritant.

Application of propylene glycol/water (50:50 by weight) to skin may produce, at most, a very slight amount of redness. According to FHSA guidelines, this liquid is not a skin irritant.

Presentation of Data

Acute Oral Toxicity of Propylene Glycol/Water in Rats

<u>Sex</u>	<u>Dose (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
M	15.4	0/5
F	15.4	0/5

Acute Dermal Toxicity of Propylene Glycol/Water in Rabbits

<u>Condition of Skin</u>	<u>Dose (gm/kg)</u>	<u>No. Dead/No. Dosed</u>
Abraded	2.0	0/3
Intact	2.0	0/3

Eye Irritation Potential of Propylene Glycol/Water in Rabbits

	Period After Exposure	VALUES Animal Nos.					
		1	2	3	4	5	6
Cornea	24 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea	48 hrs.	0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	72 hrs.	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Cornea - before stain	7 days	0	0	0	0	0	0
- after stain		0	0	0	0	0	0
Iris		0	0	0	0	0	0
Conjunctiva - redness		0	0	0	0	0	0
- chemosis		0	0	0	0	0	0

Comments

Not an eye irritant.

Skin Irritant Potential of Propylene Glycol/Water in Rabbits

<u>Parameter</u>	<u>Reading Interval (Hours)</u>	<u>Mean Score</u>
Erythema & Eschar Formation:		
Intact skin	24	0.3
Intact skin	72	0.0
Abraded skin	24	0.3
Abraded skin	72	<u>0.0</u>
Subtotal		0.6
Edema Formation		
Intact skin	24	0.0
Intact skin	72	0.0
Abraded skin	24	0.0
Abraded skin	72	<u>0.0</u>
Subtotal		0.0
TOTAL		0.6

PRIMARY IRRITATION SCORE: 0.2

SUMMARY

The results of the Biological Oxygen Demand and acute toxicity studies conducted on a 50% mixture of propylene/glycol (Ambitol NTC) in water in compliance with FHSA regulations are as follows:

<u>Test Conducted</u>	<u>Classification</u>
Acute Oral Toxicity	Not toxic and not highly toxic; LD ₅₀ >15.4 gm/kg body weight.
Acute Dermal Toxicity	Not toxic and not highly toxic; LD ₅₀ >2.0 gm/kg body weight.
Eye Irritation	Not an eye irritant.
Skin Irritation	Not a skin irritant.
Biological Oxygen Demand	0.55 ± 0.01

6. Toxicologic Test Methods

a. Acute Oral Toxicity

Male and female Sprague-Dawley rats (obtained from Spartan Research Animals, Inc., Haslett, Michigan), each weighing between 200 and 300 grams of body weight were individually housed in suspended wire-mesh cages in a temperature, humidity and light controlled room. They were maintained in accordance with the recommendations contained in H.E.W. Publication No. 74-23, "Guide for the Care and Use of Laboratory Animals" (N.I.H.) and were conditioned for a minimum of 14 days prior to initiation of the studies. Water and Purina® Rat Chow were available ad libitum.

Following a 24 hour fast, the animals were fed by single-dose intubation using a calibrated syringe and rubber catheter. Materials were administered in the undiluted form. All animals were weighed and observed at intervals over a two-week post-feeding period.

b. Acute Dermal Toxicity

Six normal, adult New Zealand white rabbits (obtained from Langshaw Farms, Augusta, Michigan), each weighing between 2.3 and 3.0 kilograms of body weight were individually housed in wire-mesh cages in a temperature, humidity and light controlled room. They were maintained in accordance with the recommendations contained in H.E.W. Publication No. 74-23. "Guide for the Care and Use of Laboratory Animals" (N.I.H.) and were conditioned for a minimum of 21 days prior to initiation of the studies. Water and Purina® Rabbit Chow were available on an ad libitum basis.

Twenty-four hours prior to use, the animals were prepared by clipping the skin of the trunk free of hair. Three of the animals were further prepared by making epidermal abrasions every 2-3 centimeters longitudinally over the test surface at the time of application. Test samples were applied under an impervious (Saran®) cuff held in place with a cloth bandage taped to the hair. Following application, the animals were returned to holding cages and permitted water and food ad libitum. After a 24 hour exposure period, the cuffs were removed and the skins were washed with soap and tap water. All animals were observed during and after exposure and weighed at regular intervals up to two weeks post-application.

c. Primary Skin Irritation Potential

Six normal adult New Zealand white rabbits (obtained from Langshaw Farms, Augusta, Michigan), each weighing between 2.3 and 3.0 kilograms of body weight were individually housed in wire-mesh cages in a temperature, humidity and light controlled room. They were maintained in accordance with the recommendations contained in H.E.W. Publication No. 74-23, "Guide for the Care and Use of Laboratory Animals" (N.I.H.) and were conditioned for a minimum of 21 days prior to initiation of the studies. Water and Purina® Rabbit Chow were available ad libitum.

Twenty-four hours prior to use, the animals were prepared by clipping the skin of the trunk free of hair. Epidermal abrasions were made on the test subjects on the day of application. A 0.5 milliliter aliquot of test material was introduced under a square, multilayer patch of surgical gauze measuring one inch by one inch which was held in place by adhesive tape. The entire trunk of each animal was then wrapped with an impervious (Saran®) cuff for the 24-hour exposure period. Following 24 hours of exposure, the patches were removed and resulting reactions were evaluated on the basis of the designated values in the following table.

<u>Erythema and Eschar Formation</u>	<u>Value</u>
No erythema.	0
Very slight erythema (barely perceptible).	1
Well defined erythema.	2
Moderate to severe erythema.	3
Severe erythema (beet redness) to slight eschar formation (injuries in depth).	4

<u>Edema Formation</u>	<u>Value</u>
No edema	0
Very slight edema (barely perceptible).	1
Slight edema (edges of area well defined by definite raising)	2
Moderate edema (raised approximately 1 millimeter).	3
Severe edema (raised more than 1 millimeter and extending beyond the area of exposure).	4

d. Primary Eye Irritation Potential

Six normal adult New Zealand white rabbits (obtained from Langshaw Farms, Augusta, Michigan), each weighing between 2.0 and 3.0 kilograms of body weight and determined to be free of eye defects were individually housed in wire-mesh cages in a temperature, humidity and light controlled room. They were maintained in accordance with the recommendations contained in H.E.W. Publication No. 74-23, "Guide for the Care and Use of Laboratory Animals" (N.I.H.) and were conditioned for a minimum of 21 days prior to initiation of the studies. Water and Purina® Rabbit Chow were available ad libitum.

Prior to initiation of each study, both eyes of each animal was examined and any animal exhibiting eye defects and/or irritation was discarded. A 0.1 milliliter aliquot of the test sample was placed into the right eye of each animal by pulling the lower lid away from the eyeball. Following instillation of the test material, the lids were gently held together for one second and the animal was returned to a holding cage. The left eye was untreated and served as a control. The eyes were examined and the grade of ocular reaction was recorded at 24, 48, 72 hours and 7 days post instillation according to the following table:

Cornea (before staining)

No ulceration or opacity.	0
Scattered or diffuse areas of opacity (other than a slight dulling of normal luster), details of iris clearly visible.	1
Easily discernible translucent areas, details of iris slightly obscured.	2
Nacreous areas, no details of iris visible, size of pupil barely discernible	3
Complete corneal opacity, iris not dis- cernible	4

Cornea (after staining)

None	0
Very slight, few areas of necrosis	1
Slight, up to 50% of eye covered with shallow necrosis	2
Moderate, 50-100% of eye necrotic, but lesions are shallow	3
Severe, marked necrosis over whole area which may result in loss of eye.	4

Iris

Normal	0
Markedly deepened folds, congestion, swelling, moderate circumcorneal injection (any of these or combination of any thereof), iris still reacting to light (sluggish reaction is positive). . .	1
No reaction to light, hemorrhage, gross destruction (any or all of these).	2

Conjunctiva-Redness

Vessels normal.	0
Some vessels definitely injected.	1
Diffuse, crimson red, individual vessels not easily discernible.	2
Diffuse beefy red	3

Conjunctival-Chemosis

No swelling.	0
Any swelling above normal (includes nictitating membrane).	1
Obvious swelling with partial eversion of lids . . .	2
Swelling with lids about half closed	3
Swelling with lids more than half closed	4

DOW HEAT TRANSFER FLUID TEST PROJECT

RUN DATE 4/19/79

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PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY

RUN DATE 4/20/79

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
12/15/78	3.00	247.4	0.00	315.3	3.00	245.9	2.00	336.4								
12/16/78	0.00	161.7	0.00	202.9	0.00	163.6	0.00	205.2								
12/17/78	0.00	102.7	0.00	123.1	0.00	105.2	0.00	126.6								
12/18/78	0.00	128.7	0.00	152.9	0.00	134.7	0.00	159.4								
12/20/78	3.00	235.0	0.00	303.4	2.50	231.1	0.00	320.8								
12/21/78	3.50	242.2	0.00	313.1	3.25	240.9	0.75	328.4								
12/22/78	2.50	244.9	0.00	319.7	2.50	247.8	1.25	335.5								
12/23/78	2.50	238.8	0.00	305.1	2.50	239.8	0.00	318.8								
12/24/78	4.00	245.9	0.00	315.9	4.25	244.2	1.75	331.2								
12/25/78	3.25	250.5	0.00	323.4	3.50	250.9	2.25	339.1								
12/26/78	4.00	248.9	0.00	321.1	4.25	249.4	2.00	335.2								
12/27/78	3.50	241.1	0.00	315.6	3.75	243.5	1.25	331.6								
12/28/78	0.00	187.5	0.00	236.7	0.00	192.9	0.00	245.6								
12/29/78	0.00	196.5	0.00	247.7	0.00	201.6	0.00	258.9								
12/30/78	0.00	187.9	0.00	238.5	0.00	192.4	0.00	248.9								
12/31/78	0.00	170.9	0.00	215.6	0.00	175.0	0.00	225.1								
TOTAL																
HRS.	29.25		0.00		29.50		11.25									
AVERAGE																
MAX.	208.2		265.6		209.9		277.9									

PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY
ENERGY RESEARCH AND DEVELOPMENT SECTION
DOW HEAT TRANSFER FLUID TEST PROJECT

RUN DATE 4/19/79

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
12/01/78	0.00	102.7	0.00	75.8												
12/02/78	0.00	92.4	0.00	68.4												
12/03/78	0.00	91.8	0.00	53.4												
12/04/78	0.00	86.8	0.00	60.9												
12/05/78	0.00	95.8	0.00	72.4												
12/06/78	0.00	87.8	0.00	64.1												
12/07/78	0.00	31.0	0.00	31.4												
12/08/78	0.00	68.4	0.00	36.3												
12/09/78	0.50	227.0	0.00	296.2												
12/10/78	0.00	87.5	0.00	105.4												
12/11/78	3.50	243.2	0.00	312.6												
12/12/78	3.00	248.4	0.00	317.0												
12/13/78	0.00	188.1	0.00	237.1												
12/14/78	3.75	244.5	0.00	311.9												
12/15/78	3.75	247.4	0.00	315.3												
12/16/78	0.00	161.7	0.00	202.9												
12/17/78	0.00	102.7	0.00	123.1												
12/18/78	0.00	128.7	0.00	152.9												
12/20/78	3.00	235.0	0.00	303.4												
12/21/78	3.50	242.2	0.00	313.1												
12/22/78	2.50	244.9	0.00	319.7												
12/23/78	2.50	238.8	0.00	305.1												
12/24/78	4.00	245.9	0.00	315.9												
12/25/78	3.25	250.5	0.00	323.4												
12/26/78	4.00	248.9	0.00	321.1												
12/27/78	3.50	241.1	0.00	315.6												
12/28/78	0.00	187.5	0.00	236.7												
12/29/78	0.00	196.5	0.00	247.7												
12/30/78	0.00	187.9	0.00	238.5												
12/31/78	0.00	170.9	0.00	215.6												
TOTAL																
HRS.	40.75		0.00													
AVERAGE																
MAX.		174.2		209.8												

PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY

RUN DATE 4/20/79

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
1/01/79	1.75	230.4	0.00	303.3	1.75	230.1	0.00	320.3								
1/02/79	2.00	234.7	0.00	309.6	2.25	235.6	1.50	329.3								
1/03/79	0.00	211.3	0.00	271.7	0.00	214.3	0.00	283.9								
1/04/79	3.50	248.1	0.00	322.3	3.50	245.5	1.75	335.0								
1/05/79	0.00	189.8	0.00	241.4	0.00	198.9	0.00	227.0								
1/06/79	0.00	161.0	0.00	203.0	0.00	170.3	0.00	198.0								
1/07/79	0.00	219.7	0.00	279.9	0.25	227.9	0.00	257.6								
1/08/79	1.00	228.5	0.00	302.9	2.00	237.5	0.00	267.1								
1/09/79	1.50	236.5	0.00	310.0	1.50	245.5	0.00	273.2								
1/10/79	3.00	247.4	0.00	323.0	3.25	255.2	0.00	286.3								
1/11/79	1.75	237.4	0.00	310.4	2.25	244.9	0.00	271.8								
1/12/79	0.00	216.7	0.00	281.0	0.00	222.9	0.00	234.8								
1/13/79	4.50	252.5	1.25	330.4	5.00	260.0	0.00	280.3								
1/14/79	0.00	221.7	0.00	292.5	0.25	228.7	0.00	250.5								
1/17/79	0.00	74.7	0.00	88.5	0.00	76.3	0.00	90.3								
1/18/79	2.25	246.4	0.00	318.5	2.50	253.0	0.00	283.3								
1/19/79	2.50	234.2	0.00	305.9	3.75	241.6	0.00	253.9								
1/20/79	3.75	247.3	0.25	325.1	4.50	250.4	0.00	281.2								
1/21/79	1.25	235.3	0.00	306.5	1.75	244.4	0.00	271.8								
1/22/79	0.50	241.4	0.00	314.8	0.50	247.6	0.00	279.0								
1/23/79	4.00	247.2	0.75	327.5	4.50	251.8	0.00	285.7								
1/24/79	0.00	141.8	0.00	175.0	0.00	153.4	0.00	180.1								
1/25/79	1.25	233.3	0.00	304.0	2.00	240.6	0.00	264.4								
1/26/79	1.75	229.6	0.00	305.3	3.00	237.4	0.00	249.4								
1/27/79	3.50	245.9	0.50	328.4	4.00	252.3	0.00	290.6								
1/28/79	4.25	245.8	0.50	327.3	4.50	251.1	0.00	289.9								
TOTAL																
HRS.	44.00		3.25		53.00		3.25									
AVERAGE																
MAX.	221.5		288.8		227.6		262.9									

