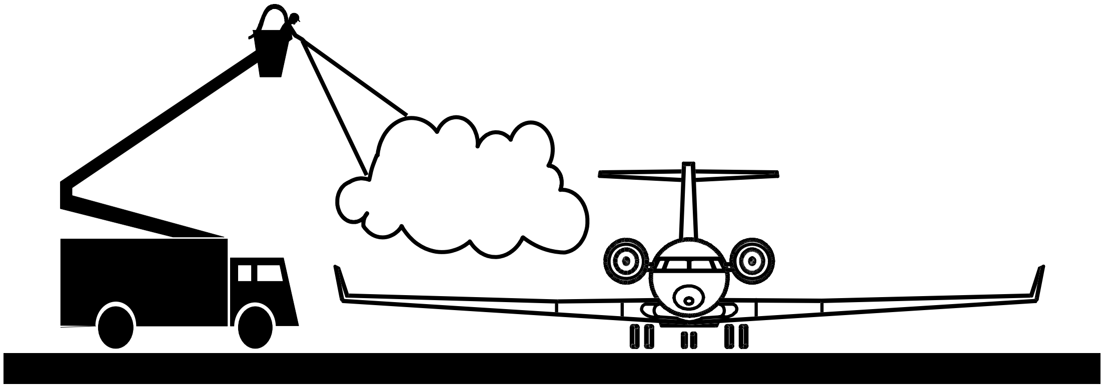
TP 13317E

Characteristics of Aircraft Anti-Icing Fluids Subjected to Precipitation



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Safety and Security
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by

APS AVIATION INC.

December 1998

Final Version 1.0

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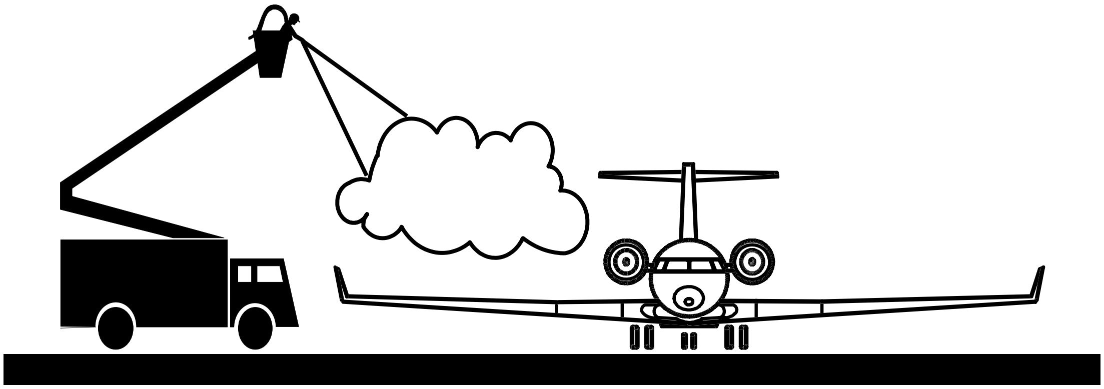

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Un sommaire français se trouve avant la table des matières.

PREFACE

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to further advance aircraft ground deicing/anti-icing technology. Specific objectives of the APS test program were:

- To develop holdover time tables for new Type IV fluids and to validate *fluid-specific* tables and SAE tables;
- To determine the influence of fluid type, precipitation, and wind on location and time to fluid failure initiation, and also failure progression on the Canadair Regional Jet and on high-wing turboprop commuter aircraft;
- To establish experimental data sufficient to support development of a *deicing only* table to serve as an industry guideline, and to evaluate freeze point temperature limits for fluids used as the first step of a two-step deicing operation;
- To establish conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft when subjected to rotation speeds;
- To document the appearance of fluid failure and the characteristics of the fluid at time of failure, through conduct of a series of tests on standard flat plates; and
- To determine the feasibility of examining the condition of aircraft wings prior to takeoff through use of ice contamination sensor systems.

The research activities of the program conducted on behalf of Transport Canada during the 1997-98 winter season are documented in six separate reports. The titles of these reports are as follows:

- TP 13318E Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1997-98 Winter;
- TP 13314E Research on Aircraft Deicing Operations for the 1997-98 Winter;
- TP 13315E Aircraft Deicing Fluid Freeze Point Buffer Requirements: *Deicing Only* and First Step of Two-Step Deicing;
- TP 13316E Contaminated Aircraft Takeoff Test for the 1997/98 Winter;
- TP 13317E Characteristics of Aircraft Anti-Icing Fluids Subjected to Precipitation; and

- TP 13489E Deicing with a Mobile Infrared System.

This report, TP 13317E addresses the following objective:

- To document the appearance of fluid failure and the characteristics of the fluid at time of failure, through conduct of a series of tests on standard flat plates.

This objective was met by conducting tests at National Research Council Canada's Climatic Engineering Facility. Various anti-icing fluids were examined under a variety of conditions to enable documentation of their appearance and properties at their point of operational limit.

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Research has been funded by the Civil Aviation Group, Transport Canada. This program of research could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Transportation Development Centre, the U.S. Federal Aviation Administration, US Airways Inc., National Research Council Canada, Atmospheric Environment Services, Transport Canada, and the fluid manufacturers for their contributions to and assistance with the program. Special thanks are extended to US Airways Inc., Air Canada, National Research Council Canada, Canadian Airlines International, Inter-Canadien, AéroMag 2000, Aéroport de Montréal, RVSI, Cox and Company Inc., KnightHawk and Shell Aviation for provision of personnel and facilities, and for their co-operation on the test program. Union Carbide, Octagon, SPCA, Kilfrost, Clariant and Inland Technologies Inc. are thanked for provision of fluids for testing. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data leading to the preparation of this document.

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16. Abstract

The objective of this study was to document the appearance and properties of anti-icing fluids when operational limits are reached.

Laboratory tests were conducted under controlled conditions of ambient temperature and artificial precipitation. Various fluids were applied to flat plates and examined at specific stages from time of application until complete contamination was reached. The appearance and properties of each fluid were documented as it progressed toward failure. Documentation included photographic and videotape records; visual description; readings from various ice detection sensors; and measurements of physical characteristics such as adherence, viscosity, concentration, and film thickness.

Appearance and measured properties of tested fluids are discussed and compared, and mechanisms of failure are described.

17. Key Words

Contamination, aircraft, anti-icing, holdover, tests, precipitation, wing, plate, deicing, ice, sensor, temperature, thickness, slurry

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Les rapports sur les recherches effectuées au cours des hivers précédents pour le compte de Transports Canada sont disponibles au Centre de développement des transports (CDT). Six rapports, dont le présent, ont été produits dans le cadre des recherches menées pendant l'hiver 1997-1998. Leur objet est précisé dans l'avant-propos.

16. Résumé

L'étude avait pour objet de documenter l'apparence et les propriétés des liquides antigivre lorsqu'ils ont atteint leur limite d'efficacité.

Des essais en laboratoire ont été réalisés dans des conditions de température ambiante et de précipitations artificielles contrôlées. Divers liquides étaient appliqués sur des plaques planes, puis ils étaient examinés à différents stades entre le moment de leur application et la contamination de toute la plaque. L'apparence et les propriétés de chacun des liquides étaient documentées tout au long de la progression de ceux-ci vers la perte d'efficacité. Cette documentation comprenait des photos, des bandes vidéo, une description visuelle, les lectures de divers capteurs de givre ainsi que des mesures de paramètres physiques, comme l'adhérence, la viscosité, la concentration, et l'épaisseur de la couche de liquide.

Le rapport offre un exposé comparatif de l'apparence et des propriétés mesurées des liquides testés, et décrit les mécanismes de perte d'efficacité.

17. Mots clés
Contamination, aéronef, antigivre, durée d'efficacité, essais, précipitation, aile, plaque, dégivrage, givre, capteur, température, épaisseur, bouillie glacio-neigeuse

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EXECUTIVE SUMMARY

At the request of the Transportation Development Centre (TDC) of Transport Canada, APS Aviation undertook a research program to examine anti-icing fluids when operational limits are reached.

The objective of the study was to document the appearance of fluid failure and the characteristics of the fluid at the time that it reached its operational limit. Documentation was to include photography and videotape; narrative description; readings from various ice detection sensors; and measurements of physical characteristics such as adherence, viscosity, concentration, and film thickness.

To satisfy this objective, laboratory tests were conducted in Ottawa at National Research Council Canada's Climatic Engineering Facility, which provided a controlled environment satisfying test variables of ambient temperature and artificial precipitation. The study was restricted to conditions that could be created in the laboratory; at the time of testing, these conditions did not include snow.

Various fluids were applied to flat plates and examined at specific stages from time of application until complete contamination was reached. The appearance and properties of each fluid were documented as it progressed toward and proceeded beyond a pre-defined standard failure.

Test conditions were established to allow examination of specific fluids under different conditions, as well as to enable the following comparisons:

- Appearance of Type I versus Type IV – light freezing rain;
- Appearance of Type IV – light freezing rain versus freezing drizzle;
- Appearance of Type IV – effect of temperature (-4ºC and -10ºC);
- Type IV ethylene glycol-based fluid versus Type IV propylene glycol-based fluid – freezing drizzle;
- Time to adhere – Type I versus Type IV; and
- Appearance of Type I versus Type IV 50/50 – light freezing rain.

Results and Conclusions

The appearance and characteristics of various fluids when operational limits are reached were recorded using a variety of techniques and instruments.

Data from the various tests enabled comparisons of the appearance and nature of fluids under different conditions. Photographs and video documentation were recorded to portray the appearance of fluid at specific phases from time of application until complete plate failure. These images could be made available to users in the field (pilots and ground staff) to assist in the visual identification of fluid at its operational limit.

An innovative approach was used to provide a relative measure of adherence among the various test conditions. It was noted that Type I fluid adhered quickly after failure, resulting in a very thin film strongly bonded to the surface. Ethylene glycol-based fluids adhered within 3 to 6 minutes following freezing in light freezing rain conditions (25 g/dm^2/h) and an ambient temperature of -10ºC.

The viscosity of fluids at their operational limits was difficult to measure. Test samples collected near the failure front and measured with a Brookfield viscometer generally provided viscosity values equivalent to water. An exception was the SPCA AD-480 neat fluid, which had a significant residual viscosity reading.

Identifying the operational limit of Type IV SPCA AD-480 fluid in freezing drizzle presented a challenge. The visual call procedure did not yield accurate results. This fluid appears to continue to provide a level of protection far beyond the point when failure calls would normally be made, with no adherence even at time of complete plate failure. Failure calls made by icing contamination sensors may be conservative. Examination of the fluid (in a contaminated state) removed from an actual wing during simulated takeoff would be useful in determining an approach to more accurately identify operational limitations.

SOMMAIRE

À la suite d'une demande formulée par le Centre de développement des transports (CDT) de Transports Canada, APS Aviation Inc. a entrepris un programme de recherche sur les liquides antigivre au moment où ils ont atteint leur limite d'efficacité.

L'objectif de cette étude était de documenter l'apparence et les propriétés que présente un liquide lorsqu'il a atteint sa limite d'efficacité. Cette documentation devait prendre la forme de photos, de bandes vidéo, d'une description narrative, de lectures de divers capteurs de givre ainsi que de mesures de paramètres physiques, comme l'adhérence, la viscosité, la concentration, et l'épaisseur de la couche de liquide.

Les essais en laboratoire ont été menés à l'Installation de génie climatique du Conseil national de recherches du Canada, à Ottawa, qui offrait un environnement contrôlé permettant d'étudier les variables d'essai que sont la température ambiante et les précipitations artificielles. L'étude a été limitée aux conditions qui pouvaient être reproduites dans le laboratoire; au moment de l'étude, ces conditions excluaient la neige.

Divers liquides étaient appliqués sur des plaques planes, puis ils étaient examinés à des stades précis entre le moment de leur application et la contamination complète de la plaque. L'apparence et les propriétés physiques de chacun des liquides étaient documentés tout au long de la progression de ceux-ci vers des critères prédéfinis de perte d'efficacité, et après cette perte d'efficacité.

Les conditions d'essai étaient établies de façon à permettre l'examen de liquides bien précis dans différentes conditions, et à autoriser les comparaisons suivantes :

- apparence d'un liquide de type I comparé à un liquide de type IV – pluie verglaçante légère;
- apparence d'un liquide de type IV – pluie verglaçante légère comparée à de la bruine verglaçante;
- apparence d'un liquide de type IV – effet de la température (-4 °C et -10 °C);
- liquide à base d'éthylène glycol de type IV comparé à un liquide à base de propylène glycol de type IV – bruine verglaçante;
- délai jusqu'à l'adhérence – liquide de type I comparé à un liquide de type IV;
- apparence d'un liquide de type I comparé à un liquide de type IV 50/50 – pluie verglaçante légère.

Résultats et conclusions

L'apparence et les caractéristiques de divers liquides au moment où leur limite d'efficacité est atteinte ont été enregistrées au moyen d'une gamme de techniques et d'instruments.

Les données issues des divers essais ont permis de comparer l'apparence et les caractéristiques des liquides dans différentes conditions. Des photos et des bandes vidéo ont offert des illustrations précises de l'apparence du liquide à des stades précis entre le moment de son application et la perte d'efficacité sur toute la plaque. Ces images, si elles étaient mises à la disposition des utilisateurs sur le terrain (pilotes et personnel au sol), pourraient aider ceux-ci à reconnaître les signes visuels d'un liquide qui a atteint sa limite d'efficacité.

Des moyens inédits ont été utilisés pour obtenir une mesure relative de l'adhérence des liquides, dans les diverses conditions d'essai. Ainsi, il a été observé que le liquide de type I adhérait rapidement après être devenu inefficace, laissant une pellicule très fine littéralement collée à la surface. Sous pluie verglaçante légère (25 g/dm^2/h), à -10 ºC de température ambiante, les liquides à base d'éthylène glycol adhéraient dans les trois à six minutes suivant leur perte d'efficacité.

La viscosité des liquides lorsqu'ils ont atteint leur limite d'efficacité s'est avérée difficile à mesurer. Les échantillons prélevés près du front de perte d'efficacité et soumis au viscosimètre Brookfield donnaient généralement des valeurs de viscosité équivalentes à celles de l'eau. Un liquide faisait exception, soit le SPCA AD-480 pur, qui présentait une viscosité résiduelle importante.

Il a été difficile de définir la limite d'efficacité du liquide de type IV SPCA AD-480 sous bruine verglaçante. La procédure d'inspection visuelle n'a pas donné de résultats fiables. C'est que ce liquide semble continuer à assurer un certain degré de protection longtemps après le moment où la perte d'efficacité aurait normalement été prononcée, n'adhérant aucunement à la surface même lorsque toute la plaque est contaminée. Il se peut donc que les pertes d'efficacité prononcées sur la foi des capteurs de givre soient par trop prudentes. Il serait bon d'examiner du liquide (contaminé) prélevé sur une aile en vraie grandeur au cours d'un décollage simulé pour définir plus clairement les caractéristiques de ce liquide lorsqu'il a atteint sa limite d'efficacité.

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GLOSSARY

APS	APS Aviation Inc.
CEF	Climatic Engineering Facility
C/FIMS	Contamination/Fluid Integrity Monitoring System
FAA	Federal Aviation Administration
FP	Freeze Point
NRC	National Research Council Canada
RVSI	Robotic Vision System Inc.
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre (Canada)
UCAR	Union Carbide

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1. INTRODUCTION

This study formed part of the winter 1997-98 research program on deicing as described in the detailed work statements (Appendix A).

Discussions within the aviation industry on the subject of wing contamination and related testing of anti-icing fluids invariably question the nature of the fluid failure.

Examples of questions commonly asked:

- What does the failure look like?
- How does a failure progress?
- How visible is the failure? Was it obvious or difficult to discern?
- Did the failure appear distinctive for different temperatures, precipitation conditions, and fluid types?
- Did contamination adhere to the underlying surface?

At the request of the Transportation Development Centre (TDC) of Transport Canada, APS Aviation undertook a research project to examine and document the appearances and properties of deicing and anti-icing fluids as they were exposed to icing precipitation conditions. The appearance and physical properties of each fluid examined were monitored on standard flat plate test surfaces from the instant of fluid application to the point at which fluid failure(s) completely covered the test surface.

Each fluid was followed as it approached, reached, and surpassed its operational limit, and discrete measurements of the fluid's physical properties at pre-selected stages of failure were made. The physical properties measured included fluid concentration, wet film thickness, viscosity, and failure adhesion. Variations in the appearances of the applied fluids were recorded using still photography (on film), videos (analog and digital), and ice detection sensors and cameras.

Within the deicing community, the lexicon of terminology describing fluid failures has not yet evolved to support the clear and precise communication of the appearance of fluid that has reached its operational limit. Consequently, there does not exist a strong common visual image of the appearance of fluid at the time of failure. A shared common image of the visible nature of the various types of fluid failure would contribute to better communication within the community involved in deicing research, and would promote better recognition of fluid failures in field operations.

To promote clearer communication in the field, narrative descriptions of the progress of fluid failures that are acceptable to seasoned observers, but can also be understood by non-seasoned observers, have also been prepared.

Throughout this report, the term *fluid failure* is frequently used to indicate *fluid at its operational limit*. In this context, fluid that is considered to have failed need not have reached its ultimate limit, but has demonstrated characteristics accepted by the industry as indicators of failure.

To satisfy the goals of this study, laboratory tests were conducted at several temperatures, while both the type and the rate of precipitation were controlled. Test conditions were established to allow examination of specific fluids under various conditions to enable the following comparisons to be made:

- Appearance of Type I versus Type IV – light freezing rain;
- Appearance of Type IV – light freezing rain versus freezing drizzle;
- Appearance of Type IV – effect of temperature (-4°C and -10°C);
- Type IV ethylene glycol-based fluid versus Type IV propylene glycol-based fluid – freezing drizzle;
- Time to adhere – Type I versus Type IV; and
- Appearance of Type I versus Type IV 50/50 – light freezing rain.

2. PROCEDURES

2.1 Test Sites

The study was conducted at National Research Council Canada's (NRC) Climatic Engineering Facility (CEF) in Ottawa. This facility provided a test environment that satisfied the need to control the ambient temperature, and both the type and rate of artificial precipitation.

Plans were developed to conduct outdoor tests at the APS Test Site. These tests were not performed due to lack of suitable snow conditions. The type of snow that can be generated at NRC's CEF does not resemble natural snow. This snow yields failures that more closely resemble those observed in thick freezing fog.

2.2 Description of Test Procedures

The experimental procedure for this study is presented in Appendix B.

The experiments were conducted following the same procedures as employed in the test program to determine fluid holdover times. Flat plates with C/FIMS sensor heads were employed as the test surfaces.

2.2.1 Fluid Quantity

A constant fluid quantity of 1.5 L was applied in all tests. Fluids were allowed to stabilize at ambient temperature prior to tests.

2.2.2 Concentration

Fluid refractive index was measured with a hand-held Brix-scale refractometer. Brix measurements were taken prior to fluid application, and periodically during the course of the test. The sampling intervals for Type I fluids and Type IV fluids were 2 minutes and 5 minutes, respectively.

For Type IV fluid tests, samples were collected from the top and bottom of the fluid layer. Top samples were obtained by laying a strip of acetate film on the surface of the fluid. Bottom samples were drawn with a syringe. The sampling location for all fluid tests was at a cross hair adjacent to the C/FIMS sensor head. As well, a Brix sample was taken at the boundary of the failed fluid when a standard plate failure call was made. This sample represented a mixture of top and bottom layers.

2.2.3 Wet Film Thickness

Fluid thickness was measured at test initiation and thereafter at 2-minute intervals for Type I fluid, and 5-minute intervals for Type IV fluid. Measurements were conducted at the 15 cm (6 in.) line.

2.2.4 Viscosity Measurements

A fluid sample for viscosity measurement was collected at the time and location of the standard plate failure call (5th cross hair to undergo failure). At complete plate failure, fluid samples were collected at both the B2 and F2 cross hairs (described in Subsection 2.3), as well as at a point adjacent to the 5th cross hair, for a total of four samples.

2.2.5 Failure Adhesion

Failure adhesion was measured at the time and point of plate failure call (5th cross hair) and at location B2. When the entire plate had failed, failure adhesion was measured again at specified points as indicated on the data sheet.

2.2.6 Photo and Video Record

Fluid application, initial failure, plate failure, and complete plate failure were photographed with a 35 mm still camera and a digital video camera. Two video cameras were focused on the test plates and allowed to run continuously during the tests to record absorption of precipitation.

2.2.7 Ice Detection Sensors and Cameras

The C/FIMS, RVSI, and Spar/Cox ice detection systems were run continuously during each test.

A *no-touch* zone (3 cm x 5 cm rectangle) was marked on each plate near the C/FIMS sensor head, to serve as a reference area for ice detection cameras. This area was to remain undisturbed when lifting fluid samples or measuring thickness.

2.3 Equipment

The same standard flat plate test equipment as employed in tests to determine fluid holdover times was used in this study.

Flat plates with installed C/FIMS ice detection sensors (Figure 2.1) were mounted on a flat plate stand positioned under a spray device designed to produce controlled precipitation rates and a satisfactory range of droplet sizes representing natural conditions. Plates were marked to show cross-hair positions that are identified in the procedure, on data sheets and throughout this report by the cross reference of row number and the position from left to right (example B1 = row B, left cross hair). A schematic of cross-hair positions on a flat plate is provided in Figure 2.1.

In addition to the C/FIMS sensor, an RVSI and a Spar/Cox ice detection sensor were employed. The two latter systems provided ongoing live images at 30-second intervals of ice formation on the subject plates. All sensors provided a data reference profile over the test duration, which gives an indication of time related extent of fluid failure. As well, the latter two systems provided on ongoing video record of the plate stand. Plate temperature was provided by the C/FIMS sensor.

Photo 2.1 shows a complete test set-up with video cameras at each end of the test stand, and RVSI and Spar/Cox sensors mounted at the far side.

A 35 mm still camera and a digital video camera were used to photograph fluid appearance at the different pre-selected stages in the process of fluid failure. Two analog video cameras were focused on test plates and ran continuously. The film recording procedure included a photograph of the test status board at the start of each new test run to assist in relating images to test runs (Photo 2.2).

Fluid thickness was measured with wet film thickness gauges as used in previous tests and as shown in Figure 2.2.

Fluid concentration was measured with a hand-held Brix-scale refractometer, based on fluid samples collected from the plate with small acetate strips and with syringes (Photos 2.3 and 2.4). The plates shown in Photo 2.4 illustrate the plate markings, including the *no-touch* zone to the right of the sensor installation.

In the absence of a standard recognized method or apparatus for measuring failure adhesion, attempts had been made during earlier tests to quantify this characteristic through use of prototype devices or ad-hoc procedures. These attempts were generally based on evaluating the resistance to movement of

FIGURE 2.1

TYPICAL FLAT PLATE

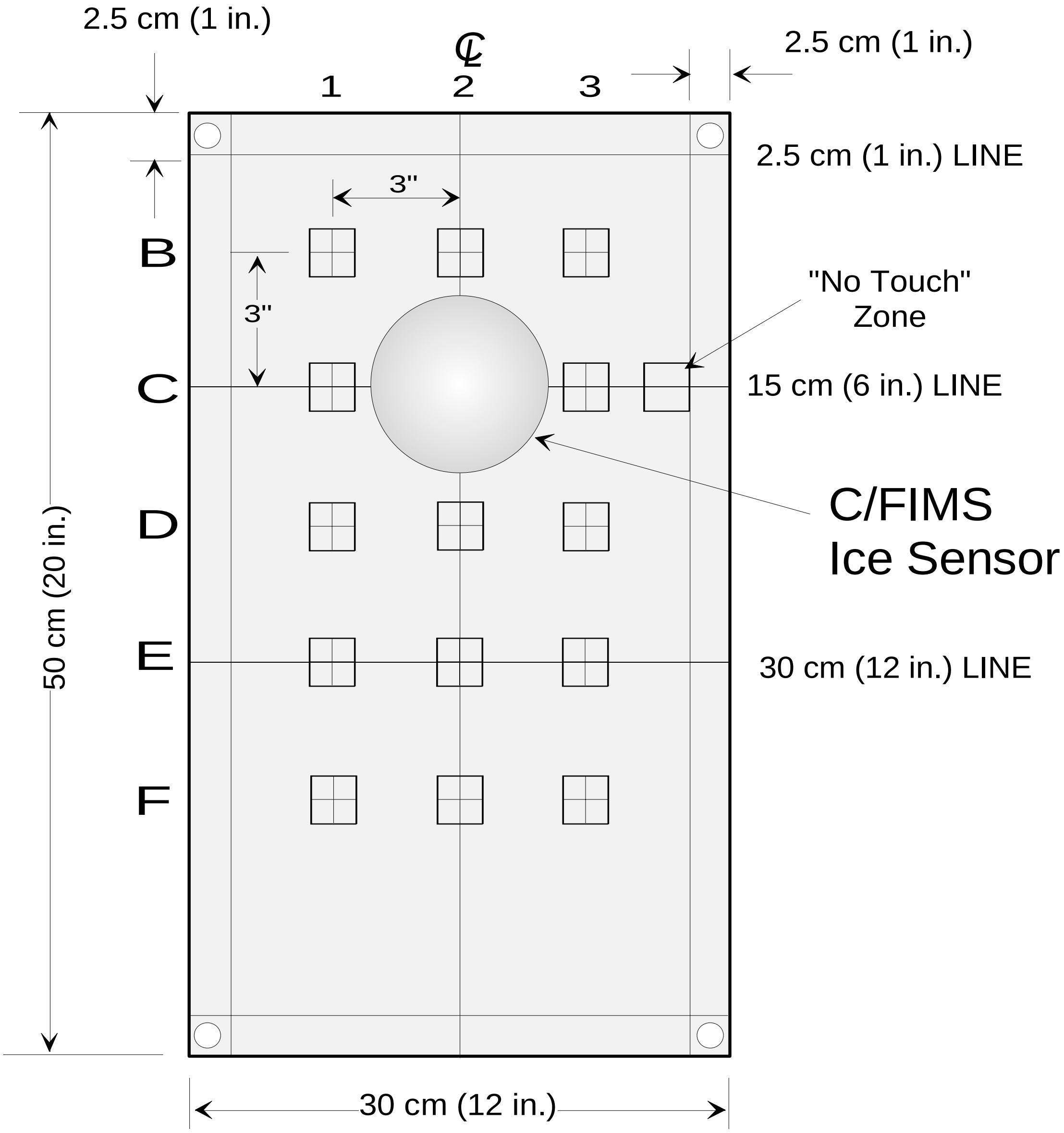
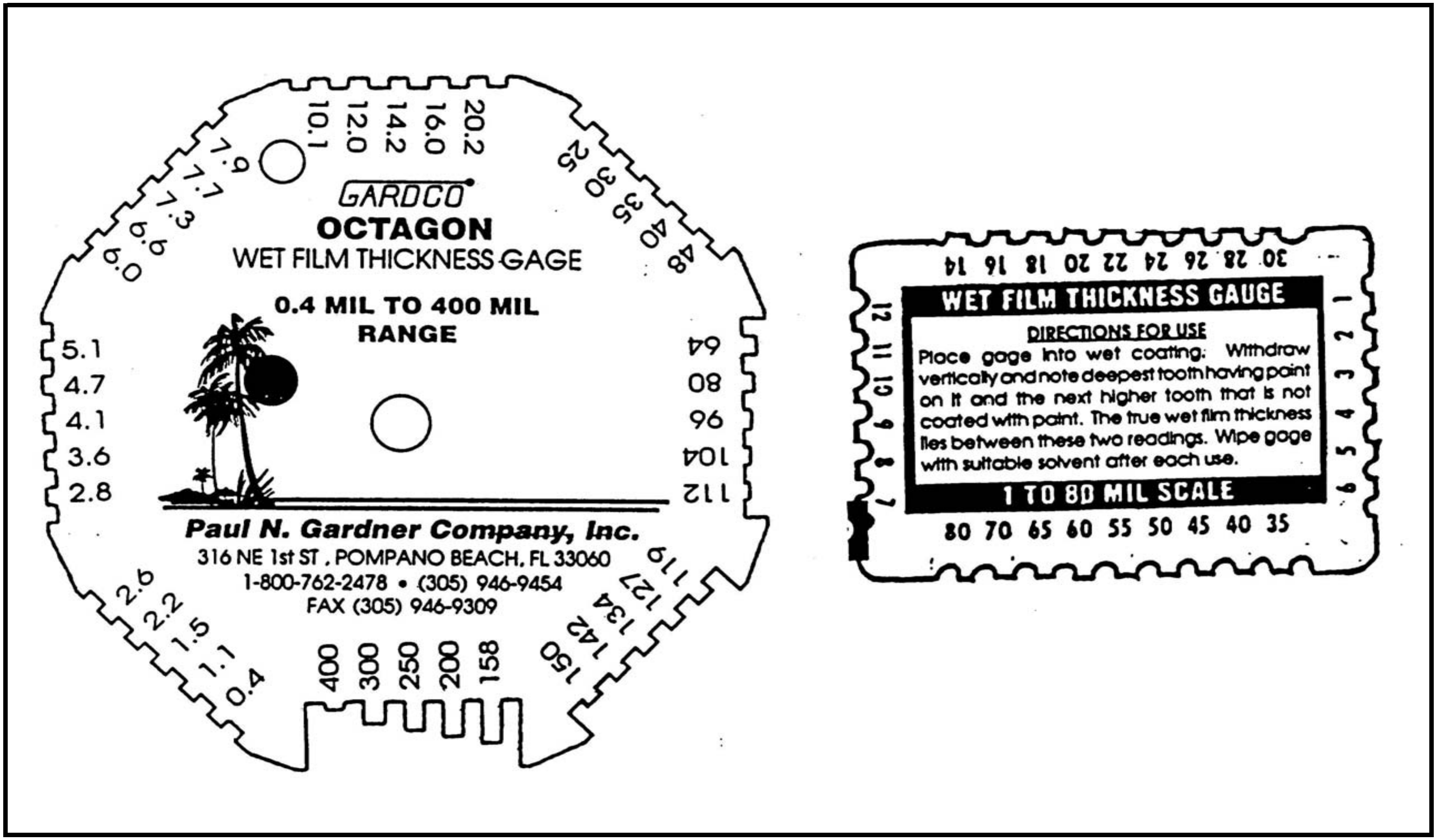


FIGURE 2.2

WET FILM THICKNESS GAUGES



Place gage into wet coating. Withdraw vertically and note deepest tooth having paint on it and the next higher tooth that is not coated with paint. The true wet film thickness lies between these two readings. Wipe gage with suitable solvent after each use.

the layer of failed fluid. One approach was based on the stiffness of the bristles of a brush mounted in a device to be drawn through the fluid. This device proved awkward and invasive, disturbing too much of the subject fluid. Another approach used pliable plastic strips of various degrees of stiffness which, when drawn through the fluid, provided a sense of fluid resistance, sliding over areas where adhesion had set in. Another approach involved directing a jet of air at the subject fluid and observing whether the fluid would be dislodged or moved. None of these approaches was fully satisfactory, and in this study, failure adhesion dimensionality and degree of bonding were determined using an electric dental flossing device (Photo 2.5).

In operation (Photo 2.6), a thread of floss was spun by the device. A floss segment extended about 3 to 4 mm from the tip of the unit, and upon spinning carved out a circle (or not, depending on whether adhesion had occurred) 3 to 4 mm in radius on a failed surface element. In a layer of non-adhered fluid, the force of the spinning floss was sufficient to expose the surface of the test plate. As the rotation speed of the unit was fixed, the applied force was constant for all tests, providing a basis of comparison among various test conditions, and between different stages of contamination for individual tests. This device proved to be the most satisfactory of the various approaches to establishing areas that had undergone surface bonding to the substrate and gave a measure of the strength of the bond formed.

Fluid samples for viscosity testing were gathered during the tests and preserved in small wide-mouth glass bottles with screw caps. Viscosity levels of these samples were subsequently measured by use of a Brookfield viscometer (Model DV-1+; Photo 2.7) fitted with a thermostatted recirculating fluid bath and micro sampling option.

A full list of equipment is provided in Appendix B.

2.4 Data Forms

Standard data forms as used in fluid holdover time tests were used for recording failure times, precipitation rates and fluid thickness measurements. Special data forms were designed to record Brix readings, viscosity sampling, adherence of fluid failure, and the subjective appearance of fluid failure. These forms are included in full in Appendix B.

2.5 Fluids

Test fluids were selected to provide a representation of SAE Type I and Type IV fluids. Both ethylene glycol- and propylene glycol-based fluids are represented by the data collected. Fluids were tested at full strength except for one particular Type IV fluid, which was diluted to a 50/50 v/v concentration in order to provide comparisons to Type I fluid.

2.6 Personnel

The nature of the tests resulted in a number of simultaneous documentation activities triggered by events of significance that occurred during the progression of fluid failure. Completion of these activities within a short time period required the involvement of an unusually high number of test personnel. The most critical event in any given test was the standard plate failure call, which required samples to be collected for concentration, wet film thickness, and viscosity measurements. Narrative descriptions of the appearance of the failed fluid, and both photography and video capture of the event were also carried out at this point, as well as failure adhesion testing. Normally, tests on two plates were run simultaneously. On two occasions, up to four flat plate tests were simultaneously in progress. As all of these activities required close access to the test plate, a sequence of activities was developed wherein test members took turns approaching the plate, performed their function, and then stepped back. This discipline prevented crowding around the test stand and minimized the risk of raising local stand temperatures from body heat and exhaled air. This was more critical in tests carried out at higher temperatures.

Ten APS personnel were involved in the test process. Additionally, personnel from both RVSI and Cox were present to provide support in operating their equipment and to ensure ongoing recording of fluid condition in tests under way. Observers from Transport Canada and the Federal Aviation Administration (FAA) were present at various times.

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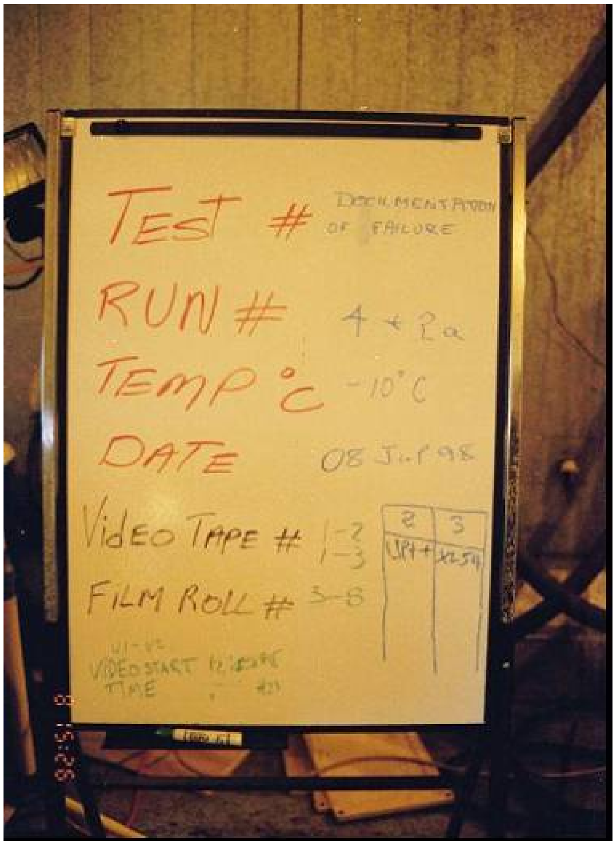
Photo 2.1

General Test Setup

Photo 2.2

Test Status Board


TEST # DOCUMENTATION OF FAILURE

RUN # 4 + 2a

TEMP °C -10°C

DATE 08 Jul 98

VideO TAPE # 1-2 1-3

FILM ROLL # 3-8

2	3
[illegible]	[illegible]

VIDEO START TIME [illegible]

Photo 2.3

Syringe for Collecting Fluid Samples from Bottom Layer

Photo 2.4

Collecting Fluid Samples with Syringe

Photo 2.5

Dental Flossing Device Used to Test Adherence

Photo 2.6

Testing Adherence with Flossing Device

Photo 2.7

Brookfield Digital Viscometer Model DV-I+ and Temperature Bath

3. DESCRIPTION AND PROCESSING OF DATA

3.1 Overview of Test Sessions

Fourteen runs, including twenty-eight individual plate tests were conducted over a two-day period. A summary of the test parameters is presented in Table 3.1.

Table 3.2 provides a log of all tests with associated test conditions and event times, and indicates duplicate tests conducted to ensure reproducibility.

3.2 Discussion of Test Variables

Test conditions were established to address the following considerations:

- Appearance of Type I versus Type IV – light freezing rain;
- Appearance of Type IV – light freezing rain versus freezing drizzle;
- Appearance of Type IV – effect of temperature (-4°C and -10°C);
- Type IV ethylene glycol-based fluids versus Type IV propylene glycol-based fluids – freezing drizzle;
- Time to adhere – Type I versus Type IV; and
- Appearance of Type I versus Type IV 50/50 – light freezing rain.

During the afternoon of the first day of testing under ambient temperature conditions of -10°C, it was noted that the test plate temperature was not as cold as was expected. Following some experimentation, it was found that the photographers' lights were a problem source of heat on the test plates. All light sources, including those associated with the ice detection sensors, were turned off or positioned farther back from the test stand for subsequent tests. Personnel concentration close to the test stand was minimized to reduce the effects of body heat, particularly during runs performed at higher temperatures.

3.3 Description of Data Collected and Analysis

Data collected during this study were focused to provide documentation of the appearances and physical nature of fluid failures. The various approaches required to provide this documentation included photography and videotaping, narrative description, readings from various ice detection sensors, and measurements of physical characteristics including concentration, film thickness, failure adhesion, and viscosity.

TABLE 3.1

DOCUMENTATION OF FLUID FAILURE

SUMMARY OF TESTS CONDUCTED

Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Precipitation Type	ZD	ZD	ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZD	ZD	ZD
Rate (g/dm²/h)	10	10	25	25	25	25	25	25	25	25	25	13	5	5
OAT (°C)	-10	-10	-10	-10	-10	-10	-10	-4	-4	-4	-4	-4	-10	-10
UCAR XL54			5	7				14			18			
UCAR Ultra+	1	4		6	9			13			19	20 22	24 27	
Octagon MaxFlight	2	3			8	11				16		21 23	25 26	
Kilfrost ABC-S						10	12							
SPCA AD-480														28
SPCA AD-480 (50%)									15	17				

NB: Values in cells represent test numbers.

TABLE 3.2

DOCUMENTATION OF FLUID FAILURE - TEST LOG

Test no.	Test season	Form no.	Date	Start time (Local)	1st time (Local)	End time (6") (Local)	Stop time (all) (Local)	Fluid name	Fld dilution	Fld type	Plate location	C/FIMS #	SPAR/ Cox	RVSI	Final Brix	Fail time (min)	1st Failure time (min)	Rate of precip. $g/dm^2/h$	Ambient temp [C]	Precip type	Duplicate tests	Comments
1	1998	1	Jul-08-98	11:13:10	11:50	12:03	12:19	UCAR ULTRA +	Neat	4	2	15		√	13	50	36	10.4	-10.3	frz_drizzle	1,4	
2	1998	1	Jul-08-98	11:23:05	11:36	11:56	12:07	OCTAGON	Neat	4	3	17		√	20	33	12	9.8	-10.3	frz_drizzle	2,3	
3	1998	2	Jul-08-98	12:53:45	13:04	13:33	13:45	OCTAGON	Neat	4	2	15		√	17.5	39	10	11.0	-10.1	frz_drizzle	2,3	
4	1998	2	Jul-08-98	12:57:05	13:52	14:01	14:18	UCAR ULTRA +	Neat	4	3	17		√		64	54	10.1	-10.1	frz_drizzle	1,4	
5	1998	3	Jul-08-98	15:38:45	15:42	15:43	15:44	UCAR XL54	Std	1	3	17		√	6	5	3	24.5	-10.5	frz_rain	5,7	
6	1998	4	Jul-08-98	15:25:50	15:30	15:57	16:05	UCAR ULTRA +	Neat	4	2	15		√		31	4	25.2	-10.3	frz_rain	6,9	
7	1998	4	Jul-08-98	15:27:10	15:29	15:31	15:32	UCAR XL54	Std	1	3	17		√	5	4	1	24.5	-10.3	frz_rain	5,7	
8	1998	5	Jul-08-98	16:11:00	16:18	16:33	16:41	OCTAGON	Neat	4	2	15		√		22	7	25.2	-10.5	frz_rain	8,11	
9	1998	5	Jul-08-98	15:54:30	16:10	16:23	16:30	UCAR ULTRA +	Neat	4	3	17		√		29	15	24.5	-10.2	frz_rain	6,9	
10	1998	6	Jul-08-98	17:01:50	17:07			KILFROST ABC-S	Neat	4	2	15		√		N/F	5	25.2	-10.5	frz_rain	10,12	Test Stopped - Chamber Temp. Problem
11	1998	6	Jul-08-98	16:37:20	16:50	16:57	17:02	OCTAGON	Neat	4	3	17		√	7.5	20	12	24.5	-10.5	frz_rain	8,11	
12	1998	7	Jul-08-98	17:40:50	17:48			KILFROST ABC-S	Neat	4	3	17		√		N/F	7	24.5	-10.5	frz_rain	10,12	Test Stopped - Chamber Temp. Problem
13	1998	8	Jul-09-98	9:13:45	9:42	9:49	9:54	UCAR ULTRA +	Neat	4	2	15		√		35	28	24.1	-3.5	frz_rain	13,19	
14	*1998*	*8*	*Jul-09-98*	*9:16:00*	*9:25*	*9:27*	*9:35*	*UCAR XL54*	*Std*	*1*	*3*	*17*		√		*12*	*9*	*24.8*	*-3.6*	*frz_rain*	*14,18*	*Intial Brix = 24.5 (Possibly wrong fluid)*
15	1998	9	Jul-09-98	9:41:15	9:55	9:57	9:59	SPCA AD-480	50%	4a	3	N/A		√		16	13	24.8	-3.3	frz_rain	15,17	
16	1998	10	Jul-09-98	10:02:40	10:17	10:25	10:27	OCTAGON	Neat	4	2	15		√	3	22	14	24.1	-3.7	frz_rain	16	
17	1998	10	Jul-09-98	10:10:00	10:23	10:26	10:27	SPCA AD-480	50%	4a	3	17		√	6	16	13	24.8	-3.7	frz_rain	15,17	
18	1998	11	Jul-09-98	10:33:45	10:40	10:42	10:47	UCAR XL54	Std	1	2	15		√	3	8	6	24.1	-4.0	frz_rain	14,18	
19	1998	11	Jul-09-98	10:37:30	11:01	11:10	11:17	UCAR ULTRA +	Neat	4	3	17		√	6	33	23	24.8	-3.7	frz_rain	13,19	
20	1998	12	Jul-09-98	12:47:30	13:34	13:44	13:51	UCAR ULTRA +	Neat	4	2	15		√	11	57	46	12.4	-3.5	frz_drizzle	20,22	
21	1998	12	Jul-09-98	12:50:05	13:12	13:28	13:35	OCTAGON	Neat	4	3	17		√	9	38	21	12.4	-3.4	frz_drizzle	21,23	
22	1998	12	Jul-09-98	12:54:45	13:34	13:52	13:57	UCAR ULTRA +	Neat	4	4	23		√	9	57	39	13.0	-3.5	frz_drizzle	20,22	
23	1998	12	Jul-09-98	12:56:15	13:13	13:20	13:37	OCTAGON	Neat	4	5	N/A		√	10	24	16	13.5	-3.1	frz_drizzle	21,23	
24	1998	13	Jul-09-98	15:29:30	16:36	16:51	16:54	UCAR ULTRA +	Neat	4	2	15		√	16	82	66	4.7	-10.6	frz_drizzle	24,27	
25	1998	13	Jul-09-98	15:31:15	15:54	16:36	16:49	OCTAGON	Neat	4	3	17		√	15	65	22	5.0	-10.6	frz_drizzle	25,26	
26	1998	13	Jul-09-98	15:33:20	15:55	16:34	16:50	OCTAGON	Neat	4	5	N/A		√		61	21	4.9	-10.6	frz_drizzle	25,26	
27	1998	13	Jul-09-98	15:32:20				UCAR ULTRA +	Neat	4	4	23		√	14	N/F	N/A	4.8	-10.6	frz_drizzle	24,27	Test Stopped at 16:26
28	1998	14	Jul-09-98	16:27:30	16:47	17:26	17:46	SPCA AD-480	Neat	4	4	23		√	24	59	19	4.8	-10.9	frz_drizzle	28	

Number of Tests:

T1	std	T4	neat	50/50
UCAR XL54=	4	OCTAGON MaxFlight=	9	
		KILFROST ABC-S=	2	
		UCAR ULTRA+=	10	
		SPCA AD-480=	1	2
Total	4		22	2
TOTAL # OF TESTS =			**28**	

Data from the various means used to document fluid failures were sorted by test and arranged in a fixed order of presentation. A full set of test results, arranged in a set order and sorted by individual tests, is presented in Appendix C. A sample of the documentation for a single test (ID #1) follows.

Figure 3.1 provides general test information, including test conditions and some quantitative results.

A set of four photos (Photos 3.1 to 3.4) shows the appearance of fluid at four specific stages during the test:

- at time of pouring,
- at time of first failure,
- at time of plate failure call, and
- at complete plate failure.

The C/FIMS sensor head and the markings (squares) denoting cross-hair locations and the *no-touch* zone are visible in the photos. In Photo 3.2 the area of initial fluid failure (appearing as surface roughness) can be seen along the near edge (top) of the plate. In Photo 3.3, failure appears in the plate area above the sensor and as fingers of failed fluid beyond. Photo titles include a time stamp designating the time after fluid application. In some cases the time is estimated from video footage, due to intermittent failure of the camera time stamp.

Figure 3.2 is a narrative description of the appearance of the fluid as it progresses toward failure. The narrative is supported by sketches illustrating points of interest.

Figure 3.3 is a record of fluid thickness over the duration of the test. This record, as with the records of other quantitative measures, includes (as vertical time lines) times of first failure, plate failure and complete failure.

Figure 3.4 is a profile of the fluid freeze point temperature as the fluid concentration is progressively diluted from its initial strength. When testing Type IV fluids, fluid concentration was sampled at both the top and bottom of the fluid layer, and the respective freeze points are shown. Profiles of ambient temperature and plate temperature are reported to serve as a base line for fluid freeze point values. A comparison of fluid freeze point temperature to plate temperature at the time of plate failure is of interest. In this case, fluid freeze point matched ambient temperature at about the time of plate failure.

FIGURE 3.1

GENERAL TEST INFORMATION

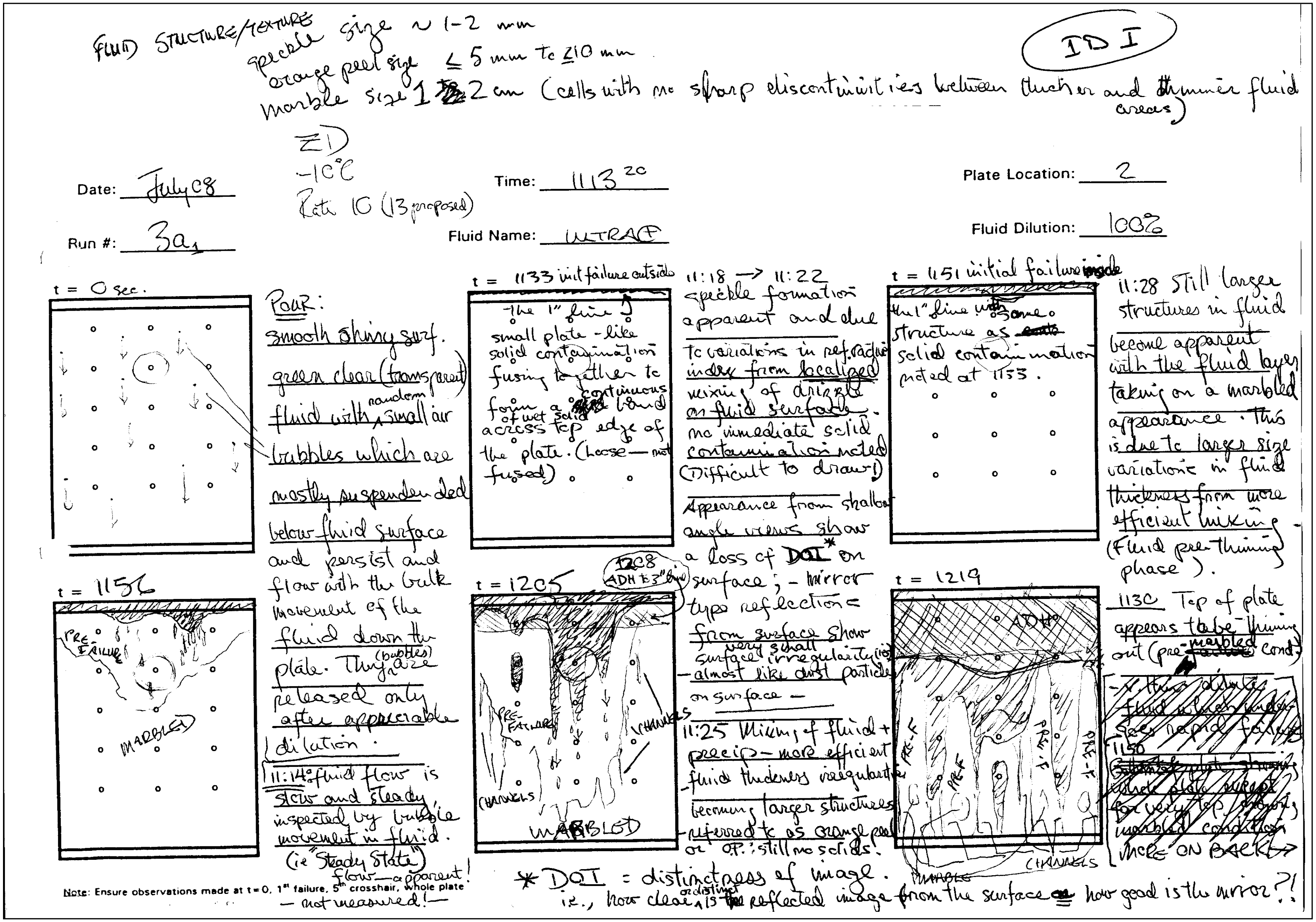
ID # 1

July 8, 1998

Ambient Air Temperature:	-10.3°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	10.4 g/dm²/h
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	11:13:10
Failure Mode:	5th Cross hair
Failure Location:	D2
Failure Time (Standard):	12:03:00
Failure Time (Complete Plate):	12:19:00

FIGURE 3.2

SUBJECTIVE APPEARANCE OF FLUID FAILURE



FLUID STRUCTURE/TEXTURE
speckle size ~ 1-2 mm
orange peel size ≤ 5 mm to ≤10 mm
marble size 1 ~~to~~ 2 cm (cells with no sharp discontinuities between thicker and thinner fluid areas)

ID I

ZD
-10°C
Rate 10 (13 proposed)

Date: July 08

Time: 1113 20

Plate Location: 2

Run #: 3a1

Fluid Name: ULTRA+

Fluid Dilution: 100%

t = 0 sec.

POUR:
smooth shiny surf.
green clear (transparent) fluid with random small air bubbles which are mostly suspended below fluid surface and persist and flow with the bulk movement of the fluid down the plate. They (bubbles) are released only after appreciable dilution.

11:14 fluid flow is slow and steady, inspected by bubble movement in fluid. (ie "Steady State" flow apparent!)

t = 1133 init failure outside

The 1" line
small plate-like solid contamination fusing together to form a continuous band of wet solid across top edge of the plate. (Loose — not fused)

11:18 → 11:22
speckle formation apparent and due to variations in refractive index from localized mixing of drizzle on fluid surface. no immediate solid contamination noted (Difficult to draw!)

Appearance from shallow angle views show a loss of DOI* on surface; - mirror type reflection from surface show very small surface irregularity(ies) - almost like dust particle on surface -

11:25 Mixing of fluid + precip - more efficient - fluid thickness irregularities becoming larger structures - referred to as orange peel or O.P.; still no solids.

t = 1151 initial failure inside

the 1" line with some structure as ~~[illegible]~~ solid contamination noted at 1133.

11:28 Still larger structures in fluid become apparent with the fluid layer taking on a marbled appearance. This is due to larger size variations in fluid thickness from more efficient mixing - (Fluid pre-thinning phase).

1130 Top of plate appears to be thinning out (pre-marbled ~~failure~~ cond.)

~~-x. this dilute fluid which undergoes rapid failure~~

1150 ~~[illegible] whole plate except for very top showing marbled condition~~

~~MORE ON BACK →~~

t = 1156

t = 1205

1208 ADH to 3" line

t = 1219

Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate
— not measured! —

*DOI = distinctness of image. i.e., how clear or distinct is the reflected image from the surface ~~or~~ = how good is the mirror?!

FIGURE 3.3

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 1

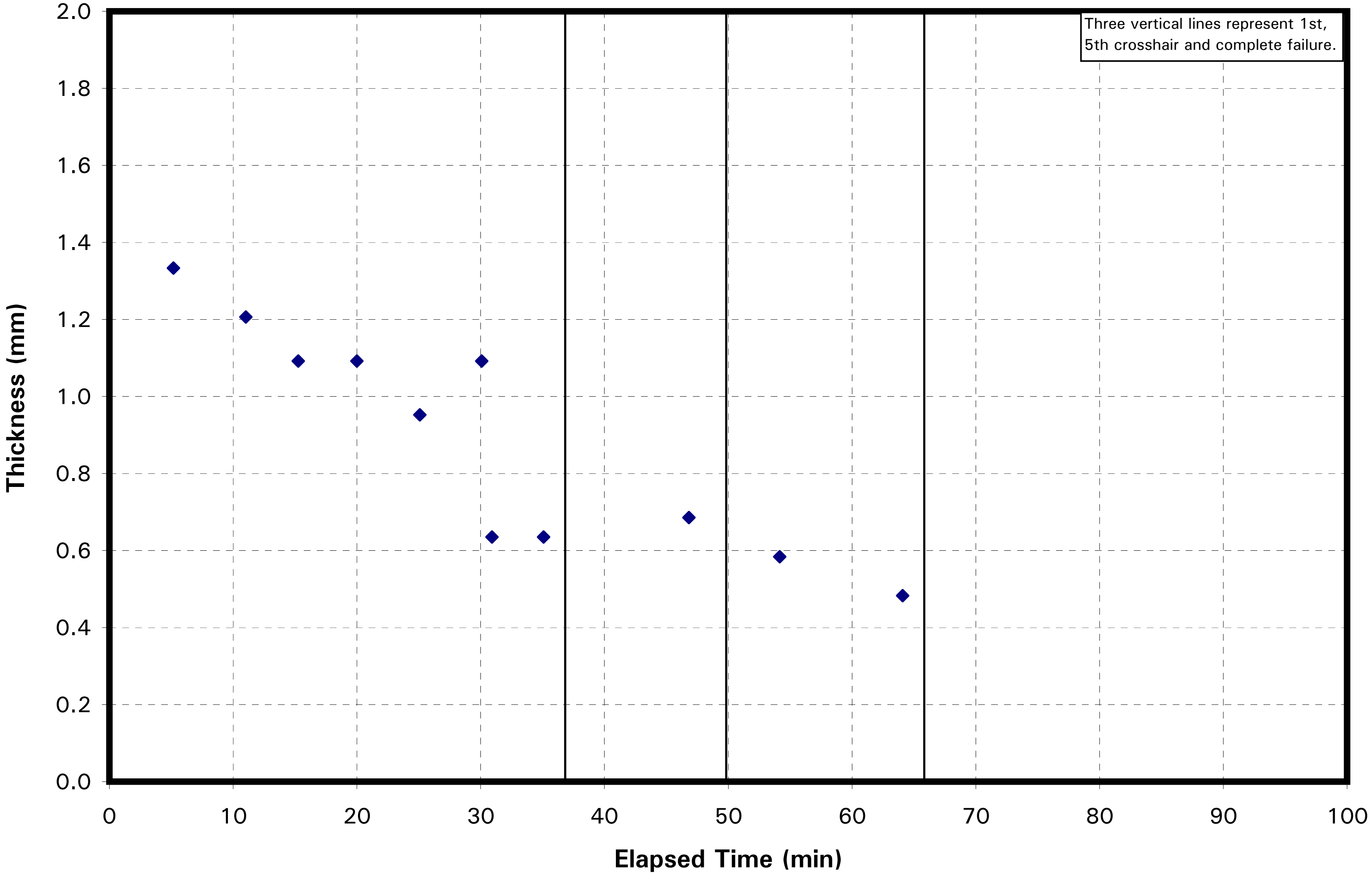


FIGURE 3.4

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 1

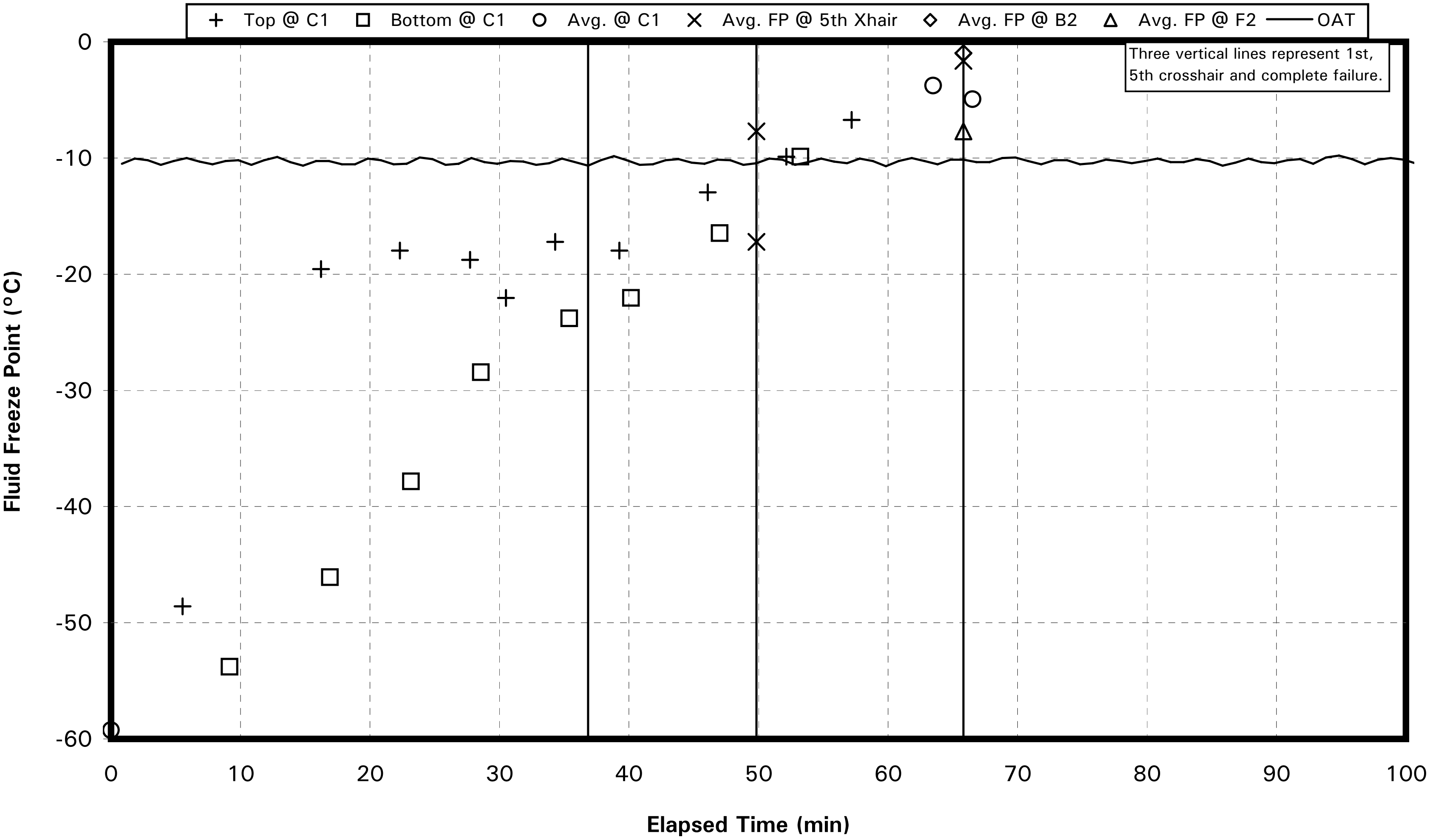


Figure 3.5 records three contamination sensing traces from the C/FIMS sensor as well as a profile of plate temperature. The sensor manufacturer did not provide a method of interpreting the sensor traces to identify the point of plate failure. In an operational installation, the C/FIMS system would normally be supplemented with decision-making software to provide the operator with a *go/no-go* indication; however, such functionality is not incorporated in the system used for these tests. In view of this deficiency, interpretation of the traces is based on a 1992-93 study by APS Aviation of the C/FIMS sensor in operation (1) that describes the nature of the C/FIMS sensor traces as fluids progressively absorb precipitation and reach the point of plate failure. The sensor records the admittance (inverse of electrical impedance) of the fluid overlaying the sensor head, to three different levels within the fluid layer. Immediately following application of fluid, the curves show a notable downturn caused by the rapid thinning of the initial fluid layer during that time frame. Subsequently, as the fluid absorbs precipitation, the curves slowly climb and then eventually reach a limit and start to decline as the ultimate capacity of the fluid to absorb water is reached. At the bottom of the decline, when the slope of the curve changes from negative to positive, the point of fluid failure has been reached. In this case, the C/FIMS sensor indicated that failure occurred at 42 minutes, as compared to the visual identification of plate failure, which was called at 50 minutes (and which may have occurred elsewhere on the plate).

Figure 3.6 records the trace from the RVSI ice contamination sensor. Fluid failure is interpreted (Source RVSI) as the point where the trace changes direction and begins a rapid downturn. In this case, the RVSI sensor identified fluid failure at about the same time (50 minutes) as visual identification.

Figure 3.7 shows a trace from the Spar/Cox ice contamination sensor. Sensor traces were made and supplied by the manufacturer. Although a limited number of sample traces were made available for this report, these were sufficient to provide a representation for each type of fluid tested (in this case, for Ultra+ fluid).

The trace shown in Figure 3.7 was generated using data from Test ID#20, which examined Ultra+ fluid in conditions of freezing drizzle and an outside air temperature of -4°C. This test illustrates the normal trace pattern for the Spar/Cox sensor that gradually ascends with time while the fluid undergoes progressive contamination. The numerical values on the vertical scale represent the *average contrast ratio*. Positive values indicate the existence of ice, and values of 0.003 (or in some tests, 0.005) or greater delimit failure in the observed area. The traces are based on sensor viewing of the *no-touch zone* on each test plate.

FIGURE 3.5

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 1

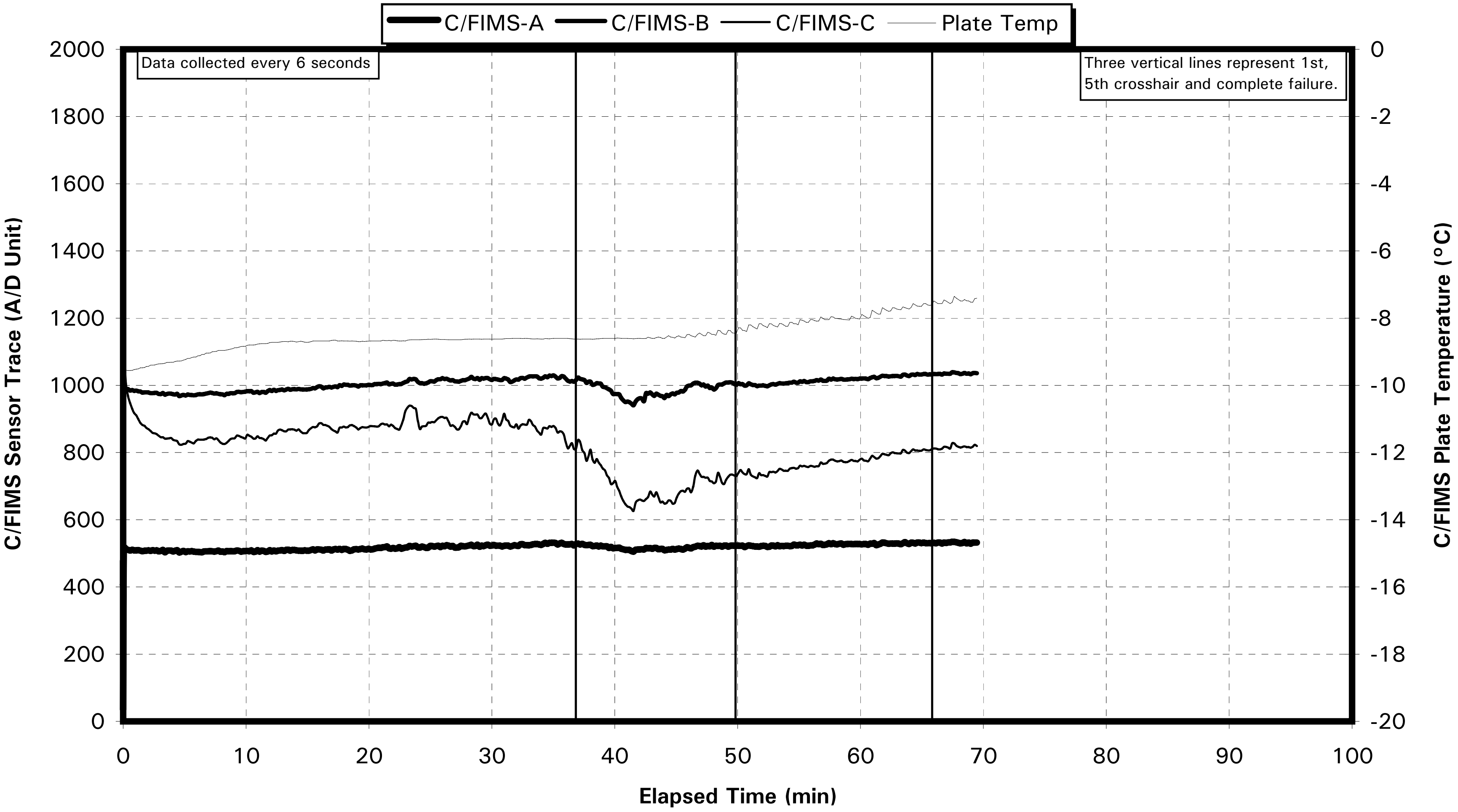


FIGURE 3.6

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 1

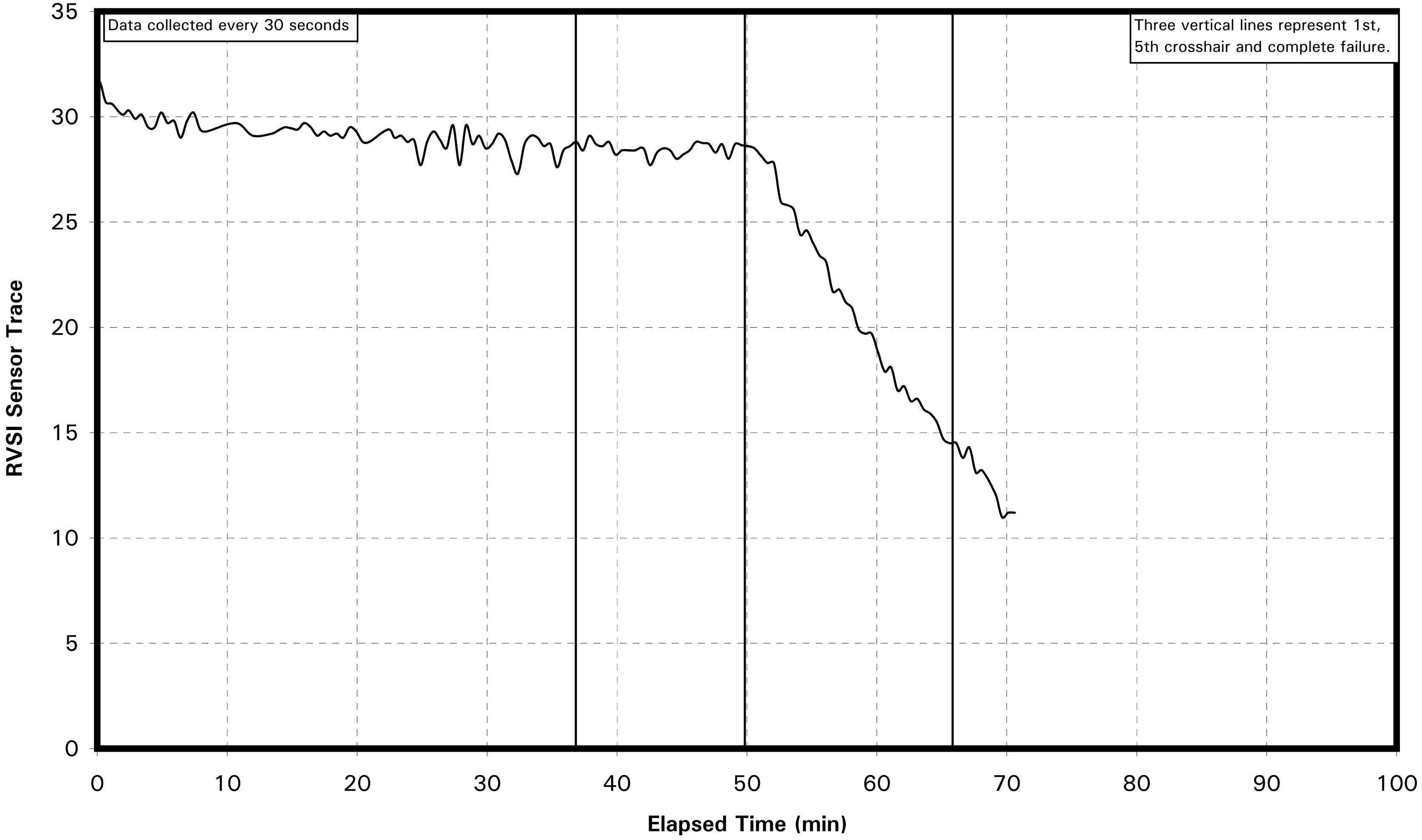


FIGURE 3.7

DOCUMENTATION OF FLUID FAILURE

SPAR/COX SENSOR TRACE

ID # 20

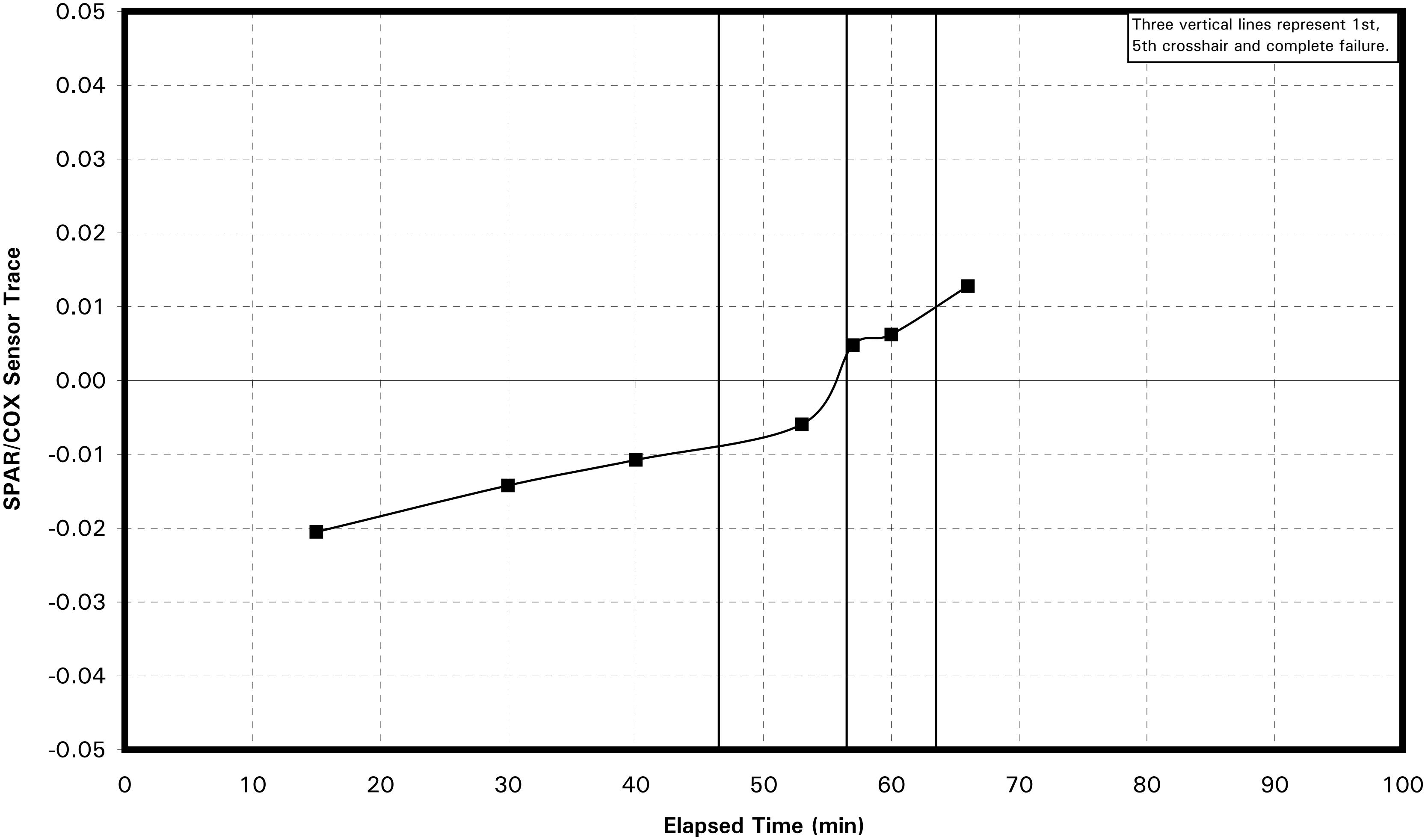


Figure 3.8 shows the record as to where the fail area fluid adhered to the plate surface at certain times during the test. The cross-hair location on the plate where adherence was measured is indicated on the left-hand margin, with a legend in the upper right corner denoting cross-hair references. In this case, at 50 minutes into the test (plate failure time), fluid failures at locations B2 and D2 had not adhered to the plate. At 74 minutes into the test (following complete plate failure), failure adhesion was noted at locations D2, E2, or F2. As the pattern of freezing initiated at the top edge of the plate and progressed downward, locations B2 and C3 had experienced longer exposure to freezing, sufficient to cause failure adhesion.

3.4 Viscosity Measurements

An attempt was made to examine the viscosity of each test fluid at time of failure. To this end, fluid samples were collected at the time and location of 5th cross-hair failure and at time of complete plate failure at positions B2, F2 and adjacent to the location of 5th cross hair failure, with the intent to measure fluid viscosity with a Brookfield viscometer. It was subsequently determined that individual samples had insufficient volume for accurate testing and consequently, samples were consolidated within each test to enable measurement. For ease of discussion, and because the results apply to various fluids and conditions tested, the results are discussed separately in Section 4.

3.5 Description of Photos and Video

In addition to the photos described in Section 2, each stage of the fluid failure progression was recorded on videotape. As well, two video cameras were focused on the *no-touch* zone of the two most frequently used plates and ran continuously. In addition, the RVSI and Spar/Cox systems maintained an ongoing video record of the events that occurred on the test stand.

3.6 Terminology and Definitions

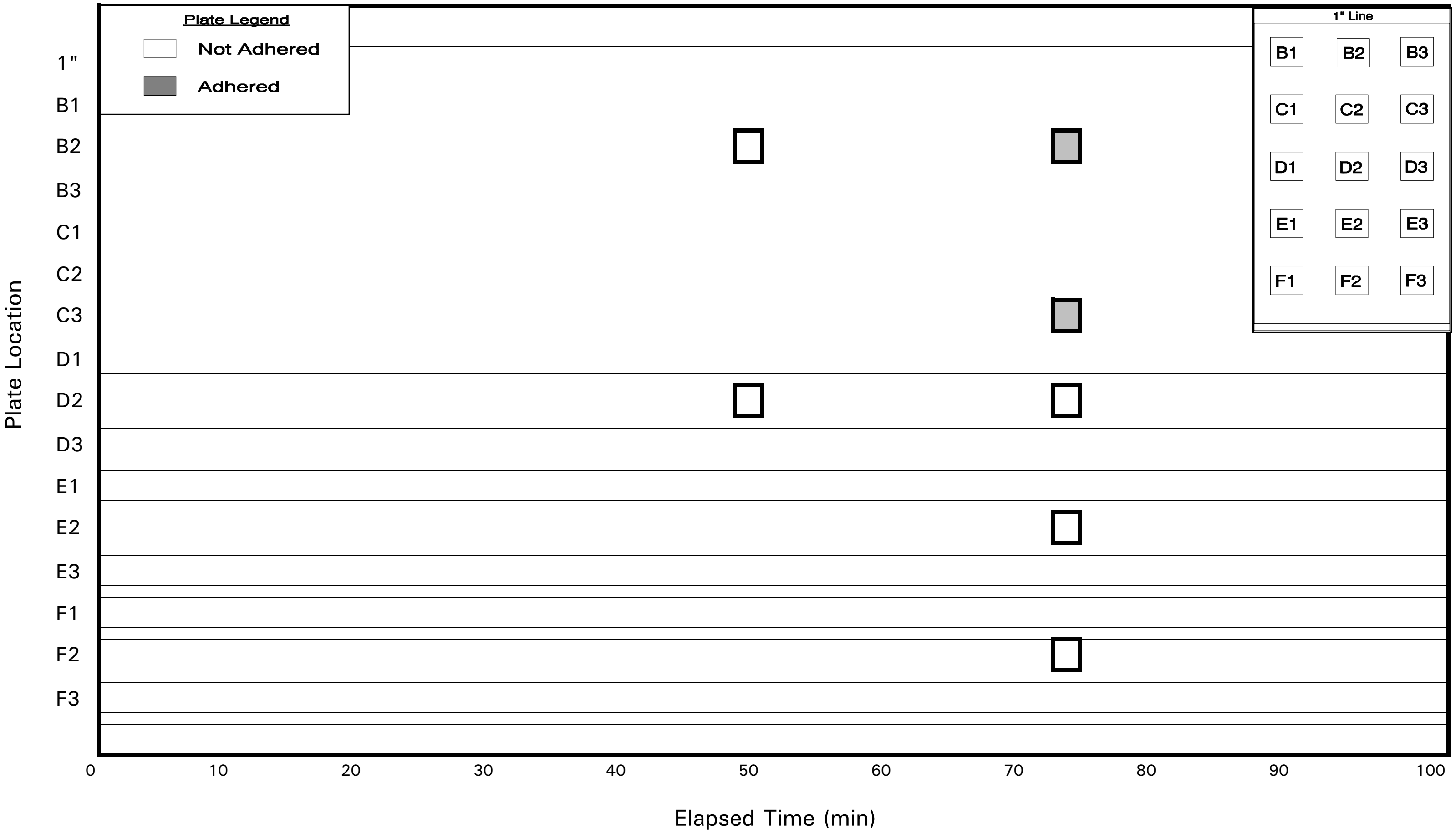
Section 1 of this report alludes to deficiencies in the clear and precise communication of the appearance of aqueous solutions of deicing and anti-icing fluids at the various stages the fluid undergoes from application to failure.