RUN DATE 4/11/79

DOW HEAT TRANSFER FLUID TEST PROJECT

		STAND 1				STAND 2				STAND 3				STAND 4			
DATE	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45		
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	
81	2/06/79	1.25	240.3	1.00	340.2	0.75	229.0	0.00	313.9	0.00	203.3	0.75	341.2	1.50	239.2	0.00	301.3
	2/07/79	4.00	248.2	3.00	346.9	4.25	250.8	3.25	351.2	0.00	221.0	3.00	355.1	4.25	247.6	0.25	326.7
	2/08/79	3.75	258.1	3.25	359.4	4.00	261.6	3.25	364.0	1.75	232.5	3.00	368.2	4.00	251.1	2.25	336.5
	2/09/79	4.75	248.8	4.25	351.7	5.25	253.1	4.00	355.6	1.25	227.0	4.00	358.4	5.25	250.9	1.25	328.2
	2/10/79	5.25	260.4	4.50	365.7	5.50	266.6	4.50	369.7	3.50	248.1	4.50	372.8	5.50	256.2	2.75	348.0
	2/11/79	4.25	261.9	3.50	363.8	5.00	265.3	3.75	367.6	3.25	249.7	3.50	372.3	4.25	256.0	3.25	345.8
	2/12/79	4.75	263.4	4.50	364.5	5.25	267.9	4.25	369.9	3.75	253.8	4.00	372.3	5.25	257.3	3.25	347.7
	2/13/79	5.25	266.1	4.25	367.7	5.50	270.2	4.50	372.4	4.50	256.7	4.50	374.1	5.50	257.5	3.50	349.6
	2/14/79	4.75	263.7	4.00	366.6	5.25	267.0	4.00	370.2	4.50	257.6	4.50	379.2	5.00	254.7	1.50	343.0
	2/15/79	3.75	256.9	2.75	351.7	4.00	261.2	2.75	356.0	3.50	255.4	3.50	367.6	3.50	252.4	0.25	327.2
	2/16/79	0.00	218.8	0.00	312.5	0.25	225.9	0.00	312.3	0.00	212.3	0.00	323.8	0.00	216.9	0.00	282.6
	2/17/79	5.00	255.8	4.25	360.2	5.00	261.0	4.25	364.4	4.50	253.8	4.75	372.4	5.00	251.1	2.50	340.5
	2/18/79	4.50	258.0	4.00	360.9	5.00	262.9	4.00	365.8	4.00	255.8	4.50	374.0	4.75	251.9	1.75	342.5
	2/19/79	4.00	244.5	3.25	344.9	4.50	251.2	3.50	348.7	3.75	244.0	4.25	360.2	4.00	242.4	0.00	315.7
	2/20/79	1.25	234.2	0.75	327.7	2.25	238.9	0.25	325.5	0.75	228.4	1.00	336.6	0.50	228.7	0.00	295.7
	2/21/79	1.25	234.2	0.00	323.7	1.50	240.3	0.50	326.7	0.75	226.5	1.25	336.0	0.75	237.3	0.00	299.5
	2/22/79	0.00	220.1	0.00	303.5	0.25	225.7	0.00	303.7	0.00	211.9	0.00	312.5	0.00	217.7	0.00	287.7
	2/23/79	3.00	245.2	2.25	346.1	3.50	249.8	1.75	345.2	1.75	240.9	2.50	357.4	2.75	242.9	0.00	319.8
2/24/79	3.25	239.5	2.75	338.0	3.75	246.1	2.50	339.0	2.50	236.0	3.25	350.1	3.50	240.5	0.00	309.6	
2/25/79	4.00	243.2	3.00	341.9	4.50	248.7	3.00	341.6	3.25	240.3	3.75	354.2	4.00	247.3	0.25	329.0	
2/26/79	0.00	223.7	0.00	312.3	1.00	229.3	0.00	311.7	0.00	215.3	0.00	319.5	0.00	223.5	0.00	289.0	
2/27/79	1.50	235.3	1.50	333.5	2.00	240.4	1.25	329.7	0.00	225.0	1.50	339.8	1.25	234.4	0.00	296.3	
2/28/79	3.75	247.8	2.25	343.9	4.25	251.0	2.75	349.4	3.25	246.5	3.50	358.7	4.25	247.4	0.50	327.9	
TOTAL HRS.		73.25		59.00		82.50		58.00		50.50		65.50		74.75		23.25	
AVERAGE MAX.		246.4		344.7		250.6		345.8		236.6		354.6		243.7		321.3	

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
3/01/79	1.25	235.4	0.25	329.8	2.00	240.8	0.25	330.0	0.00	222.4	1.00	337.8	0.75	236.5	0.00	301.6
3/02/79	0.00	183.7	0.00	249.8	0.00	189.6	0.00	250.0	0.00	167.0	0.00	240.2	0.00	183.1	0.00	246.2
3/03/79	0.75	230.1	0.00	321.1	1.25	235.4	0.00	317.4	0.00	221.1	0.25	325.1	1.25	237.7	0.00	316.5
3/04/79	4.50	252.4	3.75	355.6	4.75	256.5	3.25	355.1	4.00	253.6	4.00	364.8	4.75	251.2	3.00	343.6
3/05/79	4.50	255.5	3.75	362.1	5.00	259.6	3.75	363.1	4.00	254.4	4.25	370.7	5.00	255.1	3.50	350.9
3/06/79	4.75	254.2	3.25	352.7	5.25	260.1	3.25	355.5	4.00	252.2	4.00	366.4	5.25	252.5	3.25	345.9
3/07/79	5.00	260.7	4.25	362.5	5.25	264.5	3.75	362.1	4.50	258.9	4.25	371.0	5.50	257.9	4.00	351.3
3/08/79	4.50	258.7	3.75	362.9	5.00	264.1	3.75	361.8	4.00	255.7	4.25	372.6	5.25	256.3	3.75	352.9
3/09/79	0.00	172.6	0.00	224.1	0.00	176.0	0.00	222.2	0.00	162.7	0.00	207.5	0.00	175.3	0.00	213.8
3/10/79	4.00	249.5	3.00	349.1	4.50	255.2	3.00	351.1	3.50	245.4	3.75	363.0	4.75	253.7	4.25	373.7
3/11/79	4.50	255.8	3.75	355.5	5.00	258.0	3.75	362.5	4.00	253.8	4.00	370.8	5.25	255.9	4.75	383.3
3/12/79	5.00	259.3	4.25	358.7	5.50	262.0	4.00	364.3	4.50	257.6	4.50	373.3	5.25	258.1	4.75	384.9
3/13/79	4.75	254.1	3.75	353.3	5.25	259.4	3.50	352.8	4.00	251.4	4.00	364.6	5.50	253.1	4.50	372.9
3/14/79	2.75	236.2	2.00	332.3	3.50	242.6	2.25	335.2	2.00	321.4	3.00	346.0	4.00	334.3	3.50	357.6
3/15/79	4.50	259.2	3.75	357.1	5.00	263.4	4.00	360.7	4.25	256.1	4.25	370.6	5.00	257.7	4.75	381.2
3/16/79	3.75	242.2	2.50	338.8	4.25	248.4	2.75	342.1	3.25	238.7	3.75	353.1	4.50	247.9	4.00	364.1
3/17/79	0.25	228.6	0.00	309.7	0.50	232.5	0.00	306.1	0.00	216.0	0.00	319.0	0.25	233.9	0.50	332.1
3/18/79	3.75	244.5	3.00	343.5	4.25	249.4	2.75	343.0	3.00	239.7	3.50	354.9	4.50	250.2	4.00	365.3
3/19/79	0.50	229.7	0.00	315.7	0.75	235.3	0.00	315.9	0.00	217.3	0.25	327.8	0.75	234.4	0.75	338.2
3/20/79	2.50	243.6	1.50	338.7	4.00	249.1	1.50	340.9	1.50	237.4	2.25	352.4	3.75	255.3	3.00	364.0
3/21/79	0.25	225.2	0.00	311.9	0.25	229.9	0.00	310.2	0.00	210.7	0.00	323.8	0.25	229.9	0.25	334.9
3/22/79	1.75	237.4	1.50	333.7	2.25	242.4	1.50	332.8	1.25	231.1	2.00	345.3	2.50	247.9	2.25	354.1
3/23/79	4.75	258.6	3.75	358.7	4.75	260.5	3.75	362.9	4.00	256.1	4.00	374.3	5.00	260.5	4.50	387.4
3/24/79	5.00	257.1	4.00	355.7	5.25	260.2	3.75	360.5	4.25	255.5	4.50	371.4	5.25	263.4	4.75	382.5
3/25/79	4.00	255.8	3.25	353.8	4.75	260.2	3.00	356.5	3.50	255.4	3.50	369.3	5.00	262.8	4.25	380.2
3/26/79	5.50	277.8	4.00	355.3	5.75	282.6	3.75	358.8	4.50	256.0	4.25	371.0	5.50	263.9	4.75	381.9
3/27/79	0.50	229.5	0.00	293.3	0.50	234.6	0.00	291.5	0.00	209.1	0.00	300.1	0.00	224.2	0.00	310.2
3/28/79	1.50	250.0	0.00	322.1	1.50	255.2	0.00	321.0	0.00	222.0	0.25	337.0	0.50	236.4	0.50	348.5
3/29/79	3.50	258.1	1.75	337.1	3.50	263.6	1.75	335.7	1.50	233.5	2.50	347.6	3.25	251.8	2.75	356.3
3/30/79	5.50	275.6	3.75	353.7	5.50	280.8	4.00	357.2	4.25	254.6	4.25	368.7	5.00	257.4	4.75	379.5
3/31/79	5.00	261.5	2.75	338.8	5.25	266.3	2.75	340.9	3.25	239.4	3.50	352.6	4.50	251.1	4.00	361.1
TOTAL																
HRS.	98.75		71.25		110.25		69.75		77.00		84.00		108.00		89.00	
AVERAGE																
MAX.	244.9		335.1		249.6		336.1		238.9		345.6		248.0		348.9	

PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY

RUN DATE 5/02/79

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
4/01/79	5.25	274.1	3.75	351.2	5.50	279.3	3.75	356.1	4.00	253.1	4.25	367.1	5.00	258.1	4.50	378.4
4/02/79	5.00	265.4	3.25	345.5	5.25	270.5	3.50	347.2	3.50	242.9	4.00	359.0	4.75	255.0	4.25	368.9
4/03/79	0.75	237.5	0.00	311.0	1.00	243.4	0.00	309.4	0.50	228.9	0.00	319.2	0.50	233.7	0.25	328.4
4/04/79	5.50	275.3	4.00	357.0	5.75	280.6	4.00	358.2	5.50	263.0	4.25	364.3	5.75	277.0	4.75	379.0
4/05/79	6.00	281.5	4.25	363.5	6.00	286.4	4.25	365.8	5.75	265.5	4.75	372.2	5.75	284.4	5.00	388.6
4/06/79	2.00	273.6	1.25	351.9	1.75	260.9	0.00	324.9	2.00	264.4	1.50	360.6	2.25	277.5	1.50	373.7
4/07/79	5.75	271.9	4.00	353.6	5.75	278.3	4.00	358.0	5.50	263.4	4.50	361.4	5.75	268.2	4.75	372.7
4/08/79	5.75	278.3	4.00	357.8	5.75	284.5	4.25	364.5	5.50	266.0	4.50	368.7	5.50	282.0	5.00	384.7
4/09/79	2.00	241.6	0.00	318.7	2.50	247.5	0.00	315.7	0.75	235.9	0.25	326.2	1.50	242.2	1.25	333.7
4/10/79	0.00	220.2	0.00	289.7	0.00	223.6	0.00	289.3	0.00	210.2	0.00	294.3	0.00	214.1	0.00	305.9
4/11/79	2.75	238.7	0.00	322.0	3.25	244.0	0.00	316.7	2.25	237.1	1.00	327.6	3.25	247.8	2.00	336.8
4/12/79	4.50	250.3	1.25	328.9	4.50	255.6	1.25	328.9	4.25	248.9	2.50	342.1	4.50	256.0	3.25	349.8
4/13/79	5.50	273.9	3.75	353.0	5.75	279.1	3.75	356.3	5.25	262.2	4.25	364.0	5.75	269.0	4.75	378.5
4/14/79	5.75	281.8	4.25	363.4	6.00	286.9	4.25	364.3	5.75	266.1	4.75	371.5	5.75	284.6	5.00	386.6
4/15/79	5.75	282.6	4.25	365.3	5.75	288.3	4.25	365.0	5.50	268.8	4.50	374.0	5.75	283.1	5.00	387.0
4/16/79	3.25	266.4	1.50	340.0	3.25	269.1	1.50	340.7	3.25	260.6	2.25	354.7	3.25	267.5	2.50	365.3
4/17/79	4.50	274.0	3.25	352.3	5.00	278.5	3.25	352.1	4.00	264.8	3.25	362.1	4.25	272.3	3.75	370.4
4/18/79	5.25	269.7	3.25	346.9	5.75	273.9	3.25	348.0	1.50	243.6	0.00	318.0	5.50	271.8	4.25	365.4
4/19/79	5.25	261.2	2.25	336.3	5.75	265.0	2.25	335.0	5.00	255.7	2.75	346.1	5.50	262.9	3.25	349.5
4/20/79	5.50	276.0	3.75	353.5	5.75	280.1	3.75	354.3	5.25	263.3	4.25	362.9	5.75	273.1	4.50	372.0
4/21/79	4.50	255.6	1.75	334.5	4.50	259.7	1.50	333.2	3.25	253.9	2.00	344.2	4.00	262.3	2.75	350.7
4/22/79	5.75	272.7	3.75	350.0	6.00	276.0	3.75	348.9	5.25	260.8	4.00	355.1	5.75	272.6	4.50	365.2
4/23/79	4.00	265.0	2.75	343.8	4.25	269.9	2.50	343.0	3.75	261.9	2.75	352.4	4.00	270.6	3.00	362.9
4/24/79	5.25	266.8	1.75	344.9	5.50	270.9	1.50	341.9	4.75	260.8	1.75	350.8	5.00	270.6	2.25	361.9
4/25/79	5.25	272.6	3.50	352.4	5.75	276.2	3.00	348.8	5.00	262.3	3.50	355.5	5.25	272.5	4.00	364.5
4/26/79	5.50	276.5	3.50	356.7	6.00	281.0	3.50	355.0	5.25	263.3	3.50	364.6	5.75	274.6	3.75	373.9
4/27/79	5.75	275.3	3.75	355.1	6.00	279.1	3.50	353.7	5.50	263.8	3.75	363.3	5.75	274.5	4.25	372.6
4/28/79	5.50	280.3	3.50	359.7	5.75	283.8	3.25	358.4	5.25	264.7	3.25	367.9	5.50	275.6	4.00	376.1
4/29/79	5.75	271.0	3.75	350.1	5.75	274.8	3.50	348.5	5.50	262.4	3.75	358.5	5.50	273.3	4.25	367.1
4/30/79	5.25	271.1	2.75	349.8	5.50	275.3	2.75	348.0	5.25	261.1	3.00	358.5	5.25	273.4	3.75	367.4
TOTAL	HRS.		HRS.		HRS.		HRS.		HRS.		HRS.		HRS.		HRS.	
	138.50		82.75		145.00		80.00		123.75		88.75		137.75		106.00	
AVERAGE																
MAX.	266.7		345.3		270.7		344.3		256.0		352.9		266.7		364.6	