FIGURE 3.8

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 1



A glossary of terminology was assembled that should be helpful in facilitating the interpretation of the material presented in Section 4. The items contained are presented in the order of a topic development rather than alphabetically. Alternative terms are also provided where they exist.

i) Test surface; substrate

Any surface onto which, in this context, deicing and/or anti-icing fluids are applied. Usually used to refer to aircraft surfaces, flat plates, and airfoil sections.

ii) Distinctness of image; DOI

A measure of the quality of a reflected image off a surface treated with a coating. Usually used to describe dried painted finishes, especially on automobiles. In this context it refers to a fluid-treated surface once the fluid has stabilized or levelled itself (Photo 3.5).

iii) Contamination; contaminant(s)

Contamination generally refers to any sort of precipitation, in solid or liquid state. Liquid contamination includes rain, drizzle, freezing rain, and freezing drizzle. Fog and freezing fog are considered special cases of liquid precipitation. Examples of solid contamination include snow, hail, and ice pellets. Mixtures of solid and liquid contamination are occasionally observed in nature.

iv) Speck-covered stage (a pre-failure fluid condition)

This refers to the first visible signs of contamination on an Ultra+ fluid surface in certain conditions of freezing rain and freezing drizzle. In this stage, the fluid appears to contain specks similar to dust particles on an otherwise mirror-smooth or high-DOI surface. These are caused at points where contaminant droplets penetrate the fluid surface. No solids are actually present at this stage, but very localized refractive index variations give the impression of solids. The distances between specks in this stage are greater than the speck dimensions (Photo 3.6).

v) Streaks and dots (a pre-failure fluid condition)

Frozen precipitation in the form of short streaks or dots embedded in the fluid surface and most commonly observed in propylene glycol-based anti-icing fluids at temperatures of -10°C or below. These are not stationary or fused, but seem to form on droplet contact with the fluid surface and are more readily observed once the fluid thickness stabilizes directly following application (Photo 3.7).

vi) Orange peel; orange-peel texture (a pre-failure fluid condition)

Stage in the variation of fluid appearance prior to failure initiation in which the density of specks (defined above) is such that the distance between specks is of the order of the speck dimensions. This produces a surface that resembles that of the surface of an orange peel. It is a common term used to describe extended surface defects in paint finishes and observed in Ultra+ and sheared Octagon fluid (Photo 3.8).

vii) Gelatinous stage (a pre-failure fluid condition)

The final stage in the evolution of fluid appearance prior to failure initiation. It is seen in Ultra+ and sheared Octagon fluids and is observed when the orange-peel stage coalesces to form thicker and thinner fluid regions on the surface with no abrupt boundaries. Its appearance can be described as being similar to a warmed sample of colourless or pale-green, well-sheared gelatin, depending on whether a dye is present. It is still transparent and the test surface below takes on somewhat the appearance of polished marble (see Photo 3.9).

viii) Failure; fluid failure

The point at which stationary (immobile) ice in some form (depending on temperature and type of precipitation) begins to accumulate visibly on a fluid-treated surface.

ix) Standard plate failure; end condition definitions

The procedure and the determination of the end condition evolved from the experiences of various test programs from previous winter seasons. Plate failure time is that time required for the end condition to be achieved. This occurs when the accumulating precipitation fails to be absorbed or ice forms at any five of the cross-hair marks on the panels. A cross hair is considered failed if:

- There is a visible accumulation of snow bridging on top of the fluid at the cross hair when viewed from the front. There should be an indication that the fluid can no longer deice or absorb the precipitation at this point; OR

- When precipitation or frosting produces a *loss of gloss* (i.e. dulling of the surface reflectivity) or a change in colour (dye) to grey or greyish appearance at any cross hair, or ice (or crusty snow) has formed on the cross hair (look for ice crystals). This condition is only applicable during light freezing rain, freezing drizzle, ice pellets, freezing fog, rain on a cold-soaked surface or during a mixture of snow and light freezing rain, freezing drizzle and ice pellets.

x) Fluid Operational Limit; fluid at its operational limit

In a live operation, the physical states of a deicing or anti-icing fluid on an aircraft surface at standard failure. This nomenclature does not infer that the fluid has reached its ultimate limit.

xi) Slurry

An initial stage of fluid failure observed under certain conditions of freezing drizzle and freezing rain that can be described as a watery mixture of insoluble matter. Although in this case the solid is ice which *is* soluble in water, it is a rare (but not impossible) occasion that the return to the liquid state. Solid particles are too large to be suspended in the fluid for any significant time interval and settle on the substrate surface (Photo 3.10).

xii) Fusion

In this context, fusion refers to the process whereby the individual ice particles in a failed region undergo fusion to one another, resulting in a contiguous mass.

xiii) Fingers; fingers of failure

Pattern of failure propagation on a surface that precedes fusion.

xiv) Drainage Channels; drain channels; channels

Channels carved into the thicker fluid layer on surfaces below the failure front. They allow unfrozen precipitation and dilute fluid mixtures to drain off the test surface. These give rise to fingers early in the failure stage and persist to complete plate failure between fingers, which fail laterally between the standard plate failure and complete plate failure. Photo 3.11 shows examples of both fingers and drainage channels.

xv) Failure adhesion

The condition reached in advanced stages of fluid failure when the failures actually bond to a substrate.

xvi) Colloid; colloidal suspension

A colloid is a long-lived suspension of very fine particles in a fluid. The particle size distribution is far smaller than in slush and is usually not in a high enough concentration to agglomerate into larger particles. Colloids may appear clear or turbid. Clear colloids will still scatter light far more efficiently than true single-phase solutions. Some neat Type IV fluids can be considered colloidal suspensions in which the particles are polymer strands or coils.

xvii) Flash freezing; bloom ice

Ice formation initiated at random points on a substrate or test surface that propagate outward from the origin to form the characteristic *ice flower* or *snow fern* patterns seen on cold window panes exposed to humid air. It is usually observed after application of hot water or warm diluted deicing fluids onto cold-soaked surfaces and is an example of a super-cooled liquid that rapidly undergoes a phase transition to the solid state (Photo 3.12).

Photo 3.1

PHOTOS OF POUR - ID # 1

After Pouring, t = 0 min (Est.)

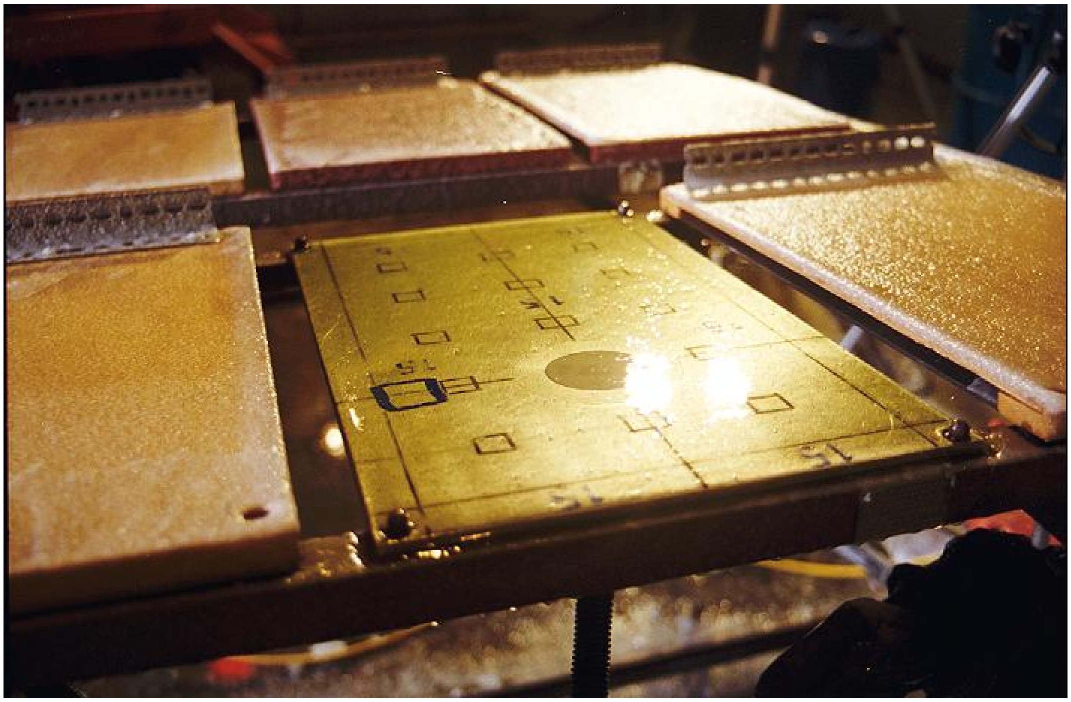


Photo 3.2

PHOTOS OF FIRST FAILURE - ID # 1

1st Failure, t = 37 min (Est.)

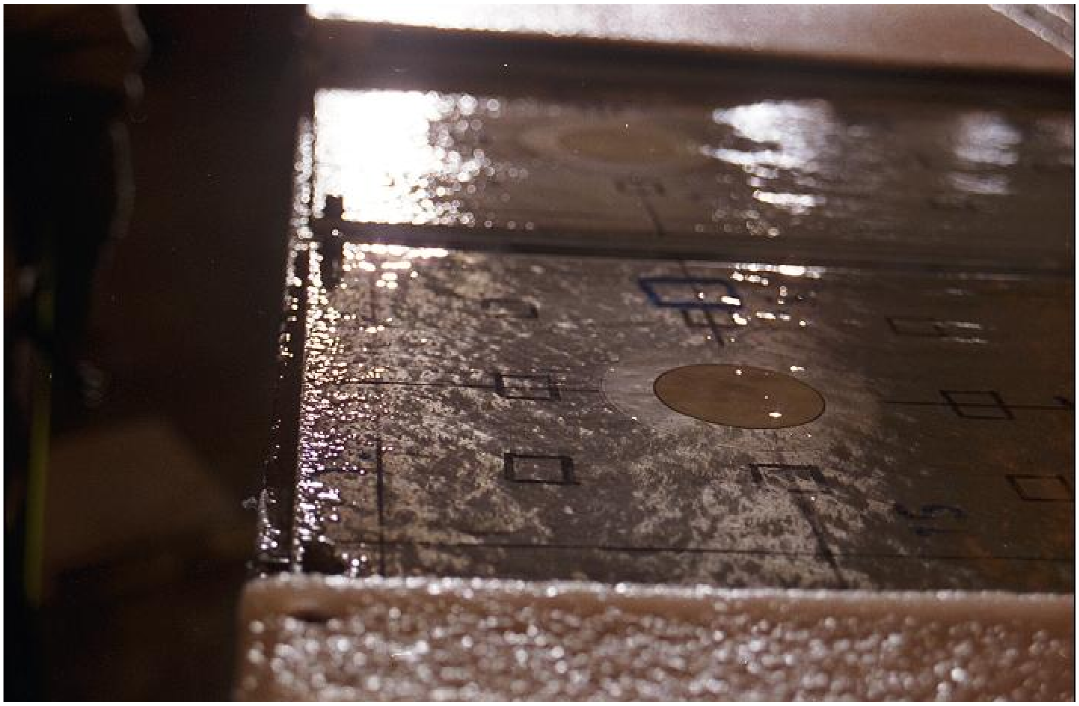


Photo 3.3

PHOTOS OF STANDARD FAILURE - ID # 1

Standard Failure (1/3 or 5th Crosshair), t = 50 min (Est.)

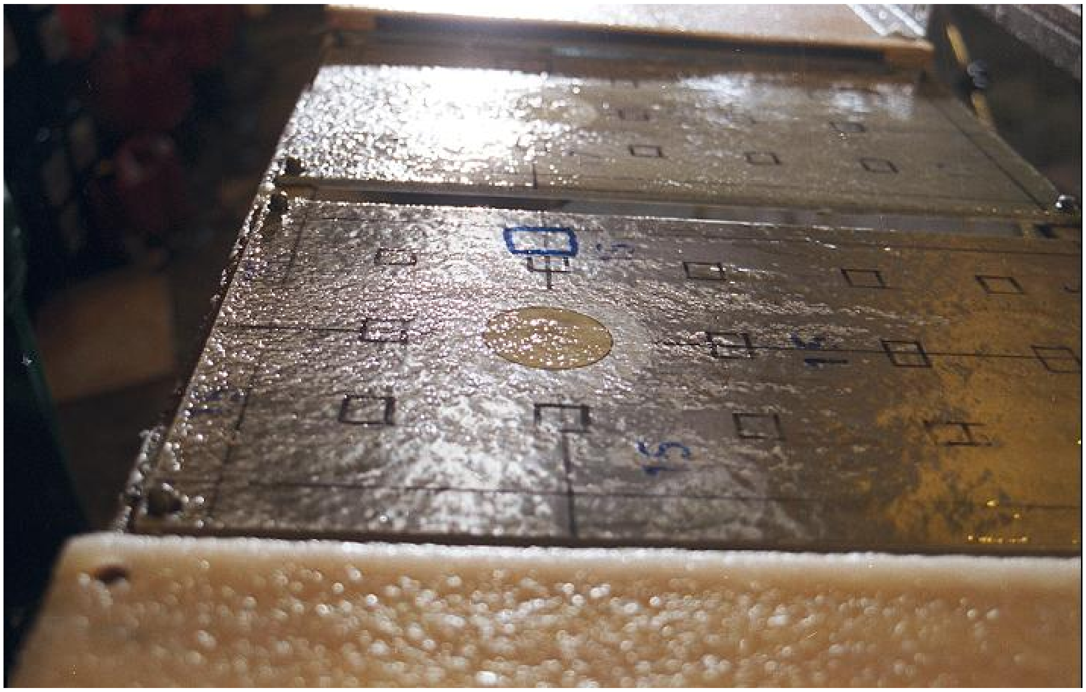


Photo 3.4

PHOTOS OF COMPLETE FAILURE - ID # 1

Complete Fluid Failure, t = 66 min (Est,)

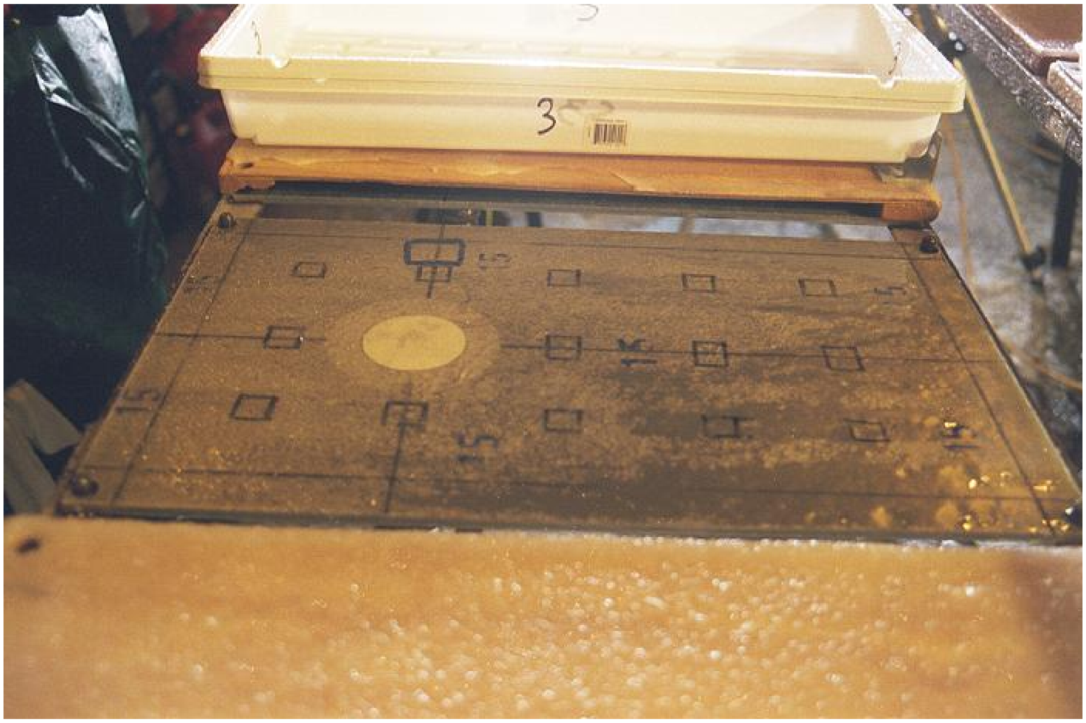


Photo 3.5

Distinctness of Image

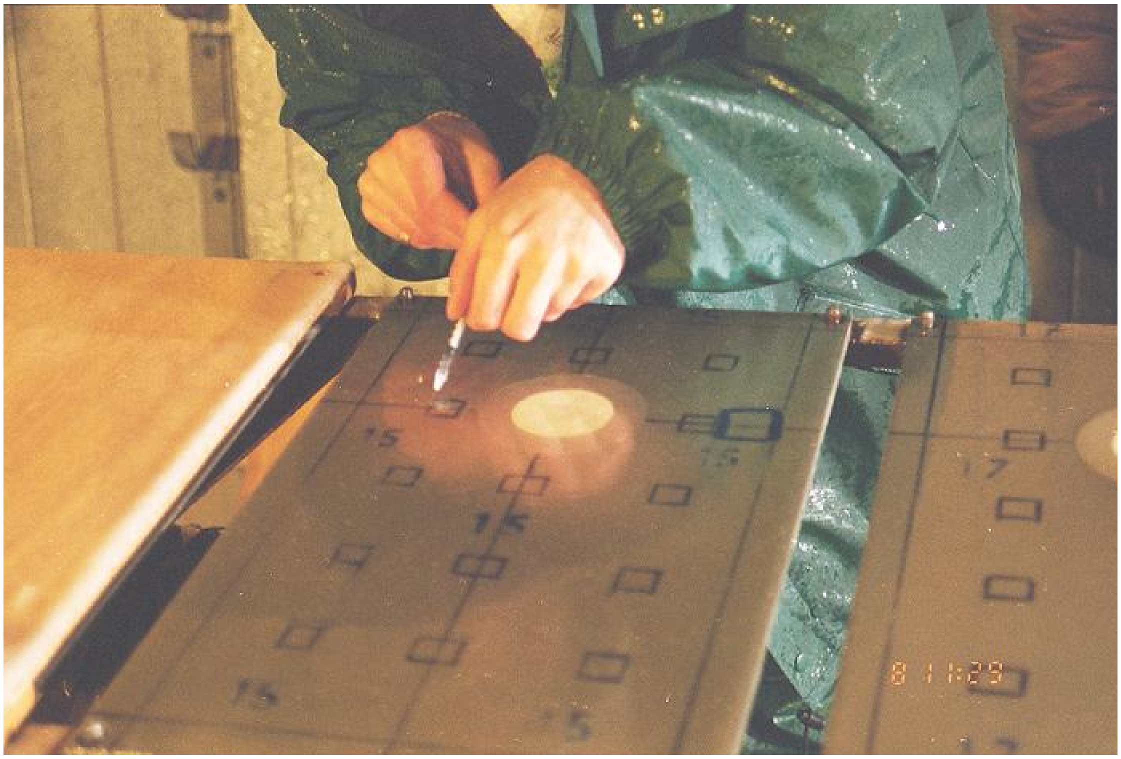


Photo 3.6

Speck Covered Stage

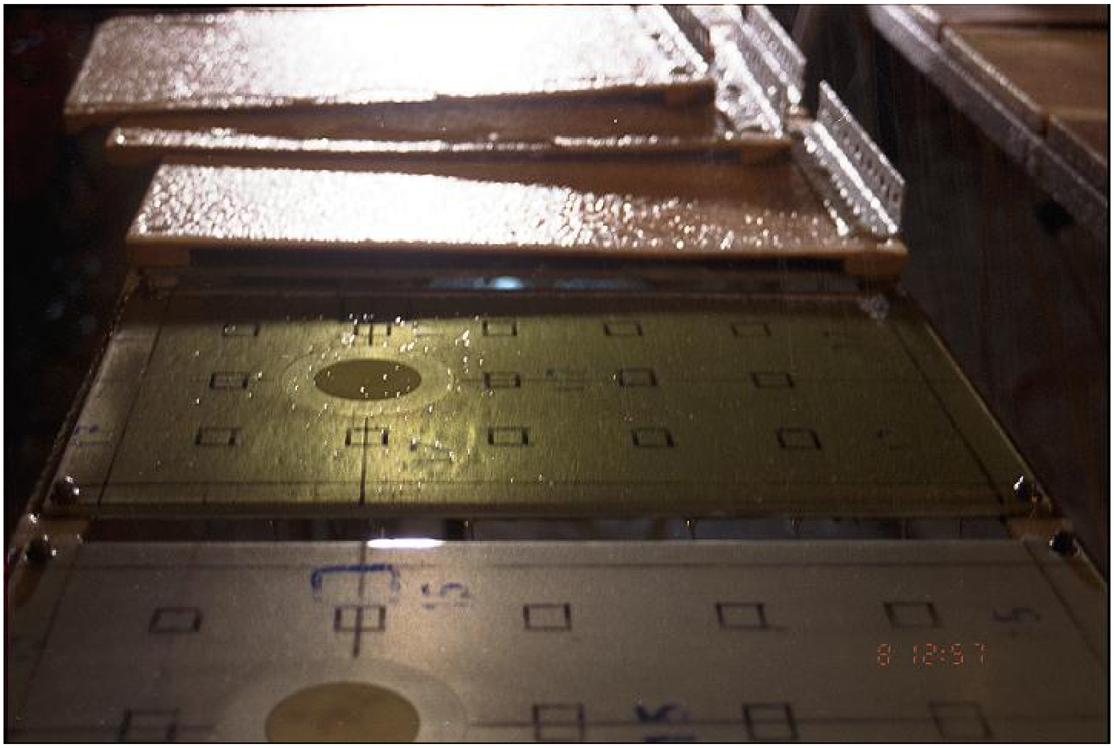


Photo 3.7

Streaks and Dots

Photo 3.8

Orange Peel

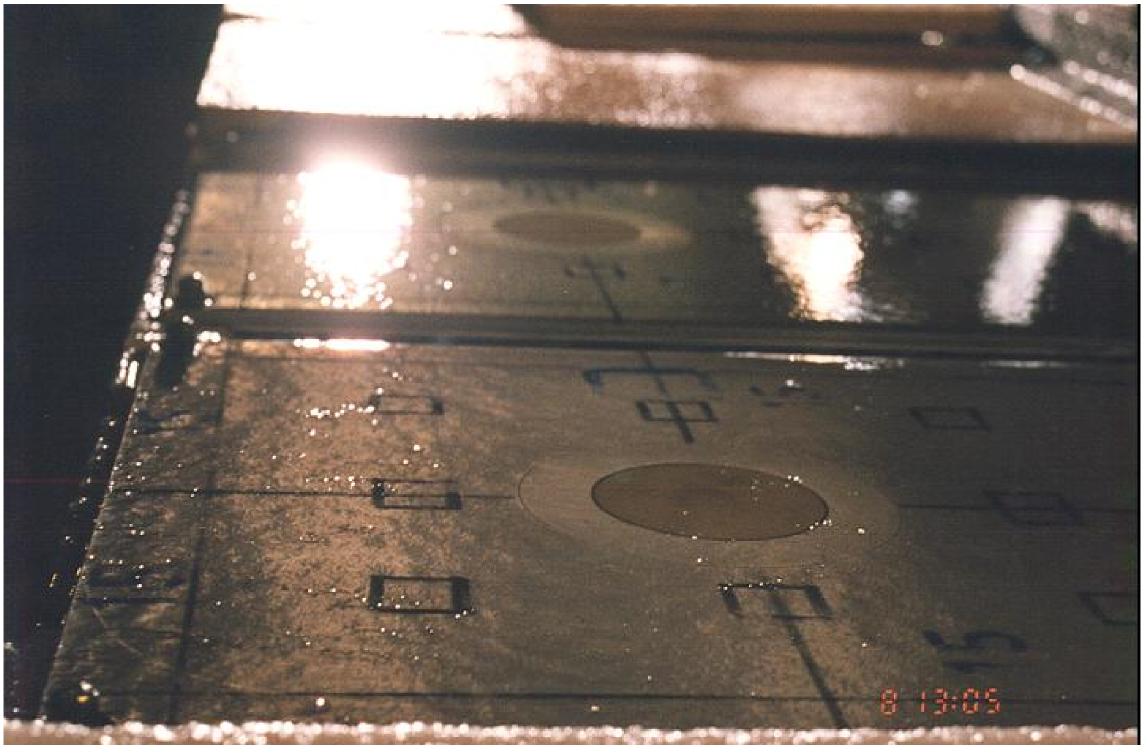


Photo 3.9

Gelatinous

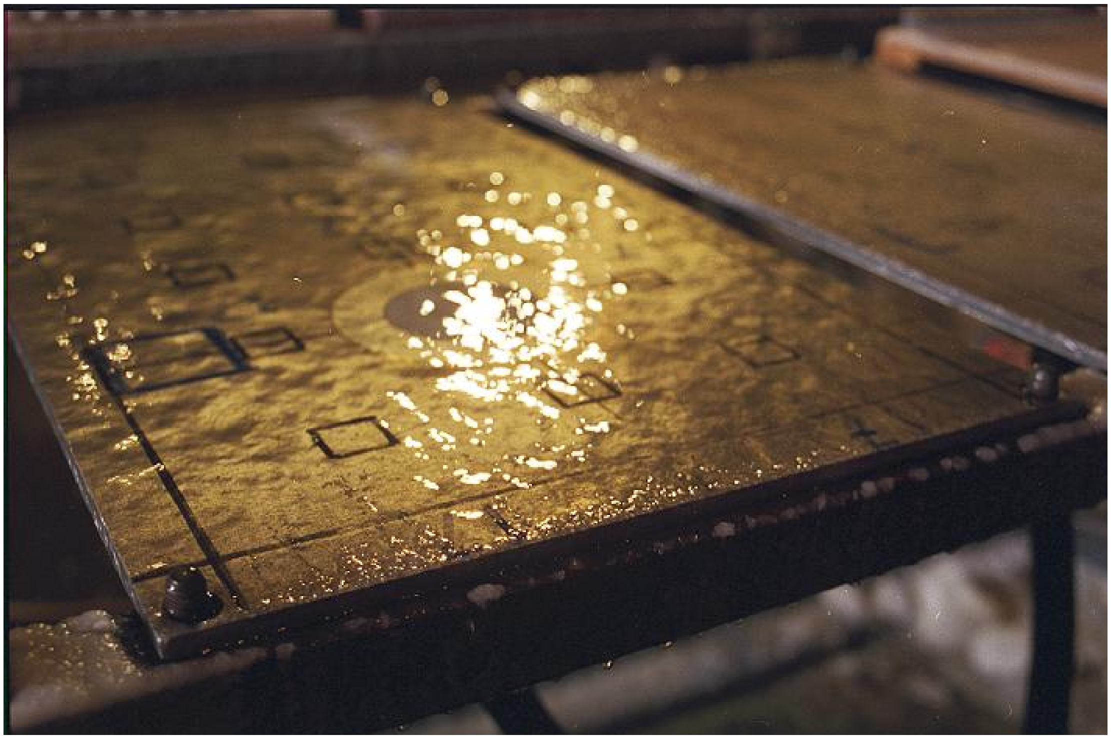


Photo 3.10

Slurry

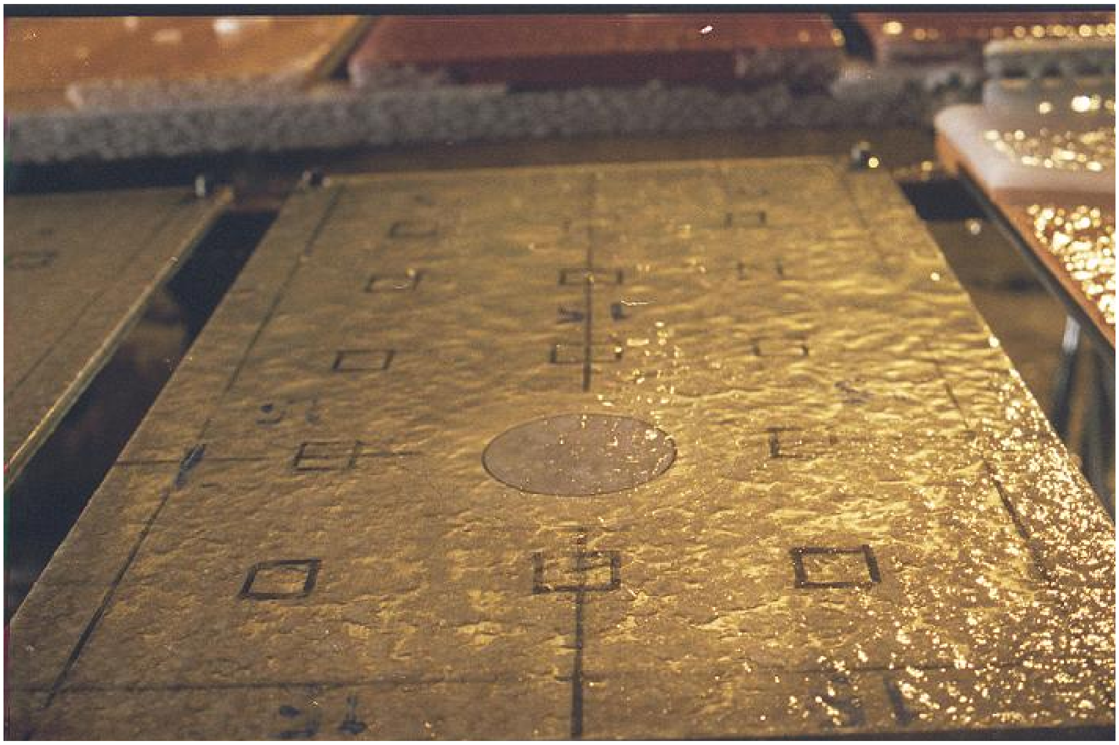


Photo 3.11

Drainage Channels and Fingers

Photo 3.12

Flash Freezing

4. ANALYSIS AND DISCUSSION

This section presents discussions of the observations made during tests and also presents discussions of the experimental data collected and reported in Appendix C, with specific consideration given to the nature of failure of the six fluids used in these tests. The discussions are intended to address (where appropriate) each of the six main objectives. Results of specific tests are used in each discussion indicated following the subsection title.

4.1 Type I Fluid

(Appendix C – Test ID #s 5, 7, 14, 18)

4.1.1 Appearance

The application of this unthickened fluid left a thin transparent orange layer of liquid on the plate. This film almost immediately began to show specks of solid precipitation poking out of the fluid surface profile when viewed at a shallow angle. The pour was accompanied by a small quantity of loose foam that quickly ran off the plate with the excess fluid (see Photo C5.1 and Photo C7.1). (Note: photo references that include the letter ‘C’ are found in Appendix C.)

Flash freezing has been observed in previous tests using Type I fluids and also in tests using 50/50 Type IV fluids. However, this mode of failure was not observed in this series of tests.

Significant differences in failure appearance were noted when the results of tests conducted with Type I fluids at higher temperatures (≥ -4°C) were compared to the results of Type I fluid tests conducted at lower temperatures (≤ -10°C).

At lower temperatures, failures tended to occur from the top to the bottom of the test plate. The resulting failures appeared to consist of slurry of small plate-like particles of ice and fluid. The particles rapidly fused together and proceeded to adhere to the plate surface.

At elevated temperature, the overall plate failures resembled extended islands of thin, shiny, wet ice that displayed well-developed snow fern patterns.

4.1.2 Film Thickness

During the first five minutes after application, the thickness of the applied fluid film diminished rapidly to leave a thin film of about 0.1 mm in depth. The film had reached minimum thickness by the time of plate failure.

4.1.3 Fluid Freeze Point

When exposed to the test precipitation conditions of light freezing rain at the rate of 25 g/dm²/h), the fluid experienced rapid dilution, with the freeze point rising to 0°C in about six minutes. This corresponds to findings regarding dilution of full strength fluid during the 1997-98 study (1).

4.1.4 Adhesion

Failure adhesion occurred shortly after freezing.

4.1.5 C/FIMS Ice Detection Sensor

The sensor traces displayed large variations and were difficult to interpret. Generally, the minimum in the curve of the sensor trace, where the slope of the curve changes from negative to positive (indicating fluid failure), occurred slightly prior to the visual identification of plate failure.

4.1.6 RVSI Ice Detection Sensor

The RVSI sensor trace shows a clearly definable downturn, indicating failure of fluid within the *no-touch* zone. The time of occurrence of the downturn coincided with the time of the visual standard failure call.

4.1.7 Spar/Cox Ice Detection Sensor

The single sensor trace provided for Type I fluid was for Test ID #7 (light freezing rain, rate = 25 g/dm²/h, outside air temperature = -10°C). The sensor trace reaches the point where the sensor system would indicate fluid failure (0.003) at about the time of visual identification of plate failure.

4.2 Dilute Type IV Fluid (SPCA AD-480 50/50 mix)

(Appendix C – Test ID #s 15, 17)

4.2.1 Appearance

Application of this 50/50 Type IV fluid resulted in a thick layer of transparent fluid (Photo C17.1) on the test plate. Some bubbles were observed to be present in the fluid (Photo C17.2) as it flowed down the plate.

Early failures appeared to resemble a slurry of small plate-like ice formations on the upper edge of the plate. The slurry then grew into finger-like projections toward the bottom of the plate. The projections widened laterally to eventually fuse and cover the entire plate. Adhesion was noted above the 7.5 cm (3 in.) line when complete plate failure was called.

Failures occurred earlier than for the neat Type IV fluids and followed a failure progression (Photo C15.2) similar to those observed for neat, pre-sheared propylene glycol-based Type IV fluid. The interval to complete plate failure was reduced to the order of that observed for Type I fluids.

4.2.2 Film Thickness

This fluid was tested under a precipitation rate of 25 g/dm²/h in common with Type I fluid tests. Initial film thickness was considerably greater than for Type I fluid (up to 1.5 mm compared to 0.5 mm), and the rate of thinning was much slower. At time of plate failure, film thickness at the failure front was about 0.2 mm as compared to the Type I fluid thickness of 0.1 mm.

4.2.3 Fluid Freeze Point

The rate of dilution was much slower than observed with Type I fluids. Concentration values measured on the top and bottom layers of the fluid did not show the large differences displayed by neat Type IV fluids. From an initial freeze point of -9°C, the fluid freeze point rose to outside air temperature (-4°C) in about 10 minutes and appeared to be somewhat higher than the plate temperature of -3°C at the time of plate failure.

4.2.4 Fluid Adhesion

The fluid failures did not adhere at the time of freezing. By the time of complete plate failure, some failure adhesion was observed at a point near the top of the plate that had been in a failed condition for about four minutes. The remainder of the plate was covered with a non-adhering layer of fluid failure.

4.2.5 C/FIMS Ice Detection Sensor

Visual identification of plate failure occurred close to the point at which the C/FIMS curve indicated failure.

4.2.6 RVSI Ice Detection Sensor

The RVSI sensor trace shows a clearly definable downturn, indicating failure of fluid within the *no-touch* zone. Time of the downturn coincided with the visual failure call.

4.2.7 Spar/Cox Ice Detection Sensor

The sensor trace provided for this fluid was generated for Test ID #15 (light freezing rain, rate = 25 g/dm^2/h, outside air temperature = -4°C). The sensor trace reaches the point where the sensor system would indicate fluid failure (0.003) following visual identification of first failure and just prior to visual identification of plate failure.

4.3 Base Case Type IV Fluid (Union Carbide Ultra+ Neat)

(Appendix C – Test ID #s 1, 4, 6, 9, 13, 19, 20, 22, 24)

Failure of this fluid was observed under various combinations of conditions; precipitation rates of 25, 13, 10 and 5 g/dm²/h, light freezing rain and freezing drizzle, and outside air temperature -4 and -10°C.

4.3.1 Appearance

This section describes the fluid appearance before failures occur and also during the actual failure progression.

4.3.1.1 Appearance before failure

Prior to actual failure (although depending on the ambient test temperature, and the intensity and type of precipitation, solid contamination may become apparent during this time), the fluid itself took on certain appearances as a result of variations in refractive index of the fluid due to concentration gradients from absorbed precipitation. In Ultra+ fluid, there was a gradual progression from application to the point at which failures begin to occur. The freshly applied fluid was a smooth, shiny, transparent green layer containing a sparse, random distribution of small air bubbles embedded in the fluid matrix (Photo C6.1). The progression of failure was always from the top edge of the plate to the bottom edge under the conditions imposed in these tests.

The first stage in the progression of this fluid's appearance can be described as one in which tiny irregularities or specks in the fluid surface, caused by the absorption of precipitation, reduced the distinctness of a reflected image. These appeared to be in the size range of 1 mm or smaller and almost looked like dust particles on the fluid surface (Photo 4.1).

The second stage of the fluid's appearance resulted when the speck density on the fluid surface increased until specks were either separated only by distances of the order of the specks themselves, or they overlapped. At this point, the surface took on a more coarse orange-peel textured appearance. These features ranged in size between 1 and 3 mm. In Photo 4.2, the surface of the fluid farther down the plate from the initial point of failure provides an illustration of this texture.

As the fluid surface absorbed more contamination, the orange-peel-like features coalesced into thicker and thinner regions, giving the substrate surface a marble-like appearance when viewed through the still transparent fluid layer. The size range of the thicker areas of fluid was from 5 mm to 2 cm, with no abrupt boundaries. The fluid itself resembled warm, sheared gelatin (Photo 4.3).

At lower precipitation rates, especially in freezing drizzle, this final pre-failure gelatinous stage can persist for a considerable time before failures begin to set in. It can also be overlapped by failure initiation.

4.3.1.2 Failure progression

The onset of failure generally overlaps with some pre-failure fluid states. The extent or duration of the overlap depends on the rate of failure propagation, which in turn is dependent on the rate and type of precipitation, and the ambient test temperature.

Solid Contamination

Dots and streaks of solidified precipitation were visible in the top surface layer and moved with the fluid as it flowed down the plate under the influence of gravity. This seemed to be more the case for the lower outside air temperatures and lower precipitation rates, where fluid mixing from mechanical and diffusional influences is less efficient.

Top Edge Failure

The onset of failure invariably took place as solid contamination across the top edge of the test plate, where the fluid is most rapidly thinned. This initial failure was in the form of slurry. Failure generally occurred first at one spot (random) on the top edge and spread across the top edge faster than down the plate (Photos 4.2 and 4.6).

However, once the progression reached the 2.5 cm (1 in.) line, most of the top edge of the plate showed failure as a continuous slurry of small plate-like ice formations that rapidly saturated the surrounding free fluid and propagated the failure down the plate.

First Failure within Work Area to Fifth Cross-hair Failure

In this time interval, failure progression continued down the plate as the failed areas grew in size. The earliest failed surface area began to accumulate a thicker layer of contamination (Photo 9.3). The wet slurry became lower in moisture content and began to fuse into a solid bumpy layer with a wet surface that, at first, showed no signs of adhesion, except above the 2.5 cm line. As failures progressed, adhesion to the plate became stronger.

By the time of the fifth cross-hair failure, the failure propagation (slurry of diluted fluid and ice) had begun to work its way into the now gelatinous fluid, and drainage channels carved the thicker fluid layer below into smaller and smaller regions until only scattered lumps of thick fluid persisted. As the test proceeded, fingers of failure progressed down the plate, which saturated the surrounding fluid and laterally fused the fingers of failure together (Photo 4.7).

Adhesion of the solid contaminant followed failure. The interval between time of failure and observed adhesion is discussed in Subsection 4.7.

Fifth Cross-hair Failure to Full Plate Failure

Failure progression continued down the plate as previously described. The remaining scattered lumps of thicker fluid were diluted and washed away, leaving a thin, dilute, fluid layer that quickly underwent failure, except where drainage from the upper portion of the plate surface maintained some clear channels and regions which were not completely failed.

Adhesion was varied and depended on the duration of the last two stages described. It could be anywhere between the 7.5 cm (3 in.) line and the 22.5 cm (9 in.) line (and sometimes even beyond the 22.5 cm line).

The thickness of the adhering contaminant layer generally followed the order in which the surface elements showed failure. That is, they grew in thickness with time once the failure was established on any given surface element.

4.3.2 Film Thickness

Film thickness measured at five minutes following application was remarkably consistent at 1.4 mm as noted in Table 4.1. Under all test conditions, fluid films had thinned notably by the time of the plate failure call. At that stage in failure, film thicknesses measured at the 15 cm (6 in.) line were in the range of 0.1 to 0.6 mm, with some pattern related to conditions as can be seen in Table 4.1.

TABLE 4.1
FLUID THICKNESS – ULTRA+

ID	**OAT (°C)**	**Precipitation type / rate (g/dm²/h)**	**Thickness at 15 cm (6 in.) line at 5 min. (mm)**	**Thickness at 15 cm (6 in.) line at plate failure (mm)**	**Time to plate failure (min)**
1,4	-10	ZD / 10	1.4	0.6	57
6,9	-10	ZR / 25	1.4	0.4	30
20,22	-4	ZD / 13	1.4	0.2	57
13,19	-4	ZR / 25	1.4	0.1	34
24	-10	ZD / 5	1.4	0.5	82

TABLE 4.2

UCAR ULTRA+ TYPE IV FLUID

ID #	Rate (g/dm²/h)	Precip. Type		OAT		Thickness (mm)		Time to Plate Failure (min)	Σ Precipitation (g/dm²)	Freeze Point at 15 cm (6") Line at Plate Failure	Plate Brix		Stabilized Freeze Point Top Layer (°C)	Adherence Location	
		ZD	ZR	-10°C	-4°C	5 Minutes After Pour	15 cm (6") Line at Plate Failure				Brix at 5th Crosshair	% Concent.		At Plate Fail	At Full Plate
1	10	√		√		1.4	0.6	50	8.3	-8	13	19	-20		B,C
4	10	√		√		1.4	0.5	64	10.7	-7	10.5	16	-20		B,C
6	25		√	√		1.5	0.3	31	12.9	-2	5.5	8	-18	B	B,C,D
9	25		√	√		1.4	0.4	29	12.1	-1	3.5	5	-20	B	B,C,D
13	25		√		√	1.5	0.1	35	14.6	0	0	0	-14		B
19	25		√		√	1.3	0.1	33	13.8	-2	6	9	-15	B	B,C,D
20	13	√			√	1.4	0.2	57	12.4	-6	11	16	-20		B
22	13	√			√	1.5	0.1	57	12.4	-4	9	13	-20	B	B
24	5	√		√		1.4	0.4	82	6.8	-11	16	24	-30		B
27	5	√		√		1.4		N/F		-9	14	21			

4.3.3 Failure Adhesion

Failure adhesion did not occur immediately upon fluid failure, but only after some period of ongoing exposure to precipitation. The earliest failure adhesion was observed to occur in the area where first failure occurred. The early appearance and severity of adherence appeared to be related primarily to the ambient test temperature, and secondly to the rate of precipitation. The most severe instances of adhesion occurred at -10°C under light freezing rain, followed by freezing drizzle at the same temperature, which afforded a slightly less severe level of adhesion. A still lower degree of failure adhesion was noted at -4°C.

4.3.4 C/FIMS Ice Detection Sensor

The C/FIMS sensor trace generally showed a well-defined pattern that clearly indicated the onset of fluid failure. This pattern frequently occurred during the interval between visual identification of initial failure and plate failure.

The temperature trace provided by the instrument is worthy of comment. In nearly every test, the temperature trace started to climb at the time of failure. This may be a result of elimination of the insulating layer of fluid that had previously isolated the sensor from the rain spray and from radiant heat from light sources. Heat of fusion may have had some influence on temperature.

This temperature effect could also be noted in test results from the Type I Union Carbide XL54 fluid.

4.3.5 RVSI Ice Detection Sensor

At an outside air temperature of -10°C, the RVSI sensor trace showed a marked downward trend, with the slope becoming strongly negative coincident with the onset of failure. The sensor indication during warmer conditions was not as marked, but was still recognizable. In almost all cases, indications of failure from the RVSI sensor were coincident with visual calls of plate failure.

4.3.6 Spar/Cox Ice Detection Sensor

The sensor trace provided for the baseline Type IV fluid (Union Carbide Ultra IV) was generated for Test ID #20 (freezing drizzle, rate = 13 g/dm²/h, outside air temperature = -4°C). The sensor trace reaches the point where the sensor system would indicate fluid failure (0.003) simultaneous with visual identification of plate failure. At that point in the progression of fluid failure, the trace appears to stray from a steadily ascending line with a brief excursion to a higher level, and then reassumes its previous climb.

4.4 Type IV Fluid (Octagon MaxFlight Neat)

(Appendix C – ID #s 2, 3, 8, 11, 16, 21, 23, 25, 26)

This fluid was examined to enable a comparison of failure characteristics of a propylene glycol-based fluid to those of an ethylene glycol-based fluid (Union Carbide Ultra+). Failure was observed under combinations of conditions similar to tests on Ultra+: precipitation rates of 25, 13, 10 and 5 g/dm²/h, light freezing rain and freezing drizzle, and outside air temperature -4 and -10°C.

It should be noted that the test samples of this fluid had been inadvertently sheared prior to testing. As noted later in the discussion of other Type IV propylene glycol-based fluids (Subsection 4.5), it was initially expected that this fluid would demonstrate a tendency to resist mixing, resulting in a mode of failure quite different from that seen with Ultra+. The fact that this did not occur is attributed to its pre-sheared treatment, and consequently, this documentation on Octagon MaxFlight should be viewed only as representative of a sheared fluid. Samples of the test fluid were measured with a Brookfield viscometer subsequent to the test, and showed viscosity values of 1700 cp versus 6000 cp for delivered fluid (spindle speed of 0.3 rpm, spindle/chamber SCR – 16/8R, temperature 20°C, time 33 min, 20 sec).

4.4.1 Appearance

This section describes the fluid appearance before failure and throughout the progression of failure. Under the test conditions employed, the neat Octagon fluid used for these tests generally failed as described in the following subsections.

4.4.1.1 Appearance before failure

Before actual failures were detected, neat Octagon fluid took on appearances similar but not identical to Ultra+ fluid. The pour resulted in a very smooth, shiny fluid layer on the surface, free of any small bubbles like those observed in the Ultra+ fluid. The fluid was a lighter or paler shade of green compared with the Ultra+ fluid and was also slightly turbid but still transparent (Photo C8.1, C11.1).

This fluid did not go through the speck-covered stage, but did enter a short-lived stage leading up to the appearance of failure, in which the surface texture was not unlike that of an orange peel. This orange-peel pre-failure fluid stage was superseded by a gelatinous stage. (Photo C8.2, C11.2). The size of the fluid structures in this final pre-failure stage of Octagon fluid were on average 3 mm to 1.5 cm across with no abrupt boundaries between the structures.

In tests conducted with this pre-sheared fluid, the general mode of failure progression was from plate top to plate bottom.

4.4.1.2 Failure progression

Dots and streaks of solidified precipitation on the fluid surface prior to fluid failure detection (Photo C8.3, C11.3 and 4.8) were numerous and easily visible.

- Top Edge Failure generally preceded by the initial appearance of small plate-like ice formations. The interval before which accumulation of solid contaminant became apparent seemed to be shorter than for the Ultra+ fluid;

- The progression of failure into the work area of the test plate preceded first by the formation of a slurry composed of the fine plate-like ice particles that grew down the plate in fingers (Photos C11.2 and 4.9). As the slurry soaked up the available fluid, it became saturated, giving rise to drainage channels in which only a thin fluid layer remained. These thinned-out fluid channels formed fingers of the failure slurry within minutes. The fingers (Photo C11.3), similar to those shown in Photo 4.7, proceeded down the plate between drainage channels, extending from the top portion of the plate. This was accompanied by fusion of the early failed regions and finally by adhesion of the earliest failed surface elements; and

- The gelatinous pre-failure stage of Octagon fluid did not break up into scattered lumps to be gradually washed away, leaving a thin dilute fluid layer, but rather maintained a thinning slurry that gradually underwent fusion as the test proceeded to the full plate failure interval. Run-off from the top portion of the plate maintained some open drainage channels to the bottom edge of the plate.

4.4.2 Film Thickness

Film thickness measured at five minutes following fluid application (Table 4.3) was considerably thinner than the Ultra+ fluid (0.7 mm versus 1.4 mm). At this stage, this fluid showed much more variability in thickness than did the Ultra+. This fluid demonstrated an increase in

TABLE 4.3
FLUID THICKNESS – OCTAGON MAXFLIGHT

ID	OAT (°C)	Precipitation Type / Rate g/dm²/h	Thickness at 15 cm (6 in.) line at 5 min. (mm)	Thickness at 15 cm (6 in.) line at Max (mm)	Thickness at 15 cm (6 in.) line at plate failure (mm)	Time to Plate Failure (min)
2,3	-10	ZD / 10	0.8	1.2	0.6	36
8,11	-10	ZR / 25	0.7	0.8	0.3	21
21,23	-4	ZD / 13	0.6	0.8	0.2	31
16	-4	ZR / 25	0.5	0.7	0.3	22
25,26	-10	ZD / 5	0.8	0.8	0.6	63

TABLE 4.4

OCTAGON MAXFLIGHT TYPE IV FLUID

ID #	Rate ($g/dm^2/h$)	Precip. Type		OAT		Thickness (mm)			Time to Plate Failure (min)	Σ Precipitation (g/dm^2)	Freeze Point at 15 cm (6") Line at Plate Failure	Plate Brix		Stabilized Freeze Point Top Layer (°C)	Adherence Location	
		ZD	ZR	-10°C	-4°C	5 Minutes After Pour	Max.	15 cm (6") Line at Plate Failure				5th Brix	% Concent.		At Plate Fail	At Full Plate
2	10	√		√		0.7	1.1	0.6	33	5.5	-11.9	21	68%	Did not Stabilize		B
3	10	√		√		0.8	1.2	0.7	39	6.5		N/A				B,C
8	25		√	√		0.7	0.8	0.3	22	9.2	-2.6	9	29%			B,C,D
11	25		√	√		0.6	0.8	0.4	20	8.2	-1.9	7.5	24%		B	B,C
16	25		√		√	0.5	0.7	0.3	22	9.3	-0.5	3.0	10%			B,C
21	13	√			√	0.6	0.8	0.1	38	8.2	-2.6	9.0	29%		B	B,C
23	13	√			√	0.6	0.7	0.2	24	5.1	-3.1	10.0	32%		B	B,C,D
25	5	√		√		0.7	0.7	0.6	65	5.4	-6.4	15.0	48%			1"
26	5	√		√		0.8	0.8	0.5	61	5.1	-5.3	13.5	44%			1"

thickness as it absorbed fluid during the initial interval after application, then thinned out prior to plate failure.

In common with the Ultra+ fluid, film thickness at time of plate failure appeared greater under lower precipitation rates (at constant temperature) and at colder temperatures (at constant precipitation).

4.4.3 Fluid Freeze Point

While fluid concentration values measured on the top and bottom layers of this fluid showed a variance, the pattern was somewhat different than that of Ultra+. The top layer freeze point quickly took on a value several degrees (3 to 8 degrees) above that of the bottom layer (Table 4.4), and then rose in concert with the bottom layer while the two values gradually converged. The Ultra+ top and bottom layer values tended to converge prior to time of plate failure, whereas, with the Octagon fluid, the values were still separate at time of failure.

For drizzle conditions, the average freeze point values of top and bottom layers matched outside air temperature at time of plate failure; however for rain conditions, the average freeze point value was considerably higher than outside air temperature at time of plate failure.

4.4.4 Failure Adhesion

As with Ultra+ fluid, failure adhesion on a given test surface element occurred some time following the actual occurrence of failure. As initial failure occurred at the top of the plate, adhesion was first observed in this area. Among the various cases tested, severity of adhesion did not follow any particular pattern related to temperature or to precipitation.

4.4.5 C/FIMS Ice Detection Sensor

With this fluid, the C/FIMS sensor traces showed the strongest patterns with widest swings during rain conditions. However, the traces *did* indicate failures that were concurrent with visual failure calls. During freezing drizzle conditions, the sensor trace gave a strong indication of failure at an outside air temperature of -10°C, but not at warmer temperatures (-4°C).

4.4.6 RVSI Ice Detection Sensor

For rain conditions, the sensor traces gave strong fluid failure signals that were registered just prior to the visual call of plate failure. In these cases, the trace proceeded on a fairly flat, horizontal line, but abruptly changed to a steeply descending slope at the point of failure detection.

For drizzle conditions, the sensor traces tended to proceed on a gradually descending curve without any apparent indications of plate failure (for example, a marked variation in slope at a given time).

4.4.7 Spar/Cox Ice Detection Sensor

The sensor trace provided for this fluid was generated in Test ID #2 (freezing drizzle, rate = 10 g/dm²/h, outside air temperature = -10°C). The sensor trace reached the point where the system indicated failure had occurred (average contrast ratio = 0.005) at a time coincident with visual plate failure identification. The sensor trace showed a steady rate of increase throughout.

4.5 Type IV Fluid (Kilfrost ABC-S and SPCA AD-480 Neat)

(Appendix C – Test ID #s 10, 12, 28)

4.5.1 Appearance

These fluids are treated in the same subsection as they demonstrated a similar type of failure progression under the conditions tested. Both fluids are propylene glycol-based (in common with the Octagon MaxFlight fluid).

The neat SPCA AD-480 fluid was a more intense green (Photo C28.1) than the Ultra+ fluid, and completely transparent.

The fluid formed a smooth shiny surface once applied to the test surface and immediately began to accumulate small dots of frozen contamination on the fluid-air interface. These appeared more dense and numerous from angles less than normal to the surface owing to the thickness of the fluid film and the resulting shadows cast on the fluid-plate interface. Plan viewing clearly showed these to be the same type of solid dots as previously described for the Ultra+ and Octagon fluids, except that these were less readily accepted by the upper layer of the anti-icing fluid film and froze in isolation as a consequence.

The neat Kilfrost fluid formed a thick, water-clear layer upon application and also showed immediate signs of supporting solid dots of frozen contamination.

The tendency to resist mixing shared by the neat Kilfrost and SPCA AD-480 fluids was also expected from the Octagon fluid. It is suspected that the pre-shearing treatment of the Octagon fluid was responsible for its unexpected mode of failure.

The pattern of failure observed for Kilfrost and SPCA fluids was solid dots running down the plate on the top of the fluid surface to accumulate at the bottom of the plate, where they eventually dammed up and caused a bottom-to-top overall failure progression. None of the tests for these fluids was continued to the point of fusion.

The point of plate failure for this fluid (59 minutes) was based on observer judgement that the aggregate area of all dots of frozen precipitation would be equivalent to 1/3 of the plate surface/area.

4.5.2 Film Thickness

Progressive thickness measurements were made for the SPCA AD-480 fluid only. Unlike the Octagon fluid, this fluid did not demonstrate an increase in thickness during the first period of exposure to precipitation, but progressively thinned from its first measured thickness (1.7 mm at 5 minutes following application) and reached a stable thickness of 1.2 mm at about 20 minutes following application. This thickness persisted until time of plate failure at 59 minutes following application.

Photo C28.4, taken at test end (time to complete plate failure was 79 minutes), shows a bare area as a result of lifting a fluid sample. This image gives a good illustration of the thickness of fluid remaining at that time.

4.5.3 Fluid Freeze Point

Upon exposure to precipitation, the freeze points of the top and bottom layers quickly diverged from the initial value of -34°C. At 40 minutes after application, the top layer had assumed a value of -12°C while the bottom layer was at -24°C. A notable spread between top and bottom layer freeze points still existed at the time that plate failure was called (59 minutes), with values of -9 and -16°C for the top and bottom layers, (outside air temperature = -10°C). Even at the time that complete plate failure was identified (79 minutes), the freeze points were -9 and -14°C.

Noting the thickness of fluid at test end, this would indicate that there was still a reasonable quantity of good fluid (capable of offering further anti-icing protection) available at that time. This is discussed further in Subsection 4.12.

Samples collected for this fluid at the time that complete plate failure was called were the only samples to demonstrate a measurable level of viscosity.

4.5.4 Failure Adhesion

There was no evidence of failure adhesion during the course of tests for these two fluids.

4.5.5 C/FIMS Ice Detection Sensor

The sensor traces provided no indication of fluid failure. The traces were very flat, showing a slight increase from the horizontal with time.

4.5.6 RVSI Ice Detection Sensor

The RVSI sensor trace progressed at a steady rate of descent during the course of the test, and did not give a clear indication of point of fluid failure. Subsequently, RVSI plate condition images were retrieved for the test and are shown in Photos 4.10 and 4.11. These images show formation of ice within the fluid, and would normally be interpreted as an indication of plate failure. The assessment of *10% Failure* was based on judgement of experienced RVSI staff.

4.5.7 Spar/Cox Ice Detection Sensor

The sensor trace provided was for a propylene glycol-based fluid (Kilfrost ABC-S) and was generated for Test ID #12 (light freezing rain, rate = 25 g/dm^2/h, outside air temperature = -10°C). The sensor trace reaches the point where the system indicates fluid failure (average contrast ratio =0.003) at about five minutes prior to visual identification of plate failure (74 minutes vs. 79 minutes). The sensor trace for this fluid does not show the same steady rate of climb seen with some other fluids, but shows significant excursions throughout, until the final reading at 76 minutes into the test.

4.6 Rheology, Mixing Processes, and Mechanisms of Fluid Failure for the Fluids Tested

This section discusses some of the processes and mechanisms operative in the degradation of the fluids as caused by freezing rain and freezing drizzle.

The formulation of a fluid determines the rheology or flow characteristics of that fluid. Likewise, rheology influences a fluid's ability to accept contamination and has important consequences on the rate and degree of mixing of fluid and contaminant. The rheological differences among the different fluid brands are manifested by the different patterns of failure propagation observed among the fluids tested.

The Ultra+ fluid is the only ethylene glycol-based fluid among the Type IV fluids tested. It appears to be the one Type IV fluid that returns to its previous viscosity after turbulent shearing. The propylene glycol-based fluids exhibit permanent shear-induced reductions to viscosity. This suggests the thixotropy of the propylene glycol-based fluids relies on a different mechanism than that of the Ultra+ fluid. The Octagon, Kilfrost, and SPCA fluids are all propylene glycol-based.

4.6.1 Influence of Droplet Impact on the Mechanical Component of Mixing

Contaminant absorption rate (mixing) is enhanced by mechanical considerations (droplet impact on fluid surface) as well as higher rates of precipitation. The mechanical component of mixing is likely an important factor in fluid failure rate differences between freezing drizzle and light freezing rain holdover times determined at the same temperatures and precipitation rates for a given fluid.

There may also be differences in contaminant absorption rate as a function of temperature due to surface tension effects on the fluid surface and on the droplets themselves.

The possibility of droplet solidification (freezing) before impact on the fluid surface also exists and presents another parameter that should be considered in natural and simulated conditions.

Futhermore, it is possible that droplet size has an influence on the fraction of precipitation impinging on a fluid-covered surface that actually remains in the fluid layer after droplet impact. This aspect of fluid and contaminant behaviour is considered in Subsection 4.6.3.

4.6.2 Comments on the Rheology and Failure Mode Generally Exhibited by the Propylene Glycol-Based Anti-Icing Fluids

The propylene glycol-based anti-icing fluids generally exhibit a reduced tendency to mix with contamination of a test surface (flat plate or aircraft wing).

It had been expected (through previous test experience with these fluids) that because of the reduced mixing tendency, failures exhibited by these fluids would occur in a manner that results in a layer of relatively undiluted fluid between the plate and the failed fluid surface.

The point at which this uppermost surface layer fuses and becomes too solidified to be sheared completely off the wings upon rotation of the aircraft should be investigated.

Some propylene glycol-based fluids can be sheared to permanently reduce the fluid’s viscosity.

That the viscosity can be permanently reduced by mechanical shearing suggests that a thixotrope composed of long delicate polymer strands is present in this fluid. Mechanical shearing of the fluid from turbulent flow probably is sufficient to break the length of these polymer chains and permanently alter such a fluid’s rheological properties.

4.6.3 Surface Tension Effects

Surface tension effects operative on a fluid surface and also on falling droplets themselves influence the ability of fluid to accept contamination into its surface layer. Although it was not measured for these tests, it is almost certain that the surface tension of these fluids is lower than for pure water. This would tend to enhance the acceptance of contamination into the surface layer of the fluid.

On the other hand, the surface tension on a droplet of liquid is inversely proportional to the radius of the droplet, and tends to infinity as the droplet radius approaches zero. One might be tempted to believe that smaller droplets should display a reduced tendency to be absorbed by the fluid surface and an enhanced tendency to bead or bounce and roll off the test surface. Along this line of thinking, larger droplets would be expected to penetrate the fluid surface and subsequently mix more efficiently with the surrounding fluid.

However, consideration of the results from tests carried out in this study showed that failures occurred more rapidly in freezing drizzle than in freezing rain, which is not the hypothetical mechanism postulated above. Perhaps the smaller droplets (with their higher surface tension) more effectively penetrate the fluid surface to result in enhanced mixing, leading to more rapid failures. Larger drops may be prone to splatter into smaller beads upon impact, subsequently rolling or bouncing off the fluid-covered surface.

4.6.4 Mixing Tendency / Dilution

A thicker fluid would tend to remain in a thicker layer on a surface and have a smaller tendency to flow off. Some of these fluids tend to resist mixing and are thus diluted at a much slower rate. This resistance to mixing may be due to surface tension effects or possibly due to the presence of an additive that has a coagulating effect. A coagulant might tend to attract fluid around the contaminant without allowing complete mixing. The mixing seems to be most efficient in the Ultra+ fluid and least efficient for the Kilfrost and SPCA AD-480 Type IV fluids.

4.6.5 Flow-off

The rheology of the fluid is responsible for maintaining a thick fluid layer on test surfaces. One rheological property is the viscosity of the fluid. The higher the viscosity, the greater the resistance to flow. Flow is influenced by dilution, which reduces the fluid viscosity especially on the top of the fluid layer and to various depths, depending on the mixing tendency of the fluid. The more easily the fluid is diluted, the more easily fluid will flow off the plate, with subsequent reduction in effective fluid thickness. This is often referred to as erosion of the fluid. A fluid that resists mixing to too great a degree will accumulate a solid surface above the good fluid layer, leading to an encapsulating type of adhesion due to fusion of fluid surface contamination in a layer parallel to the substrate surface.

4.6.6 Bounce and Roll-off

It was observed that in flat plate experiments, a considerable portion of contamination consisting of water droplets actually bounced on impact and rolled off the plate. This was noted for all fluids and has important consequences as to the difference between a larger surface like an

aircraft wing and the relatively small surface element provided by a standard test plate.
If much of the contamination is able to escape the surface in a bounce and roll-off fashion, this means that not all the impinging precipitation at a given precipitation rate ends up being absorbed into the fluid surface. While this is true for the first bounce on an extended surface, the roll-off counterpart to this phenomenon is only significant close to the edge of the extended surface (like an aircraft wing). There is a significant difference between a flat plate and an aircraft wing for the categories of precipitation including freezing rain, freezing drizzle, and ice pellet conditions.

It would be worthwhile to investigate what fraction of the precipitation impacting on a given surface element actually remains on or is accepted by the fluid layer at known rates of precipitation. This might be accomplished using a hooded trap at the bottom of the plate that allows the flow-off to continue to fall to the floor, and the bouncing droplets to be caught in the trap and weighed. It might also be interesting to monitor the refractive index of the recovered droplet mix to determine how much fluid is picked up by the bouncing droplets escaping the plate.

4.7 Comparison of Type I and Type IV in Failures in Light Freezing Rain (25 g/dm^2/h)

Type I Union Carbide XL54 **Test ID #s 5, 7 and 14, 18**	**Type IV Union Carbide Ultra+** **Test ID #6, 9 and 13, 19**
Appearance • Unthickened fluid; • Left a thin, transparent orange layer when applied; • Almost immediate accumulation of solid contaminant; and • Rapid failure with complete adhesion.	*Appearance* • Thickened fluid; • Left a thick, smooth, shiny, transparent green layer with suspended bubbles when applied; • Fluid progressed through several phases prior to failure; • Failures propagated from the top of plate and carved drain channels in fluid below; and • Contamination fused into solid, bumpy layer appearing as fingers of failed fluid.
Film Thickness • Rapid reduction to 0.1 mm thickness.	*Film Thickness* • Common thickness at 5 minutes of 1.4 mm; • Initially stabilizes at about 1.0 to 1.3 mm then progressively decreases until failure; and • Thickness just prior to failure is function of temperature and precipitation.
Fluid Freeze Point • Dilution to 0°C in 6 minutes.	*Fluid Freeze Point* • Rate of dilution much slower than Type I; and • Top and bottom layers take on different freeze points.
Failure Adhesion • Rapid and complete adhesion following freezing.	*Failure Adhesion* • Adhesion trails failures by some time. Severity is function of temperature and time.
C/FIMS Sensor Trace • Strong indication of failure, slightly ahead of visual call.	*C/FIMS Sensor Trace* • Well defined indicator of failure, generally between time of visual call of initial and standard plate failures.
RVSI Sensor Trace • Clearly definable downturn indicates plate failure, concurrent with visual call.	*RVSI Sensor Trace* • At -10°C, trace provides strong indicator of failure, concurrent with visual failure call; and • Trace indicator less strong at warmer temperatures.

4.7.1 Discussion

Ambient temperature appears to have a direct effect on the appearance of Type I and Type IV failures in light freezing rain conditions.

- At -10°C, the Type I and Type IV failures are virtually identical in appearance, and both consist of solid, bumpy contamination that progresses in a top-to-bottom manner on the plate (Photos 4.12 and 4.13).

- At -3°C, Type IV failures, observed in flat plate tests, are similar to those of tests conducted at -10°C, and consist primarily of hardened, bumpy contamination (Photo 4.14). This same appearance of failure was documented in a Type IV fluid failure test, conducted on a McDonnell Douglas DC-9 wing in 1995/96 (Photo 4.15). The ambient temperature for this test was -1°C.

- At -3°C, Type I fluid failures consisted primarily of a clear, glossy ice surface. This is apparent in photo documentation from a flat plate test (Photo 4.16.) and a full-scale fluid failure test conducted on a Boeing 737 wing in 1996/97 (Photo 4.17).

Another noticeable difference between Type I and Type IV failures in light freezing rain was the adhesion of the failure to the test plate.

A comparison of the degree of failure adhesion was made for two tests. The first test, ID #7, used Type I fluid and the second test, ID #9, used Type IV neat fluid. The two tests were conducted under light freezing rain at 25 g/dm²/h and the ambient air temperature was -10°C. Data from these tests are plotted in Figure 4.1 to illustrate, for particular locations on the plate, the observed extent of adhesion in relation to the time of fluid failure. Because adhesion was measured only at two events during the process of failure, at the time of plate failure (1/3 plate or 5th cross hair) and again when the plate was completely failed. The precise time of onset of adherence is not known. The line representing fluid failure, based on four data points (start of test, initial failure, plate failure, and complete plate failure), provides an estimate of time of failure at any plate position.

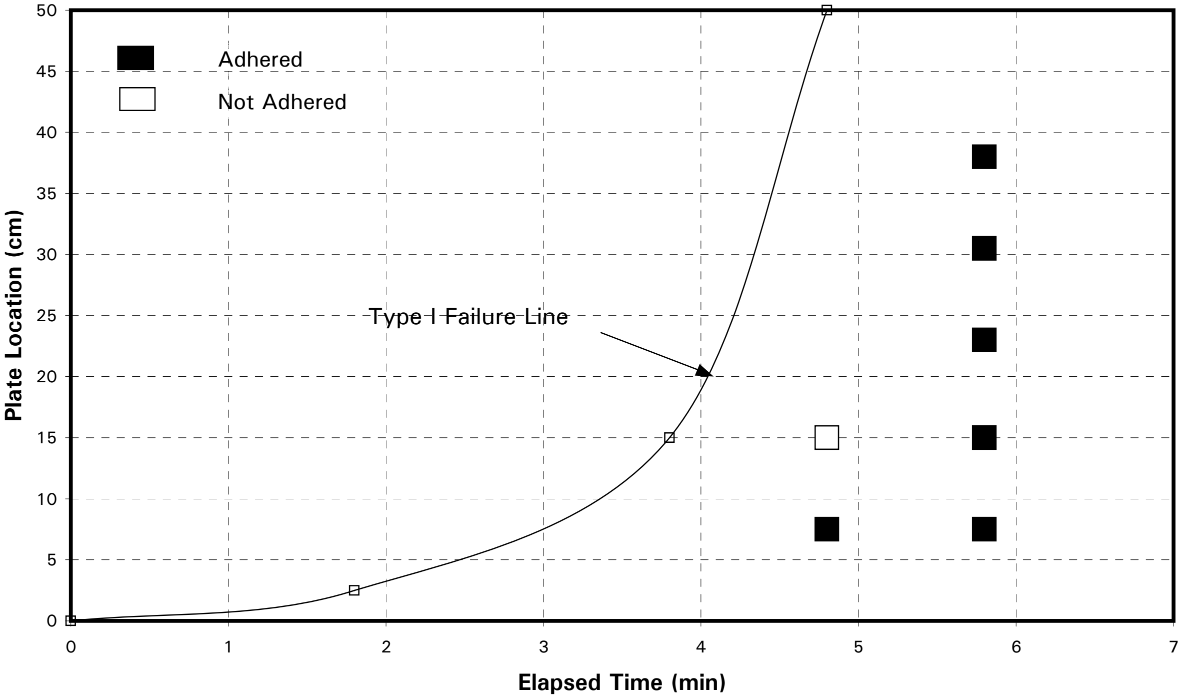
Charted data for the Type I fluid test demonstrate that failure adhesion at any position measured occurs either simultaneously with fluid failure or very shortly thereafter. In contrast, data on the Type IV fluid test demonstrates a longer delay from the time of fluid failure to failure adhesion, in the range of 3 to 6 minutes.

FIGURE 4.1

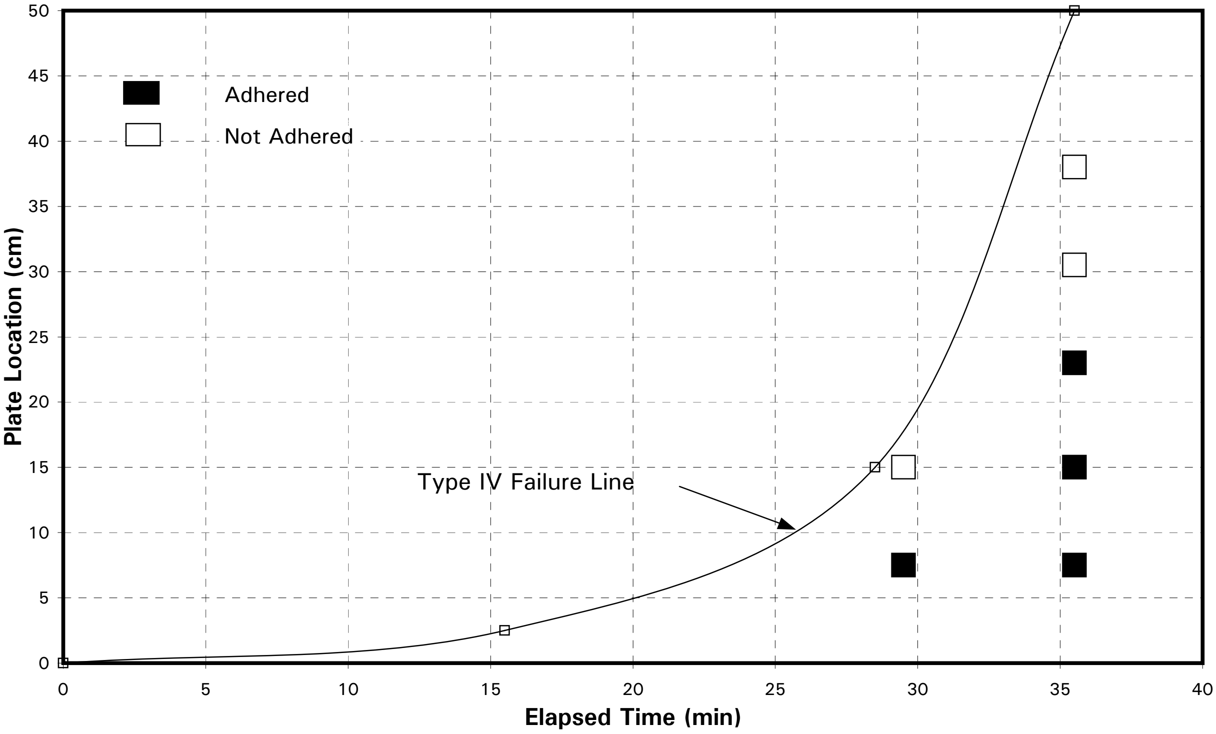
FAILURE ADHESION COMPARISON: TYPE I versus TYPE IV FLUID

Light Freezing Rain (25 g/dm²/h) at -10°C

ID # 7 (UCAR XL54)



ID # 9 (UCAR ULTRA+ Neat)



Two other similar tests (Test IDs 5 and 6) provide almost the same results.

The steepness of the Type I curve demonstrates the severity of freezing rain at cold temperatures when using Type I for protection. A pilot could potentially view the aircraft wing just prior to time of initiation of failure and determine that it is uncontaminated. Within four minutes the fluid on the wing could be completely failed and more importantly, would probably be bonded over the entire wing surface. With an application of neat Type IV fluid, the time required for bonding to reach significant levels following initial failure is probably greater than 15 minutes under these conditions.

4.8 Comparison of Type IV: Freezing Rain versus Freezing Drizzle

Union Carbide Ultra+
Freezing Drizzle, Test ID #s 1, 4

Appearance

- Thickened fluid;
- Left a thick, smooth, shiny transparent green layer with suspended bubbles when applied;
- Fluid progressed through several distinct stages prior to failure;
- Failures propagated from the top of plate and carved drain channels into the thick fluid below to form fingers of failure;
- Thick fluid below drainage channels broke up into scattered lumps that were washed away to give rise to rapid failure; and
- Contamination fused into a mottled bumpy layer from the fingers of failed fluid.

Film Thickness

- Common thickness at 5 minutes of 1.4 mm;
- Initially stabilizes at about 1.0 to 1.3 mm then progressively decreases until failure; and
- Film thickness at time of plate failure is 0.5 mm.

Fluid Freeze Point

- At 15 cm line at time of plate failure:

OAT (°C)	*FP (°C)*
-10	-7
-4	-4

Failure Adhesion

- Occurs later than with freezing rain.

C/FIMS Sensor Trace

- Weaker indicator of failure than in freezing rain.

RVSI Sensor Trace

- Strong indication of failure.

Union Carbide Ultra+
Freezing Rain, Test ID #s 6, 9, 8, 11

Appearance

- Thickened fluid;
- Left a thick, smooth, shiny transparent green layer with suspended bubbles when applied;
- Fluid progressed through several distinct stages prior to failure;
- Failures propagated from the top of plate and carved drain channels in the fluid below to form fingers of failure;
- Thick fluid below channels broke up into scattered lumps and was superseded by more rapid failure; and
- Contamination fused into a mottled bumpy layer from the fingers of failed fluid.

Film Thickness

- Common thickness at 5 minutes of 1.4 mm;
- Initially stabilizes at about 1.0 to 1.3 mm then progressively decreases until failure; and
- Film thickness at time of plate failure is 0.3 mm.

Fluid Freeze Point

- At 15 cm line at time of plate failure:

OAT (°C)	*FP (°C)*
-10	-1
-4	-1

Failure Adhesion

- Occurs earlier and is more severe than with freezing drizzle.

C/FIMS Sensor Trace

- Stronger indicator of failure than in freezing drizzle.

RVSI Sensor Trace

- Strong indication of failure.

4.8.1 Discussion

The difference in fluid appearance at the time of failure between tests conducted in light freezing rain and freezing drizzle conditions was not significant. At failure, the contamination fused into a mottled, bumpy layer in both conditions (Photos 4.18 and 4.19). The time required for the Type IV fluid to exhibit this failure in freezing drizzle tests was significantly longer than that of light freezing rain tests. Scattered lumps of fluid endured longer in freezing drizzle than in freezing rain.

Tests conducted in freezing drizzle exhibited greater film thicknesses at failure than light freezing rain tests (0.5 mm compared to 0.3 mm). The adhesion of failures to test surfaces was observed to initiate sooner and be more severe in light freezing rain tests.