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
5/01/79	1.75	260.6	0.25	334.0	2.00	264.7	0.25	330.6	1.25	253.2	0.25	336.4	1.50	257.8	0.50	345.7
5/02/79	5.00	263.0	3.00	342.6	5.50	268.0	3.00	341.1	4.75	260.0	3.50	349.0	5.25	270.7	3.75	358.2
5/03/79	4.75	268.4	2.75	349.6	5.50	273.1	2.50	347.0	4.25	259.4	2.75	354.4	4.50	271.2	3.25	363.0
5/04/79	5.50	272.3	2.50	354.2	5.50	277.3	2.25	353.0	4.50	258.9	2.50	364.0	5.00	273.3	3.00	373.3
5/05/79	5.75	276.6	3.75	357.1	5.75	280.6	3.75	356.0	5.50	262.0	4.00	364.7	5.75	275.2	4.50	371.8
5/06/79	6.00	269.9	3.75	350.1	6.00	274.6	3.50	348.6	5.75	262.4	3.75	356.2	5.75	273.8	4.50	364.5
5/07/79	5.25	265.5	3.00	345.2	5.50	270.1	3.00	343.4	5.00	260.3	3.00	351.4	5.25	272.1	3.75	360.7
5/08/79	5.00	259.9	3.00	340.7	5.25	263.4	2.75	338.1	4.75	258.2	3.25	346.8	5.25	266.3	3.75	356.1
5/09/79	1.25	250.5	0.25	326.7	1.50	254.6	0.00	322.6	0.50	237.4	0.25	327.5	0.50	242.1	0.25	337.6
5/10/79	4.25	267.3	2.50	348.7	4.50	271.5	2.25	347.7	4.00	258.3	2.75	357.8	4.50	273.9	3.75	365.9
5/11/79	5.75	271.3	4.00	352.7	5.75	275.5	3.75	351.5	4.75	260.2	3.75	360.2	5.50	273.6	4.25	369.3
5/12/79	5.75	269.9	4.00	350.3	5.75	274.7	3.75	348.6	5.50	258.3	4.00	356.4	5.75	272.5	4.50	365.3
5/13/79	6.00	271.9	4.00	353.7	6.00	276.4	3.75	352.4	5.50	259.4	4.00	361.5	6.00	271.6	4.75	369.9
5/14/79	6.00	273.2	3.75	354.9	6.25	277.3	3.75	353.0	5.75	259.4	4.00	362.1	6.00	273.6	4.50	371.4
5/15/79	5.50	266.3	3.25	347.6	5.50	271.0	3.25	344.8	5.25	258.5	3.25	352.1	5.50	271.1	4.25	361.2
5/16/79	5.00	265.4	2.75	344.9	5.25	270.9	2.00	343.2	5.00	257.3	3.00	351.6	5.00	270.5	3.50	359.2
5/17/79	5.25	278.6	2.75	359.6	5.75	284.1	2.75	360.1	5.00	260.1	3.25	371.2	5.25	276.5	4.00	380.8
5/18/79	0.00	191.4	0.00	239.5	0.00	194.3	0.00	238.5	0.00	187.6	0.00	228.8	0.00	194.4	0.00	232.3
5/19/79	5.75	275.8	3.75	356.1	5.75	280.4	3.75	355.2	5.25	260.0	4.00	365.0	5.50	273.6	4.50	373.2
5/20/79	1.50	260.6	0.75	339.3	1.75	265.0	0.50	335.7	1.25	252.9	0.75	346.0	1.25	260.5	0.75	355.6
5/21/79	4.00	268.0	1.25	348.8	4.25	272.6	1.25	344.3	3.50	254.9	1.25	358.7	4.00	269.6	3.00	369.6
5/22/79	5.75	275.4	4.25	355.1	5.75	280.1	4.00	353.4	5.50	259.2	4.25	361.6	1.50	252.2	0.25	329.3
5/23/79	5.25	259.3	3.00	338.0	5.50	264.0	2.75	336.8	5.25	255.3	3.25	344.7	5.50	265.9	4.25	355.4
5/24/79	1.25	242.4	0.00	315.2	1.75	246.1	0.00	312.4	0.25	231.1	0.00	317.8	0.50	234.7	0.25	329.0
5/25/79	3.25	253.6	0.50	328.1	3.25	258.7	0.50	327.5	2.50	250.5	1.25	334.3	2.75	257.0	1.50	343.1
5/26/79	4.75	269.0	2.50	346.8	5.00	274.5	4.25	494.9	4.25	257.3	2.50	355.4	4.50	269.7	3.50	364.5
5/27/79	3.75	278.6	2.25	359.3	3.75	284.4	1.75	360.1	3.00	260.5	2.50	367.9	3.50	277.9	2.50	377.3
5/28/79	1.25	240.0	0.00	310.3	1.25	244.0	1.00	620.8	0.50	232.0	0.00	312.1	0.50	237.7	0.00	320.1
5/29/79	5.50	265.2	2.25	343.4	5.75	270.5	2.00	342.0	5.25	256.7	2.25	348.9	5.50	268.7	3.00	357.3
5/30/79	5.25	278.1	3.25	358.7	5.25	283.0	3.00	357.2	4.75	260.6	3.50	367.1	4.75	274.8	3.75	375.4
5/31/79	5.25	279.7	3.75	359.0	5.25	284.5	3.75	358.0	4.25	263.1	3.75	366.8	4.75	276.7	4.00	374.0
TOTAL																
HRS.	136.25		76.75		141.50		74.75		122.50		80.50		126.75		92.00	
AVERAGE																
MAX.	264.1		342.3		268.7		355.4		253.7		348.3		264.5		355.8	

PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY

RUN DATE 7/05/79

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
6/01/79	3.00	250.5	1.00	329.1	3.25	255.5	0.75	328.1	2.75	249.0	1.75	335.2	3.00	256.3	2.00	344.5
6/02/79	4.50	261.7	2.00	343.0	4.75	266.9	1.75	342.5	3.75	255.0	2.50	353.6	4.00	267.8	3.50	362.4
6/03/79	4.50	256.5	1.25	333.4	4.75	261.3	1.00	330.8	3.50	252.9	1.25	340.3	4.00	259.5	1.75	350.8
6/04/79	0.00	177.1	0.00	219.0	0.00	181.5	0.00	220.5	0.00	175.2	0.00	207.0	0.00	178.2	0.00	212.8
6/05/79	4.50	275.5	3.50	354.2	4.75	280.3	3.25	353.5	4.25	258.9	3.50	363.1	4.50	275.5	3.75	370.8
6/06/79	5.25	266.1	2.50	343.0	5.50	270.6	2.50	342.3	5.00	257.4	2.75	349.7	5.50	269.9	3.50	358.6
6/07/79	5.75	263.6	3.00	340.4	5.75	268.2	2.50	338.7	5.25	257.4	3.25	345.5	5.50	268.4	3.75	353.0
6/08/79	3.50	268.0	2.50	346.4	3.50	272.9	2.50	344.3	3.25	256.8	2.50	352.6	3.25	270.8	2.50	358.7
6/09/79	5.50	266.1	3.50	348.4	5.50	270.9	3.00	345.7	5.00	257.9	3.50	353.5	5.50	269.8	3.75	362.1
6/10/79	4.00	254.6	1.50	336.7	4.50	259.7	1.00	334.2	3.50	251.4	2.25	345.3	3.75	257.5	3.00	355.0
6/11/79	5.25	260.4	3.25	344.0	5.50	265.3	2.75	342.2	5.25	256.9	3.25	351.9	5.25	269.2	4.00	359.9
6/12/79	6.00	276.1	4.00	358.3	6.00	281.1	3.75	356.9	5.75	262.6	4.25	366.5	6.00	281.3	4.25	374.2
6/13/79	6.25	280.5	4.25	361.6	6.25	285.3	4.25	360.5	6.00	262.1	4.50	368.6	6.00	282.9	5.00	378.5
6/14/79	6.25	273.8	4.25	355.3	6.25	279.0	4.25	355.3	6.00	262.1	4.25	364.5	6.25	281.0	4.75	373.2
6/15/79	6.00	272.1	4.00	352.0	6.25	277.3	4.00	351.4	5.75	263.1	4.25	360.7	6.00	283.3	4.75	367.8
6/16/79	4.75	266.0	1.00	340.2	4.75	270.4	0.75	336.9	4.50	257.9	1.75	346.3	4.50	264.2	2.25	355.3
6/17/79	4.75	268.1	1.25	344.9	5.00	273.4	1.25	344.5	4.25	258.5	1.50	357.3	4.75	274.0	2.25	362.8
6/18/79	5.75	265.7	3.25	344.0	5.75	270.6	3.25	343.3	5.50	259.4	3.50	350.3	5.75	276.0	4.00	357.0
6/19/79	6.00	268.8	3.75	349.0	6.00	273.5	3.50	347.2	5.50	259.6	3.75	355.8	5.75	278.4	4.25	362.9
6/20/79	6.25	284.1	4.50	365.9	6.50	288.9	4.25	363.5	6.25	264.9	4.50	372.8	6.25	285.2	5.00	380.2
6/21/79	6.25	271.5	3.75	349.2	6.50	276.4	3.75	347.8	6.00	261.3	3.75	356.5	6.25	277.8	4.50	364.0
6/22/79	5.75	275.0	3.25	353.1	6.00	279.9	3.25	351.5	5.50	262.9	3.25	361.0	5.50	279.9	4.25	368.2
6/23/79	6.50	282.7	4.25	362.9	6.50	287.5	4.25	361.1	6.25	264.6	4.25	370.9	6.25	292.5	4.75	377.4
6/24/79	5.75	263.2	3.00	343.0	6.00	267.8	3.00	341.7	5.50	259.2	3.25	350.1	5.75	272.3	3.75	359.0
6/25/79	6.00	274.2	4.25	354.8	6.50	278.9	4.00	350.3	6.00	261.5	4.25	358.4	6.00	285.8	4.75	368.8
6/26/79	6.25	275.0	3.75	353.1	6.25	280.1	3.50	349.1	6.00	262.0	4.00	357.4	6.00	285.3	4.50	366.8
6/27/79	6.00	277.0	4.00	355.7	6.25	281.3	3.50	351.8	5.75	262.7	4.25	359.5	6.00	287.0	4.50	368.8
6/28/79	6.50	283.2	4.50	362.7	6.50	287.7	4.00	358.6	6.25	265.1	4.25	366.8	6.25	291.9	4.75	375.3
6/29/79	5.50	269.7	3.75	351.5	5.50	274.4	3.50	347.9	5.25	261.2	4.00	358.0	5.25	280.9	4.25	368.9
6/30/79	5.75	271.7	3.00	353.3	5.75	277.0	3.00	350.3	5.50	261.5	3.50	359.8	5.50	280.1	3.75	369.6
TOTAL																
HRS.	158.00		91.75		162.25		86.00		149.00		97.50		154.25		111.75	
AVERAGE																
MAX.	266.6		344.9		271.5		343.1		256.7		351.3		272.8		359.6	

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225 MAX		>325 MAX		>225 MAX		>325 MAX		>225 MAX		>325 MAX		>225 MAX		>325 MAX	
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
7/01/79	5.00	281.2	2.50	360.3	5.00	285.7	2.50	357.4	4.25	264.5	2.75	366.9	4.75	287.5	2.75	375.6
7/02/79	1.25	261.3	0.25	335.0	1.50	267.1	0.25	330.4	1.50	255.2	0.25	338.9	1.50	258.1	1.00	346.8
7/03/79	4.00	259.6	1.50	332.4	4.00	263.8	0.75	330.2	4.00	256.5	1.50	336.1	4.00	262.9	2.00	345.9
7/04/79	2.25	256.0	0.25	327.5	2.50	260.7	0.00	324.7	2.00	251.9	0.50	332.6	1.75	255.8	1.00	341.4
7/05/79	6.25	277.4	4.25	357.4	6.50	282.4	4.00	354.7	5.50	261.5	3.50	362.8	6.00	288.2	4.75	372.2
7/06/79	5.75	276.5	3.75	355.7	6.25	280.9	3.50	352.6	5.75	258.5	4.00	361.3	5.75	284.9	4.50	369.5
7/07/79	5.00	262.4	3.00	341.4	5.25	267.5	2.50	338.6	4.75	254.7	3.25	345.5	5.25	272.3	3.75	354.9
7/08/79	6.25	281.6	4.25	360.0	6.75	286.3	4.00	356.7	6.00	260.8	4.50	364.0	6.50	291.6	4.75	371.5
7/09/79	6.50	282.4	4.50	363.8	6.75	287.3	4.50	359.5	6.25	262.3	4.75	365.3	6.75	292.2	5.00	375.7
7/10/79	6.50	285.3	4.50	365.9	6.75	290.1	4.50	363.7	6.25	263.4	4.25	372.4	6.75	296.8	4.75	379.9
7/11/79	6.75	287.4	4.50	369.2	6.75	291.7	4.25	366.1	6.50	262.0	4.25	375.3	6.75	297.6	4.50	382.5
7/12/79	6.25	284.2	4.50	367.4	6.25	289.3	4.25	364.8	6.00	262.1	4.50	374.2	6.50	297.2	5.00	382.7
7/13/79	6.50	282.9	4.25	364.3	6.50	287.6	4.00	361.6	6.25	261.8	4.25	371.0	6.75	294.9	5.00	380.1
7/14/79	6.25	283.2	4.00	364.3	6.75	288.1	3.75	361.5	6.25	263.6	4.00	370.8	6.75	295.9	5.00	379.9
7/15/79	5.00	279.9	2.25	361.7	5.25	284.8	2.25	359.4	4.00	258.7	2.50	370.0	5.50	292.2	2.75	378.1
7/16/79	1.25	253.2	0.00	322.3	1.25	259.7	0.00	316.1	0.50	233.9	0.25	328.3	1.25	254.1	0.25	347.4
7/17/79	1.00	251.4	0.00	317.7	1.00	254.7	0.00	308.3	0.50	233.3	0.00	311.8	0.75	249.8	0.25	332.6
7/18/79	0.00	218.5	0.00	277.8	0.00	222.0	0.00	274.5	0.00	198.6	0.00	266.3	0.00	222.3	0.00	289.8
7/19/79	0.00	215.6	0.00	268.8	0.00	222.1	0.00	265.8	0.00	200.3	0.00	250.3	0.00	215.9	0.00	291.8
7/20/79	1.25	243.4	0.00	315.0	1.25	248.2	0.00	313.1	0.75	235.3	0.00	319.0	1.25	254.2	0.50	327.5
7/21/79	2.50	258.8	0.25	327.7	2.75	262.0	0.00	323.9	1.50	250.2	0.50	330.8	2.25	269.0	0.75	340.3
7/22/79	6.25	276.5	4.00	354.3	6.25	280.9	4.00	352.6	6.00	256.6	4.25	361.1	6.50	290.5	4.75	371.6
7/23/79	6.25	279.6	4.25	358.8	6.25	284.0	4.00	356.0	6.00	259.4	4.25	364.0	6.75	294.4	4.75	375.2
7/24/79	6.25	282.4	4.75	363.0	6.25	286.4	4.25	359.3	6.00	260.7	4.50	367.2	6.75	296.8	5.00	377.7
7/25/79	2.25	263.4	1.25	343.5	2.25	267.4	1.00	339.0	2.00	255.5	1.25	348.1	2.25	278.0	1.50	355.9
7/26/79	6.00	277.5	3.75	357.0	6.00	281.9	3.50	354.7	5.75	258.4	3.75	362.2	6.50	291.9	4.25	371.1
7/27/79	6.00	275.3	4.25	353.6	6.25	279.3	3.75	350.7	5.75	258.3	4.25	359.7	6.50	286.3	5.00	368.2
7/28/79	5.75	269.5	3.25	347.4	6.00	274.2	2.75	344.5	5.50	256.5	3.50	351.9	6.25	283.7	4.25	359.3
7/29/79	5.00	272.7	3.75	353.4	5.25	277.5	3.50	350.6	4.50	257.8	3.75	359.4	5.50	287.7	4.00	366.9
7/30/79	4.75	272.0	3.25	352.0	4.75	276.9	3.25	349.5	4.50	257.0	3.50	357.5	5.00	288.0	3.75	366.2
7/31/79	5.75	264.7	3.25	343.9	5.75	270.2	2.75	340.9	5.50	255.1	3.50	348.8	6.00	280.5	4.00	354.6
TOTAL																
HRS.	139.75		84.25		144.00		77.75		130.00		86.00		144.75		99.50	
AVERAGE																
MAX.	268.3		344.6		272.9		341.3		252.4		348.2		277.8		359.1	

PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY

RUN DATE 9/24/79

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS.	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
8/01/79	5.75	268.9	3.25	349.2	6.00	273.5	3.00	346.3	5.50	254.8	3.50	354.3	6.50	284.2	4.00	361.5
8/02/79	5.50	275.7	4.00	357.0	5.50	280.4	4.00	354.6	5.25	258.0	4.25	364.5	5.75	287.7	4.75	372.3
8/03/79	5.50	264.2	3.50	344.3	6.00	268.1	3.25	347.8	5.25	254.0	3.50	349.3	6.25	279.5	4.00	355.7
8/04/79	5.75	263.5	3.50	346.4	5.75	268.3	3.25	344.8	5.25	254.9	3.75	353.4	6.25	279.8	3.75	359.6
8/05/79	1.75	248.3	0.00	321.4	1.75	252.4	0.00	315.8	1.25	238.7	0.25	326.6	2.25	259.2	0.50	332.4
8/06/79	5.75	271.1	3.75	352.1	5.75	275.3	3.25	347.8	5.50	256.4	4.00	357.4	6.25	287.1	4.50	365.7
8/07/79	6.00	269.7	3.75	351.9	6.00	274.4	3.50	347.4	6.00	257.2	3.75	356.3	6.50	284.9	4.25	363.2
8/08/79	6.25	271.3	3.50	352.2	6.50	275.7	3.50	350.0	6.00	256.8	3.50	356.1	7.00	286.0	4.25	363.8
8/09/79	6.00	278.0	3.75	361.4	6.00	283.3	3.75	357.6	5.75	258.9	4.25	371.8	6.00	292.7	4.50	379.1
8/10/79	1.50	246.7	0.00	317.9	1.75	251.0	0.00	310.7	0.75	235.9	0.00	323.2	2.50	263.6	0.25	338.5
8/11/79	3.50	253.9	1.00	334.5	4.25	258.7	0.75	330.6	3.25	251.8	1.50	341.5	4.00	266.3	2.00	349.3
8/12/79	5.00	262.0	3.00	346.4	5.25	267.6	2.50	343.0	4.50	254.4	3.50	352.3	5.50	276.5	3.50	361.2
8/13/79	5.25	278.9	1.75	362.0	5.25	284.9	1.25	357.3	4.50	255.8	1.75	371.6	5.00	293.5	2.75	381.3
8/14/79	0.25	225.4	0.00	287.3	0.50	229.4	0.00	283.8	0.00	216.8	0.00	288.2	0.50	235.6	0.00	296.0
8/15/79	0.00	157.7	0.00	183.1	0.00	155.8	0.00	179.6	0.00	146.9	0.00	175.0	0.00	151.0	0.00	183.1
8/16/79	3.75	252.5	0.75	332.2	4.25	257.3	0.25	327.2	3.00	245.0	1.25	336.1	4.00	263.7	2.00	346.9
8/17/79	3.75	243.8	0.00	311.5	4.00	257.8	0.00	304.6	1.75	230.9	0.00	314.0	3.50	251.7	0.00	323.7
8/18/79	4.00	271.9	3.00	353.2	4.00	276.4	3.00	348.5	3.50	254.2	3.25	359.4	4.25	285.5	3.50	370.3
8/19/79	5.75	274.1	3.75	356.3	6.00	279.2	3.25	351.1	5.25	255.9	4.00	362.4	6.00	289.0	4.75	372.7
8/20/79	5.50	278.6	4.25	362.6	5.75	284.4	3.75	358.8	5.25	258.5	4.50	368.9	6.00	293.6	4.75	378.8
8/22/79	2.50	276.2	1.50	360.3	2.75	281.1	1.50	355.6	2.50	258.4	1.50	362.4	2.75	289.1	1.75	373.5
8/23/79	6.00	281.6	4.25	366.4	6.00	285.7	4.00	361.3	5.50	258.8	4.25	369.2	6.50	293.5	4.75	381.6
8/24/79	6.00	269.8	3.75	354.2	6.00	274.5	3.50	350.2	5.50	256.0	4.00	359.1	6.25	282.3	4.25	368.2
8/25/79	5.75	264.0	3.75	348.7	5.75	269.1	3.25	344.9	5.50	254.2	3.75	352.5	6.00	278.1	4.50	363.3
8/26/79	5.50	267.1	3.50	350.1	5.50	272.0	3.00	346.4	5.25	254.7	3.50	353.8	6.25	280.1	4.25	364.5
8/27/79	4.00	264.8	3.00	346.0	4.00	269.4	3.00	342.8	4.00	253.9	3.00	349.4	4.25	276.9	3.25	359.6
8/28/79	6.00	272.5	3.75	355.9	6.00	277.3	3.50	351.6	5.75	257.2	3.75	359.6	6.25	284.1	4.50	369.4
8/29/79	5.50	274.9	3.75	356.1	5.75	279.1	3.50	352.6	5.00	257.6	3.75	361.7	6.00	286.2	4.25	370.7
8/30/79	5.25	266.4	3.50	347.9	5.50	270.5	3.00	345.9	5.25	255.5	3.75	351.5	6.00	278.2	4.25	360.6
8/31/79	5.75	276.8	4.00	359.9	6.00	282.1	4.00	357.9	5.50	257.2	3.75	365.9	6.25	286.9	4.25	374.1
TOTAL																
HRS.	138.75		81.25		143.50		74.50		127.25		85.50		150.50		98.00	
AVERAGE																
MAX.	262.3		340.9		267.2		337.2		252.0		345.6		277.5		354.7	

PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY

RUN DATE 10/02/79

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
9/01/79	6.25	279.9	4.25	360.4	6.25	284.1	4.25	357.3	6.00	258.9	4.25	365.8	6.50	289.8	4.75	374.4
9/02/79	5.50	272.3	3.50	353.1	5.75	276.7	3.25	350.2	4.75	257.2	3.25	357.7	6.00	283.5	3.75	366.3
9/03/79	5.50	266.8	3.50	347.7	5.50	270.6	3.25	344.9	5.25	256.3	3.75	353.7	5.75	278.9	4.25	362.4
9/04/79	5.75	275.7	4.00	358.5	5.75	279.5	3.50	353.7	5.50	258.4	3.75	364.0	6.00	289.0	4.50	374.3
9/05/79	6.00	283.7	4.25	365.7	6.50	287.3	4.25	362.6	5.75	258.1	4.50	372.6	6.50	294.7	4.75	381.4
9/06/79	4.75	281.1	3.75	362.1	4.75	285.3	3.50	358.9	4.50	258.1	3.75	368.0	5.50	291.3	4.00	376.5
9/07/79	4.50	277.2	3.75	357.0	4.75	281.5	3.50	354.3	4.25	256.9	3.75	362.4	5.00	288.0	4.00	371.8
9/08/79	4.75	259.6	2.25	344.4	4.75	264.9	2.00	341.1	4.25	252.1	2.50	351.1	5.25	274.5	3.50	361.0
9/09/79	4.00	263.8	1.50	348.9	4.00	269.1	1.50	346.0	3.25	250.7	1.75	355.6	4.50	277.8	2.75	365.1
9/10/79	5.50	259.6	3.25	342.7	5.75	264.3	2.75	339.2	5.25	251.4	3.25	347.0	6.00	271.8	4.25	355.9
9/11/79	5.25	266.5	3.25	346.1	5.50	270.7	3.00	343.6	4.75	251.2	3.50	351.0	5.75	278.3	4.00	361.3
9/12/79	5.50	270.4	3.50	350.0	5.75	274.5	3.25	346.6	5.25	252.3	3.50	354.0	5.00	280.5	4.25	364.6
9/13/79	4.50	255.0	2.00	334.1	4.75	259.2	1.50	330.0	4.25	248.8	2.25	336.3	5.25	266.8	3.00	346.3
9/14/79	3.00	258.8	0.75	340.1	3.00	263.4	0.50	337.0	2.50	248.9	1.25	347.0	3.25	272.5	1.50	356.9
9/15/79	0.00	117.2	0.00	130.4	0.00	119.2	0.00	127.0	0.00	102.1	0.00	119.4	0.00	108.9	0.00	126.2
9/16/79	0.00	115.5	0.00	132.1	0.00	120.3	0.00	133.1	0.00	106.2	0.00	122.7	0.00	116.1	0.00	136.5
9/17/79	0.00	159.9	0.00	197.2	0.00	164.9	0.00	199.0	0.00	156.6	0.00	185.7	0.00	171.6	0.00	208.6
9/18/79	1.75	263.1	1.25	348.0	2.00	267.8	1.25	352.3	1.50	247.3	1.25	354.9	2.25	278.9	1.75	366.2
9/19/79	5.25	274.4	3.50	357.4	5.25	279.1	3.50	355.4	5.00	253.9	3.50	364.9	6.00	289.0	4.00	376.0
9/20/79	5.25	271.1	3.50	353.8	5.75	275.5	3.50	361.2	5.00	252.6	3.50	358.0	6.00	284.2	4.25	369.4
9/21/79	5.00	266.6	2.75	348.5	5.25	271.4	3.00	344.7	4.50	251.4	3.00	352.5	5.50	280.4	3.50	364.5
9/22/79	5.25	266.6	3.50	347.6	5.75	271.1	3.25	343.9	5.00	249.8	3.50	351.2	6.00	279.0	4.25	362.7
9/23/79	5.25	273.8	3.75	357.0	5.25	278.3	3.25	352.7	5.00	253.1	3.50	360.7	5.75	286.0	4.00	371.6
9/24/79	5.50	269.3	3.75	351.8	5.50	273.9	3.25	347.8	5.25	253.1	3.50	354.5	5.75	281.7	4.25	365.6
9/25/79	5.00	265.2	3.00	347.8	5.25	269.7	2.75	345.0	4.75	250.1	3.00	352.5	5.75	278.1	3.75	364.1
9/26/79	5.00	259.7	2.75	342.6	5.00	264.5	2.50	339.3	4.50	249.3	2.75	346.3	5.50	272.4	3.50	356.9
9/27/79	4.75	263.4	1.75	345.3	5.50	267.6	1.50	341.1	4.25	249.2	1.75	349.8	5.75	275.5	2.50	359.8
9/28/79	4.75	266.2	2.50	344.8	5.00	269.9	2.25	340.0	4.75	250.8	2.75	346.0	5.25	274.5	3.75	355.9
9/29/79	5.50	266.6	3.50	347.4	6.00	271.1	3.00	343.2	5.25	253.1	3.50	352.7	6.00	279.1	4.25	362.3
9/30/79	4.50	272.6	2.25	352.4	5.00	276.8	2.25	348.6	4.25	254.4	2.50	356.3	5.00	282.5	3.25	365.5
TOTAL																
HRS.	133.50		81.25		139.25		75.25		124.50		83.00		147.75		100.25	
AVERAGE																
MAX.	254.7		330.5		259.1		328.0		239.7		333.8		265.8		344.3	

PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY

RUN DATE 11/01/79

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
10/01/79	4.25	270.7	3.25	349.8	4.25	275.2	2.75	346.1	4.00	254.5	3.00	353.9	4.25	281.0	3.25	362.9
10/02/79	5.00	273.3	3.25	357.3	5.25	278.1	3.00	356.3	4.75	251.9	4.00	371.0	5.50	285.2	4.25	378.3
10/03/79	5.00	275.0	3.25	358.5	5.00	279.7	3.25	357.8	4.75	252.7	3.75	373.2	5.25	287.2	3.75	380.7
10/04/79	0.25	226.4	0.00	299.6	1.00	230.2	0.00	298.2	0.00	217.4	0.00	311.3	1.25	239.1	0.00	317.9
10/05/79	5.25	279.1	4.00	364.8	5.50	283.7	4.00	364.6	5.00	252.7	4.25	378.5	5.75	290.9	4.50	386.7
10/06/79	5.50	276.6	4.25	364.9	6.00	282.0	4.25	364.7	5.50	250.0	4.75	378.9	6.25	288.9	5.00	386.5
10/07/79	5.75	279.9	4.00	366.7	5.75	284.7	4.00	366.5	5.50	252.6	4.75	381.6	6.00	292.2	5.00	389.2
10/08/79	5.50	278.9	4.25	369.0	5.75	284.8	4.25	367.8	5.25	253.6	4.75	383.2	5.75	292.6	5.00	392.0
10/09/79	3.50	264.6	2.25	353.2	3.75	269.8	2.25	352.8	3.25	247.6	2.75	368.9	4.00	278.3	3.25	377.9
10/10/79	5.50	279.1	4.25	368.6	5.50	284.0	4.00	368.4	5.25	249.7	4.75	382.4	5.75	289.1	5.25	391.4
10/11/79	5.50	286.0	4.50	376.2	5.75	290.8	4.50	375.3	5.50	256.6	4.75	389.1	6.00	295.5	5.00	397.9
10/12/79	5.50	281.5	4.25	378.0	5.50	287.1	4.00	373.1	5.25	254.3	4.75	387.6	5.75	292.7	5.00	396.6
10/13/79	3.50	266.7	2.50	359.4	3.75	271.5	2.50	355.3	3.00	246.9	2.75	371.5	4.00	279.0	3.25	378.9
10/14/79	4.75	262.3	4.00	355.3	5.25	267.7	3.50	350.1	4.75	246.1	4.25	366.3	5.25	272.6	4.50	372.7
10/15/79	6.00	283.3	4.75	379.4	6.00	288.1	4.50	374.3	5.75	253.9	5.00	387.7	6.25	296.6	5.25	396.8
10/16/79	5.75	282.7	4.75	378.8	6.00	287.2	4.50	373.8	5.75	250.3	5.00	389.0	6.25	296.4	5.25	396.8
10/17/79	5.00	279.7	4.00	374.1	5.25	284.6	3.75	368.8	4.75	250.8	4.50	382.6	6.00	292.0	4.75	390.4
10/18/79	4.50	261.2	2.25	346.7	5.00	265.9	1.75	340.3	3.50	248.9	2.75	362.3	5.50	278.6	3.00	369.7
10/19/79	4.00	269.6	2.50	361.8	4.25	274.3	2.25	356.7	3.75	244.9	3.25	372.2	4.75	281.9	3.75	379.5
10/20/79	5.00	265.8	3.75	358.3	5.25	270.9	3.25	352.3	4.50	245.8	4.00	368.5	5.75	278.3	4.50	376.1
10/21/79	0.00	203.2	0.00	269.7	0.00	207.8	0.00	263.2	0.00	184.4	0.00	272.8	0.00	222.3	0.00	293.1
10/22/79	5.25	268.8	4.00	363.4	5.50	273.6	4.00	357.6	4.75	243.8	4.50	373.0	5.75	280.4	4.75	381.4
10/23/79	5.50	275.6	4.50	372.0	5.75	281.0	4.00	367.4	5.25	247.7	4.75	381.8	5.75	288.4	5.00	391.2
10/24/79	5.50	277.6	4.25	371.5	5.75	282.9	4.25	367.9	5.25	249.9	4.75	382.1	6.25	290.4	5.25	390.8
10/25/79	5.50	275.2	4.50	368.8	6.00	281.0	4.25	365.9	5.25	249.0	4.75	380.4	6.25	288.4	5.25	388.9
10/26/79	5.50	278.8	4.25	374.1	5.75	284.1	4.25	370.8	5.25	250.1	4.75	385.3	6.00	291.9	5.00	393.5
10/27/79	5.50	278.5	4.25	373.6	5.75	283.9	4.25	370.9	5.25	250.6	4.75	384.2	6.00	291.7	5.00	393.5
10/28/79	5.25	265.6	4.25	358.5	5.25	270.5	3.75	353.1	5.00	244.1	4.50	368.4	5.50	277.6	4.75	376.3
10/29/79	4.50	253.7	3.50	347.7	4.75	258.7	3.00	343.1	4.25	242.7	4.00	359.6	5.00	266.6	4.25	365.5
10/30/79	0.50	229.0	0.00	309.4	1.00	234.7	0.00	302.9	0.00	215.0	0.00	319.2	1.50	250.9	0.50	339.7
10/31/79	4.75	266.0	3.50	361.3	5.25	271.3	3.50	360.5	4.50	243.7	4.25	374.8	5.50	280.0	4.50	383.9
TOTAL	HRS.															
	142.75		107.00		150.50		101.50		134.50		118.75		158.75		127.75	
AVERAGE																
MAX.	268.2		357.8		273.2		354.4		245.2		369.1		281.2		378.0	