4.9 Comparison of Type IV: Effect of Temperature (-4°C versus -10°C)

Union Carbide Ultra+ **OAT = -4°C, Test ID #s 13, 19**	**Union Carbide Ultra+** **OAT = -10°C, Test ID #s 6, 9**
Appearance • Thickened fluid; • Left a thick, smooth, shiny transparent green layer with suspended bubbles when applied; • Fluid progressed through several stages prior to failure: specked, orange-peel, and gelatinous; • Failures propagated from the top of plate and carved drain channels in the fluid below to form fingers of failure down the plate; • Fluid below drainage channels broke up into scattered lumps of thick fluid that were washed away to give rise to rapid failure; and • Contamination fused into a mottled, bumpy layer from the fingers of failed fluid.	*Appearance* • Thickened fluid; • Left a thick, smooth, shiny transparent green layer with suspended bubbles when applied; • Fluid progressed through several stages prior to failure: specked, orange-peel, gelatinous; • Failures propagated from the top of plate and carved drain channels in the fluid below to form fingers of failure down the plate; • Fluid below drainage channels broke up into scattered lumps of thick fluid that were washed away to give rise to rapid failure; and • Contamination fused into a mottled bumpy layer from the fingers of failed fluid.
Film Thickness • Avg thickness at 15 cm line at time of plate failure = 0.1 mm.	*Film Thickness* • Avg thickness at 15 cm line at time of plate failure = 0.4 mm.
Fluid Freeze Point • At 15 cm line at time of plate failure; freeze point = -1°C; • Top layer temporarily stabilizes at -15°C; and • Top and bottom layer freeze point converge prior to time of plate failure and rapidly dilute thereafter.	*Fluid Freeze Point* • At 15 cm line at time of plate failure; freeze point = -1°C; • Top layer temporarily stabilizes at -19°C; and • Top and bottom layer freeze point converge at time of plate failure and rapidly dilute thereafter.
Failure Adhesion • Adhered over smaller area at complete failure.	*Failure Adhesion* • Adhered over larger area at complete failure.
C/FIMS Sensor Trace • Strong signal, not temperature related.	*C/FIMS Sensor Trace* • Strong signal, not temperature related.
RVSI Sensor Trace • Relatively weak indication of failure.	*RVSI Sensor Trace* • Strong indication of failure coincident with visual call.

4.9.1 Discussion

The appearance of fluid failure is not temperature dependent for this ethylene glycol-based fluid. In previous holdover time tests, it was observed that certain propylene glycol-based Type IV fluids exhibited different failure mechanisms at colder temperatures. Documentation of fluid failure tests were conducted with a propylene glycol-based Type IV fluid, but due to the inadvertent shearing of the fluid prior to testing, the results were inconclusive.

4.10 Comparison of Type IV: Propylene versus Ethylene Base (Freezing Drizzle, Outside Air Temperature = -10°C)

Octagon MaxFlight **Test ID #s 2, 3**	**Union Carbide Ultra+** **Test ID #s 1, 4**
Appearance • Similar to Ultra+ but without bubbles, slightly paler and slightly turbid; • Progression to failure had short-lived orange-peel stage followed by a gelatinous stage. Size of features observed in the gelatinous phase were 2/3 that observed with Ultra+ fluid; and • Fluid maintained thinning slurry that gradually underwent fusion. Run-off maintained open channels to bottom edge.	*Appearance* • Left a thick, smooth, shiny transparent green layer with suspended bubbles when applied; • Fluid progressed through several stages prior to failure: specked, orange-peel, and gelatinous; • Failures propagated from the top of plate and carved drain channels in the fluid below; and • Contamination fused into a mottled, bumpy layer from the fingers of failed fluid.
Film Thickness • At 5 minutes = 0.8 mm; • Fluid increased notably during initial interval to 1.2 mm; and • Similar thickness to Ultra+ at time of plate failure (0.6 mm).	*Film Thickness* • At 5 minutes = 1.3 mm • Fluid thinned progressively. No increase as in Octagon; and • 0.6 mm at time of plate failure.
Fluid Freeze Point • At 15 cm line at time of plate failure; freeze point = -10°C; • Top layer quickly rose about 5 degrees above the bottom layer and then rose in concert with bottom layer; and • Top and bottom layer freeze points had not converged by time of plate failure.	*Fluid Freeze Point* • At 15 cm line at time of plate failure; freeze point = -8°C; • Top layer temporarily stabilizes at -20°C; and • Top and bottom layer freeze points converge at time of plate failure and rapidly dilute thereafter.
Failure Adhesion • Adhesion occurred some time after failure.	*Failure Adhesion* • Adhesion occurred some time after failure.
C/FIMS Sensor Trace • Not as strong an indication of failure as with Ultra+.	*C/FIMS Sensor Trace* • Strong indication of failure.
RVSI Sensor Trace • Progressively decreasing lines without strong indication of failure.	*RVSI Sensor Trace* • Strong indication of failure.

SPCA AD-480
TEST ID #28

Appearance

- Very thick and intense green transparent fluid layer when applied; and
- Dots of contamination accumulate without mixing on the fluid surface. Test was not continued to the point of fusion, but a slushy layer was beginning to form on the surface as the density of dots approached a continuum.

Film Thickness

- At 5 minutes = 1.7 mm;
- Fluid thickness stabilized shortly after pouring; and
- 1.2 mm at time of plate failure.

Fluid Freeze Point

- At 15 cm line at time of plate failure; freeze point = -16° C;
- Top and bottom layer freeze points had not converged by time of standard plate failure; and
- Following complete plate failure, freeze point of top layer was still 7°C higher than that of the bottom layer.

Failure Adhesion

- No adhesion was noted at the time of complete plate failure.

C/FIMS Sensor Trace

- Not a strong indicator of failure.

RVSI Sensor Trace

- Progressively decreasing lines without a strong indication of failure.

4.10.1 Discussion

It was found during the process of previous holdover time testing (Transport Canada report TP 13131E (3)) that two behaviour extremes occurred in the dilution mechanisms of propylene and ethylene glycol-based fluids at colder temperatures. One extreme was exhibited by the ethylene glycol-based Type IV, Ultra+, which tended to be diluted in a more homogeneous fashion through the fluid depth. The other extreme was exhibited by the propylene glycol-based Type IV, Octagon, which resisted dilution by maintaining the precipitation at the top of the fluid profile.

The diagram in Figure 4.2 helps show the difference in behaviour during a freezing drizzle test at -10°C. The Ultra+ fluid failure mechanism is described as follows:

- Initial exposure caused the fluid to absorb precipitation into its upper layers, promoting the fluid to swell;
- Continued dilution enhanced the fluid's ability to flow; and
- The diluted fluid eroded off the surface, and its thickness was diminished until failure occurred.

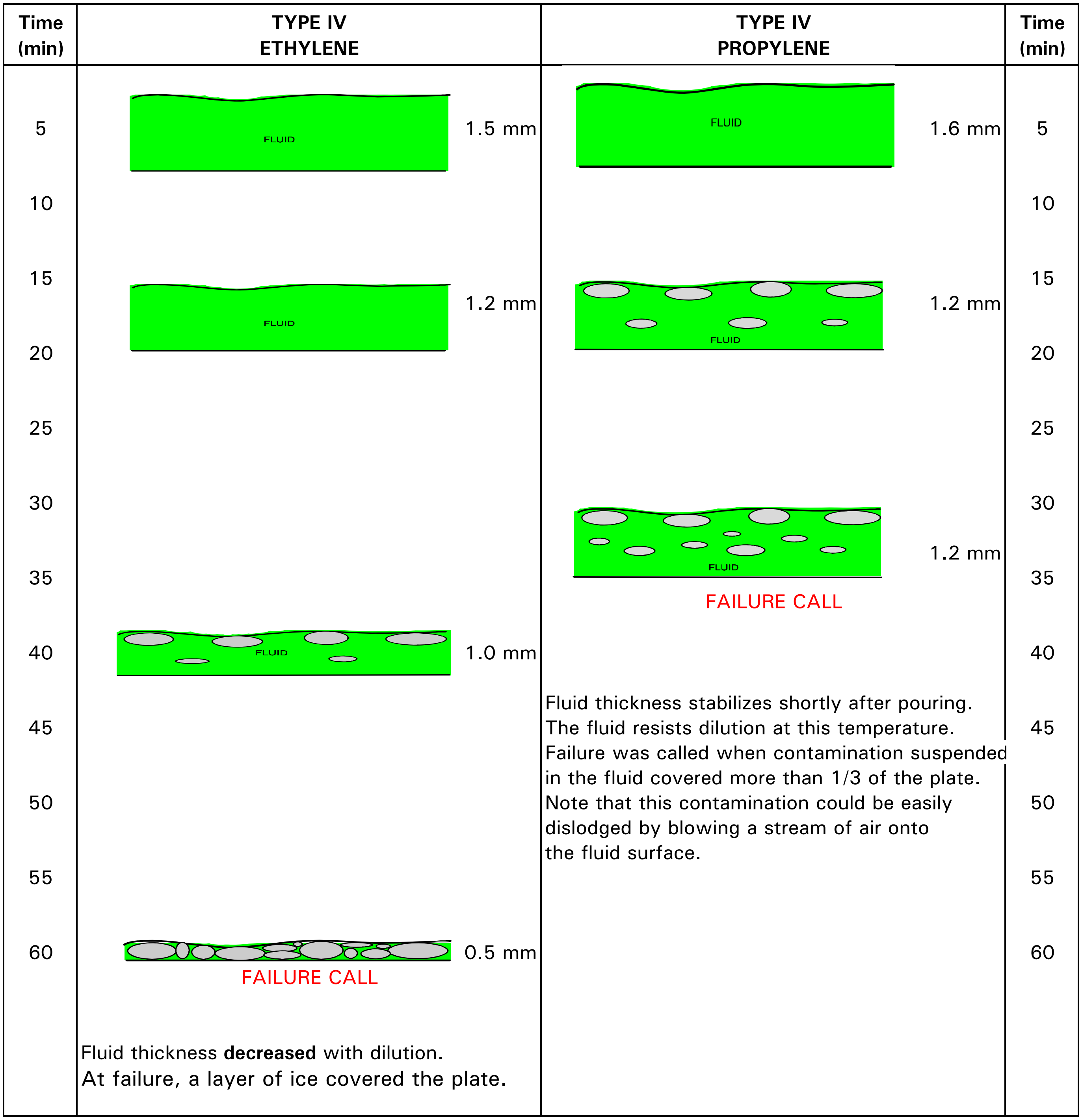
The typical failure was characterised by a thin layer of solidified precipitation. Octagon fluid failed by accumulation of precipitation in the upper fluid layers. This fluid resisted dilution (especially at these lower temperatures). The upper layers did flow but damming of the failed surface layer occurred, trapping the failures in place. This situation was interpreted as a failure by an observer because the fluid had developed a layer of solid ice even though considerable unfailed fluid lay below the upper failed surface.

The mechanism of failure described above for Octagon propylene glycol-based Type IV fluid was not observed in documentation of fluid failure tests. The Octagon fluid used in these tests was inadvertently sheared prior to testing and its viscosity reduced substantially. As a result, the fluid failure appearance was similar to that of the Ultra+ fluid. It should be noted, however, that the Octagon Type IV fluid documented in this report may be an adequate representation of an operational fluid since shearing does occur during fluid application on a wing surface.

Following the discovery that the fluid chosen for testing had undergone shearing, a replacement test was performed with another propylene glycol-based Type IV fluid in neat concentration, SPCA AD-480 (ID #28).

FIGURE 4.2

TYPE IV ETHYLENE vs TYPE IV PROPYLENE
SCHEMATIC OF FAILURE MECHANISM
FREEZING DRIZZLE; T = -10°C, Rate = 5g/dm²/h



Fluid thickness stabilizes shortly after pouring. The fluid resists dilution at this temperature. Failure was called when contamination suspended in the fluid covered more than 1/3 of the plate. Note that this contamination could be easily dislodged by blowing a stream of air onto the fluid surface.

Fluid thickness **decreased** with dilution.
At failure, a layer of ice covered the plate.

The appearance of this fluid was similar to that observed in previous tests with propylene glycol-based fluid. Prior to the failure of the fluid, the surface was covered with a thin layer of fine slush. At failure, the surface of the fluid was covered with fine, solid contamination that had started to fuse. Below this top layer of solid contamination, a layer of good fluid remained. Absolutely no adhesion had occurred at or soon after plate failure. The film thickness of the SPCA AD-480 fluid at the time of plate failure was 1.2 mm, equivalent to twice that of the Ultra+ and the sheared Octagon fluid at the same stage of failure.

4.11 Appearance of Flash Freezing: Type I versus Type IV (50/50, Freezing Rain)

Union Carbide XL54 **Test ID #s 14, 18**	**SPCA AD-480 50/50** **Test ID #s 15, 17**
Appearance • Unthickened fluid; • Left a thin, transparent orange layer when applied; • Almost immediate accumulation of solid contaminant; • Fluid layer thinned rapidly, with drying along the top edge; • Islands of frozen fluid formed after 10 minutes, with rapid adhesion to plate; and • No flash freezing occurred.	*Appearance* • Thickened fluid; • Left a thick, transparent green layer when applied; • Failures were similar to other Type IV fluids with accumulation of solid contaminant; • Time to failure about 2 times that of Type I (16 minutes versus 8); • No adherence at time of failure; at complete plate failure, some adherence noted at top of plate (4 minute lag); and • No flash freezing occurred.
Film Thickness • Rapid reduction to 0.1 mm thickness.	*Film Thickness* • Initial fluid layer much thicker than Type I (1.5 mm versus 0.5 mm); • Rate of thinning much slower; and • Thickness at failure was 0.2 mm.
Fluid Freeze Point • Dilution to 0°C in 6 minutes.	*Fluid Freeze Point* • Rate of dilution much slower than Type I fluids; and • Dilution to -4°C in 10 minutes.
Failure Adhesion • Rapid and complete adhesion following freezing.	*Failure Adhesion* • No adhesion at time of failure; at complete plate failure, some adherence noted at top of plate (4 minute lag).
C/FIMS Sensor Trace • Strong indication of failure, slightly ahead of visual call.	*C/FIMS Sensor Trace* • Visual identification of failure slightly ahead of visual call.
RVSI Sensor Trace • Clearly definable downturn indicates plate failure, concurrent with visual call.	*RVSI Sensor Trace* • Clearly definable downturn indicates plate failure, concurrent with visual call.

4.11.1 Discussion

No flash freezing occurred in documentation of fluid failure tests using Type I and Type IV 50/50 fluids. The appearance of failure for both fluid types in this comparison were consistent with previous descriptions of Type I and Type IV failures.

4.12 Viscosity Measurements

An attempt was made to examine the viscosity of the fluid at time of failure. To this end, fluid samples were collected at the time and location of fifth cross-hair failure and at time of complete plate failure at positions B2, F2 and adjacent to the location of 5th cross-hair failure, with the intent to measure fluid viscosity with a Brookfield viscometer. It was subsequently determined that individual sample volumes were insufficient for accurate testing and consequently, individual test samples were consolidated to enable testing.

The results of these consolidated samples are shown in Table 4.5, which presents the test sample concentrations in terms of Brix-scale refractive index values, as well as the measured viscosities. With one exception, the consolidated samples provided a measurement of viscosity equivalent to water. Fluid concentrations were quite low, as indicated by the Brix numbers. To understand whether the measured viscosity values were typical of Type IV fluids at low concentration, two Type IV brands (one ethylene glycol-based, one propylene glycol-based) were diluted to various concentrations, and their viscosities measured. The resulting data are displayed graphically in Figures 4.3 and 4.4, which show the viscosities plotted as a function of concentration.

These curves displayed very different characteristics for the two fluids. The ethylene glycol-based fluid (Union Carbide Ultra+) demonstrated a direct relationship between concentration and viscosity, with viscosity values decreasing rapidly as concentration decreased. At a 50/50 concentration, the fluid viscosity had reduced to zero. In contrast, the propylene glycol-based fluid (SPCA AD-480) displayed an initial increase in viscosity while concentration was decreased, with viscosity value peaking at about a 60/40 concentration, and returning to initial value at about a 45/55 concentration. Viscosity values then decreased rapidly, reaching a value of zero at a 30/70 mix.

The only fluid sample having a measurable viscosity was from a single test on Type IV (SPCA AD-480) fluid. The measured viscosity value for this fluid was probably less than actual as the sample volume was slightly less than specified (3.8 ml vs. 4.1 ml). Plate failure for this fluid was called when an observer judged the extent of the aggregate plate reached 33% coverage due to isolated frozen particles suspended in the fluid. During discussion of the test results for this fluid, it was noted that a considerable amount of protective capacity (not yet failed fluid) appeared to exist at the time of the plate failure call. Even at test end, when the plate was considered to be fully failed, this appeared to be the case.

TABLE 4.5

Failure Samples Collected in Ottawa
Fluid Brix and Viscosity

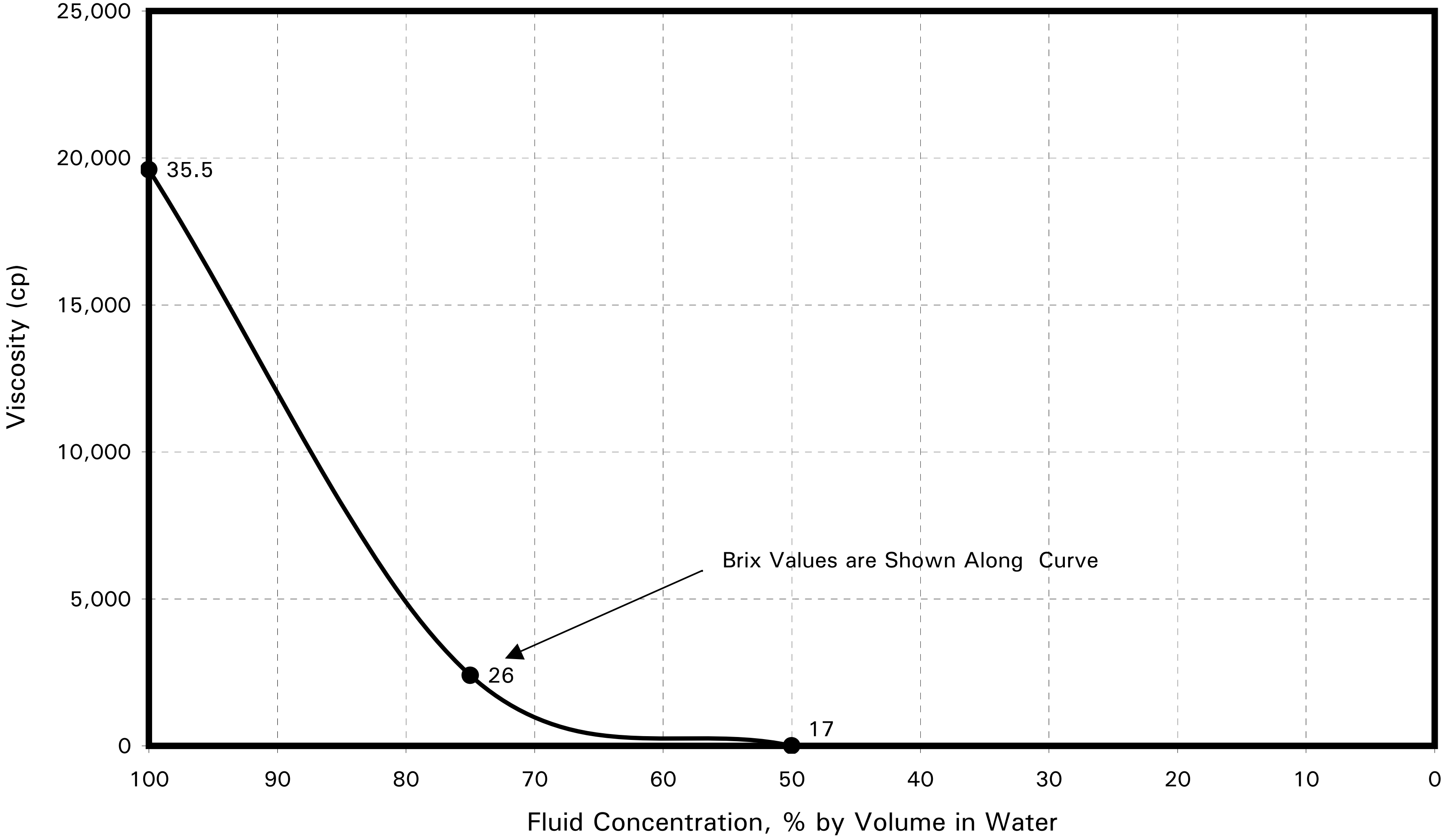
Fluid	Test ID	Exp. Brix	Visc. (cp) 0.3 rpm	Visc. (cp) 6 rpm	Visc. (cp) 30 rpm	Sample Locations
U+/100	1,4	5.5	0	0	0	All Locations
O 4/100	2,3	12	N/A	N/A	N/A	All Locations
XL54	5,7,14,18	0	0	0	0	All Locations
U+/100	6,9	1.5	0	0	0	All Locations
O 4/100	8,11	2.5	0	0	0	Remainder
O 4/100	8,11	5.5	N/A	N/A	N/A	At Failure Boundary
U+/100	13,19	0	0	0	0	All Locations
S480/100	15,17	0.2	0	0	0	All Locations
O 4/100	16	0	N/A	N/A	N/A	All Locations
U+/100	20,22	1.5	N/A	N/A	N/A	All Locations
O 4/100	21,23	1	N/A	N/A	N/A	All Locations
U+/100	24	10.5	N/A	N/A	N/A	All Locations
O 4/100	25,26	10	0	0	0	Remainder
O 4/100	25,26	15	N/A	N/A	N/A	At Failure Boundary
S480/100	28	23	15200	1600	492	All Locations

Note: Viscosity recorded using Brookfield LVII at 20°C, SCR-16/8R
- N/A (not enough fluid available to measure viscosity)

FIGURE 4.3

VISCOSITY VERSUS CONCENTRATION FLUID PROFILE

(Ultra +) at 20°C



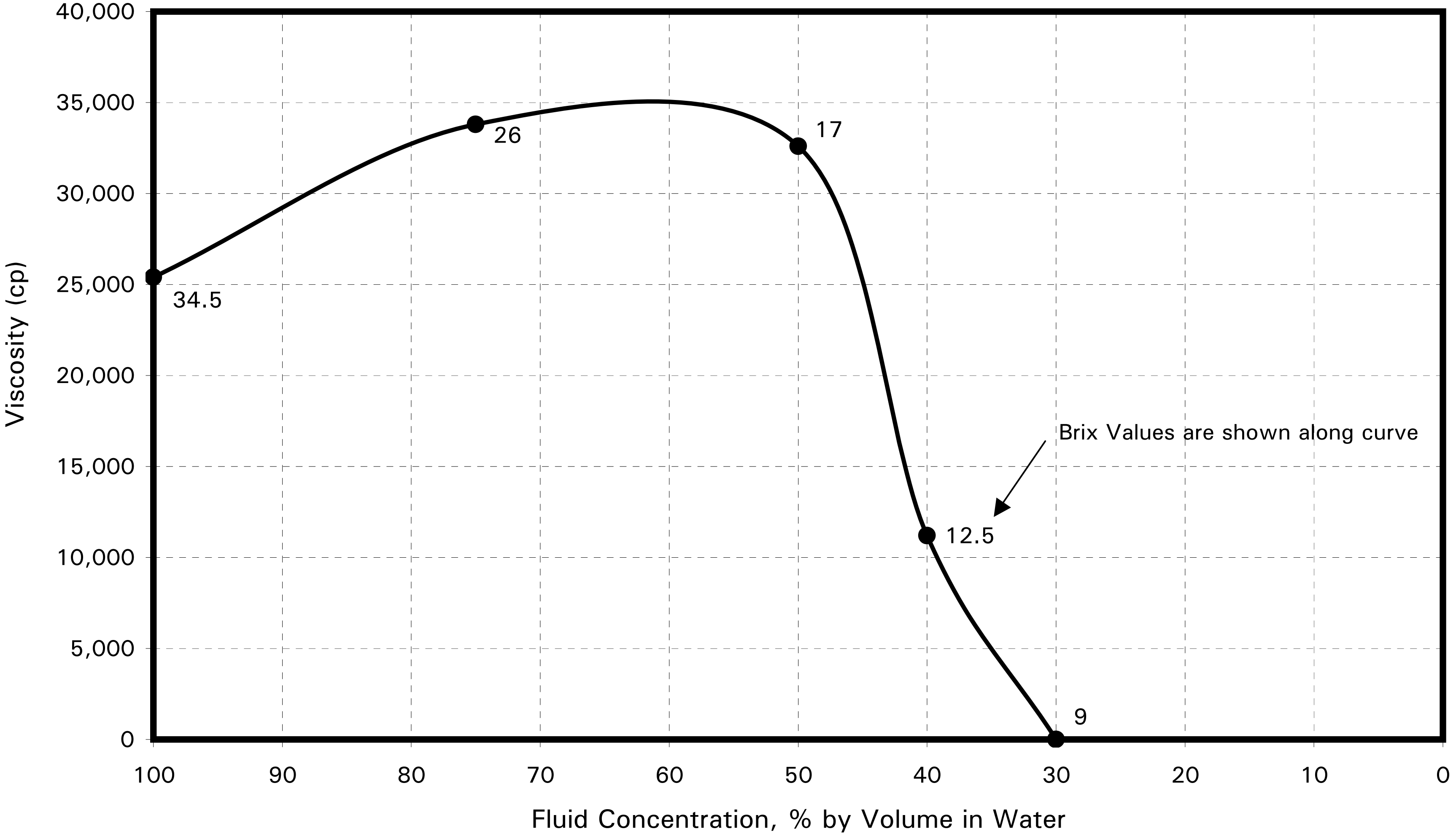
cm1380/report/fluiddoc/PETRVISC
At: U+
9/21/2006

Viscosity measurements taken at 0.3 rpm, SCR-34/13R

FIGURE 4.4

VISCOSITY VERSUS CONCENTRATION FLUID PROFILE

(SPCA AD-480) at 20°C



Viscosity measurements taken at 0.3 rpm, SCR-34/13R

cm1380/report/fluiddoc/PETRVISC
At: SPCA
9/21/2006, 9:48 AM

Viscosity tests tend to support this observation, indicating that an important degree of protective capacity still existed at time of failure call. This observation draws attention to the difficulty in making valid visual judgements on fluid failure for fluids exhibiting this failure mode. It also infers it to be possible that the full anti-icing capacity of the fluid is not being utilized in field operations.

It was noted that neither the C/FIMS nor the RVSI ice detection sensor traces gave a clear indication of the point of fluid failure. Interpretation of images from the RVSI system (Photos 4.1 and 4.2), however, do lead to the conclusion that the fluid had reached its operational limit.

It is possible that the visual failure calls are correct, and those fluids that accumulate frozen precipitation in the upper strata of the applied fluid film may become immobilized. This could occur upon fusion of the contamination layer. This may be so in spite of a layer of uncompromised fluid remaining in the lower strata of the applied fluid film.