PHYSICAL SCIENCE LABORATORY, NEW MEXICO STATE UNIVERSITY

ENERGY RESEARCH AND DEVELOPMENT SECTION

DOW HEAT TRANSFER FLUID TEST PROJECT

RUN DATE 11/07/79

DATE	STAND 1				STAND 2				STAND 3				STAND 4			
	CH 18		CH 21		CH 26		CH 29		CH 34		CH 37		CH 42		CH 45	
	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX	>225	MAX	>325	MAX
	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F	HRS	F
11/01/79	4.75	266.7	4.00	362.7	5.25	272.4	3.75	358.6	4.50	242.7	4.50	373.1	5.50	279.4	4.50	383.1
11/02/79	3.25	263.6	2.00	357.8	3.25	269.2	2.00	354.5	2.75	242.6	2.50	371.3	3.50	278.4	3.00	380.0
11/03/79	4.75	255.5	3.50	348.3	5.00	260.3	3.25	345.0	4.25	239.4	4.00	362.4	5.25	269.7	4.50	369.0
11/04/79	4.00	254.0	2.00	346.2	4.25	259.0	1.75	342.1	3.75	240.8	3.50	358.8	4.75	267.2	3.75	366.2
11/05/79	5.25	271.1	4.25	368.0	5.50	276.7	4.00	362.9	5.00	245.7	4.75	378.1	5.75	283.9	5.00	387.6
11/06/79	0.00	183.8	0.00	242.7	0.00	185.7	0.00	239.4	0.00	165.5	0.00	233.6	0.00	192.1	0.00	254.5
TOTAL HRS.	22.00		15.75		23.25		14.75		20.25		19.25		24.75		20.75	
06 AVERAGE MAX.	249.1		337.6		253.9		333.7		229.4		346.2		261.8		356.7	

C. Metals Corrosion Analysis

SUMMARY REPORT

CORROSION EVALUATION OF ABSORBER PANELS USED IN DOW CORNING STAGNATION TEST PROGRAM

By :

A.P. Castillo and
Dr. E.F. Smith, III

Olin Metals Research Laboratory
New Haven, CT

INTRODUCTION

Within the auspices of a DOE contract (EM-78-C-04-4296) the Dow Corning Corporation contracted with New Mexico State University to provide exposure testing of flat plate solar collectors. The test program was established to provide long term durability data on four heat transfer fluids tested under no flow (stagnation) conditions. Each fluid was tested in a loop containing two single glazed, selectively coated collectors. The collectors were manufactured by P.P.G. and contained Cu and Al Solar Bond® absorber panels.

Each fluid loop contained both an Al and Cu absorber, and on a twice daily schedule, the fluid was pumped through each loop to ensure a reasonable mixing. Fluid samples were taken at fixed intervals throughout the program to monitor chemical and physical changes in the fluids.

At the conclusion of the stagnation testing, all eight absorber panels were shipped to the Olin Metals Research Laboratory for a corrosion evaluation. The Olin investigation was limited to a metallurgical evaluation of the absorber panels. Olin did not provide input on either the selection of the heat transfer fluids or the parameters used in the stagnation test program. This summary report is intended to be used as an addendum to the final report issued by the Dow Corning Corporation.

This report was issued in an effort to provide Dow Corning with written documentation of the Olin results within the 1979 calendar year. This report is a condensed summary of the results detailed in an unrestricted Olin technical service report to be issued in early 1980.

TEST FLUIDS.

The four commercially available heat transfer fluids selected for this program were:

- 1) SylthermTM 444 - a silicone based fluid produced by the Dow Corning Corporation of Midland, Michigan.
- 2) PAO[®]-LV - a polyalphaolefin fluid produced by the Uniroyal Corporation of Oxford, CT.
- 3) Prestone[®] II - an ethylene glycol based fluid produced by the Union Carbide Corporation of New York City, NY.
- 4) Ambitrol[®] NTC - a propylene glycol based fluid produced by the Dow Chemical Corporation of Midland, Michigan.

The SylthermTM 444 and PAO[®]-LV fluids were tested in the as-received condition. The Prestone[®] II and Ambitrol[®] NTC were tested as a 50^V/o solution with water.

EXPERIMENTAL PROCEDURES

Materials Preparation

In the as-received condition, each of the absorber panels still contained an appreciable volume of the individual heat transfer fluids. This fluid was drained and discarded. Any residual liquid was removed by rinsing the fluid channels of the panel with the solvent recommended by the fluid manufacturers. The solvents were removed by a stream of laboratory air. A dry inner fluid channel wall was required to ensure maximum resolution for the initial radio-graphs taken of each panel.

Radiography

An industrial X-ray camera was used to obtain a minimum of seven radiographs from each absorber panel. Three radiographs were obtained from each inlet and outlet section. Additionally, at least one radiograph was taken from a representative section of the fluid channels.

This technique is non-destructive, and the different photographic density levels seen in the radiograph suggest areas for further investigation. The various density levels reflect differences in the X-ray absorption characteristics. Past experience has shown these areas are often associated with corrosion products, localized corrosion, or scale deposition.

Visual Observations

In an effort to determine the presence of any uniform deposit, the inlet tube of each absorber was sectioned for observation with a binocular microscope (7-30x). Additionally, the radiographs were used to identify areas of potential corrosion or scale deposition. Each of these areas were sectioned and the physical cause of each anomaly was identified.

After the initial observations, any scale or corrosion product was removed according to the procedures outlined in ASTM standard G1-72. The samples were then re-examined in the binocular microscope for any evidence of corrosive attack under the original deposit.

SCANNING ELECTRON MICROSCOPY

An AMR model 900 Scanning Electron Microscope with energy dispersive and wavelength dispersive X-ray spectrometers was employed to provide qualitative elemental analyses of corrosion product and scale deposits.

METALLOGRAPHY

Metallographic cross sectioning of fluid channels was accomplished to document extent and directions of pit propagation. Cross sections were also

prepared to determine the structure and relative thicknesses of multi-layered scale deposits.

RESULTS

Copper and Aluminum Absorbers versus SylthermTM 444 and PAO[®]-LV Liquids

Radiography of copper and aluminum absorbers exposed to SylthermTM and PAO[®]-LV liquids revealed negligible susceptibility to localized attack. Sectioning of the inlet tube length of the header section revealed negligible scale buildup. For both fluids, a uniform thin dark brown oxide was observed on the copper inlet pipes.

Copper and Aluminum Absorbers Versus Prestone[®] II

Radiography revealed negligible localized attack in either copper or aluminum Solar Bond[®] absorbers. Sectioning of the copper absorbers did reveal thin white powdery residue on top of a thin uniform layer copper oxide. The thin white residue was also noted on the aluminum absorber channel wall surfaces. No effort was made to analyze the solid white powder since acid cleaning of the metal absorbers revealed negligible localized attack.

Copper and Aluminum versus Ambitrol[®] NTC

Radiography of copper panels exposed to the Ambitrol[®] NTC liquid indicated evidence of scale deposit within the header section. The heaviest deposition occurred along the downstream edges of the tackdown areas. Removal of the scale revealed evidence of corrosive attack along the tube root. Although the attack was non-uniform in nature, no significant localized penetration was observed. A detailed analysis of the scale products will be presented in the final report.

Radiography of the aluminum panels revealed areas of localized attack within the header section and the fluid channel walls. In both areas, significant scale deposition was also observed. After sectioning and removal of the scale products, visual observations revealed two forms of localized corrosion. In two areas of header section, severe crevice attack was observed. In one of these areas, the attack resulted in complete perforation of the panel. In addition, pitting was observed to be uniformly distributed throughout the remainder of the header and channel walls.

In all cases, metallographic cross-sections clearly revealed that the localized attack initiated from the interior of the panel. SEM/microprobe analysis of the corroded areas revealed the scale to contain significant amounts of P, Cu, and Ti. (The presence of the Ti reflects the TiO_2 used as stopweld in the Olin Solar Bond® absorber processing).

CONCLUSIONS

1. Within the test conditions and exposure periods used in this program, three of the four fluids tested (SylthermTM 444, PAO®-LV, and Prestone® II) provided adequate corrosion protection for both Al and Cu absorbers.

2. The Ambitrol® NTC fluid produced severe localized corrosion of an aluminum absorber panel placed in a test loop containing copper components. This test procedure cannot be used to predict the performance of Ambitrol® NTC in an all aluminum fluid loop.

3. The Ambitrol® NTC fluid produced localized, non-uniform attack of a copper absorber panel. Although the resultant metal penetration was relatively shallow, it is difficult to predict the long term performance of this fluid in an all copper system.

4. All of the conclusions in this report refer to a specific fluid. Since each product is known to contain a number of specific additives (i.e. buffers, inhibitors, antioxidants, etc.), extreme caution must be used in

extending these results to the generalized performance of each fluid type (i.e. all silicone fluids, all propylene glycol base fluids, etc.).

D. Fire Hazards Testing Report

FIRE HAZARD CHARACTERISTICS OF FIVE HEAT TRANSFER FLUIDS

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ABSTRACT

Five heat transfer fluids, intended for use in solar collectors, were tested to compare their fire hazard characteristics. Fluids tested include two silicones, two glycols, and a synthetic hydrocarbon. Small scale tests were run to determine ignition properties, heats of combustion, relative fire size, smoke density, and fire behavior of construction materials saturated with fluids.

Large scale pool tests were performed to determine convective and radiant heat release trends, extent of burning, and ease of extinguishment. Fire hazard characteristics obtained from large scale tests are expected to be suggestive of what one would find during a real pool fire situation.

The silicones have the highest thermal and oxidative stability and the best resistance to ignition. Large pool fires show that the silicones and an ethylene glycol have the lowest total heat release and lowest rates of heat release. The silicones are moderate in ease of extinguishment relative to the organics tested. Release of amorphous silica during burning conditions causes the silicones to give high smoke evolution in the National Bureau of Standards (NBS) smoke chamber tests. However, silicones evolve little smoke under smoldering conditions.

No one fluid can be recommended as safest with respect to all fire hazard characteristics under all conditions of use. The glycol/water mixtures show the lowest degree of fire hazard. However, in a spill or rupture condition during use, water would be expected to evaporate from hot fluid leaving a neat glycol. Under these conditions, a silicone (Syltherm® 444) exhibits the best overall fire safety performance. It is recommended that more complete data be obtained on toxicity of smoke and fire gases emitted under smoldering and burning conditions.

Videotapes of the large scale pool burns and extinguishment tests are included with this report.

TABLE OF CONTENTS

ABSTRACT

I. Introduction

II. Results and Discussion

A. Materials

B. Fire and Thermal Stability Properties

C. Small Scale Pool Burns

D. Fluid/Construction Material Burn Tests

E. Smoke Density

F. Extinguishment Tests

G. Large Scale Pool Burns

1) Explanation of Operation

2) Data from Burns

H. Combustion Analysis and Heat Release

I. Summary

III. Experimental

A. Small Scale Analytical Tests

B. Small Scale Pool Burns

C. Fluid/Construction Material Burn Tests

1) Materials

2) Horizontal Burns

3) Vertical Burns

D. Modified NBS Smoke Density Test

E. Extinguishment Tests

F. Large Scale Pool Burns

G. Residue Analysis

IV. Acknowledgements

I. Introduction

With the recent restrictions on the use of PCB's, the heat transfer industry has increased the use of glycol/water mixtures, hydrocarbons, and phosphate esters as replacements for PCB's. Currently, a great deal of concern has developed to assure the safety of these 'new' heat transfer fluids before widespread utilization. The industry is therefore searching for alternative heat transfer fluids that will best meet performance, cost, environmental, and toxicity requirements.

But equally of importance are thermal stability and "flammability" properties. Flammability properties are often assessed simply from flash and fire points and autoignition temperatures (AIT). These properties more appropriately refer to ease of ignition as they ignore consequences of the fire itself (i.e. heat release, fire gases, smoke, etc.). Properties which cover all aspects of fire may be classed as fire hazard characteristics^{1,2}. These are best determined by tests which simulate actual conditions and scale of use with real life modes of failure.

In this study, the fire hazard characteristics of the fluids themselves are examined. In addition, fire hazards of the fluids in conjunction with common construction materials were screened in a preliminary manner.

Those fire hazard characteristics which are most applicable to heat transfer fluids are as follows:

- 1) Ease of ignition is determined by small scale tests such as flash and fire points and AIT.

¹C. J. Hilado, "Flammability Handbook for Plastics", 2nd ed., Technomic, Westport, Conn., 1974, Chapter 2.

²J. Lipowitz and M. J. Ziemelis, "Flammability of Poly(dimethyl-siloxanes). II. Flammability and Fire Hazard Properties", J. Fire and Flammability, 7, 504 (1976)

- 2) Fire growth/flame spread is best determined in large scale tests. Relative fire growth/flame spread was also screened in small burns of common construction materials saturated with the fluids.
- 3) Smoke evolution is commonly determined using a National Bureau of Standards (NBS) smoke density chamber.
- 4) Pyrolysis gas toxicity was screened by chemical analysis for common fire gases.
- 5) Heat release data was obtained in large scale pool burns by following energy release, weight loss, and temperature of the fire.
- 6) Extinguishment data was obtained by comparing effects of various extinguishing agents on the fire.

Fire hazard properties of two Dow Corning heat transfer fluids and three competitive fluids were compared.

II. Results and Discussion

A. Materials

The materials studied in this work were chosen to be representative of developmental or commercially available heat transfer fluids for solar collectors. These materials consist of two Dow Corning fluids and 3 competitive fluids.

- 1) Syltherm® 444 is a 20 cs. polydimethylsiloxane (PDMS).
- 2) DC® X2-1162 is a 10 cs. PDMS containing a stabilizer.
- 3) Uniroyal PAO-LV is a synthetic polyalphaolefin.
- 4) Prestone II is an ethylene glycol containing additives.
- 5) Ambitrol NTC is a propylene glycol containing additives.

Both glycols were used as supplied, although the end-use application would be as a water/glycol mixture. The water/glycol mixtures would not burn until the water was nearly all vaporized. An accidental spill or leak would likely occur during operation, when the fluid is hot. Water would readily evaporate under such conditions. Thus, fire testing of the neat glycols represents a realistic "worst case" situation. References to either glycol indicate the neat glycol unless specified as water/glycol mixtures.

B. Fire and Thermal Stability Properties

Some fire properties of the fluids (flash and fire point, autoignition temperature, and heat of combustion) are listed in Table 1.

Flash, fire, and autoignition temperatures decrease as follows:
Syltherm® 444 > DC® X2-1162 > PAO-LV > Prestone II > Ambitol NTC.

Heats of combustion in kcal/g decrease as follows:
PAO-LV > DC® X2-1162 > Syltherm® 444 > Ambitol NTC > Prestone II.

Volatility and thermal and oxidative stability data are shown in Table 2 and Figures 1 to 10. Ambitol NTC and Prestone II are monomeric glycols with additives. They have distinct boiling points. The silicones and PAO-LV are polymers and thus do not have boiling points in air, though some volatile, low molecular weight oligomers are present. The silicones and PAO-LV must undergo thermal decomposition at high temperature to give catastrophic weight loss. Thus, they show higher flash and fire points than the glycols.

Thermal gravimetric analysis (TGA) of fluids in an inert atmosphere such as argon gives weight loss as a function of increasing temperature due to simple volatilization or to thermal decomposition. Differential scanning calorimetry (DSC) in air gives information concerning endothermic (heat absorbing) or exothermic (heat releasing) processes. Endothermic processes for fluids are generally volatilization or thermal decomposition. Exothermic processes for fluids in air are generally oxidative.

Decreasing volatility follows the order:
Syltherm® 444 > DC® X2-1162 > PAO-LV > Ambitol NTC > Prestone II.

Decreasing oxidative stability is given by:
DC® X2-1162 > Syltherm® 444 > PAO-LV > Ambitol NTC > Prestone II.

C. Small Scale Pool Burns

Small scale pool burns are a simple preliminary screening to estimate fire hazard characteristics. These tests give an indication of how the sample will respond in large scale tests².

Data for the small scale pool burns of Ambitrol NTC, Prestone II, PAO-LV, DC® X2-1162, and Syltherm® 444 are presented in Table 3. Test results for decane, ethylene glycol, and DC® 561 (a 50 cs. PDMS fluid) are included for comparison. Fluids contained 9% decane to provide constant ignition energies.

Both glycols burned to 98-99% weight loss. The ambitrol NTC flame height was 15-20 cm (6-8 in.), lasting ~7 min., while the Prestone II flame was <15 cm (6 in.) and lasted ~8 min. The ethylene glycol test compared closely to Prestone II. Neither of the glycol/H₂O mixtures would burn after the decane had burned. The PAO-LV burned completely with 15-20 cm (6-8 in.) flames throughout most of the 14-15 minute burn period.

Syltherm® 444 and DC® X2-1162 self extinguished short of complete combustion (~30% wt. loss). During the process of volatilization and thermal degradation, the surface of the silicone pool oxidizes^{2,3}. Partially oxidized siloxanes form gels and fully oxidized siloxanes form silica. The self extinguished silicone pools have a white silica surface ash with a gel layer just beneath. Unburned fluid is found beneath the ash and gel layers. This formation acts to shield unburned fluid from energy feedback by the flame. Thus, both silicones burned ~14 min. with maximum flame heights of only 8-10 cm (3-4 in.). Flame heights gradually diminished as crust and gel formation increased.

The five fluids have decreasing relative fire intensities as follows:
PAO-LV>Ambitrol NTC>Prestone II>DC® X2-1162>Syltherm® 444

³J. Lipowitz, "Flammability of Poly(dimethylsiloxanes). I. A Model for Combustion", J. Fire and Flammability, 1 482 (1976).

D. Fluid/Construction Material Burn Tests

These tests represent a screening study of the burning behavior of the heat transfer fluids absorbed in selected common construction materials; fiberglass, ceiling tile, wood paneling, plywood, and asphalt shingle. The 1.3 cm x 13 cm (0.5 in. x 5 in.) saturated construction materials are tested in both horizontal and vertical configurations as described in Sec. III. C. Data from these tests are presented in Tables 4-13.

Goldbond ceiling tile and Owens Corning fiberglass insulation, for all practical purposes, served as inert substrates. With the exception of the water/glycol mixtures on fiberglass and ceiling tile, all samples burned including water/glycol mixtures on paneling and asphalt shingle. Borderline burning occurred with water/glycols on plywood. Water/glycol saturated substrates which did burn had long ignition times. Plywood samples saturated with water/glycols had very low flames (<2 cm) and extinguished in 1-2 min. All other fires engulfed the samples.

In general, Syltherm® 444 burns with a lower intensity than DC® X2-1162 while PAO-LV appears most intense. It is interesting to note that for Prestone II/water on asphalt shingles in the horizontal position and Prestone II/water on paneling in the vertical position, more of the substrate burned than in the control. As expected, vertical burns with ignition at the bottom were more vigorous than horizontal burns.

E. Smoke Density

Smoke includes both particulate matter and liquid aerosols. Smoke contributes to hazards in the following ways:

- 1) Smoke can be highly toxic and/or hot enough to damage the respiratory system.
- 2) Smoke causes obscuration of light and/or eye irritation, which reduces probability of escape and may contribute to panic.
- 3) Smoke may cause equipment damage or corrosion.

Statistics show that smoke and fire gas inhalation causes far more deaths and injuries in fires than actual flame contact⁴.

⁴A. F. Robertson, ed., "Fire Standards and Safety", ASTM Special Publication 614, 1976; see also proceedings of ASTM Committee E-5 on Fire Standards.

The NBS Smoke Density Chamber⁵ is used to determine relative smoke densities for solids held in a horizontal position. This test was modified as described in section III. D. for liquids.

Smoke densities (D_s) for the five fluids under flaming and smoldering conditions are shown in Figures 11-13. The time required to reach $D_s = 16$ (visibility equals ten feet) is also indicated.

Under flaming conditions, the glycols did not generate smoke. The 10 cs. silicone fluid (DC® X2-1162) rapidly generated white smoke ($D_s = 16$, 0.4 min.). PAO-LV reached $D_s = 16$ in 0.6 min., but gave a lower maximum D_s than either silicone.

Under smoldering conditions, the glycols gave measureable D_s values due to vaporization of the glycol. Of the remaining fluids, PAO-LV gave $D_s = 16$ in the shortest time (3.1 min.) and the highest maximum smoke density. The relative hazard based on D_s is:

Smoldering, D_s max.;

PAO-LV>DC® X2-1162>Ambitrol NTC>Prestone II>Syltherm® 444.

Smoldering, $D_s = 16$;

Ambitrol NTC>Prestone II>PAO-LV>DC® X2-1162>Syltherm® 444.

Flaming, D_s max.;

DC® X2-1162>PAO-LV>Syltherm® 444>Ambitrol NTC~Prestone II.

Flaming, $D_s = 16$;

DC® X2-1162>PAO-LV>Syltherm® 444>Ambitrol NTC~Prestone II.

Levels of CO and CO₂ at the time of maximum D_s are indicated in Table 14. In this preliminary screening, CO levels are higher under flaming than smoldering conditions with PAO-LV giving the highest values.

A more complete study of toxicity of combustion and pyrolysis gases, both by chemical analyses and by animal toxicity tests, is recommended.

⁵J. R. Gaskill, "Smoke Development in Polymers During Pyrolysis or Combustion", J. Fire and Flammability, 1, 183 (1970).

F. Extinguishment Tests

Once a fire becomes established a major concern is extinguishment. Knowledge of the response of a burning fluid to particular extinguishing agents is vital.

Extinguishment tests were performed outdoors during calm wind conditions and after each sample had reached full burning intensity. Agents used were water spray, carbon dioxide, dry chemical, 3% protein foam, and high expansion foam.

The glycols were more easily extinguished with all 5 agents than any of the other fluids. Both silicones appeared to be more easily extinguished than the hydrocarbon with carbon dioxide, high expansion foam and 3% protein foam. DC® X2-1162 required more time for extinguishment than PAO-LV and Syltherm® 444 using dry chemical.

Finally, water spray caused substantial flare up with both silicones and the hydrocarbon. These three fluids required approximately 10 sec. for extinguishment.

High expansion foam appears to be the best extinguishing agent tested. Water spray appears least desirable. Dry chemical and carbon dioxide are quite sufficient for extinguishing these fluids in the size of pool fires tested.

All fluids could be extinguished with each of the extinguishing agents. Table 15 indicates the relative ease of extinguishment of the 5 agents on each fluid. These tests were recorded on video tape and are included with this report.

G. Large Scale Pool Burns

One major consequence of a large spill of solar heat transfer fluid could be a large pool fire. Pool fires release their combustion energy in three ways:

- 1) Convective: The energy of the hot gases produced in a fire, which tend to rise and can cause damage to ceiling, roof, and other overhead structures; often the major mode of energy release.

- 2) Radiative: Emission of radiant energy from the hot flame, primarily in the infrared, which tends to be released more or less uniformly in all directions. Radiant energy release from a large pool fire can be considerable, causing ignition of adjacent structures and preventing close approach of fire-fighters.
- 3) Conductive: The flow of energy from the hot, burning material to the pan, ground, or floor; usually a minor path of energy release from large fires.

The rate of heat release (RHR) is more relevant to fire hazard, or the potential for harm, than is the total heat released. This is readily seen in a simple example. A gallon of gasoline or 10.4 pounds of lump coal will release 34,000 kcalories on total combustion. However, gasoline is considered more hazardous because it is likely to release its energy far more rapidly.

The maximum amount of heat which can be released by combustion of a material is given by its standard heat of combustion, listed for these fluids in Table 17.

The maximum theoretical heat release (Q , in kcal) in a fire is the product of the heat of combustion (ΔH_C^O , in kcal/g) and the mass burned (m , in grams).

$$Q = m\Delta H_C^O$$

The maximum RHR (in kcal/sec. or kwatts) is determined by the mass burning rate ($\dot{m}$, in g/sec.) and ΔH_C^O .

$$RHR = \dot{m}\Delta H_C^O$$

Burning pools of 1.2m (4 ft.) diameter and larger have received prime attention for two reasons:

- 1) Large fires, of course, present the greatest hazard.
- 2) A hydrocarbon pool of 1.2m diameter is the smallest which closely models the steady-state burning rate per unit area ($\text{g/m}^2\text{-sec}$) and RHR per unit area (kwatts/m^2) of large fires. (Figure 14)

A major difficulty in modeling of liquid fires is that small, readily studied pool fires (Fig. 14 region B) tend to be diffusion controlled. Burning occurs under laminar flow conditions with a low burning rate controlled by gas phase diffusion of air and fuel. Heat loss from the pan surface and from flame radiation which does not feed back to the fuel is considerable.

Large fires (region C) are radiation controlled. Gas flow (and the flame itself) is highly turbulent. Turbulence is an important means of fuel-air mixing. Heat losses from the pan and by radiation are small. Burning rate (or RHR) per unit area is high, controlled by feedback of radiation from flame to fuel, and almost independent of pool size. Very large pools show a slight decrease in burning rate due to decreased access of air.

Large scale pool burns were conducted with instrumentation recording the sum of convective and radiant heat release, radiant heat release alone, temperature, and mass burning rate.

1) Explanation of Operation

A schematic of the location of the equipment for these tests is found in Figure 15. Comparative weight loss curves are shown in Figure 16. Maximum temperatures 1.8m above and 0.6m lateral to the fire are shown in Figures 17 and 18. Maximum temperature was found above the center of the pan. Maximum temperature found lateral to the pan was 2 feet above the pan. The sum of convective and radiant energies per cm^2 , measured at the center of the gas plume by a calorimeter is shown in Figure 19. Total radiant energies are shown in Figure 20. The location of the thermocouples and calorimeter remained constant throughout the tests for comparison of data. However, due to large differences in radiant energy, the radiometer location ranged from 3.7 to 6.7m (12 to 22 ft.) from the center of the pan to maintain detector response in the range of 1 to 10 m.v. The relocation of the radiometer presents no problem in comparison of data since the millivolt output of the radiometer is proportional to w/cm^2 .

$$mv = 105 \frac{w}{cm^2}$$

Total radiant energy (w) is obtained by integrating radiometer output over the surface of a sphere of radius r (r = distance from center of flame to radiometer in cm.).

w = total radiant energy in watts

$$w = \frac{4\pi r^2 (mv)}{105}$$

This calculation assumes that the flame can be treated as a point radiant energy source. This is a good approximation for the ratio of flame height to radius (0.5 maximum) found in these fires.

Initial surges in energy flux may be seen on some of the energy curves. This results from the gasoline used to ignite the fluids, which burns off in 4-5 minutes. In Tables 16 and 17, which summarize heat release data, initial temperature and energy surges due to gasoline burning were ignored.

2) Data from Burns

The PAO-LV gave 100% weight loss. Both glycols gave ~96.5% weight loss and 3.5% non-flammable residue resulting from additives. Syltherm® 444 gave a 29% weight loss (~37% combustion⁶) and DC® X2-1162 showed a 66% weight loss.

The glycols are readily ignited, as shown by their low flash and fire points, low Auto Ignition Temperature (AIT), and their low vaporization temperatures (Tables 1 and 2). Prestone II and Ambitrol NTC also have the lowest heats of combustion (ΔH_C^0). Though readily ignited, the glycols exhibit low temperatures and low rates of heat release (RHR) during large scale pan burns, suggesting low hazard once ignited.

⁶See Sec. III. F. for calculation of % combustion.

Silicones demonstrate the highest resistance to ignition with the highest flash and fire points and the highest AIT's. Silicones also have the highest thermal stability, and the highest oxidative stability. They have an intermediate heat of combustion. Their low fire temperatures and low energy emissions indicate low hazard once ignited. The hydrocarbon, on the other hand, demonstrates moderate ease of ignition and moderate volatility with the highest heat of combustion. The hydrocarbon also exhibits high hazard once ignited with the highest temperatures during pan burns, and the highest rate of heat release.

These tests were recorded on video tape and are included with the report.

H. Combustion Analysis and Heat Release

Samples obtained from large scale pan burns were homogenized and analyzed for %C and H, and %Si where appropriate. Percent combustion was determined from these analyses for the silicones. Calculation of % combustion assumes that the silicones combust as volatile cyclic siloxanes². A sample calculation is shown Section III. E. Data in Table 17 for % combustion and heat release was corrected in this way for the silicones.

I. Summary

1) Ease of Ignition

Ambitrol NTC>Prestone II>PAO-LV>DC® X2-1162>Syltherm® 444.

2) Small Scale Fire Intensities

PAO-LV>Ambitrol NTC>Prestone II>DC® X2-1162>Syltherm® 444.

3) Rate of Heat Release

Total rate of heat release;

PAO-LV>Ambitrol NTC>DC® X2-1162>Prestone II>Sytherm® 444.

Radiant heat release;

PAO-LV>DC® X2-1162>Syltherm® 444~Ambitrol NTC>Preston II.

4) Smoke Density

Smoldering, D_s max.;

PAO-LV>DC® X2-1162>Ambitrol NTC>Prestone II>Syltherm® 444.

Smoldering, $D_s = 16$;

Ambitrol NTC>Prestone II>PAO-LV>DC® X2-1162>Syltherm® 444.

Flaming, D_s max.;

DC® X2-1162>Syltherm® 444>PAO-LV>Ambitrol NTC~Prestone II.

Flaming, $D_s = 16$;

DC® X2-1162>PAO-LV>Syltherm® 444>Ambitrol NTC~Prestone II.

5) Ease of Extinguishment

Prestone II>Ambitrol NTC>Syltherm® 444>DC® X2-1162>PAO-LV

No one fluid can be recommended as the safest with respect to all fire hazard characteristics. In choosing a fluid for a solar heat transfer application, the particular location and use of the equipment must be considered. All applicable fire hazard characteristics must be weighed with respect to the intended use and potential modes of failure and ignition.

Fire hazard considerations, of course, must be weighed with performance, environmental, toxicity and economic factors in arriving at an optimal fluid for a solar heat transfer system.

III. Experimental

A. Small Scale Analytical Tests

Some of the data used in this study was obtained using Corporate Test Methods of the Analytical Department at Dow Corning. Corporate

Test Methods are similar to the listed ASTM Tests.

Flash point, fire point - ASTM D-92, Cleveland Open Cup.

Autoignition Temperature - ASTM D-2155

Heat of Combustion - ASTM D-240

Thermal Gravimetric Analysis (TGA) - Dupont 400 Thermal Analyzer with Dupont 950 TGA.

Differential Scanning calorimetry/DSC - Dupont 900 Thermal Analyzer with Dupont DSC cell.

Data are shown in Tables 1 and 2, and Figures 1 to 10.