Photo 4.1
Speck Stage of Failure

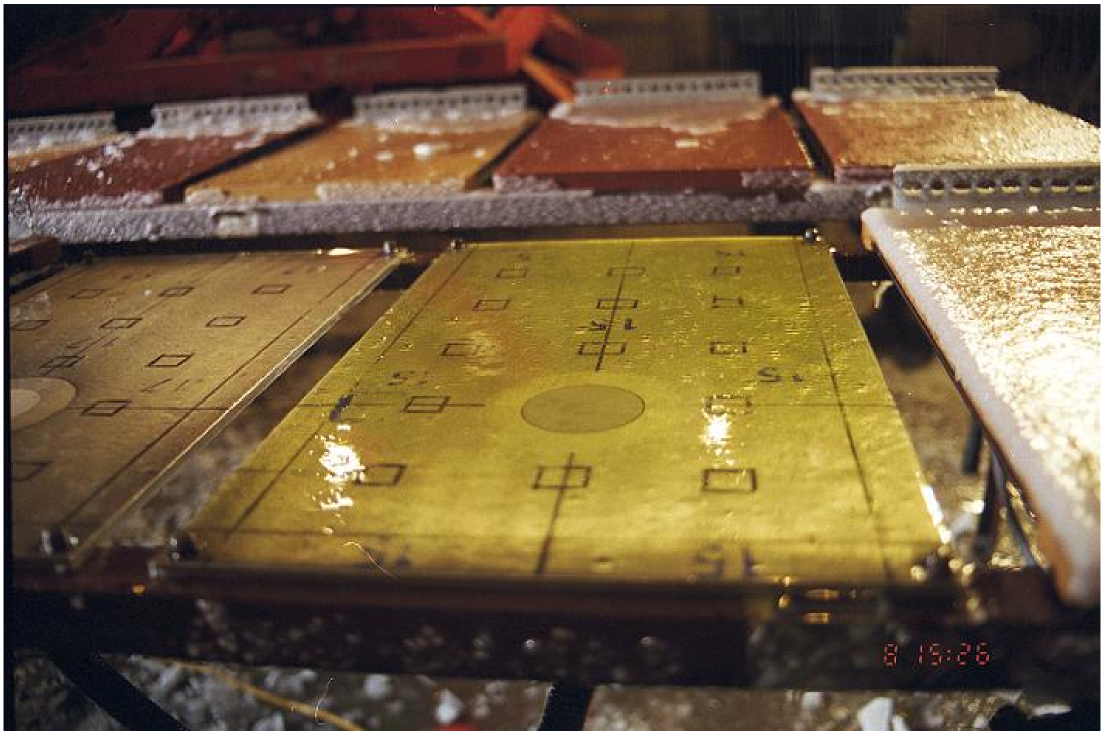


Photo 4.2
Orange-Peel Texture

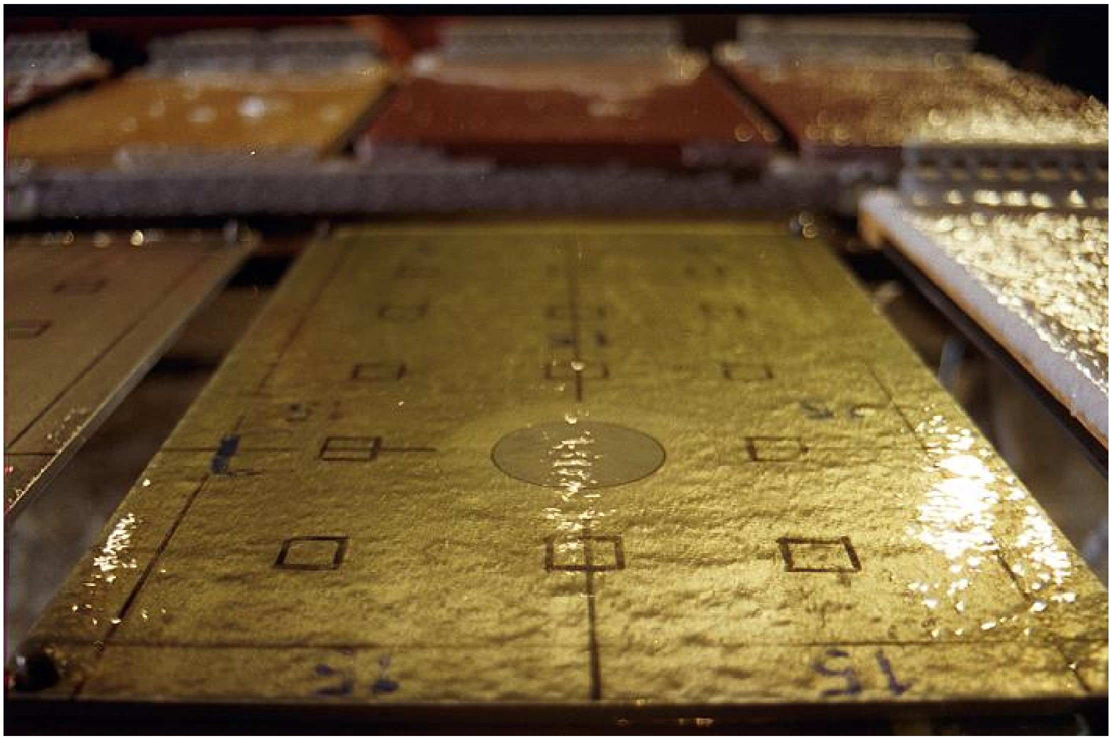


Photo 4.3
Gelatinous Stage of Failure

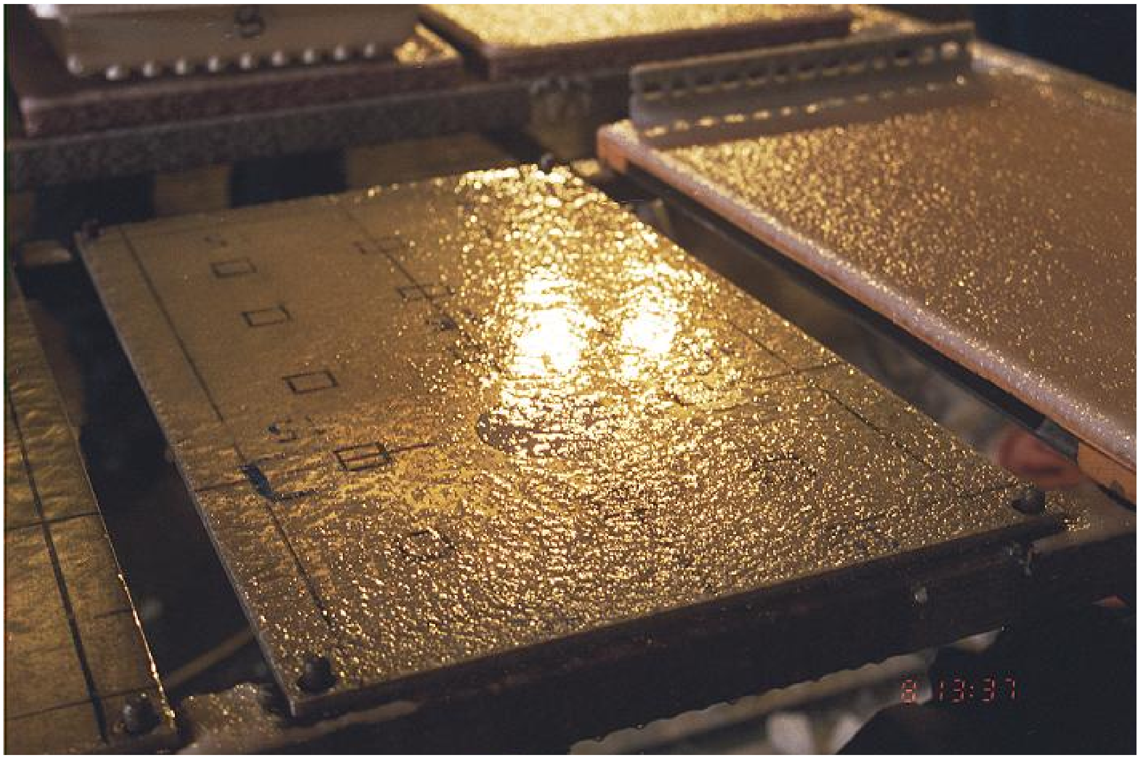


Photo 4.4
Streaks of Solidified Precipitation

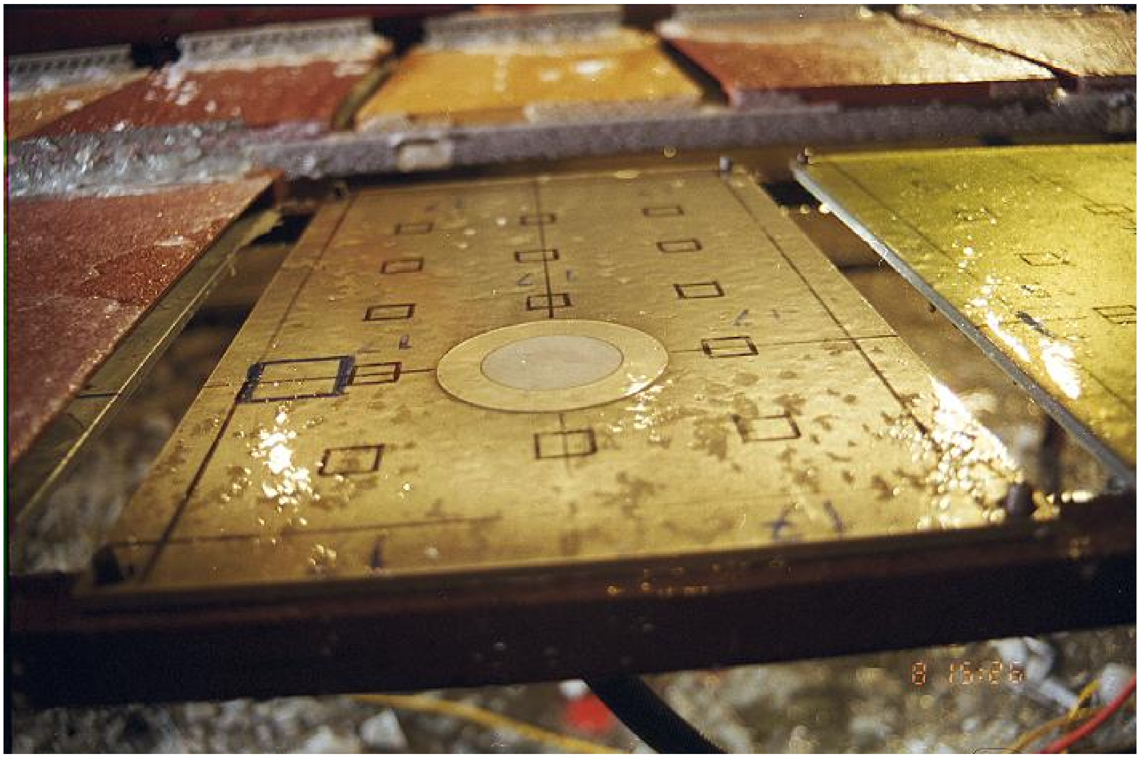


Photo 4.5

Solidified Precipitation Flowing Down Plate

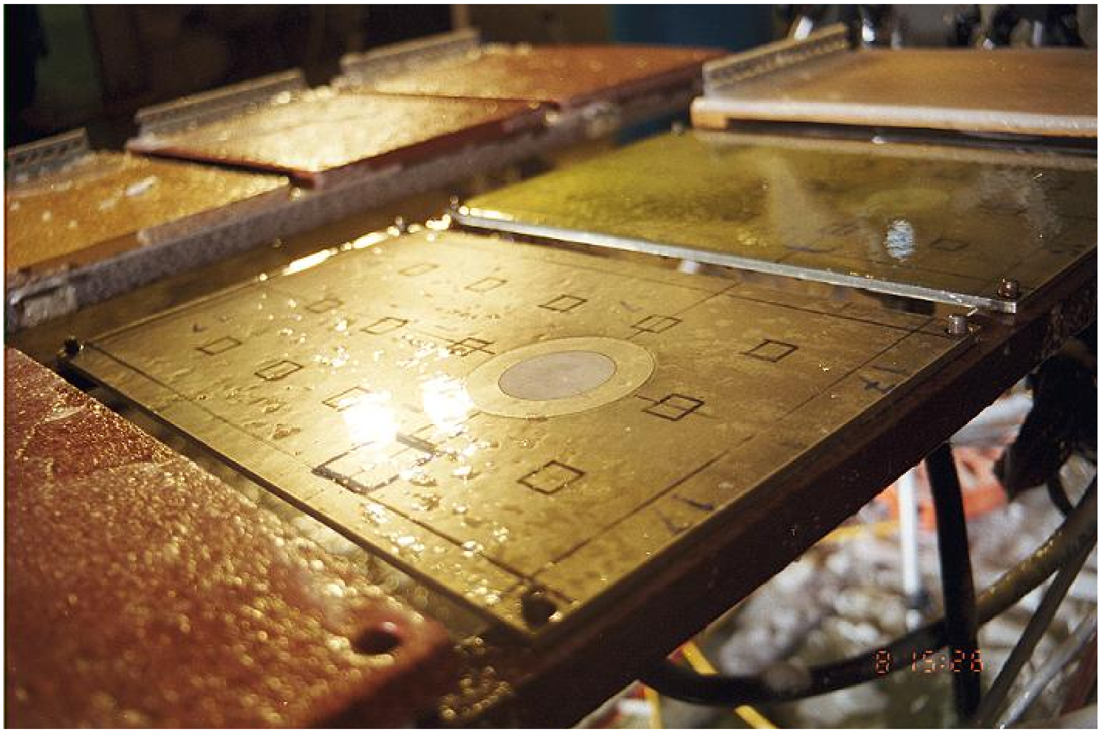


Photo 4.6

Top Edge Failure

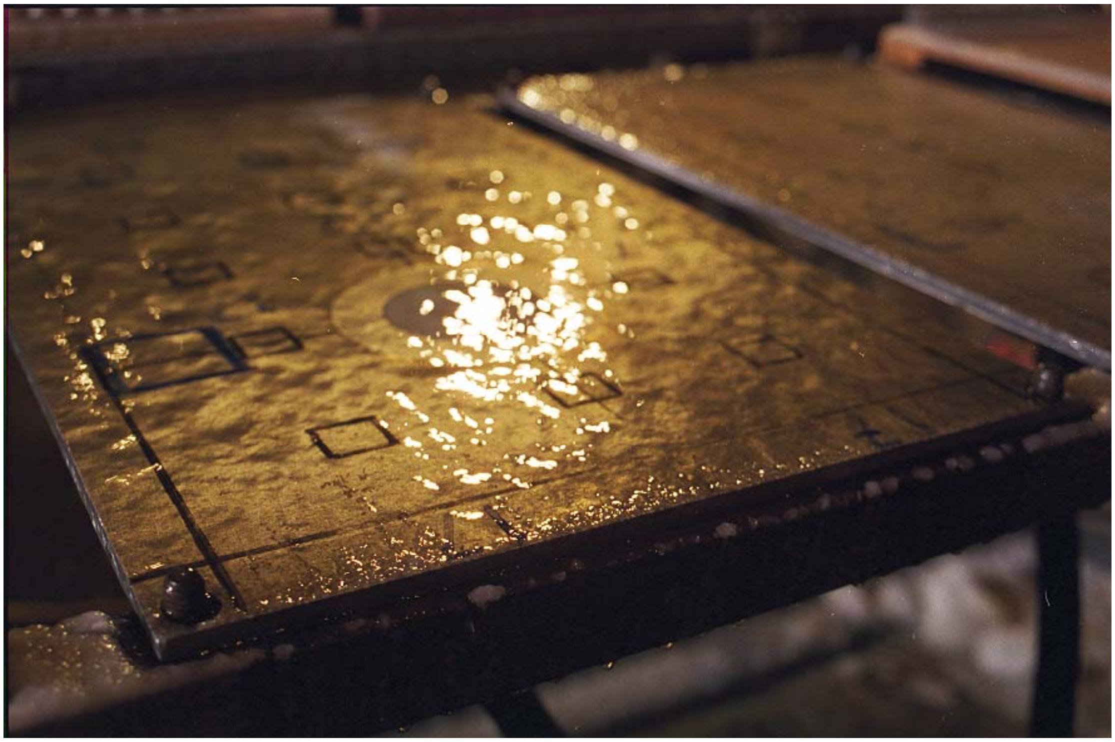


Photo 4.7

Fingers of Failure

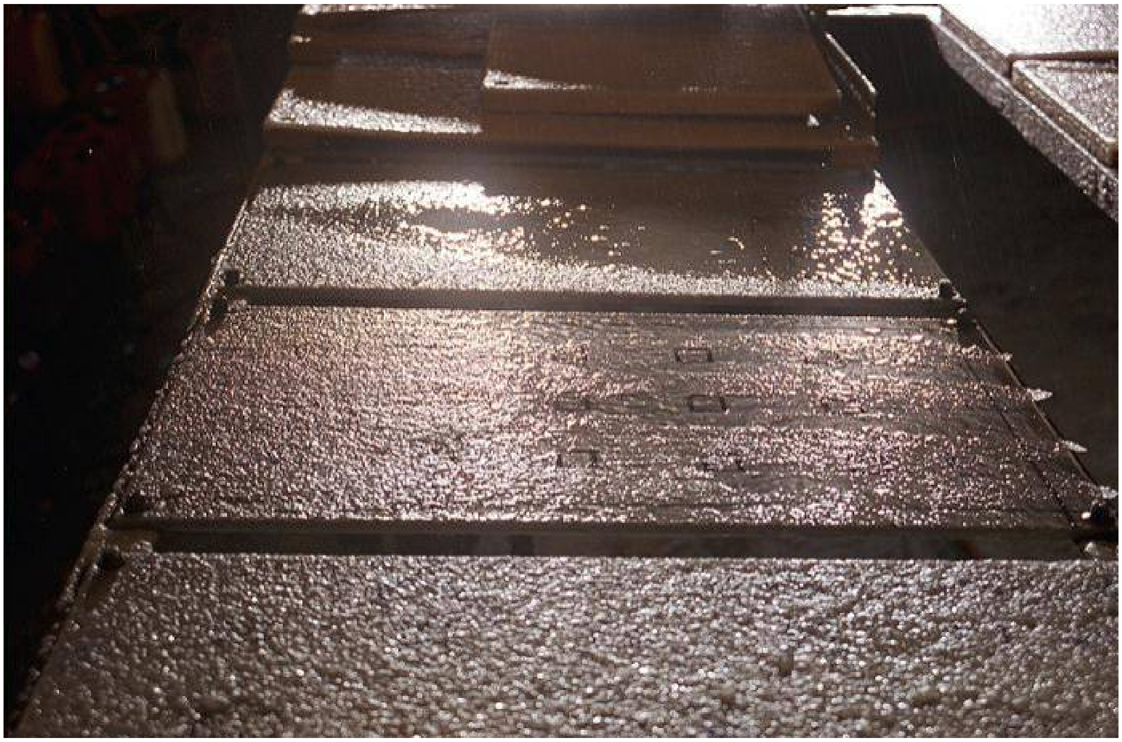


Photo 4.8

Dots and Streaks of Solidified Precipitation

Photo 4.9

Fingers of Plate-like Ice Particles

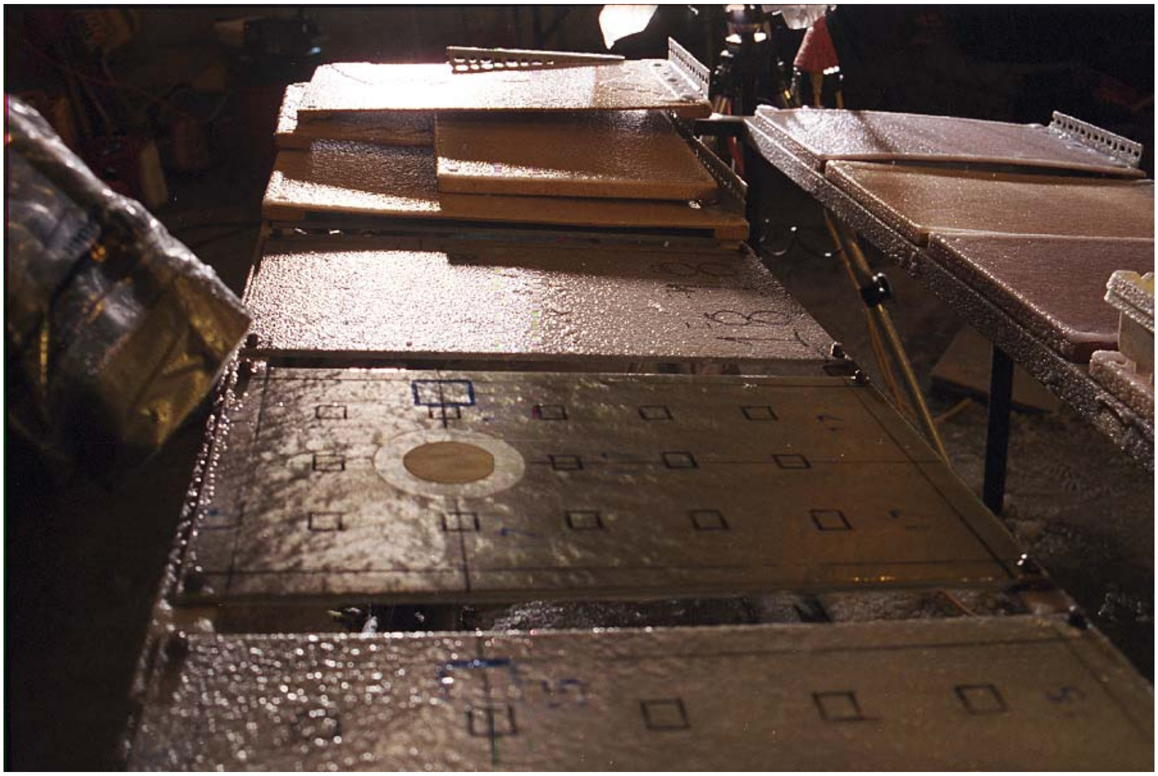


Photo 4.10

RVSI IMAGE - ID # 28 (3rd Plate from right)

SPCA AD-480 AT 10% FAILURE

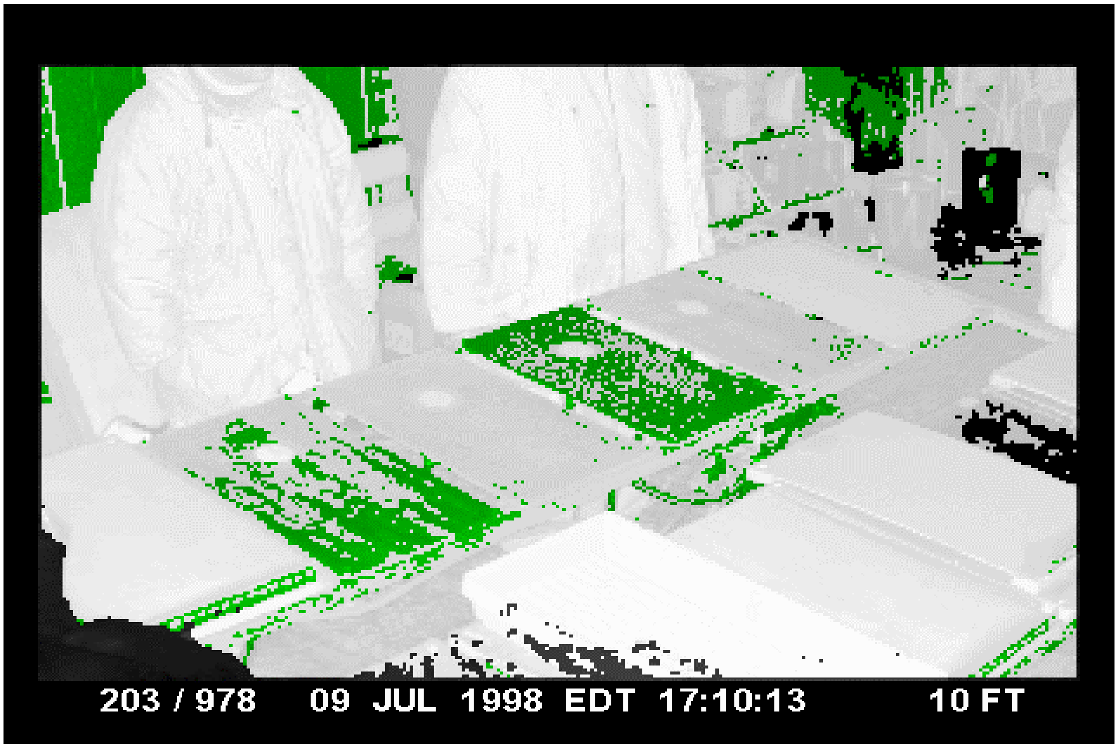


Photo 4.11

RVSI IMAGE - ID # 28 (3rd Plate from right)

SPCA AD-480 AT COMPLETE FAILURE

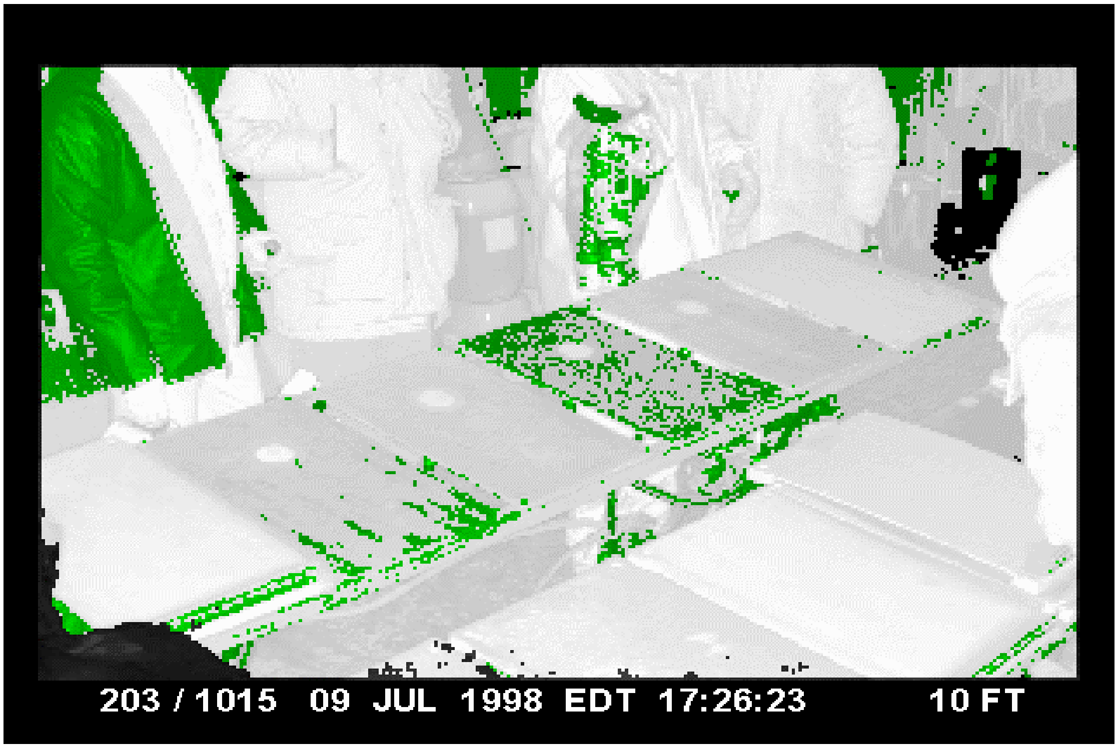


Photo 4.12

TYPE I FLUID FAILURE

Light Freezing Rain, Temperature = -10°C

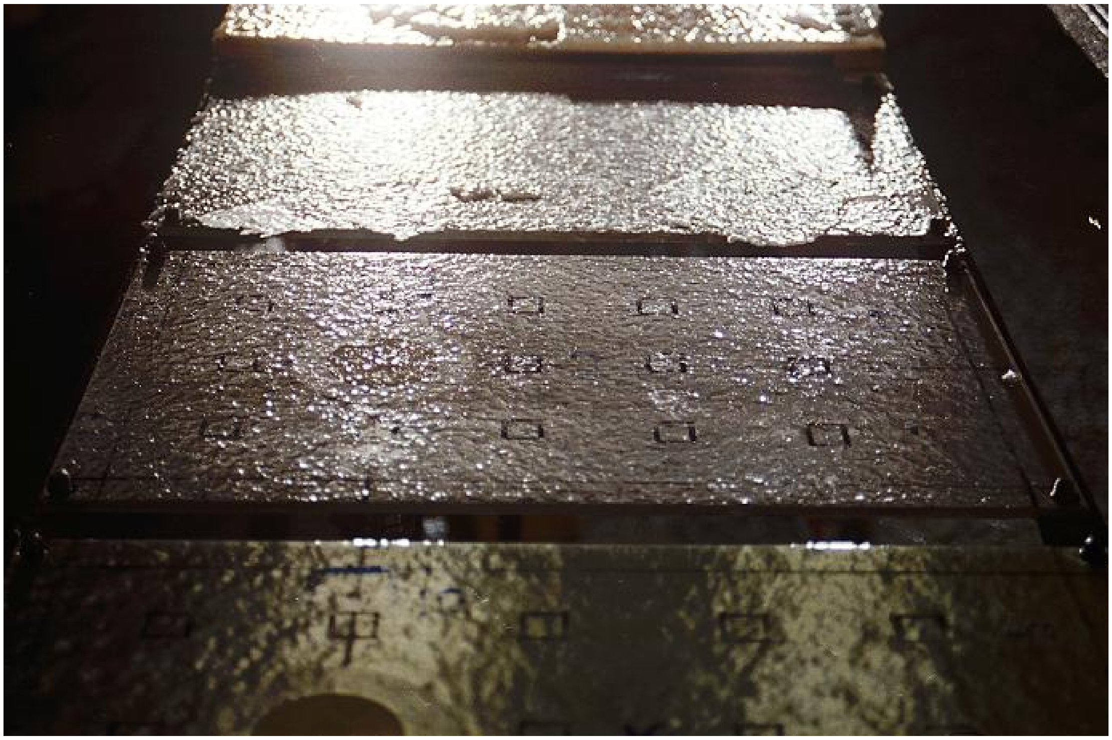


Photo 4.13

TYPE IV FLUID FAILURE

Light Freezing Rain, Temperature = -10°C

Photo 4.14

TYPE IV FLUID FAILURE

Light Freezing Rain, Temperature = -3°C

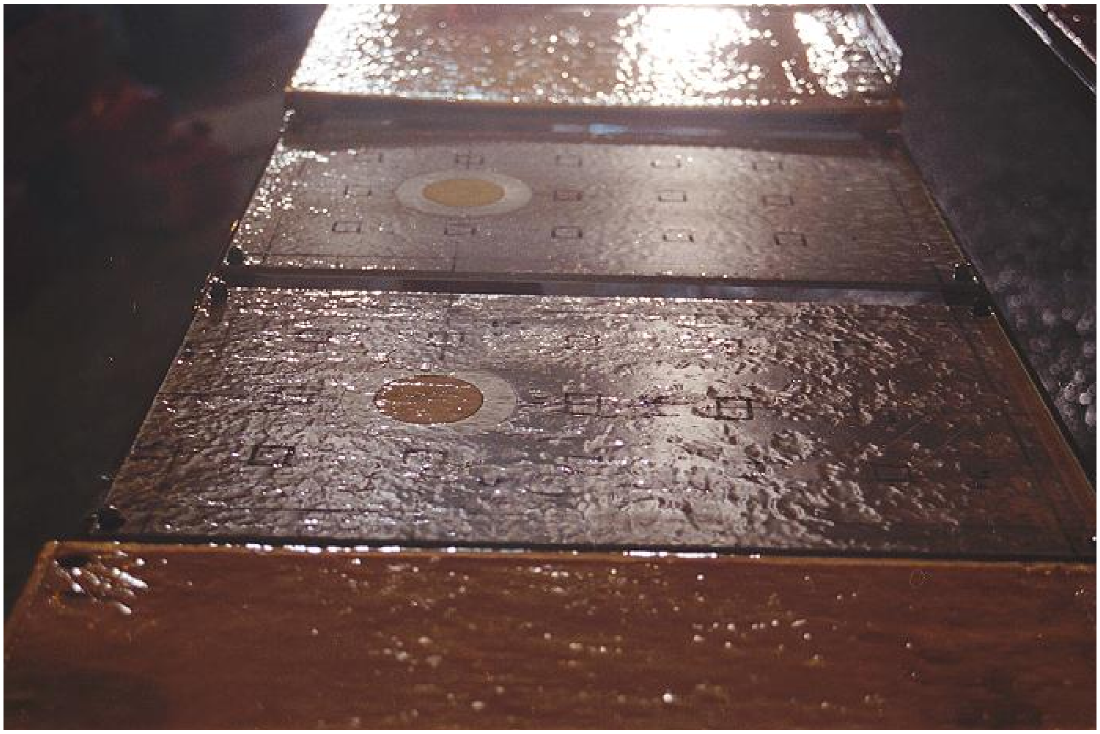


Photo 4.15

TYPE IV FLUID FAILURE ON A DC-9 WING

Light Freezing Rain, Temperature = -1°C

Photo 4.16

TYPE I FLUID FAILURE

Light Freezing Rain, Temperature = -3°C

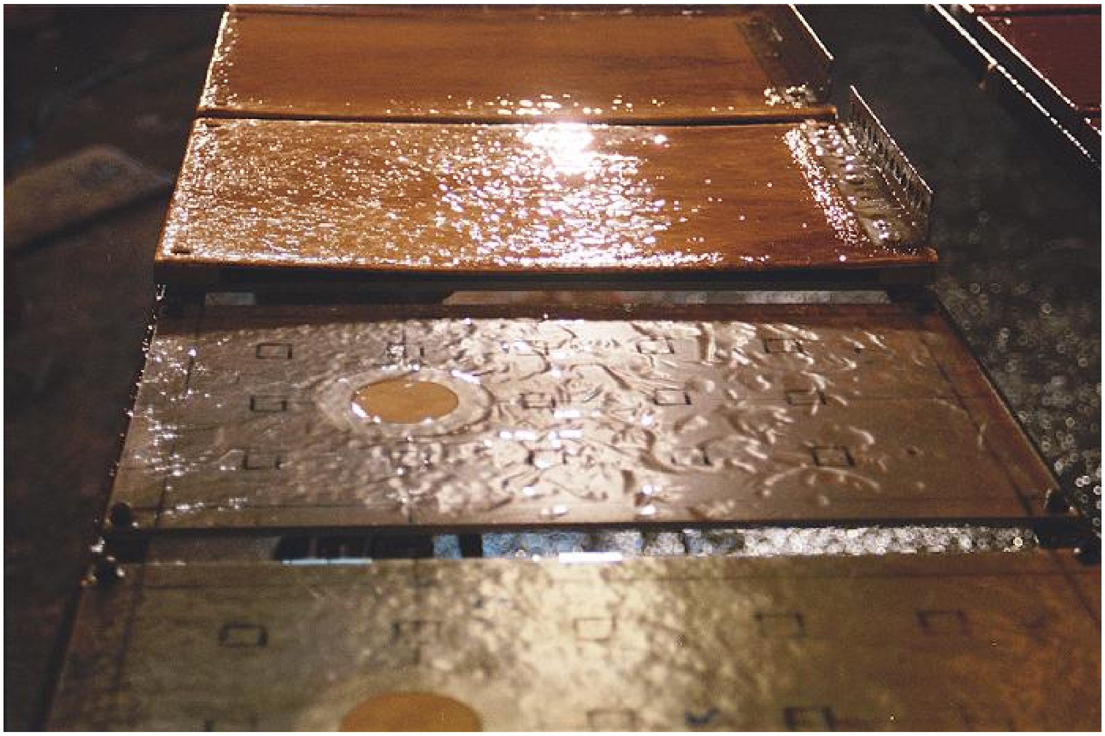


Photo 4.17

TYPE I FLUID FAILURE ON A DC-9 WING

Light Freezing Rain, Temperature = -1.5°C

Photo 4.18

TYPE IV FLUID FAILURE – FREEZING DRIZZLE

Temperature = -10°C, Precip. Rate = 10 g/dm²/h

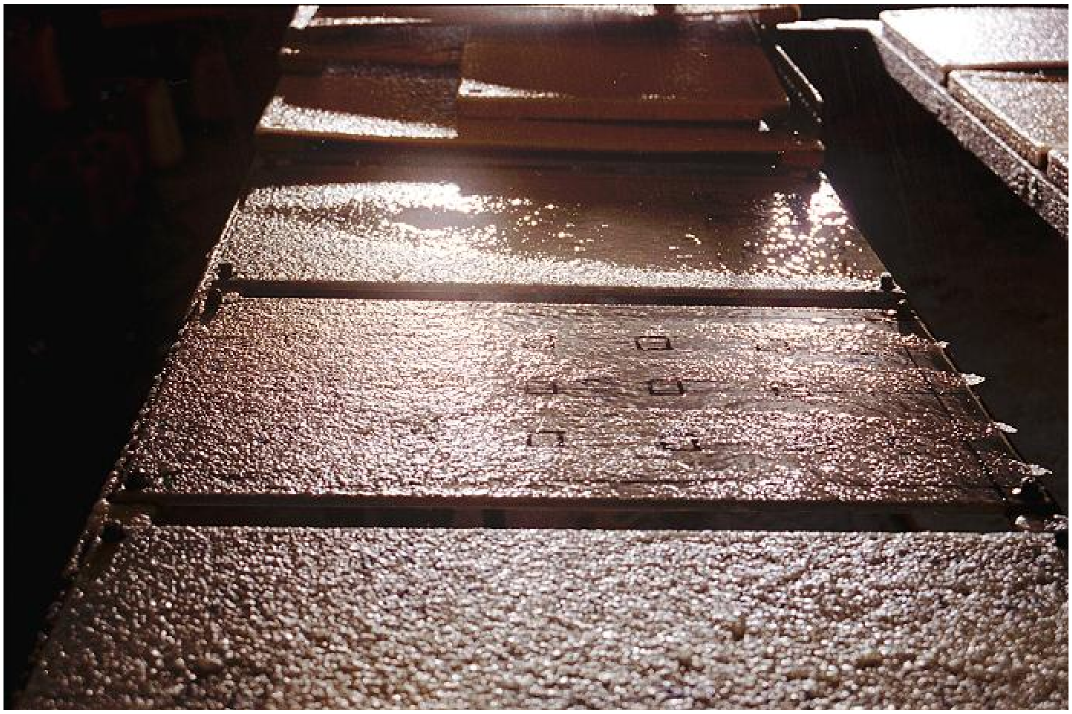
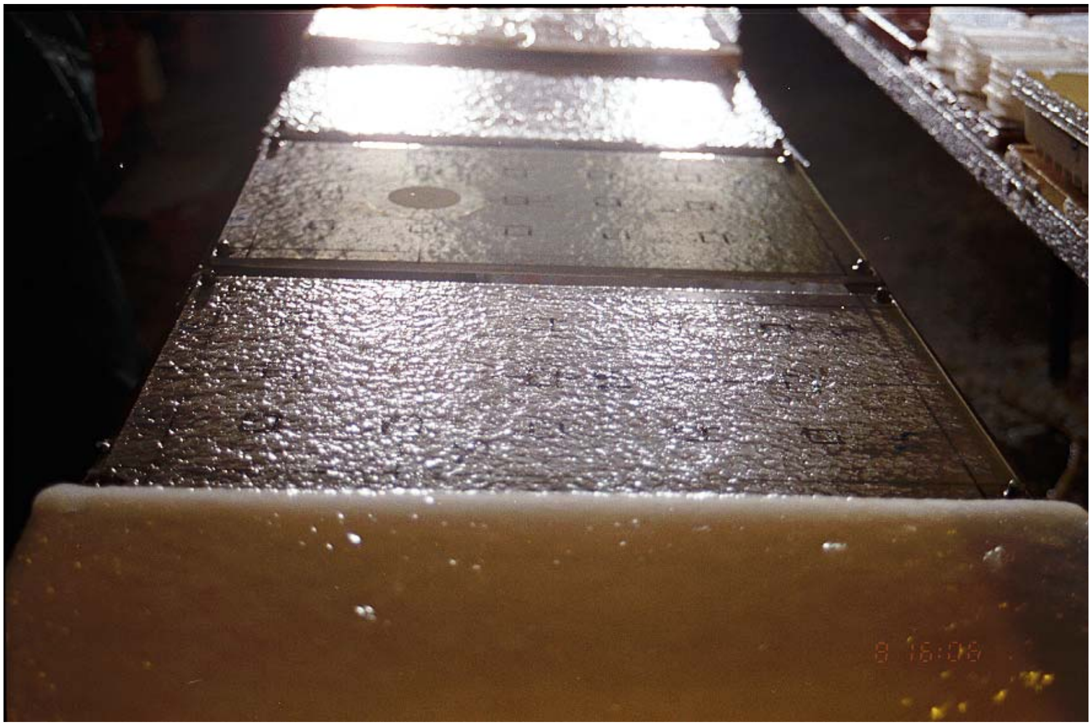


Photo 4.19

TYPE IV FLUID FAILURE – LIGHT FREEZING RAIN

Temperature = -10°C, Precip. Rate = 25 g/dm²/h



5. CONCLUSIONS

This study recorded the appearance and characteristics of various fluids at the time that the fluid reached its operational limit, according to a variety of recording techniques and instruments.

Data from the various tests enabled comparisons of the appearance and nature of fluids under different conditions as detailed in Section 4. Photographs and video records were documented to portray the appearance of fluid at specific phases from time of application until complete plate failure. These images could be made available to users in the field (pilots and ground staff) to assist in the visual identification of fluid at its operational limit. Descriptions of the characteristics of different fluids tested and various comparisons attempt to answer questions commonly posed during discussions on the nature of the fluid failure: What did the failure look like? How did it progress? How visible was it? Was the failure obvious or difficult to discern? Did it appear distinctive for different precipitation conditions and for different fluid types? Did it adhere to the underlying surface?

The adhesion of failure fluid once it has reached its operational limit is an important measure of the fluid condition, but one that has not been well reported in the past. This study used an innovative approach to provide a relative measure of adhesion relating to the various test conditions and provides an improved understanding of this characteristic. It was generally noted that Type I fluid adheres very quickly (in the order of one minute) after failure, resulting in a very thin film that is strongly bonded to the surface. Type IV ethylene glycol-based fluids demonstrated a longer delay from time of freezing until adherence, in the order of 3 to 6 minutes. SPCA AD-480, a Type IV propylene glycol-based fluid, experienced no adherence even at the time when complete plate failure was identified. These test conditions were severe, and adherence of Type I and ethylene glycol-based Type IV fluid should be further examined at lower precipitation rates and higher ambient temperature.

Fluid viscosity at its operational limit was found difficult to measure. The fluid concentration within the fluid layer may be stratified and may offer varying viscosities at different depths. Indicators of failure may reside only at the top layer. The nature of frozen contamination present in the fluid, if allowed to warm and melt in the sample container and then be recooled to test temperature for viscosity testing, will not necessarily take on the same structure as was present during the test. For this test, samples collected near the failure front and measured with a Brookfield viscometer generally provided viscosity values equivalent to water. An exception was the SPCA AD-480 fluid, which had a significant residual viscosity reading.

The Type IV Octagon MaxFlight fluid, which had initially been selected to represent propylene glycol-based Type IV fluids, had been pre-sheared prior to testing and the resultant documentation, while important, can be viewed only as representative of that fluid in a sheared state. Documentation of this fluid at a viscosity experienced in normal operations should be considered in any future activities of this sort. This may require evaluation of the viscosity levels of various fluids after application onto the aircraft wing.

Identifying operational limits for Type IV SPCA AD-480 fluid in freezing drizzle presented a challenge. The visual call procedure (based on observer judgement that the individual particles, if consolidated, would cover 1/3 of the plate surface) does not promote reproducibility and does not provide a high level of confidence in the accuracy of failure calls. The nature of this fluid during the process of absorbing contamination appears to continue to provide a level of protection far beyond the point when failure calls would normally be made. The accuracy of failure calls made by icing contamination sensors may be equally suspect. Examination of the fluid (in a contaminated state) removed from an actual wing during takeoff would provide useful additional information and may assist in determining an approach to more accurately identify operational limitations.

This study was restricted to conditions that could be created in NRC's laboratory; the conditions at the time of testing did not include snow. Being a critical condition for winter operations, documentation of fluid failure in natural snow conditions is worthy of examination. Laboratory tests should also be conducted when a snowmaking facility becomes available.

5.1 Procedural Enhancements for Further Testing

In general, the procedures developed for this series of tests were satisfactory and supported collection of valid and complete data. Some areas of potential improvement were identified and are described in the following.

- **Maintenance of ambient temperature at the test stand**. Numbers of team personnel must be held to a minimum, and their proximity to the test stand must be controlled to avoid transfer of body heat to test surfaces. Similarly, lights supporting photographic and ice contamination sensor activities must be positioned well back from the stand.

- **Ice contamination sensor traces**. The interpretation of ice contamination sensor traces was not always obvious, and it may be more useful to employ images of plate contamination from the camera sensors. Images captured at specific phases of the fluid failure process could be compared to other visual documentation.

- **Fluid viscosity**. Measurement of the fluid's viscosity in the condition as it exists on the plate is difficult as the structure of any ice formations that exist within the fluid sample will change as a result of the test process, either through melting and refreezing or as a result of the dynamic viscosity test. As well, test samples of sufficient volume for testing must be taken. Future testing should consider testing only one sample, lifted at the failure boundary at the time that plate failure is called.

- **Failure adhesion**. In addition to measuring failure adhesion at time of plate failure (1/3 plate) and complete plate failure, it should be measured progressively following fluid failure at defined positions to determine time of onset of adherence.

- **Photo records**. The developed photos showed that the camera time stamp function failed intermittently during the duration of testing. As this feature plays an important role in documentation, any future tests must ensure ongoing operation by whatever means necessary.

- **Wide-angle video camera**. Video records of all activities occurring at the test stand would assist in the analysis and resolution of any discrepancies in the interpretation of the data.

- **Transparent plates**. During this series of tests, a transparent plate was tested in an ad-hoc test to determine the feasibility of observing the fluid from the underside, or lighting the fluid from the underside to assist in visibility of contamination. Test results showed that this was possible. This approach should be explored and developed for any future testing.

- **Fluid absorption.** The quantity of contaminant impacting on the fluid-treated test surface cannot be calculated from the rate. The significant contaminant loss observed from droplets that subsequently splatter and roll or bounce off the surface should be collected and weighed, and the refractive index of this recovered fraction should be measured to determine the extent to which the escaping droplets pick up the deicing and/or anti-icing fluids.

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6. RECOMMENDATIONS

It is recommended that:

i) This study be extended to include documentation of fluid failure outdoors during suitable snow conditions, and indoors when a laboratory snow-making facility becomes available;

ii) An investigation of the impacts of freezing drizzle and light freezing droplets be conducted to document, using strobe photography, how the contaminant is actually accepted by the fluid and also to determine what fraction of contamination impinging on a fluid-covered surface actually remains in the film (gravimetric analysis). A measure of the quantity of deicing and anti-icing fluid picked up by escaping droplets would be afforded from refractive index measurements of the collected fraction.

iii) Photo documentation of fluids at various stages of contamination be made available to potential users in the aviation industry to assist in identifying when a fluid has reached its operational limit;

iv) Type IV SPCA AD-480 fluid, or other similar propylene glycol-based Type IV fluid, be further examined under various conditions and levels of contamination to determine its true operational limit and to determine a means of identifying when the fluid has reached its limit. This should include tests to determine levels of contamination at which the fluid ceases to flow from an aircraft wing during a simulated takeoff run;

v) Type IV Octagon MaxFlight fluid having a viscosity typical of normal operations be documented in any future activities to compare with this study documentation of a highly sheared fluid; and

vi) The initial findings related to onset and progress of adherence following fluid failure be augmented by further study designed to provide more precise data under various test conditions.

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REFERENCES

1. Bilgen, E., Chan, G., Cleary, C., D'Avirro, J., Foo, H., *Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1992-1993 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, October 1993, TP 11836E, 122.

2. Chaput, M., Dawson, P., Hanna, M., *Aircraft Deicing Fluid Freeze Point Buffers Requirements: Deicing Only and First Step of Two-Step Deicing*, APS Aviation Inc., Transportation Development Centre, Montreal, November 1998, TP 13315E, 167.

3. D'Avirro, J., Peters, A., Hanna, M., Dawson, P., Chaput, M., *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1996-97 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, November 1997, TP 13131E, 232.

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APPENDIX A

TERMS OF REFERENCE – WORK STATEMENT

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 97/98
(Short Title: Winter Tests 97-98)
(December 1997)

1 INTRODUCTION

Following the crash of a F-28 at Dryden in 1989 and the subsequent recommendations of the Commission of Inquiry, the Dryden Commission Implementation Project (DCIP) of Transport Canada was set up. Together with many other regulatory activities an intensive DCIP research program of field testing of deicing and anti-icing fluids was initiated with guidance from the international air transport sector through the SAE G-12 Committee on Aircraft Ground De/Anti-icing. As a result of the work performed to date Transport Canada and the US Federal Aviation Administration (the FAA) have been introducing holdover time regulations and the FAA has requested that the SAE, continue its work on substantiating the existing ISO/AEA/SAE Holdover Time (HOT) tables (DCIP research representing the bulk of the testing).

The times given in HOT Tables were originally established by European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted initially by the DCIP R&D Task Group and subsequently by Transport Canada, Transportation Development Centre (TDC), which has taken over the functions of the DCIP, has been to determine the performance of fluids on standard flat plates in order to substantiate the times, or if warranted, to recommend changes.

DCIP has undertaken most of the field research and much other allied research to improve understanding of the fluid HoldOver Times. Most of the HOT table cells been substantiated, however low temperatures have not been adequately explored and further tests are needed.

The development of ULTRA by Union Carbide stimulated all the fluid manufacturers to produce new long lasting anti-icing fluids defined as Type IV. All the Type IV fluids were upgraded in early 1996 and therefore all table conditions need to be re-evaluated and the table revised if necessary. Certain special conditions for which advance planning is particularly difficult such as low temperatures with precipitation, rain or other precipitation on cold soaked surfaces, and precipitation rates as high as 25 gm/dm^2/hr need to be included in the data set. All lead to the need for further research.

Although the Holdover tables are widely used in the industry as guides to operating aircraft in winter precipitation the significance of the range of time values given in each cell of the table is obscure. There is a clear need to improve the understanding of the limiting weather conditions to which these values relate.

An important effort was made in the 94/95 and 95/96 seasons to verify that the flat plate data were representative of aircraft wings. Airlines cooperated with DCIP by making aircraft and ground support staff available at night to facilitate the correlation testing of flat plates with performance of fluids on aircraft. An extension of this testing was to observe patterns of fluid failure on aircraft in order to provide data to assist pilots with visual determination of fluid failure failure, and to provide a data to contamination sensor manufacturers. The few aircraft tests made to validate the flat plate tests were inconclusive and more such tests are needed. Additional tests testing with hot water and with hot air for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 96/97 winter.

2 PROGRAM OBJECTIVE (MCR 16)

Take an active and participatory role to advance aircraft ground de-icing/anti-icing technology. Develop international standards, guidance material for remote and runway-end de-icing facilities, and more reliable methods of predicting de-icing/anti-icing hold-over times.

3 PROGRAM SUB-OBJECTIVES

3.1 Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions.
3.2 Substantiate the guideline values in the existing holdover time (HOT) tables for fluids that have been qualified as acceptable on the basis of their impact on aircraft take-off performance.
3.3 Perform tests to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces.
3.4 Support development of improved approaches to protecting aircraft surfaces from winter precipitation.

4 PROJECT OBJECTIVES

4.1 Develop new Holdover Time Tables applicable (a) to anti-icing fluids wiwhich offer extended HoldOver Times within a particular temperature /precipitation regime;and (b) applicable to de-icing operations, only.

4.2 Determine the influence of fluid type, precipitation and wind on location of fluid failure initiation, time to fluid failure initiation, pattern of fluid failure progression, and visibility of failed fluid on a sample high wing tubo-propeller and a low wing turbojet commuter aircraft.