B. Small Scale Pool Burns

Ten grams of fluid were placed in a lightweight aluminum cup, 5.6 cm in diameter. Ten percent by weight of n-decane was added to each fluid to provide a constant ignition energy. The aluminum cup was placed on a screen 8.5 cm above the bottom of a 20 cm x 38 cm x 36 cm (8"x15"x14") high metal, draftfree container with a glass face. Air entered through 2.5 cm diameter holes in the bottom of the container and smoke escaped through a 1.3 cm open rim at the top. The decane was ignited with a propane torch. Flame heights, length of burn and weight of residue were recorded (Table 3).

C. Fluid/Construction Material Burn Tests

1) Materials

The following representative construction materials were tested:

- a) Owens Corning 5/8" (1.6 cm) fiberglass backing from ceiling tile.
- b) 1/4" (0.6 cm) plywood.
- c) Goldbond ceiling tile, Goldbond, Inc.
- d) 3/16" (0.5 cm) paneling, plywood type, Plywood Panels, Inc.
- e) Celetex 'Sol-Seal' Asphalt Roofing Shingles, Celetex Co.

2) Horizontal Burns

Samples of the construction materials (1.3 cm x 13 cm) were immersed in the fluids to saturation. After removal from the fluid, excess was allowed to drain off. The sample was weighed and clamped horizontally 1.3 cm above a wire screen in the draft free box described in section III. B. A propane torch was used to ignite the sample at the end opposite the clamp. Flame heights, length of burn, and residual weights were recorded. This screening test is similar to ASTM D-1692 and D-635. Data are shown in Tables 4 to 8.

3) Vertical Burns

Samples were prepared as in the horizontal test and clamped vertically to a ring stand 51 cm (20 in.) above the base. A 30.5 cm x 30.5 cm x 76 cm (12" x 12") asbestos-walled, ventilated burn chamber (with glass face) was placed over the ring stand. The sample was ignited at its lowest point with a propane torch. Ignition times, flame heights, length of burn, and final weights were recorded. This test is similar to the Underwriters Laboratory UL94 Vertical Burning Test. Data are shown in Tables 9 to 13.

D. Modified NBS Smoke Density Test

A NBS Smoke Chamber at Dow Chemical Co. was used. The procedure is normally performed on solid samples in a vertical configuration⁵ but has been modified² to accommodate fluids in a lightweight aluminum cup. To obtain flaming conditions, four 1.3 cm (1/2 in.) propane flames from 1.6 mm I.D. tubes were directed on the surface of four grams of the fluid in a 5.6 cm. diameter lightweight aluminum cup. Simultaneously, 2.5 w/cm² of radiant heat was directed at the surface of the fluid from a 600 w quartz-iodine lamp (Dyna-Lume High Intensity Radiant Heat Projector, model No. 3151-60). The lamp was located 5.1 cm above the plane of the fluid and 8.4 cm lateral to the center of the cup to avoid interference with the smoke.

Under smoldering conditions, 10 grams of fluid was irradiated similarly in the absence of the propane flames.

Smoke density (D_s) was calculated according to:

$$D_s = \frac{V}{AL} \log \frac{100}{T}$$

V = chamber volume, 18 ft.³

A = exposed sampled area, 0.0269 ft.²

L = light beam path length, 3 ft.

T = % transmission

As D_s approached a maximum, a gas sample was withdrawn and analyzed by glc for % CO₂, and CO (Table 14).

E. Extinguishment Tests

19 liters (5 gal.) of each fluid were placed in a 1.2 m (4') diameter by 5 cm (2") inside depth, 3.7 mm (7 gage) thick steel pan. To aid in the ignition of each fluid, 900 ml of gasoline were poured over the fluid. The gasoline was then ignited with a kerosene torch. The fire was allowed to burn for several minutes to allow gasoline to burn-off and the test fluid to reach full burning intensity. Five extinguishing agents were used; carbon dioxide, dry chemical (Ansul Purple K), water spray, 3% protein foam, and high expansion foam. A fresh supply of fluid in a clean pan was used when the fluid surface was contaminated by extinguishing agent.

F. Large Scale Pool Burns

36.3 kg (80 lb.) of each fluid were placed in a 1.2 m (4') diameter by 5 cm (2") inside depth, 3.7 mm (7 gage) thick steel pan. The pan was mounted on a platform loadcell with digital read-out. Cement blocks supported the pan to protect the platform from heat. Four thermocouples were mounted with junctions 1.8 m (6 feet) above the pan surface. A water cooled pipe served to protect their plastic connectors and wire leads from heat. Four thermocouples were similarly mounted to a vertical, cooled pipe with junctions 6 cm (2 ft.)

lateral to the pan edge. The thermocouple above the center of the pan registered the highest temperatures and was taken to be representative of temperatures in the hot gas plume as shown in Figure 17. The thermocouple 60 cm. (2 ft.) lateral to the pan edge, and 60 cm (2 ft.) above the pan surface registered the highest radiant temperature, shown in Figure 18. Thermocouples were connected to a multipoint strip chart recorder calibrated in °C. Figure 15 shows the test geometry.

A Hy-Cal⁷ Water-Cooled Asymtropic® Calorimeter, type C-1300, was placed 1.8 m above the center of the pan with output displayed on a 10 mv. strip chart recorder. The calorimeter was attached to the end of a boom to allow the sensing surface to be removed from the fire for cleaning. This was most critical for the silicone, which quickly deposited a layer of silica. A Sensors, Inc.⁸, type C-1 radiometer was placed at 3.7 m to 6.7 m (12'-22') from the center of the pan and level with the center of the flame. Output from the radiometer was displayed on a 10 mv. strip chart recorder. Calibration curves for the calorimeter and radiometer were provided by the manufacturers.

Once the burn pan was filled with test fluid, 900 mls. of gasoline (1.5 lb.) were spread over the surface to provide a constant ignition energy. The pool of fluid was ignited and allowed to burn to extinction. Weight loss, burn times, temperatures, and heat release were followed throughout the burn.

G. Residue

Following large scale pan burns of silicones, residue was homogenized and submitted for elemental analysis. From these analyses, percent

⁷Hy-Cal Engineering, Sante Fe Springs, CA.

⁸Sensors, Inc., Ann Arbor, Mich.

combustion was determined as in the following example:

Syltherm® 444 (80 pts. burned)

	Initial (80 pts.)		Residual (57 pts.)		Net Chge.	Equivalents
	% Found	pts.	% Found	pts.		
Si	37.8	30.24	38.3	21.83	-8.41 pts.	.3
C	33.5	26.80	30.3	17.27	-9.53	.8
H	8.54	6.83	7.7	4.39	-2.44	2.4
O		16.13		13.51	-2.62	.16

Ratio of C to H; 1:3. Assuming all C and H was lost as CH_3 groups, % combusted can be calculated as 0.4 equivalents $(\text{CH}_3)_2\text{Si}$. Further assume for simplicity that the residue is $(\text{CH}_3)_2\text{SiO}$ and SiO_2 only.

0.4 eq. combusted as PDMS	13.4 kg (29.6#)	combusted PDMS
<u>0.3</u> eq. SiO_2 lost in smoke	<u>-2.7</u> kg (6.0#)	SiO_2 remaining in
0.1 eq. SiO_2 remaining in residue	10.7 kg (23.6#)	residue calculated weight loss
	10.4 kg (23.0#)	experimental weight loss

IV. Acknowledgements

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J. Marinik, F. Plante and J. Woods.

Table 1 Some Fire Properties of Fluids

<u>Fluid</u>	<u>Flash Pt. (°C)^a</u>	<u>Fire Pt. (°C)^a</u>	<u>Autoignition Temp. (°C)^b</u>	<u>Heat of Combustion (Kcal/g)^c</u>
Prestone II	124	124	216	4.4
Ambitrol NTC	113	113	210	5.5
Uniroyal PAO-LV	132	160	327	11.3
DC® X2-1162	162	188	393	6.6
Syltherm® 444	249	282	393	6.3

^aASTM D-92

^bASTM D-2155

^cASTM D-240

Table 2 Thermal Stability Properties of Fluids

<u>Fluid</u>	<u>Boiling Pt. (°C)</u>	<u>Volatility in Inert Atmosphere by TGA (°C)</u>		<u>Onset of Volatilization in Air by DSC (°C)</u>	<u>Onset of Oxidation in Air by DSC (°C)</u>
		<u>10% Wt. Loss</u>	<u>50% Wt. Loss</u>		
Prestone II	197	70	110	30	~120 ^b
Ambitrol NTC	189	80	115	45	~120
Uniroyal PAO-LV	a	125	190	c	170
DC® X2-1162	a	155	220	c	297
Syltherm® 444	a	255	300	c	250

^adecomposes

^bslight exotherm at 250° due to oxidation of additive

^cnot detected by DSC

Table 3 Small Scale Pan Burns of Heat Transfer Fluids

Fluid	Initial Wt. (g)	Amount Decane	Final Wt. (g)	% Wt. Loss	Burn Time (min.)	Max. ^a Flame Height (cm)	Comments
Decane	11.0	---	0	100	4.2	28	Black smoke.
PAO-LV	10.0	1.0	<0.1	100	14.5	20	Black smoke.
DC® X2-1162	10.0	1.0	7.0	30	13.5	10	White smoke, white crust.
Syltherm® 444	10.0	1.0	6.9	31	14.5	5	White smoke, white crust.
Prestone II	10.0	1.0	0.1	99	8.0	15	Blue flame grows to yellow, snappy flame. no smoke.
Ambitrol NTC	10.0	1.0	0.2	98	7.3	20	Yellow flame, no smoke.
Ethylene Glycol	10.0	1.0	0	100	8.3	10	Blue flame throughout. 3-4 in. ht. at 4 min. no smoke.
DC® 561	10.0	1.0	7.8	22	14.0	2.5	White smoke and crust.

^aAfter burning of decane.

Table 4 Horizontal Burns of 5/8" Fiberglass + Fluid

	<u>Dry</u> <u>Wt. (g)</u>	<u>Soaked</u> <u>Wt. (g)</u>	<u>Sec. to</u> <u>Ignite</u>	<u>Burn</u> <u>Time (min.)</u>	<u>Final</u> <u>Wt. (g)</u>	<u>%Wt.</u> <u>Loss</u>	<u>Max. Flame</u> <u>Ht. (cm)</u>	<u>Wdt. (cm)</u>	<u>Comments</u>
Control	1.0				1.0	0			Contact with propane flame caused scorching, but no burning.
PAO-LV	1.0	13.0	10-12	4.5	1.0	92	28	12.5	
DC® X2-1162	1.0	16.8	10	8.1	6.4	62	17.5	12.5	
Sytherm® 444	1.0	17.5	10	16.9	6.0	66	10	5	Sample extinguished and reignited at 5 min.
Prestone II	1.4	22.7	5	7.3	1.7	93	12.5	12.5	
Ambitrol NTC	1.8	26.8	5	5.6	1.6	94	23	12.5	
Amb./H ₂ O	1.0	14.0							Withstood 4, 30 sec. contacts with propane flame without igniting.

Table 5 Horizontal Burns of 9/16" Ceiling Tile + Fluid

<u>Fluid</u>	<u>Dry Wt. (g)</u>	<u>Soaked Wt. (g)</u>	<u>Sec.to Ignite</u>	<u>Burn Time(min.)</u>	<u>Final Wt.(g)</u>	<u>%Wt. Loss</u>	<u>Max. Flame Ht.(cm)</u>	<u>Wdt. (cm)</u>	<u>Comments</u>
Control	6.9				6.3	9	30 sec. contact with propane flame caused smoldering on a 3 cm. area but did not burn.		
PAO-LV	6.6	20.5	4	7.3	5.0	76	>28	12.5	
DC® X2-1162	6.7	22.6	3	8.7	10.2	55	20	10	
Syltherm® 444	6.6	23.1	5	10.9	10.4	55	12.5	11	
Prestone II	6.6	25.5	5	7.5	5.3	79	15	12.5	
Ambitrol NTC	6.6	23.7	1.6	5.7	5.3	78	22.5	12.5	
Amb./H ₂ O	6.8	24.6			22.2	10	Withstood 10 contacts (10 sec. each) with propane flame without igniting.		

Table 6 Horizontal Burns of 3/16" Paneling + Fluid

	<u>Dry</u> <u>Wt. (g)</u>	<u>Soaked</u> <u>Wt. (g)</u>	<u>Sec. to</u> <u>Ignite</u>	<u>Burn</u> <u>Time (min.)</u>	<u>Final</u> <u>Wt. (g)</u>	<u>%Wt.</u> <u>Loss</u>	<u>Max. Flame</u> <u>Ht. (cm)</u>	<u>Wdt. (cm)</u>
Control	3.4		10	5.7	0.6	82	7.5	1.3
PAO-LV	3.4	4.9	2	2.8	0.6	88	15	6
DC® X2-1162	3.6	5.2	3	2.8	1.1	79	12.5	5
Syltherm® 444	3.5	5.1	5	4.8	1.1	78	15	2.5
Prestone II	3.6	4.7	3	2.9	0.7	85	12.5	6
Ambitrol NTC	3.4	5.2	3	2.3	0.5	90	12.5	9
Amb./H ₂ O	3.6	5.5	25	10	1.6	71	3	1.3
Pres./H ₂ O	3.5	5.0	30	10.6	1.1	78	3	1.3

Table 7 Horizontal Burns of 1/4" Plywood + Fluid

<u>Fluid</u>	<u>Dry Wt. (g)</u>	<u>Soaked Wt. (g)</u>	<u>Sec.to Ignite</u>	<u>Burn Time(min.)</u>	<u>Final Wt. (g)</u>	<u>%Wt. Loss</u>	<u>Max. Flame Ht.(cm)</u>	<u>Wdt.(cm)</u>	<u>Comments</u>
Control	5.3	--	12	5.6	1.5	72	7.5	5	
PAO-LV	4.9	6.4	2	4.2	1.7	73	12.5	10	
DC® X2-1162	4.1	6.2	2	3.3	1.9	69	10	12.5	
Syltherm® 444	5.1	6.4		5.8	2.1	67	12.5	12.5	
Prestone II	4.8	7.2	2	3.7	1.3	82	10	12.5	
Ambitrol NTC	4.8	6.2	2	1.7	1.4	77	10	12.5	
Pres./H ₂ O	4.7	8.3		0.8	6.8	18	2		Withstood 6 contacts (10 sec each) with propane flame before igniting.

Table 8 Horizontal Burns of Asphalt Shingle + Fluid

Fluid	Dry Wt. (g)	Soaked Wt. (g)	Sec. to Ignite	Burn Time (min.)	Final ^a Wt. (g)	%Wt. Loss	Max. Flame Ht. (cm)	Wdt. (cm)
Control	6.6	--	6	11.0	0.8	88	5	1.3
PAO-LV	7.7	8.9	4	3.0	0.4	96	17.5	12.5
DC® X2-1162	7.2	7.8	5	7.1	0.7	91	12.5	2.5
Syltherm® 444	7.9	8.6	4	5.6	2.5	71	12.5	2.5
Prestone II	8.5	9.2	5	7.5	0.7	92	10	12.5
Ambitrol NTC	8.3	9.2	3	2.5	0.5	95	17.5	7.5
Amb./H ₂ O	7.8	8.4	8	13	1.2	86	5	1.3
Pres./H ₂ O	8.3	8.9	10-15	11.8	0.7	92	5	1.3

^aDoes not include tar which fell from sample.

Table 9 Vertical Burns of 5/8" Fiberglass + Fluid

Fluid	Dry Wt. (g)	Soaked Wt. (g)	Burn Time (min)	Final Wt. (g)	%Wt. ^b Loss	Max. Flame Ht. (cm)	Comments
Control	1.0			1.0	0		See horizontal burn.
PAO-LV	1.0	11.9/6.5 ^a	3.5	1.0	81	35.5	
DC® X2-1162	1.0	15.5/6.2 ^a	4.0	4.9	47	24	
Syltherm® 444	1.0	16.0/6.7 ^a	3.4	4.0	57	19	
Prestone II	1.0	19.9/4.1 ^a	4.9	1.0	94	34	
Ambitrol NTC	1.0	21.9/5.3 ^a	3.8	1.9	89	33	
Amb./H ₂ O	1.0	13.3/0 ^a					Withstood 10 contacts (10 sec. each) with propane flame without ignition.

^aUnburned fluid which dripped from sample during burn.

^b%Wt. loss = $100 - 100 (\text{final wt.}) / (\text{soaked wt.} - \text{wt. unburned fluid.})$

Table 10 Vertical Burns of 9/16" Ceiling Tile + Fluid

Fluid	Dry Wt. (g)	Soaked Wt. (g)	Burn Time(min)	Final Wt. (g)	%Wt. ^b Loss	Max. Flame Ht. (cm)	Comments
Control	6.9			6.3	9		See horizontal burn.
PAO-LV	6.8	20.7/1.7 ^a	4.8	4.4	77	43	
DC® X2-1162	6.6	23.0/0.8 ^a	6.3	11.2	50	30.5	
Syltherm® 444	6.6	24.3/9 ^a	8.7	12.8	47	25	
Prestone II	6.7	27.2/1.0 ^a	5.2	5.8	78	28	
Ambitrol NTC	6.6	25.0/0 ^a	4.9	5.5	78	38	
Pres./H ₂ O	6.6	26.5/0 ^a		22.8	14		Withstood 10 contacts (10 sec. each) with 1/2 in. propane flame without igniting.

^aUnburned fluid which dripped from sample during burn.

^b% Wt. loss = $100 - 100(\text{final wt.})/(\text{soaked wt.} - \text{wt. unburned fluid})$.

Table 11 Vertical Burns of 3/16" Paneling + Fluid

<u>Fluid</u>	<u>Dry Wt. (g)</u>	<u>Soaked Wt. (g)</u>	<u>Burn Time (min)</u>	<u>Final Wt. (g)</u>	<u>%Wt.^b Loss</u>	<u>Max. Flame Ht. (cm)</u>
Control	3.7		1.7	0.4	89	18
PAO-LV	3.7	5.0/0.3 ^a	1.5	0.3	94	28
DC® X2-1162	3.7	5.3/0.2 ^a	1.8	0.7	86	27
Syltherm® 444	3.7	5.5/0.3 ^a	1.9	0.3	94	28
Prestone II	3.6	4.9/0.1 ^a	1.5	0.2	96	23
Ambitrol NTC	3.4	4.9/0.2 ^a	1.4	0.6	87	24
Amb./H ₂ O	3.7	5.2/0 ^a	2.0	0.5	90	18
Pres./H ₂ O	3.6	5.0/0.1 ^a	2.2	0.1	98	15

^aUnburned fluid which dripped from sample during burn.

^bWt. loss = $100 - 100(\text{final wt.}) / (\text{soaked wt.} - \text{wt. unburned fluid})$.

Table 12 Vertical Burns of 1/4" Plywood + Fluid

<u>Fluid</u>	<u>Dry Wt. (g)</u>	<u>Soaked Wt. (g)</u>	<u>Burn Time (min)</u>	<u>Final Wt. (g)</u>	<u>%Wt. Loss</u>	<u>Max. Flame Ht. (cm)</u>	<u>Comments</u>
Control	4.7		2.6	0.8	83	19	
PAO-LV	5.3	6.7	2.1	0.9	87	27	
DC® X2-1162	5.0	6.4	2.3	0.8	88	27	
Syltherm® 444	5.3	6.5	2.3	1.7	74	22	
Prestone II	5.4	7.2	2.1	0.7	92	19	
Ambitrol NTC	4.7	6.4	1.8	1.2	81	23	
Amb./H ₂ O	5.2	8.4	0.8	6.1	27	0.2	5 contacts (10 sec. each) with propane flame to ignite, ex- tinguished at 5 min.

Table 13 Vertical Burns of Asphalt Shingle + Fluid

<u>Fluid</u>	<u>Dry Wt. (g)</u>	<u>Soaked Wt. (g)</u>	<u>Burn Time (min)</u>	<u>Final Wt. (g)</u>	<u>%Wt. Loss</u>	<u>Max. Flame Ht. (cm)</u>
Control	7.2	-	2.4	4.6	36	18
PAO-LV	7.9	8.9	2.0	6.2	30	28
DC® X2-1162	7.6	8.3	2.4	5.3	36	19
Syltherm® 444	6.9	7.7	2.5	5.3	31	19
Prestone II	8.2	8.7	1.9	6.0	31	27
Ambitrol NTC	7.8	8.8	2.7	5.9	33	28
Amb./H ₂ O	7.1	8.0	2.4	5.2	35	19
Pres./H ₂ O	7.3	7.7	2.4	4.7	39	22

Table 14 Generation of Gases During NBS Smoke Chamber Tests

<u>Fluid</u>	<u>Condition</u>	<u>CO₂ (%)^a</u>	<u>CO (ppm)^a</u>
PAO-LV	Flaming	1.5	190
	Smoldering	0.19	20
DC® X2-1162	F	1.0	b
	S	0.26	b
Syltherm® 444	F	.71	135
	S	.38	b
Prestone II: H ₂ O	F	.079	80
	S	.067	b
Prestone II	F	.889	90
	S	.337	b
Ambitrol NTC: H ₂ O	F	.937	60
	S	.285	b
Ambitrol NTC	F	.669	100
	S	.297	b
Air		.03	b

^a Average of multiple tests (1-3)

^b Levels too low to detect

Table 15 Relative Ease of Extinguishment

<u>Extinguishing Agents</u>	<u>Uniroyal PAO-LV</u>	<u>DC® X2-1162</u>	<u>Syltherm® 444</u>	<u>Ambitrol NTC</u>	<u>Prestone II</u>
CO ₂	3	2	2	1	1
Dry Chemical	2	3	2	1	1
3% Protein Foam	4	3	3	2	1
Water spray	5	5	4	2	1
High Expansion Foam	2	1	1	1	1

Ease of extinguishment: 5 most difficult,
1 easiest

Table 16 Summary of Heat Release Data

Temperatures

	<u>1.8 m above pan Maximum °C</u>	<u>0.6 m Lateral to pan Maximum °C</u>
Ambitrol NTC	310	80
Prestone II	185	75
Uniroyal PAO-LV	590	225
DC® X2-1162	215	120
Syltherm® 444	160	100

Energies

	<u>Calorimeter₂ Maximum w/cm²</u>	<u>Radiometer Maximum kw</u>
Ambitrol NTC	3.0	94
Prestone II	1.2	46
Uniroyal PAO-LV	8.5	510
DC® X2-1162	1.3	150
Syltherm® 444	.85	96

Table 17 Heat Release Data^a

	ΔH_c° (kj/g)	Wt. Loss%	Comb. %	Burn Time (min.)	Total Heat ^b Release (kj)	Rate of ^c Heat Release (kw)	Radiant Heat Release (kw)	Time Range ^f for Slopes (min.)
Ambitrol NTC	23.0	96.3	96.3	33.5	8.0×10^5	487	94	6-28
Prestone II	18.4	96.9	96.9	52.5	6.4×10^5	284	46	7-35
Uniroyal PAO-LV	47.1	100	100	34	17.1×10^5	1311	510	4-24
DC® X2-1162	27.5	66	72 ^d	80	7.1×10^5	425 ^e	150	4-23
133 Syltherm® 444	26.4	29	37 ^d	88	3.5×10^5	264 ^e	96	4-11

^a 36.3 Kg fluid, 1.17 m² surface area

^b Calculated from wt. combusted x ΔH_c°

^c Calculated from slope of wt. loss curve during most active period (g/sec.) times ΔH_c

^d Determined from elemental analysis of burn residue

^e Slope is corrected for % combustion (see d)

^f Portion of slope used to determine rate of heat release

INSTRUMENTS

SAMPLE: 10422 Danny, 37107-E Glycol	SIZE 13.7 mg	ATM. Air 200cc/min	RUN NO. 2100 DS3000
	REF.	T ΔT	DATE 7/24/79
ORIGIN:	PROGRAM MODE	SCALE SETTING 50 $\frac{^{\circ}\text{C}}{\text{IN.}}$ 0.5 $\frac{^{\circ}\text{C}}{\text{IN.}}$	OPERATOR CS
	RATE 10 $\frac{^{\circ}\text{C}}{\text{MIN.}}$ START $^{\circ}\text{C}$

INSTRUMENTS

SAMPLE: 10422
Danny, 37107-E
Glycol

SIZE 16.6 mg.

X-AXIS

TEMP. SCALE 100 $^{\circ}\text{C}$
inch

SHIFT 0 inch

Y-AXIS

SCALE $\frac{\text{mg.}}{\text{inch}}$
(SCALE SETTING X2)

SUPPRESSION 0 mg.

RUN NO. DT2257 DATE 7/26/77

OPERATOR CS

HEATING RATE 2 $^{\circ}\text{C}$
min.

ATM. Argon 200cc/min

TIME CONSTANT 1 sec.

INSTRUMENTS

SAMPLE: 10421
Danny, 37107-D
Glycol

ORIGIN:

SIZE 9.6 mg

REF.

PROGRAM MODE

RATE 10 $\frac{^{\circ}\text{C}}{\text{MIN.}}$, START $^{\circ}\text{C}$

ATM. Air 200cc/min

T

 ΔT SCALE
SETTING50 $\frac{^{\circ}\text{C}}{\text{IN.}}$ 0.5 $\frac{^{\circ}\text{C}}{\text{IN.}}$

RUN NO. DS2099

DATE 7/24/79

OPERATOR CS

INSTRUMENTS

SAMPLE: 10421
Danny, 37107-D
Glycol

SIZE 17.2 mg.

X-AXIS

TEMP. SCALE 100 $\frac{^{\circ}\text{C}}{\text{inch}}$

SHIFT 0 inch

Y-AXIS

SCALE $\frac{\text{mg.}}{\text{inch}}$
(SCALE SETTING X2)

SUPPRESSION 0 mg.

RUN NO. DT2256 DATE 7/26/79

OPERATOR CS

HEATING RATE 2 $\frac{^{\circ}\text{C}}{\text{min}}$

ATM. Argon 200cc/min

TIME CONSTANT 1 sec.

100%

137

% WEIGHT, mg.

0%

Figure 4. Thermal Gravimetric Analysis
Prestone II

T, °C (CORRECTED FOR CHROME/ALUMEL THERMOCOUPLES)

INSTRUMENTS

SAMPLE: 10418 Danny, 37107-A Polyalpha olefin ORIGIN:	SIZE 12.6mg	ATM. Air 200cc/min	RUN NO. DS2096
	REF.	T	DATE 7/24/79
	PROGRAM MODE	SCALE 50 $\frac{^{\circ}\text{C}}{\text{IN.}}$	OPERATOR CS
	RATE 10 $\frac{^{\circ}\text{C}}{\text{MIN.}}$, START $^{\circ}\text{C}$	SETTING 0.5 $\frac{^{\circ}\text{C}}{\text{IN.}}$

INSTRUMENTS

SAMPLE: 10418
Danny, 37107-A
Polyalpha olefin
SIZE 12.0 mg.

X-AXIS
TEMP. SCALE 100 °C
SHIFT 0 inch

Y-AXIS
SCALE _____ mg.
(SCALE SETTING X2)
SUPPRESSION 0 mg.

RUN NO. DT2253 DATE 1/24/79
OPERATOR CS
HEATING RATE 2 °C/min.
ATM. Argon 200cc/min
TIME CONSTANT 1 sec.

INSTRUMENTS

SAMPLE: 10419
Danny, 37107-B
Silicone

SIZE 14.7 mg

REF.

PROGRAM MODE

ORIGIN:

RATE 10 $\frac{^{\circ}\text{C}}{\text{MIN.}}$, START $^{\circ}\text{C}$

ATM. Air 200cc/min

RUN NO. DS2097

DATE 7/24/79

OPERATOR CS

	T	ΔT
SCALE	50 $\frac{^{\circ}\text{C}}{\text{IN.}}$	0.5 $\frac{^{\circ}\text{C}}{\text{IN.}}$
SETTING

INSTRUMENTS

SAMPLE: 10419 Danny, 57107-B Silicone SIZE <u>14.4</u> mg.	X-AXIS	Y-AXIS	RUN NO. <u>DT2254</u> DATE <u>7/25/7</u>
	TEMP. SCALE <u>100</u> °C inch	SCALE _____ mg. inch (SCALE SETTING X2)	OPERATOR <u>CS</u>
	SHIFT <u>0</u> inch	SUPPRESSION <u>0</u> mg.	HEATING RATE <u>2</u> °C min.
			ATM. <u>Argon 200cc/min.</u>
			TIME CONSTANT <u>1</u> sec.

SAMPLE: 10420 Danny, 37107-C Silicone	SIZE 13.9 mg	ATM. Air 200cc/min	RUN NO. DS2098
	REF.	T	DATE 7/24/79
ORIGIN:	PROGRAM MODE	SCALE 50 $\frac{^{\circ}\text{C}}{\text{IN.}}$	OPERATOR CS
	RATE 10 $\frac{^{\circ}\text{C}}{\text{MIN.}}$, START $^{\circ}\text{C}$	SETTING 0.5 $\frac{^{\circ}\text{C}}{\text{IN.}}$

INSTRUMENTS

SAMPLE: 10420

Danny, 37107-C

Silicone

SIZE 11.5 mg.

X-AXIS

TEMP. SCALE 100 $^{\circ}\text{C}$
inch

SHIFT 0 inch

Y-AXIS

SCALE $\frac{\text{mg.}}{\text{inch}}$
(SCALE SETTING X2)

SUPPRESSION 0 mg.

RUN NO. DT2255 DATE 7/25/79

OPERATOR CS

HEATING RATE 2 $^{\circ}\text{C}$
min.

ATM. Argon 200cc/min.

TIME CONSTANT 1 sec.

100%

143

WEIGHT %

0%

Figure 10. Thermal Gravimetric
Analysis

Syltherm® 444.

T. $^{\circ}\text{C}$ (CORRECTED FOR CHROMEL ALUMEL THERMOCOUPLES)

FIGURE 11. Smoke Generation Under Smoldering Conditions

FIGURE 12. Smoke Generation Under Smoldering Conditions

FIGURE 13. Smoke Generation Under Flaming Conditions

FIGURE 14

BURNING RATE PER UNIT AREA vs.
DROPLET (OR POOL) DIAMETER

REGION A - COLLOIDAL DROPLET FLAMES
(PREMIXED COMBUSTION)

REGION B - DROPLET FLAMES
(DIFFUSION CONTROLLED COMBUSTION)

REGION C - POOL FIRES
(RADIATION CONTROLLED COMBUSTION)

FIGURE 15 SCHEMATIC OF LARGE SCALE BURN TEST APPARATUS

Figure 16. Weight Loss during Large Scale Pool Burn

Figure 17. Temperatures at 1.8m
above fluid.

- * ———— Ambitrol NTC
- + Prestone II
- x - - - Uniroyal PAO-LV
- o ———— DC® X2-1162
- # - - - Syltherm® 444

Figure 18. Temperature at 61 cm.
Lateral to pan and
61 cm. above pan.

*——— Ambitrol NTC
+..... Prestone II
x - - - Uniroyal PAO-LV
o ——— DC® X2-1162
—.— Syltherm® 444

Figure 19. Radiant and Convective
Energy at 1.8m above pan

* ———— Ambitrol NTC
+ Prestone II
x - - - Uniroyal PAO-LV
o ———— DC® X2-1162
—.— Syltherm® 444

Note: calorimeter failed at
10 min. for PAO-LV

Figure 20. Total Radiant Energy