4.3 Collect data on the taxi time from start of de-icing or anti-icing, as applicable, to start of the take-off roll under conditions of winter precipitation at sample airports.

4.4 Assess the practicality of using a vehicle mounted remote area detection contamination sensor for pre-flight (end of runway) checks.

5. DETAILED STATEMENT OF WORK

5.1 Planning and Preparation

5.1.1 Scope of Work

The work Shall be executed as eleven separate sub-projects:

1) Planning and Preparation.
2) Holdover Time Testing and Evaluation of de/anti-icing fluids.
3) ʻNegative Buffer' De-icing Fluids
4) Development of a Low Glycol ʻDe-icing onlyʼ Fluid Table.
5) Aircraft Full Scale Tests.
6) Documentation of Pilot field of View, and Wing Visibility
7) Documentation of the Appearance of Failed Fluids.
8) Potential use of Remote Sensors for End-of-Runway inspection.
9) Taxi Times under conditions of Precipitation.
10) Support for Review of Alternative Technologies.
11) Provision of Support Services.

5.1.2 Program management

The work shall be broken down into the distinct areas of activity consistent with the project objectives.

A detailed workplan, activity schedule, cash flow projection, project management control and documentation procedure shall be developed for each of the seven sub-projects, and delivered to the TDC project officer for approval within one week of the pertinent start date.

5.1.3 Coordination

Prepare, plan, and coordinate with personnel from TDC, airlines, airport authorities, fluid manufacturers, Instrumentation suppliers, and the National Research Council of Canada (NRC) with respect to site requirements and test procedures; training of test personnel; conduct of dry-run(s) and tests.

5.1.4 Safety of Personnel and Aircraft

Planning shall include precautions to ensure safety of personnel, and safety (freedom from damage) of aircraft.

A safety officer shall be nominated to prepare an appropriate plan, and monitor its implementation.

Conduct of tests shall respect recognized safety standards and applicable sections of Federal and Provincial labour codes. Where exceptions are taken due to the nature of the work, e.g. emplacement of power and instrumentation cables in the work area, test personnel shall be made aware of potential hazards.

Within the work area, comprising the de-icing pad and access ways, test personnel shall co-ordinate their movements and be made aware of all other operations taking place. Movement of airline equipment - aircraft, tow trucks, de-icing trucks, shall have precedence over test personnel activities.

Care shall be taken to ensure that mobile equipment, such as inspection platforms, lighting stands etc. are not in contact with aircraft surfaces. Potential contact points for such equipment shall be padded.

Movements of visitors and personnel not directly involved in tests at any given time shall be tightly controlled, with safety as the governing criteria.

Obtain 'Airport owners and operators premises and products liability insurance' to indemnify and hold harmless the airport and the operators against any claim arising.

5.1.5 Coordination with the National Research Council, Environmental Test Facility

Arrangements will be made by Transport Canada for use of the National Research Council, Climatic Engineering Facility (NRC, CEF) for conduct of certain tests.

Coordinate with NRC for use of the Test facility, including setting of dates for tests, environmental conditions to be simulated, and equipment and test materials to be supplied by the respective agencies.

5.1.6 Supply and Condition of De/Anti-icing Fluids

Fluids will be made available by TDC at no cost to the contractor.

The contractor shall make arrangements for fluids delivery and on-site storage.

For dedicated flat plate tests, the contractor shall ensure and record that Type IV fluids are pre-sheared prior to delivery, and are representative of the manufacturer's marketed product, i.e. the samples used in the conduct of tests should not be those with the manufacturer's lowest level of viscosity.

Where exceptions are taken to this requirement these shall be noted, and every effort shall be made to obtain samples which comply with the requirements.

Where testing necessitates application of fluids sheared consistent with normal truck application, and such fluids are not available, the contractor shall subject the fluids to appropriate shearing by similar means.

5.2 Holdover Time Testing and Evaluation of de/anti-icing fluids

5.2.1 Site preparation.

Set up experimental sites and install sensors as inspection aids to provide consistent plate failure conditions under field and laboratory conditions.

5.2.2 Flat Plate Tests for New Type IV fluids

Conduct flat plate tests under conditions of natural snow and freezing drizzle precipitation to record the holdover times, and to develop individual Holdover Time Tables based on samples of new and previously qualified Type IV fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Tests shall be anticipated for at least four different manufacturer′s fluids and shall be conducted in the field and the laboratory.

5.2.3 Validation of “Fluid-Specific” and SAE Tables

Conduct flat plate tests to validate “fluid-specific” and SAE tables that currently lack sufficient supporting data. For the “freezing fog” condition the current upper holdover time shall be revised as necessary.

5.2.4 Evaluation of Snow Weather Data

Evaluate snow weather data (precipitation rate/temperature data) from previous winters to ascertain the suitability of the data ranges used to date for evaluation of HOT limits.

Obtain data from Environment Canada for four sites in Quebec: Rouyn, Mingan (Sept Isles), Pointe-au-père (Mont Joli), and Ancienne Lorette (Qebec City), in addition to Dorval (Montreal).

5.2.5 Analysis of Current Type I and Type II Holdover Time Tables

Conduct an analysis of current Type I and II fluid holdover time data to determine their concurrence with values determined from the data ranges established in task 5.2.4 above. This evaluation will be conducted for all fluid dilutions and precipitation conditions. Develop appropriate regression equations.

5.2.6 Evaluation of the SPAR Aerospace Ice Detection Camera

TDC will arrange for provision of a SPAR Aerospace (Also referred to as a “SPAR/Cox”) camera, with software modifications appropriate for data collection and evaluation.

Install the Camera at the Dorval “Field” test site for use in standard flat plate tests.

Calibrate camera output to characterize fluid ‘failure’ consistent with visual and other instrumented failure ‘calls’. Compare camera observations during conduct of flat plate tests with visual observations of fluid behaviour under conditions of precipitation, and similar observations by other sensing devices.

5.2.7 Supplementary Tests

Conduct supplementary tests in the NRC Climatic Engineering Facility to:

- Measure film thickness of 'new' fluids (fluids made available by TDC, but not previously tested) on flat plates.
- Observe the effects of fluids on ice-phobic materials on standard (aluminum) plates.
- Determine the effect on holdover time of spraying versus pouring of Type IV fluids.
- Determine the effect on holdover time of applying heated versus cold Type IV fluids for standard flat plate tests.

5.2.8 Compatibility with De-icing Fluids

Holdover time tests shall in general be conducted with fluid applied directly to clean plates. Additional tests shall be conducted to determine compatibility of the Type IV fluid samples with a proposed new category, "Type 0" fluid, derived from reclaimed spent fluid.

5.2.9 Measurements and instrumentation

In addition to measurements and records of environmental conditions pertinent to the tests, measurements shall be made during the conduct of the tests to obtain histories at selected locations on the plates of fluid thickness, refractive index, and viscosity through to the end of the tests.

SPAR/Cox and RVSI remote sensors shall also be used to record the initiation and progression of fluid failure.

5.2.10 Location of Tests

Planning shall be based on conduct of outdoor (field) tests at Dorval Airport, Montreal, and indoor laboratory tests in the NRC Climatic Engineering Facility, Ottawa. Anticipate 20 days occupancy in the laboratory.

Consideration shall be given to conduct field tests at alternate sites where desirable test conditions may occur more frequently.

5.3 'Negative Buffer' De-icing Fluids

(Note: The guidelines for holdover times given in the SAE Tables call for the freezing points of fluid mixtures to be at least 10^0C (18^0F) for Type I, and 7^0C (13^0F) for Type II below the ambient air temperature).

Conduct tests to determine the limits of the use of hot water, and reduced glycol content de-icing fluids under conditions of precipitation.

Focus of activity shall be conduct of tests in the laboratory (NRC

Environmental Test Facility) under controlled conditions. Availability of aircraft and procurement of laboratory services will be by TDC.
All other services and facilities shall be provided by the contractor.

5.3.1 Aircraft Tests

- Conduct a test with a selected aircraft at Dorval Airport, Montreal to establish a ʻreferenceʼ case for comparison with laboratory results. Choice of aircraft shall be determined in cooperation with US Airways and TDC. Test records shall include relative humidity at the time of test, and the fuel load of the aircraft to be tested.
- Test shall be conducted under conditions without precipitation, at zero or low wind velocity, and with low level of insolation - i.e. overcast or night-time. Plan for conduct of tests at the lowest temperature possible, based on forecast conditions.
- Tests shall be conducted with hot water heated and applied in accordance with the first step of SAE ARP4737, latest edition, Two-Step de-icing/anti-icing procedure.
- Tests shall be repeated for at least two different glycol concentrations, Type I fluid, only, to be selected in coordination with TDC. Fluids to be tested shall include at least one propylene glycol- and one ethylene glycol-based fluid.
- Condition of fluid as applied, duration of application, and quantity and thickness distribution of fluid applied shall be recorded.
- Temperature histories on the wing surfaces at selected locations shall be recorded starting prior to fluid application and terminating after fluid freezing. Locations shall include ʻover fuel tankʼ and low thermal inertia surfaces such as control surfaces.
- Simultaneous tests shall be conducted adjacent to the aircraft using standard 1/8" (1.2mm) thick ʻSAEʼ flat plates, increased thermal capacity 1/4" (6mm) plates, and ʻCold-Soakʼ boxes developed for laboratory simulation of cold-soaked wing. Boxes of appropriate depth shall be provided, as necessary, to ensure that the observed range of fluid behaviour on the wing can be adequately simulated in the laboratory.

5.3.2 Laboratory Tests

- Schedule a test session of one-week nominal duration in the NRC Environmental Test Facility in coordination with TDC. Notify TDC of the anticipated start date with minimum of two weeks notice.
- Anticipate tests using Type I ethylene glycol, and Type I propylene glycol de-icing fluids, and at least one Type IV fluid, heated and applied in accordance with the first step of SAE ARP4737, latest edition, Two-Step de-icing/anti-icing procedure.

- Conduct a matrix of tests using standard 1/8" (1.2mm) thick 'SAE' flat plates, increased thermal capacity 1/4" (6mm) plates, and 'Cold-Soak' boxes developed for laboratory simulation of cold-soaked wing, based on:
    - A range of selected temperatures (e.g. -3^{0}C, -7^{0}C, -14C, -25^{0}C,).
    - A range of appropriate precipitation rates, based on simulated light Freezing Rain.
    - A range of selected buffers, i.e. fluid dilutions.

  Relative humidity at time of test shall be recorded.
  Effects of wind are not to be considered.
- Record all test conditions, and time to fluid failure.
- Prepare recommendations for use of 'Negative Buffer' fluids based on ambient temperature, an appropriate, conservative delay (e.g. 3 minutes) before application of Anti-icing fluid, and limitations which might be imposed by wind conditions.

5.4 Development of a Low Glycol 'De-icing only' Fluid Table

Conduct tests to develop a 'De-icing Only' table for removal of ice, slush, snow or frost, in the absence of precipitation when the fluid is applied in accordance with SAE ARP 4737, latest revision. It is anticipated that the table would give values of minimum acceptable de-icing fluid glycol content, with appropriate buffer, as a function of a set of ambient temperature ranges.

Focus of activity shall be conduct of tests in the laboratory (NRC Environmental Test Facility) under controlled conditions. Procurement of laboratory services will be by TDC.

5.4.1 Laboratory Tests

- Schedule a test session of one-week nominal duration in the NRC Environmental Test Facility in coordination with TDC. Notify TDC of the anticipated start date with minimum of two weeks notice.
- Anticipate tests using water; a proposed new category "Type “0” fluid based on recycled spent fluid; and Type I ethylene glycol, and Type I propylene glycol diluted to provide a range of 'low-glycol' heated de-icing fluids.
- Conduct a matrix of tests using standard 1/8" (1.2mm) thick 'SAE' flat plates, increased thermal capacity 1/4" (6mm) plates, and 'Cold-Soak' boxes developed for laboratory simulation of cold-soaked wing, based on:
    - A range of five or more selected temperatures.
    - A range of selected precipitation rates, based on simulated light Freezing Rain.
    - A range of simulated wind velocities, representative of those encountered in operational service.
    - A range of selected buffers, i.e. fluid dilutions.
- Record the relative humidity.
- Record all test conditions including history of test surface temperature, and

time to fluid failure.

- Develop a draft ‘De-Icing, only,Table’
- Prepare a presentation to the SAE G-12 HoldOver Time Subcommittee.

5.5 Aircraft Full Scale Tests

5.5.1 Purpose of tests

Conduct full scale aircraft tests:

- to generate data which can be used to assist pilots with visual identification of fluid failure;
- to assess a pilot's field of view during adverse conditions of winter precipitation for selected aircraft;
- to assess whether Representative Surfaces can be used to provide a reliable first indication of anti-icing fluid failure;
- to explore the potential application of point detection sensors to warn the Pilot in Command (P.I.C.) of an 'unsafe to take-off condition';
- to obtain failed fluid contamination distributions and profiles which can serve as inputs to a theoretical program designed to assess the effects of such contamination on possible aircraft take-off performance; and
- to compare the performance of de/anti-icing fluids on aircraft surfaces with the performance of de/anti-icing fluids on flat plates.

5.5.2 Test Locations

Conduct tests at the Central De-icing Facility, Dorval International Airport, Montreal using aircraft made available by airlines.

Contingency plans shall be made to conduct tests at alternative sites: Ottawa, Uplands Airport; Quebec City, Ancienne Lorette Airport.

Tests shall be performed at the new central de-icing facility. Coordinate with the facility operator for application and clean-up of fluids.

5.5.3 Facilities to be Provided

Provide all necessary equipment and facilities for conduct of the tests. Negotiate provision of ancillary equipment and services where possible with the pertinent airlines. Notify TDC of such arrangements. Equipment shall include lighting fixtures as necessary, observation platforms, vehicles, storage facilities, office facilities and personnel rest accommodation. Additional facilities and test equipment, if required, may be requested subject to agreement by all parties involved.

5.5.4 Test Plans

Prepare Test Plans for full-scale aircraft tests to include the following:

a) A detailed statement of work for each of the participants;

b) A specific test plan, for review by all parties, which will include as a minimum:

- Schedule and sequence of activities;
- Detailed list of responsibilities;
- Complete equipment list;
- List of data, measurements and observations to be recorded; and
- Test procedures.

c) A list of test activities including:

- Visual and Instrumented Data Logging;
- Monitoring and recording environmental conditions, including:
  - Air temperature,
  - Wing surface temperature at selected locations,
  - Wind velocity and direction, and
  - Precipitation type and rate;
- Record of aircraft and plate orientation to the wind; and
- Use of instrumentation to determine the condition of the fluid.

d) Data to be acquired from the tests including:

- Identification of fluid failure criteria;
- Location and time of first point of fluid failure on the wing, and of subsequent failure progression;
- Correlation of fluid failure time to environmental conditions;
- Correlation of fluid failure times on flat plates and aircraft; and
- Behaviour of fluid on the "representative" surface.

Plans shall include concurrent comparison tests of fluids on flat plates with the aircraft tests.

Present plans for review and approval by the TDC project officer.

Present the approved program to the airline and de-icing facility operator involved prior to the start of field tests.

5.5.5 Test Scheduling

Schedule tests on the basis of forecast freezing precipitation.

Notify the airline and de-icing facility operator in advance of the desired test set-up, including aircraft orientation with respect to the forecast wind direction, sequence of fluid applications, and any additional services requested.

Confirm that the de-icing equipment used for the tests is equipped with a nozzle suitable for the application of the pertinent fluids. Application of fluids will be by de-icing facility operator personnel.

5.5.6 Personnel and facility preparation

Recruit and train local personnel who will conduct test work.

Secure necessary approvals and passes for personnel and vehicle access for operation on airport airside property.

Provide all equipment and all other instrumentation necessary for conduct of tests and recording of data.

Arrange (with the cooperation of TDC) for deicing equipment and aircraft to be made available for the tests .

Arrange for the provision of fluids for spraying an aircraft.

Arrange for spray application during the initial tests to be observed by the fluid manufacturer's representative for endorsement.

5.5.7 Aircraft, De-Icing Pads and Crews

Planning shall be based on the following aircraft and facilities:

Aircraft	Airline	Test Locn.	De-Icing Pad	De-Icing Crew
Canadair RJ	Air Canada	Dorval	Central	Aeromag 2000
DHC-8	Air alliance	Dorval	Central	Aeromag 2000

5.5.8 Dry Runs

Conduct a 'dry run' for test team personnel to ensure familiarity with their requested roles. Dry runs shall be scheduled as early in the winter season as can reasonably be achieved and shall be scheduled at the participating airline's convenience. Operations shall include Type I and Type IV fluid applications and re-orientation of the aircraft.

5.5.9 Full-Scale Tests

Conduct up to 8 full all-night test sessions.

Note: In general, aircraft will be made available for testing outside regular service hours, i.e. available between 23:00 hrs. and 06:00 hrs. Subject to weather conditions additional test sessions may be requested.

Tests shall be conducted under a selection of the following conditions:

Aircraft orientations:	Headwind, Crosswind, Tailwind
Precipitation:	Snow, Freezing drizzle (If possible)
Fluids:	Type I, Type IV ʻUltraʼ and Octagon.
Engine Operations:	Anticipate dry run & full scale tests with engines running for Turbo-prop aircraft.

The following matrix of tests is anticipated:

Aircraft	No. of Tests	A/C Orient's*	Comments
Canadair RJ	1	T, C, H	Dry Run
Canadair RJ	4	T, C, H	
DHC-8	3	T, C, H	Engines running
Total Tests	7 + 1 dry run		

T = Tail Wind, C = Cross- Wind, H = Head Wind

5.5.10 Priority of Tests

Initial planning for tests shall be based on the matrix of tests covered by items 5.5.7 and 5.5.9, above.

Plans shall be made such that the number of tests with each aircraft and sequence of tests can be easily revised.

5.5.11 Aircraft Orientation and Fluid Application:

Tests shall be conducted in the following sequence: Tail to wind, Cross wind, Head wind.

Type IV tests shall be conducted with UCAR ULTRA, unless otherwise indicated.

For tests with Tail to wind and Nose to wind, Type I fluid shall be applied to the port wing, and Type I fluid followed by Type IV fluid shall be applied to the starboard wing in a standard 2-step application procedure. Tests with Type I fluid, only, shall be repeated without change in aircraft orientation until failure of the Type IV fluid.

For cross-wind tests both wings shall be treated with Type I only and observations of fluid behaviour shall be to failure of the fluid on both wings.

Under conditions of light precipitation when the expected time to failure of the Type IV fluid is judged to be be 'excessive' the Type IV test shall be aborted, and the aircraft re-orientaion shall proceed for further Type I tests.

Under conditions of heavy precipitation when the expected time to failure of the Type IV fluid is judged to be be 'short', Type IV test(s) shall also be conducted in a cross-wind, with the same fluid application to both wings.

A maximum of three (3) Type I tests and one Type (IV) test are contemplated for each orientation, on a given test night.

5.5.12 Tests with a Canadair RJ

Tests with a Canadair RJ shall include sessions with a local area of the wing having fluid thinly applied. Thickness distribution and history shall be monitored, and observations made to determine whether local fluid failure occurs, and in such an event whether the failure propagates prematurely.

Tests shall also be conducted during a single test session with UCAR ULTRA and with OCTAGON fluids to compare their behaviours.

5.5.13 Tests with Turbo-prop aircraft

True functional tests with Turbo-prop aircraft require that the engines should be running.

Gather available information applicable to the ground operations of these aircraft in regular service. Based on observation and the observations of others, assess the influence of propeller 'wash' on fluid flow-back patterns, and on precipitation behaviour, particularly under cross wind conditions.

Particular consideration shall be given to safety. In the event of conflict between access for data gathering to obtain required test results and safety considerations, safety shall govern.

5.5.14 Test Measurements

Make the following measurements during conduct of each test:

Contaminated thickness histories at points on wings, selected in cooperation with TDC.

Contamination histories at points on wings to be selected in cooperation with TDC.

Location and time of first failure of fluids on wings -

Concurrent measurement of time to failure of fluids on flat plates; plates to be mounted on standard frames and on aircraft wings at agreed locations.

Pattern and history of fluid failure Progression.

Wing temperature distributions.

Amount of fluid applied in each test run, and fluid temperature

Meteorological conditions.

5.5.15 'Clean' Fluid Thickness Measurements

In the event that there is no precipitation at the time of the dry run, or during full scale tests, advantage shall be taken to make measurements of fluid thickness distributions on the wings. These measurements shall be repeated for a number of fluid applications to assess uniformity of fluid application.

5.5.16 Pilot Observations

Contact airlines and arrange for pilots to be present during tests to observe fluid failure and failure progression. Record pilot observations for later correlation with aircraft external observations.

5.5.17 Remote sensor records

Record the progression of fluid failure on the wing using RVSI and/or SPAR remote contamination detection sensors.

5.5.18 Videotape Records

Make videotape records of tests. Provide professional video tape coverage for at least two overnight test sessions.

5.5.19 Return of equipment

Return any equipment obtained from airlines for use during the tests to its original condition at the end of the test program.

5.5.20 Assembly and analysis of results

Assemble and analyze all results.

5.5.21 Flat plate tests

Conduct standard flat plate tests concurrently with the aircraft tests.

One of the flat plates to be used for flat plate measurements of fluid behaviour in all tests shall be fitted with a C/FIMS sensor.

5.6 Documentation of Pilot field of View, and Wing Visibility

5.6.1 Aircraft Types

Document the area of the wing that is visible to the PIC from inside the cockpit and from inside the cabin for as many aircraft types in service in Canada as can reasonably be checked. Aircraft types shall include at least DC-9, B-767, Canadair RJ, DHC-8 and Bae-146.

5.6.2 Lighting Conditions

Area of visibility shall be recorded under conditions of ‘normal’ daylight, and at night under conditions of precipitation with on-board lighting, only.

5.6.3 Documentation

Provide sketches, illustrations and photographic records of the visible area(s) of the wing.

5.7 Documentation of the Appearance of Failed Fluids

5.7.1 Tests

Conduct flat plate tests in the NRC CEF laboratory, and in the field designed to address the following issues:

What is the appearance of a failed fluid.

How does the appearance of a Type I fluid failure differ from a Type IV fluid failure.

How does the appearance of failure under conditions of freezing drizzle differ from failure under conditions of freezing rain, and under conditions of snow fall.

Under what conditions do de/anti-icing fluids “Flash freeze”.

Are there differences in failure appearance between ethylene-, and propylene-glycol fluids when exposed to freezing drizzle.

Do strong winds significantly affect failure appearance.

5.7.2 Records

For each test record the following information with appropriate instrumentation:

Fluid thickness history at selected locations.

Viscosity history at selected locations.

Refractive Index history at selected locations.

Video camera appearance of flat plate at time of fluid failure.

Video camera appearance of ‘cross-hair’ detail at time of fluid failure.
RVSI remote sensor record of fluid failure.
SPAR/COX remote sensor record of fluid failure.
C/FIMS point sensor record of fluid failure.

and record the description of the visual appearance of fluid failure

5.7.3 Documentation

For each test provide the following documentation:

Record of purpose of test, and test conditions.
Photographic record of initiation and progression of failure.
Output ‘traces’ for each of the three sensors as a function of time.
Fluid freeze point temperature history.
Fluid viscosity history.
Fluid thickness history.
A subjective determination of failed fluid adherence, together with criteria used.

5.8 Potential use of Remote Sensors for End-of-Runway inspection

5.8.1 Preparation

Purpose of the task is to determine the problems and possible solutions with respect to operation of remote sensors for to supplement the PIC’s visual pre-takeoff contamination inspection.

Arrange for installation of a SPAR/COX remote sensor to be installed on a mobile vehicle.

Arrange with pertinent agencies having jurisdiction for the sensor and vehicle to be operated on a trial basis suitable for conduct of pre-takoff inspection of aircraft at, or close to, the end of runway immediately prior to start of the take-off roll.

Anticipated duration of the test period will be approximately two weeks and shall encompass at least two periods of freezing precipitation.

5.8.2 Records

Anticipated problems include:

accessibility of the vehicle to the end of runway,
liasion with the tower
communication between vehicle, tower, and aircraft,
responsibility for communication of sensor observations to the PIC,
qualifications required for the vehicle/sensor operator.

Solutions to these problems will be reported.

5.8.3 Sensor Outputs

Sensor electronic outputs shall be recorded for analysis at the end of the winter season. During conduct of the task the sensor operator shall NOT report the sensor observations of the condition of the aircraft critical surfaces.

5.9 Taxi Times under conditions of Precipitation

Record and report taxi times from start of hold-over time to start of take-off roll (Nominal time of conduct of the pre-takeoff inspection) under conditions of winter precipitation to assess actual taxi times experienced and the impact of conditions of precipitation on ground operations.

Record and report taxi times under daylight conditions in the absence of precipitation, for aircraft requiring de-icing only, in order to provide reference times for sample runway use.

5.9.1 Locations

Collect data for operations at Montreal, Dorval Airport, and at Toronto, Lester B. Pearson Airport, and supply any additional relevant data as may be readily available.

5.10 Support for Review of Alternative Technologies

Provide support services for the evaluation of an infra-red heating device to be demonstrated by Infra-Red Technologies Inc. as a low cost and zero environmental impact alternative technology for aircraft de-icing.

5.11 Provision of Support Services

Provide support services to assist with reduction of data and presentation of findings in areas related to the content of this work statement, but not specifically included.

5.12 Presentations of test program results

5.12.1 Preliminary Findings

Prepare and present preliminary findings of test programs involving field tests with aircraft to representatives of Transport Canada and the Airlines involved at end of the test season, but no later than May 30 1997.

5.12.2 Presentation of findings to the SAE

Participate at the SAE meeting to be held in Vienna in May1998, and present the results of the work conducted during the winter season 1997/98.

5.13 Reporting

Reporting shall be in accordance with section 10 "Reporting", below.

Separate final reports shall be issued for each area of activity consistent with the project objectives.

APPENDIX B

EXPERIMENTAL PROGRAM PROCEDURE FOR THE DOCUMENTATION OF FAILED FLUIDS

CM1380.001

EXPERIMENTAL PROGRAM
PROCEDURE FOR THE DOCUMENTATION OF THE APPEARANCE OF FAILED FLUIDS FOR OUTDOOR TESTS

Winter 1997-98

APS AVIATION INC.

October 9, 1998
Version 1.1

EXPERIMENTAL PROGRAM
PROCEDURE FOR THE DOCUMENTATION OF THE APPEARANCE OF FAILED FLUIDS FOR OUTDOOR TESTS

Winter 1997-98

1. OBJECTIVES

APS will conduct flat plate tests in the National Research Council Canada (NRC) Climatic Engineering Facility laboratory, and in the field designed to address the following issues:

- What is the appearance of a failed fluid;
- How does the appearance of a Type I fluid failure differ from a Type IV fluid failure;
- How does the appearance of failure under conditions of freezing drizzle differ from failure under conditions of freezing rain, and under conditions of snowfall;
- Under what conditions do de/anti-icing fluids *flash freeze*;
- Are there differences in failure appearance between ethylene, and propylene glycol fluids when exposed to freezing drizzle; and
- Do strong winds significantly affect failure appearance.

2. TEST PROCEDURES

- Flat plate tests will be conducted at the Dorval test site and at the NRC Climatic Engineering Facility in Ottawa for comparison purposes.

- Flat plate tests will be conducted using the same procedures as shown in the *Experimental Program for Dorval Natural Precipitation Flat Plate Testing*.

- For each test, the following additional information should also be recorded:
  - i) Fluid thickness at selected locations;
  - ii) Fluid viscosity at selected locations;
  - iii) Refractive index (Brix) at selected locations;
  - iv) Video and photos of the plate and crosshairs at the time of fluid failure;
  - v) RVSI sensor record of fluid failure;
  - vi) Spar/Cox sensor record of fluid failure;
  - vii) C/FIMS point sensor record of fluid failure; and
  - viii) Fluid adherence at selected locations.

- Plate pan rates should be measured every five minutes. Three or four pans should be used.

- Fluid thickness measurements should be taken at the 15 cm (6") line at the start of the test and every two minutes thereafter for Type I tests and at the start of the test and every five minutes thereafter for Type IV tests. Thickness measurements and times should be noted on the data form (Figure B-1). Refer to the detailed procedure in Transport Canada report, TP 13130E, Appendix C (Attachment VI).

- Fluid quantity applied to plate should be 1.5 L for outdoor tests and tests conducted at the NRC Climatic Engineering Facility.

- Fluid viscosity samples should be collected at the point of fifth crosshair failure. A 10 mL sample should be collected using a spatula and placed in an air-tight sample container. Sample containers should be labelled with a date, sample collection time, stand and run number, fluid type and plate number. Because of the destructive nature of the sample process, it is recommended that a separate plate be run solely for the purpose of collecting samples.

- The refractive index of each fluid should be taken prior to application using a hand-held refractometer and recorded on the Brix data form (see Figure B-2). For Type I tests, samples should be collected at two-minute intervals thereafter on a crosshair adjacent to the C/FIMS. For Type IV tests, top and bottom fluid samples will be collected at five-minute intervals on a crosshair adjacent to the C/FIMS. Top samples will be obtained by resting a piece of plastic film on the surface of the fluid. Bottom samples will be taken with a syringe by drawing small amounts of fluid at several points near the sample location. Brix values and corresponding sample times should be recorded accurately on the Brix data form (use one form per test plate). Brix of the mixed fluid should also be measured on an adjacent location.

- Fluid application, initial plate failure, 7.5 cm (3") failure, 15 cm (6") failure (15 crosshairs) and entire plate failure should be recorded using a digital video camera and 35 mm still camera. Records should be taken from the front and back of the stand. In addition, a video camera mounted on a tripod should be focused on one crosshair on the 15 cm (6") line to record precipitation absorbency.

- Personnel must ensure that the RVSI and Spar/Cox sensors, and C/FIMS point sensors are operational prior to each test and are left running until complete plate failure. Also, when measuring brix and thickness etc. on the 15 cm (6") line, do not disrupt the fluid over the C/FIMS sensor head (take measurements on an adjacent crosshair).

- Fluid adherence should be determined at the 15 cm (6") line immediately following failure at this location (not over the C/FIMS). When the entire plate (15 crosshairs) has failed, again verify the fluid adherence at the 15 cm (6") line on the opposite crosshair. Adherence should be noted by the plate observer on plate data form.

FIGURE B-1

FLUID THICKNESS ON FLAT PLATES

DATE: ____________________

OAT (°C): ____________________

RUN NUMBERS: ____________________

PERFORMED BY: ____________________

LOCATION: YUL

WRITTEN BY: ____________________

<table>
<tr><th colspan="8">THICKNESS (mil)</th></tr>
<tr><td colspan="4">Plate: Fluid:
Fluid Application Time:</td><td colspan="4">Plate: Fluid:
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FIGURE B-2

BRIX DATA FORM

Location: ______________________________ C/FIMS #:

Date: ______________________________ Plate:

Run #: ______________________________ Time of fluid application:

Sample location:

Time	**Brix Top**	**Brix Bottom**
____________	____________	
____________	____________	
____________	____________	
____________	____________	
____________	____________	
____________	____________	
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Comments:

3. PERSONNEL

Personnel requirements for the conduct of documentation of the appearance of failed fluid tests for outdoor tests are:

- One Test Coordinator (NB);
- One End Condition Tester (monitor the progression of failures on the plates) (MC);
- One Meteo Tester (measure plate pan weights, record meteo, ensure sensors are operational);
- Two General Observers (measure and record brix, adherence and thickness, collect samples);
- One Photographer (take photographs of fluid application and failures); and
- One Video Tester (video fluid application and failures, ensure that the fixed video camera for recording precipitation absorbency is operational).

4. EQUIPMENT

A kit comprising the following equipment should be prepared for the conduct of documentation of failure tests:

- Thickness gauges;
- Sample bottles;
- Spatulas;
- Hand-held refractometer;
- Plastic film;
- Syringe;
- Two video cameras (one digital);
- One video camera tripod;
- 35 mm camera; and
- Adherence tester.

TABLE B-1

DOCUMENTATION OF FAILURES

#	Activity Description	Location	Temp °C	Wind	Precip. type	Rate g/dm^2/h	Fluid brand	Fluid Type	Concentration
1	Appearance of Type I vs Type IV failures	AES	0 to -5	<10kph	Snow	5 to 20	UCAR ADF UCAR Ultra+	I IV	XL54 Neat
2	Appearance of Type I vs Type IV failures in high wind conditions	AES	0 to -5	>20kph	Snow	5 to 20	UCAR ADF UCAR Ultra+	I IV	XL54 Neat
3	Appearance of Type IV failures in ZD vs Type IV failures in ZR	NRC	-10	N/A	ZD/ZR		Kilfrost ABC-4 Octagon MaxFlight	IV IV	Neat Neat
4	Ethylene vs propylene Type IV failures in ZD	NRC	-10	N/A	ZD		UCAR Ultra+ Kilfrost/Octagon	IV IV	Neat Neat
5	Time for Type I and Type IV failures to adhere to the plate following failure	AES	0 to -5	N/A	Snow	5 to20	UCAR ADF UCAR Ultra+	I IV	XL54 Neat
6	Time for Type I and Type IV failures to adhere to the plate following failure	NRC		N/A	ZR		UCAR ADF UCAR Ultra+	I IV	XL54 Neat
7	*Flash freeze* of Type I or Type IV 50/50 in ZD/ZR.	NRC	0 to -3	N/A	ZD/ZR		UCAR ADF Hoechst	I IV	XL54 50/50
8	Appearance of failures in wet vs dry snow	AES	0 to -5	N/A	Snow	5 to 20	UCAR Ultra+	IV	Neat
9	Appearance of high rate vs low rate Type IV fluid failures (snow bridging).	AES	0 to -5	N/A	Snow	5 to 10 >20	UCAR Ultra+	IV	Neat

APPENDIX C

FLUID DOCUMENTATION

DOCUMENTATION OF FLUID FAILURE

SUMMARY OF TESTS CONDUCTED

Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Precipitation Type	ZD	ZD	ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZD	ZD	ZD
Rate (g/dm²/h)	10	10	25	25	25	25	25	25	25	25	25	13	5	5
OAT (°C)	-10	-10	-10	-10	-10	-10	-10	-4	-4	-4	-4	-4	-10	-10
UCAR XL54			5	7				14			18			
UCAR Ultra+	1	4		6	9			13			19	20 22	24 27	
Octagon MaxFlight	2	3			8	11				16		21 23	25 26	
Kilfrost ABC-S						10	12							
SPCA AD-480														28
SPCA AD-480 (50%)									15	17				

NB: Values in cells represent test numbers.

GENERAL TEST INFORMATION

ID # 1

July 8, 1998

Ambient Air Temperature:	-10.3°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	10.4 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	11:13:10
Failure Mode:	5th X-hair
Failure Location:	D2
Failure Time (Standard):	12:03:00
Failure Time (Complete Plate):	12:19:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 1

Photo C1.1 - After Pouring, t = 0 min (Est.)

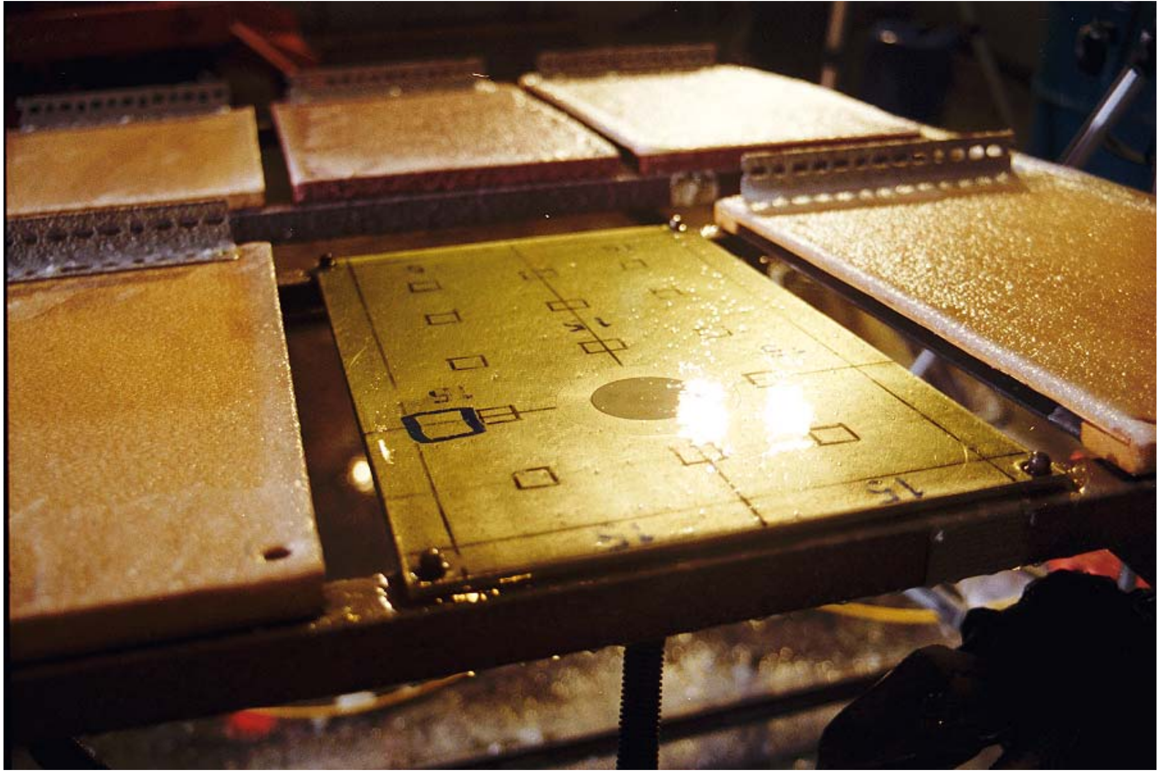
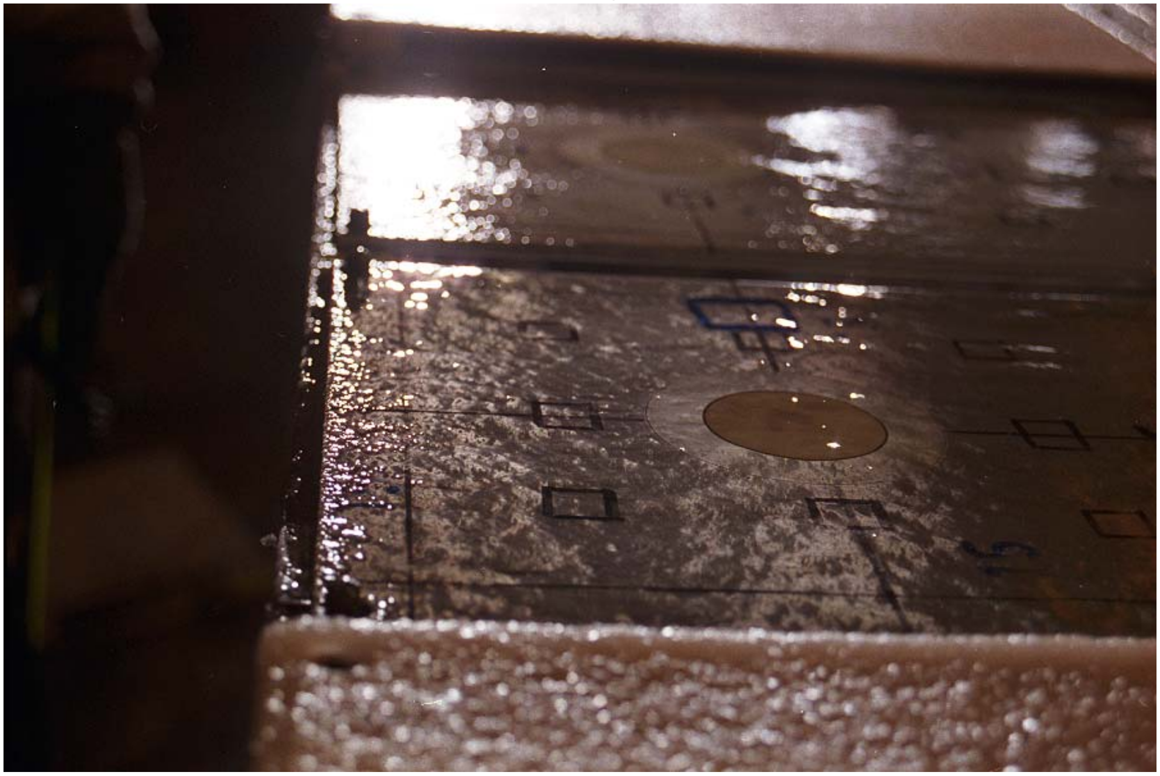


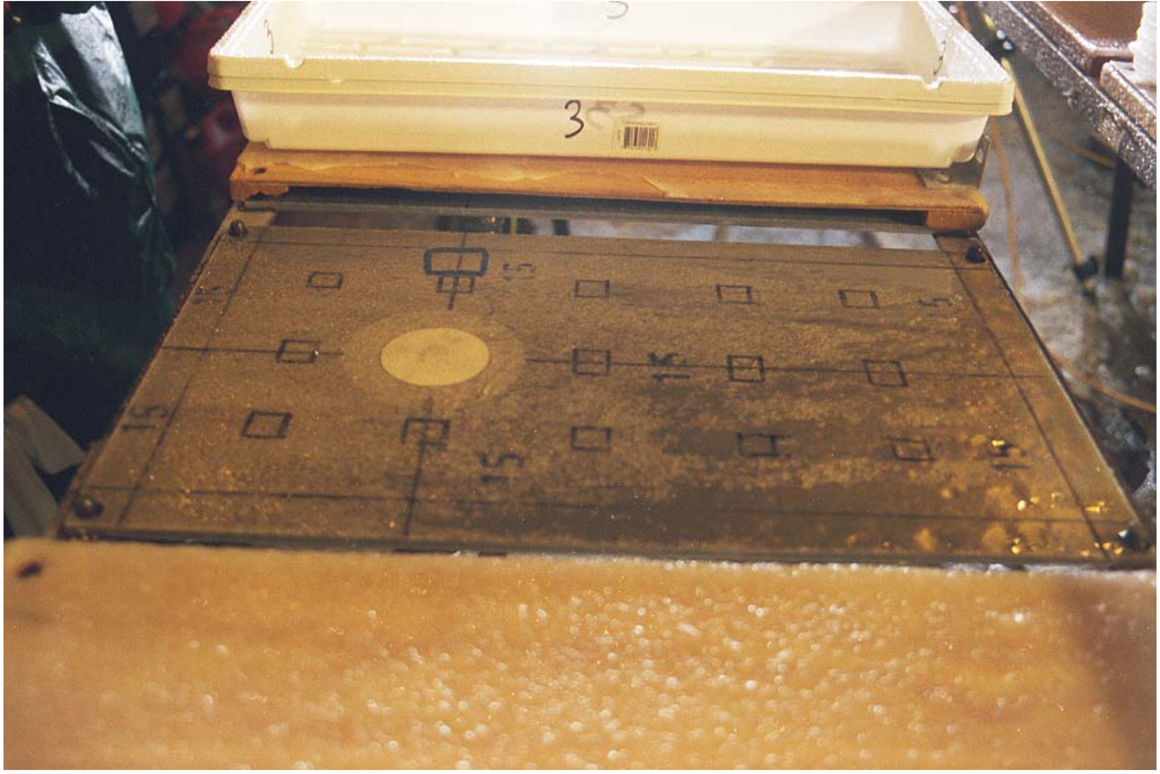
Photo C1.2 - 1st Failure, t = 37 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 1

Photo C1.3 - Standard Failure (1/3 or 5th Crosshair), t = 50 min (Est.)

Photo C1.4 - Complete Fluid Failure, t = 66 min (Est.)



FLUID STRUCTURE/TEXTURE
speckle size ~ 1-2 mm
orange peel size ≤ 5 mm to ≥10 mm.
marble size 1 ~~to~~ 2 cm (cells with no sharp discontinuities between thicker and thinner fluid areas)

ID I

SUBJECTIVE APPEARANCE OF FLUID FAILURE

ZID
-10°C
Rate 10 (13 proposed)

Date: July 08

Time: 1113 20

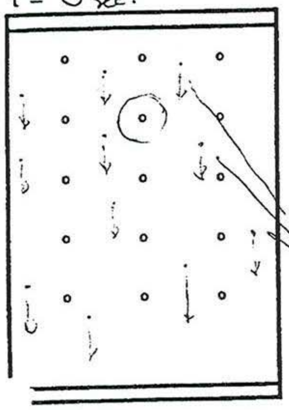
Plate Location: 2

Run #: 3a1

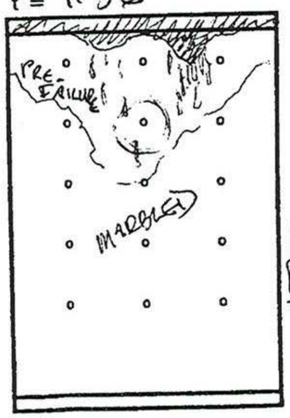
Fluid Name: ULTRA+

Fluid Dilution: 100%

t = 0 sec.



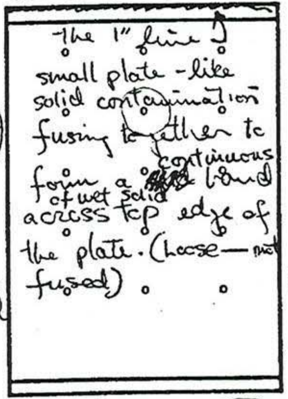
t = 1156



POUR:
smooth shiny surf.
green clear (transparent) fluid with random, small air bubbles which are mostly suspended below fluid surface and persist and flow with the bulk movement of the fluid down the plate. They (bubbles) are released only after appreciable dilution.

11:14: fluid flow is slow and steady, inspected by bubble movement in fluid. (ie "Steady State" flow — apparent! — not measured! —

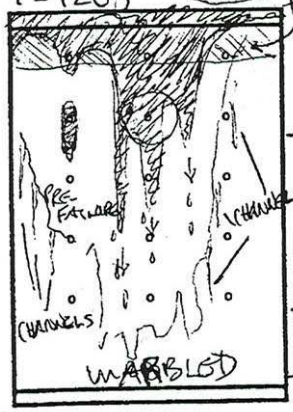
t = 1133 init failure outside



The 1" line!
small plate-like solid contamination fusing together to form a continuous band of wet solid across top edge of the plate. (Loose — not fused)

t = 1205

1208 ADH E3"

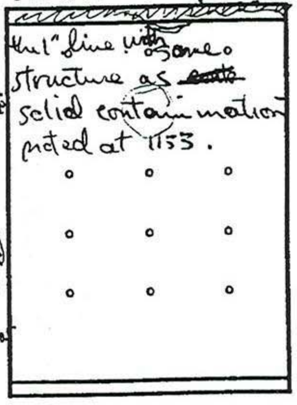


11:18 → 11:22
speckle formation apparent and due to variations in ref. radiu index from localized mixing of drizzle on fluid surface. no immediate solid contamination noted (Difficult to draw!)

Appearance from shallow angle views show a loss of DOI* on surface; - mirror type reflections from surface show very small surface irregularity(ies) - almost like dust particles on surface -

11:25 Mixing of fluid + precip - more efficient - fluid thickness irregularities becoming larger structures - referred to as orange peel or O.P.; still no solids!

t = 1151 initial failure inside



the 1" line with some structure as ~~[illegible]~~ solid contamination noted at 1153.

t = 1219

11:28 Still larger structures in fluid become apparent with the fluid layer taking on a marbled appearance. This is due to larger size variations in fluid thickness from more efficient mixing (Fluid pre-thinning phase).

1130 Top of plate appears to be thinning out (pre-marbled ~~failure~~ cond.)

~~- A thin dilute fluid which undergoes rapid failure~~
~~1150 [illegible] whole plate surface for very top (showing) marbled condition~~
MORE ON BACK →

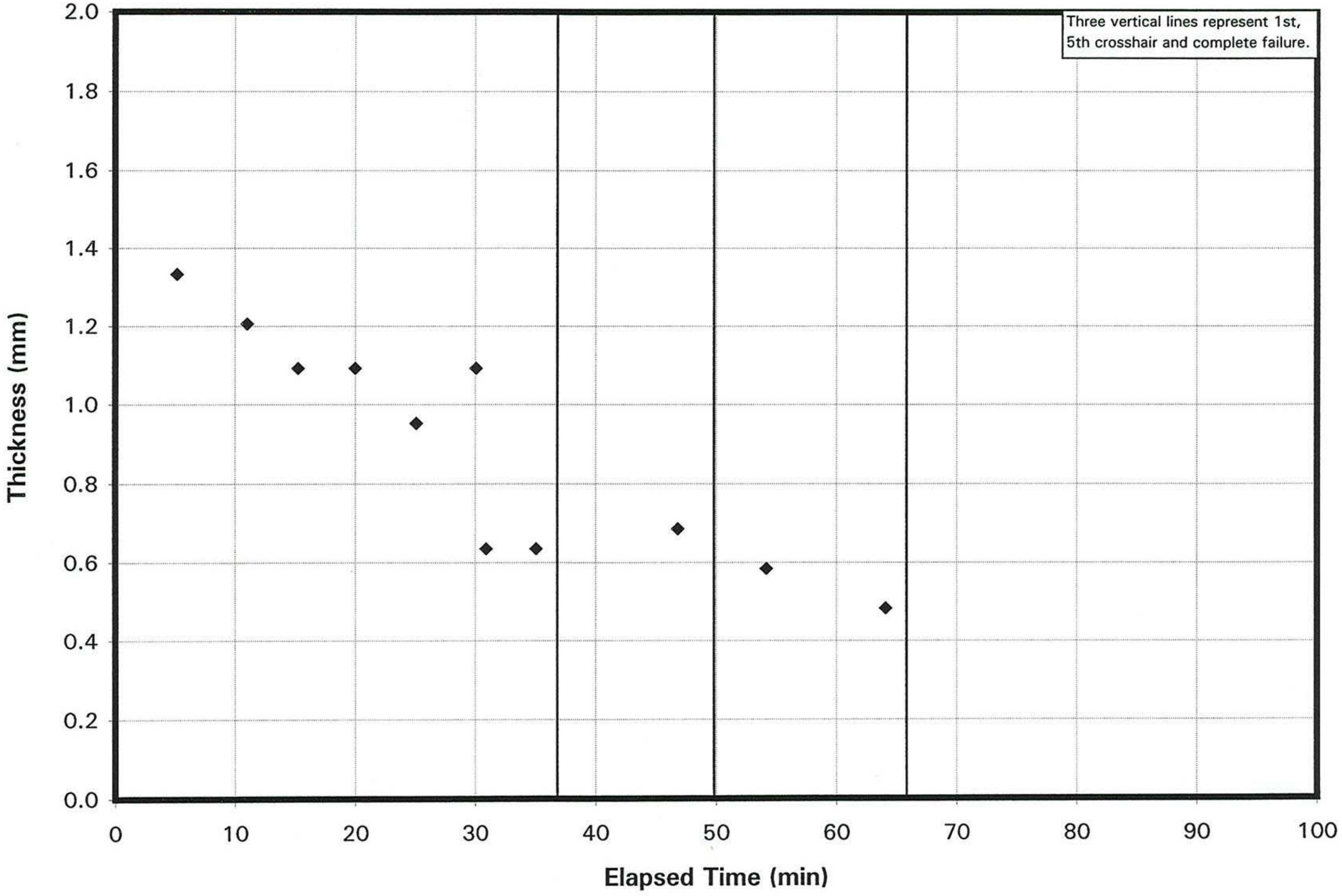
Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

*DOI = distinctness of image.
i.e., how clear or distinct is ~~the~~ reflected image from the surface = how good is the mirror?!

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 1

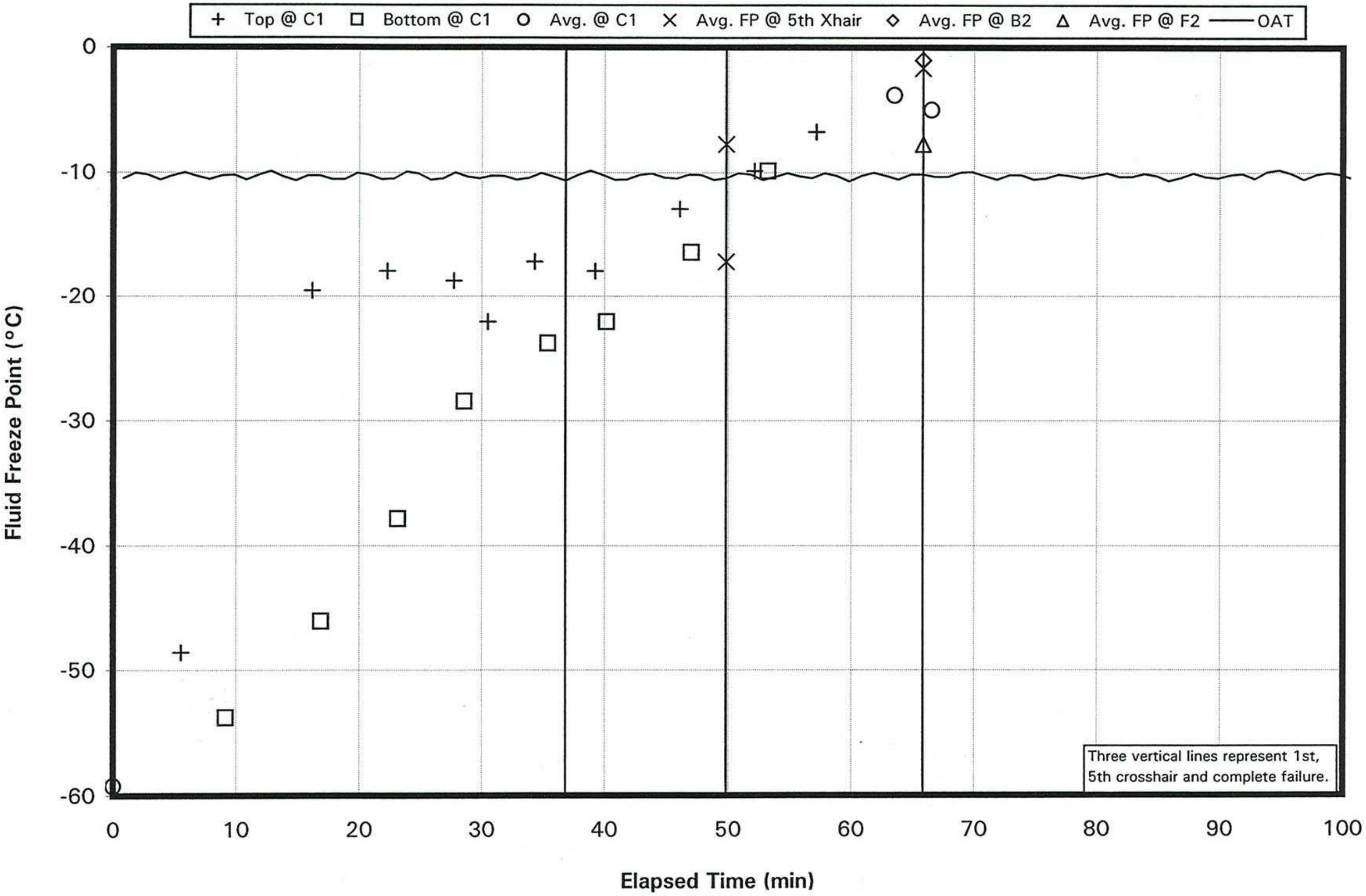


cm1380/analysis/doc_fail/thicknes/Thk_id01
10/22/98, 7:57 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 1



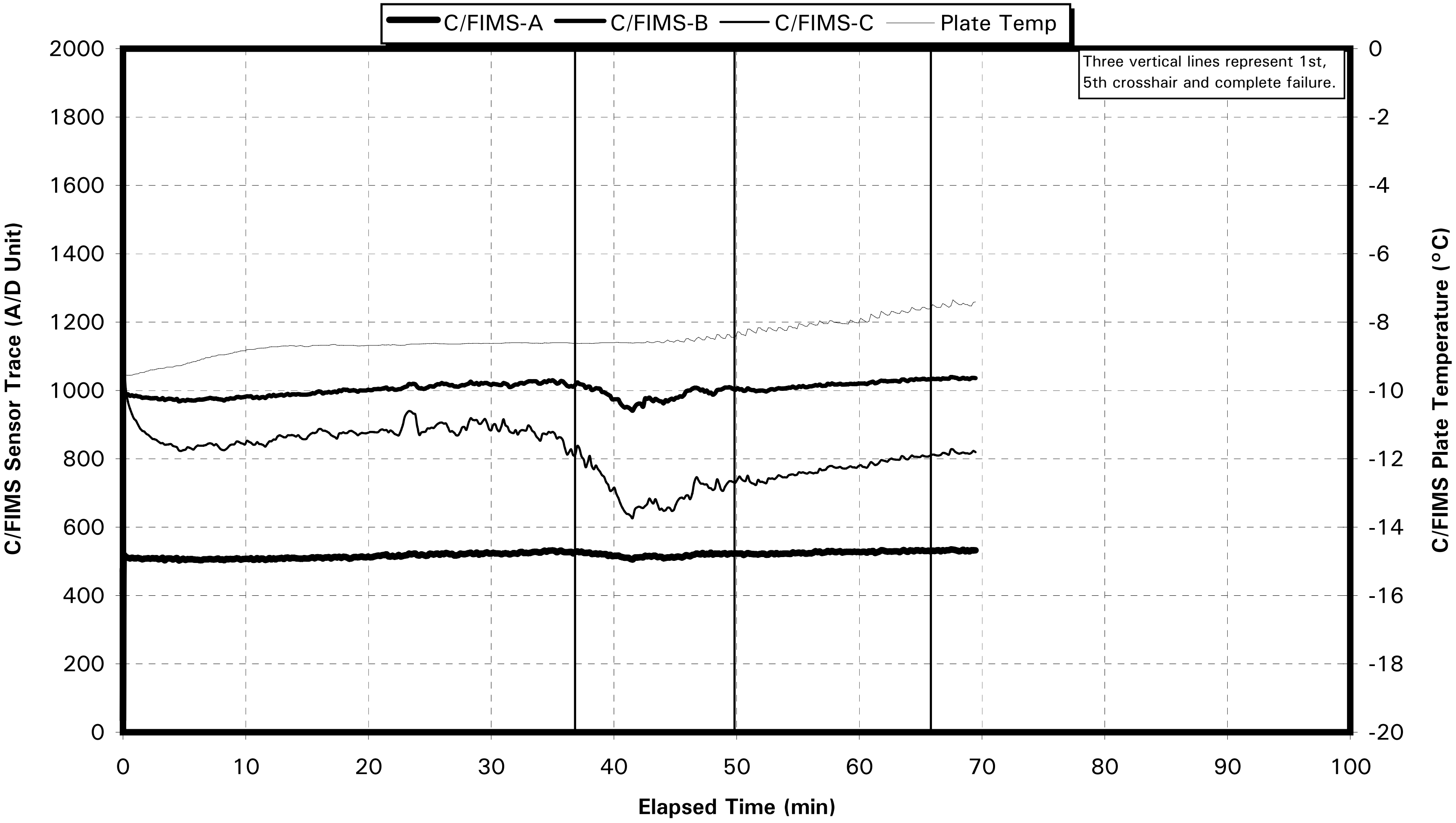
Three vertical lines represent 1st, 5th crosshair and complete failure.

cm1380/analysis/doc_fail/brix/Brx_id01
10/22/98, 7:57 AM

DOCUMENTATION OF FLUID FAILURE

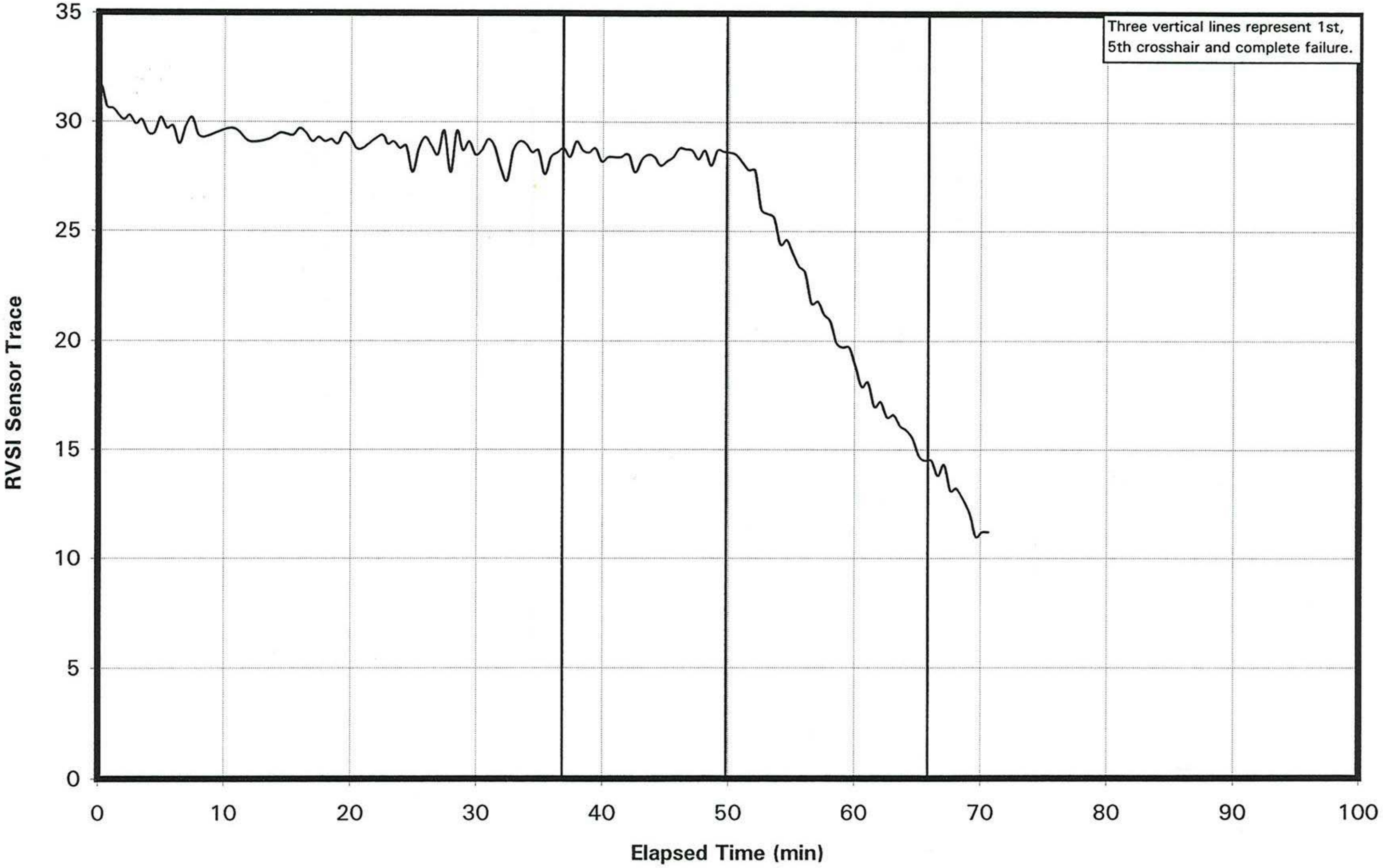
C/FIMS SENSOR TRACE

ID # 1



cm1380/analysis/doc_fail/cfims/CFM_ID01
9/21/2006, 10:34 AM

DOCUMENTATION OF FLUID FAILURE
RVSI SENSOR TRACE
ID # 1



Three vertical lines represent 1st, 5th crosshair and complete failure.

cm1380/analysis/doc_fail/rvsi/Rvs_id01.xls
10/15/98, 11:30 AM

DOCUMENTATION OF FLUID FAILURE

COX/SPAR SENSOR TRACE

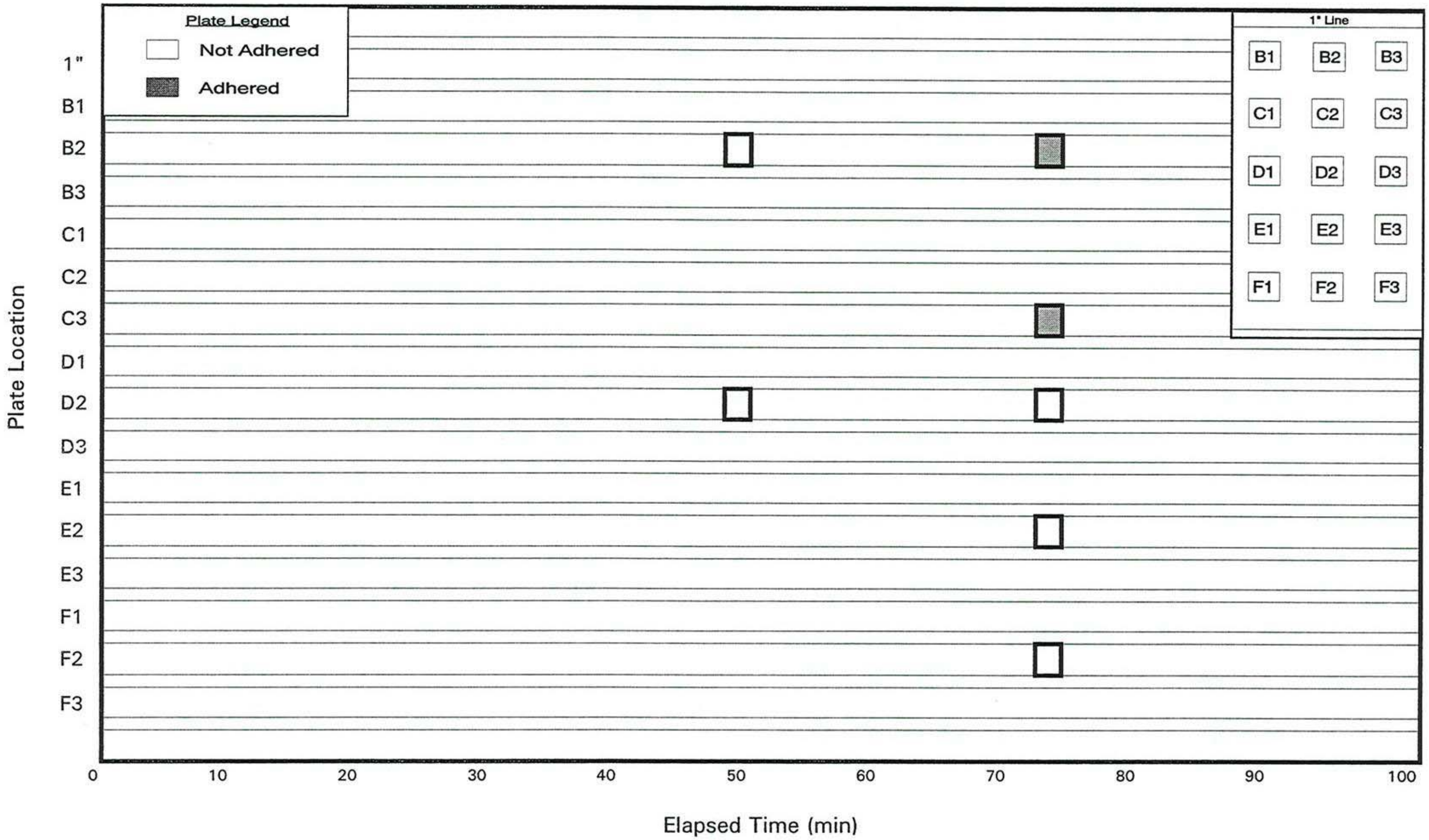
ID # 1

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 1



cm1380/analysis/doc_fail/Adh_id1
At: 1
7/28/98, 9:19 AM

GENERAL TEST INFORMATION

ID # 2

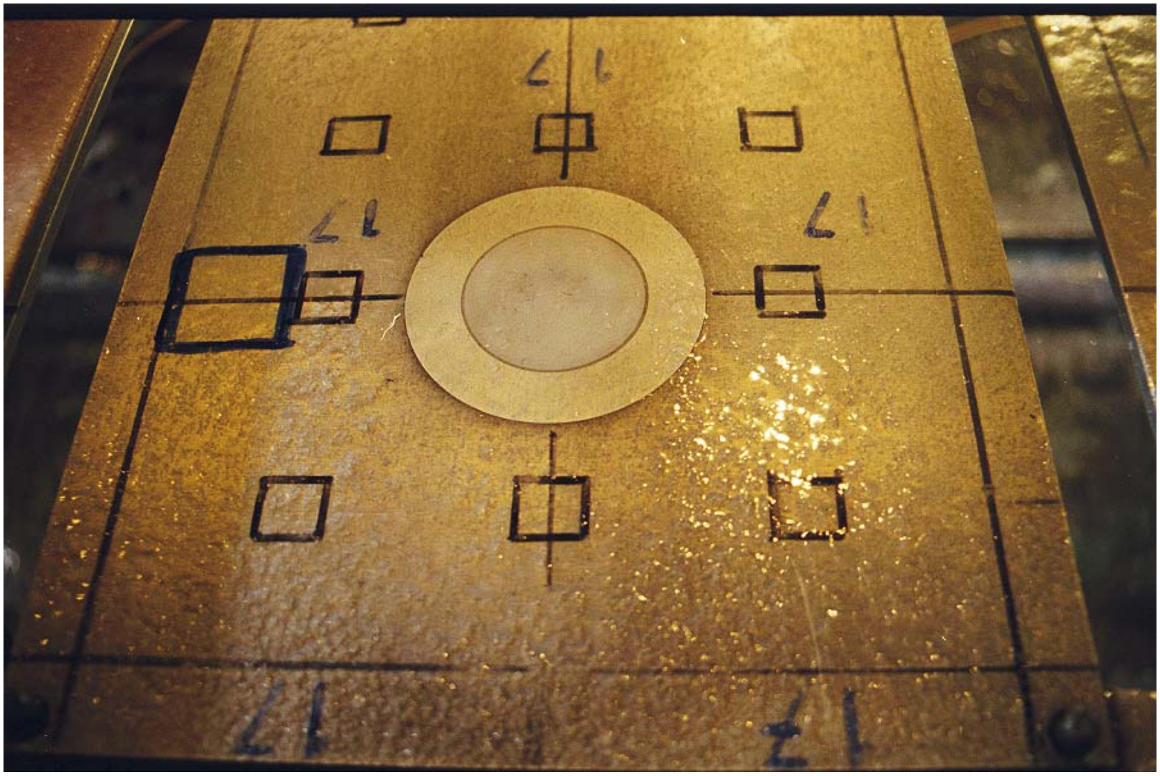
July 8, 1998

Ambient Air Temperature:	-10.3°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	9.8 g/dm²/hr
Fluid:	OCTAGON
Dilution:	Neat
Start of Test:	11:23:05
Failure Mode:	5th X-hair
Failure Location:	C3
Failure Time (Standard):	11:56:00
Failure Time (Complete Plate):	12:07:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 2

Photo C2.1 - After Pouring, t = 0 min (Est.)

Photo C2.2 - 1st Failure, t = 13 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 2

Photo C2.3 - Standard Failure (1/3 or 5th Crosshair), t = 33 min (Est.)

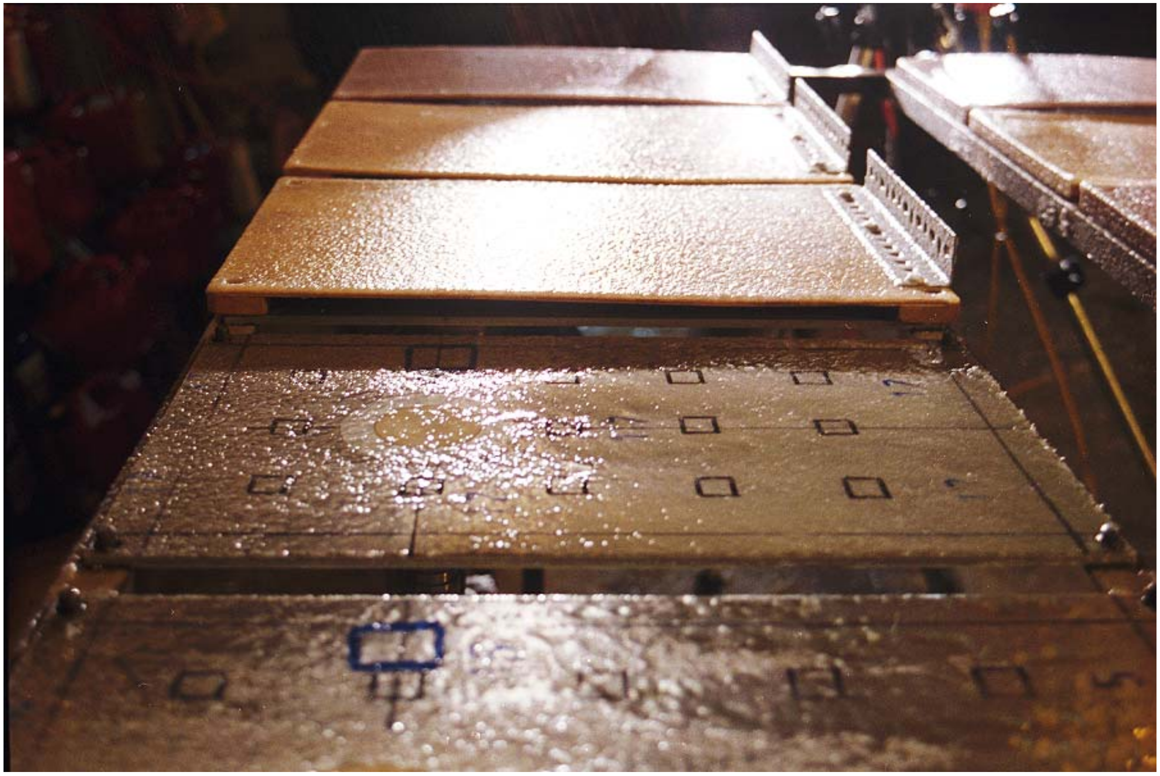


Photo C2.4 - Complete Fluid Failure, t = 44 min (Est.)

\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAILS\SUBJECTV\SUB_ID02.doc
Last printed 10/13/98 2:36 PM

ID# 2

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08

Time: 1123^{30}

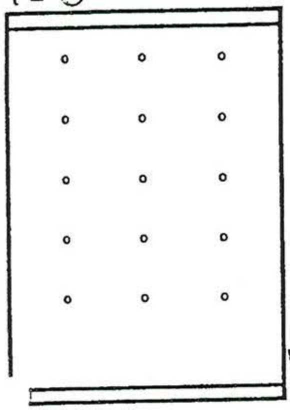
Plate Location: 3

Run #: 3$_{x_2}$

Fluid Name: Oct Max

Fluid Dilution: 100%

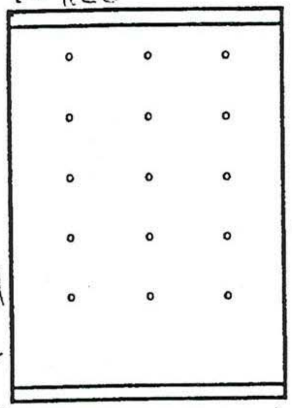
t = 0



Time

smooth shiny srf. green and turbid but still transparent, no bubbles. Ultra smooth surface. 1125 srf still smooth.

t = 1128



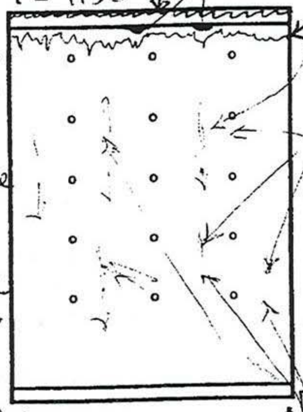
1128

Surface still shiny but not smooth above 6" ~~line. Still no~~ orange peel. Speckle stage not observed as with ULTRA+

1132 top ⅓ of plate beginning to ~~f~~ assume orange-peel texture

1133 top edge failure observed

t = 1133



1136

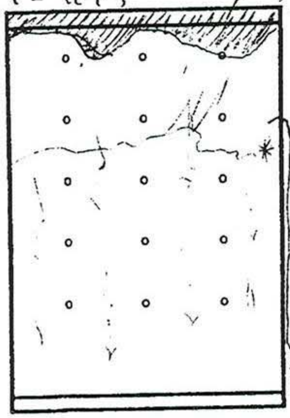
1140 {Beginning of streak-type failure formation cont'd ↓}

1136 initial contam inside top 1" line.

1140 (cont'd) Streaks are mobile on fluid surface. ~~Due to freezing of~~ contaminant droplets ~~which are elongated~~ as they impinge on ~~fluid surface~~ bomb and roll and are ~~finally absorbed~~

V. fine and appear to be amorphous or (gelatinous) i.e. non crystalline

t = 1145

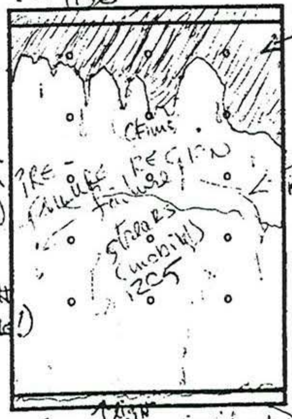


failure area appears to be overlapping small platelets which eventually fuse. [50% failed above 3" line]

Streak contamination more evenly dispersed over plate; surface + susp. in fluid. no ADH and no fusion. (MOBILE!)

upper fluid on plate appears like fine wet sandpaper surface from shallow angle

t = 1156^{20}



Ridge

1155 Ridge of solid contam beginning to accum. at bottom of plate

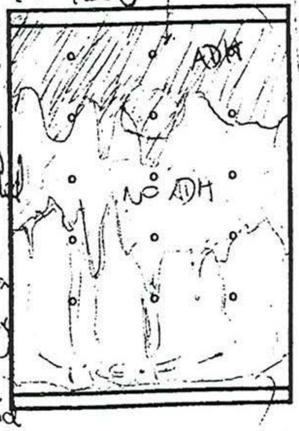
1156 5th X-Hair failed

1205 fluid thinning

*uniformly distributed over entire plate below failed region

Reduced tendency to assume marbled state. PRE-FAILURE condition for this fluid

t = 1208



1208 Complete plate failure

Heavier ridge of failure
—beginning of dam formation

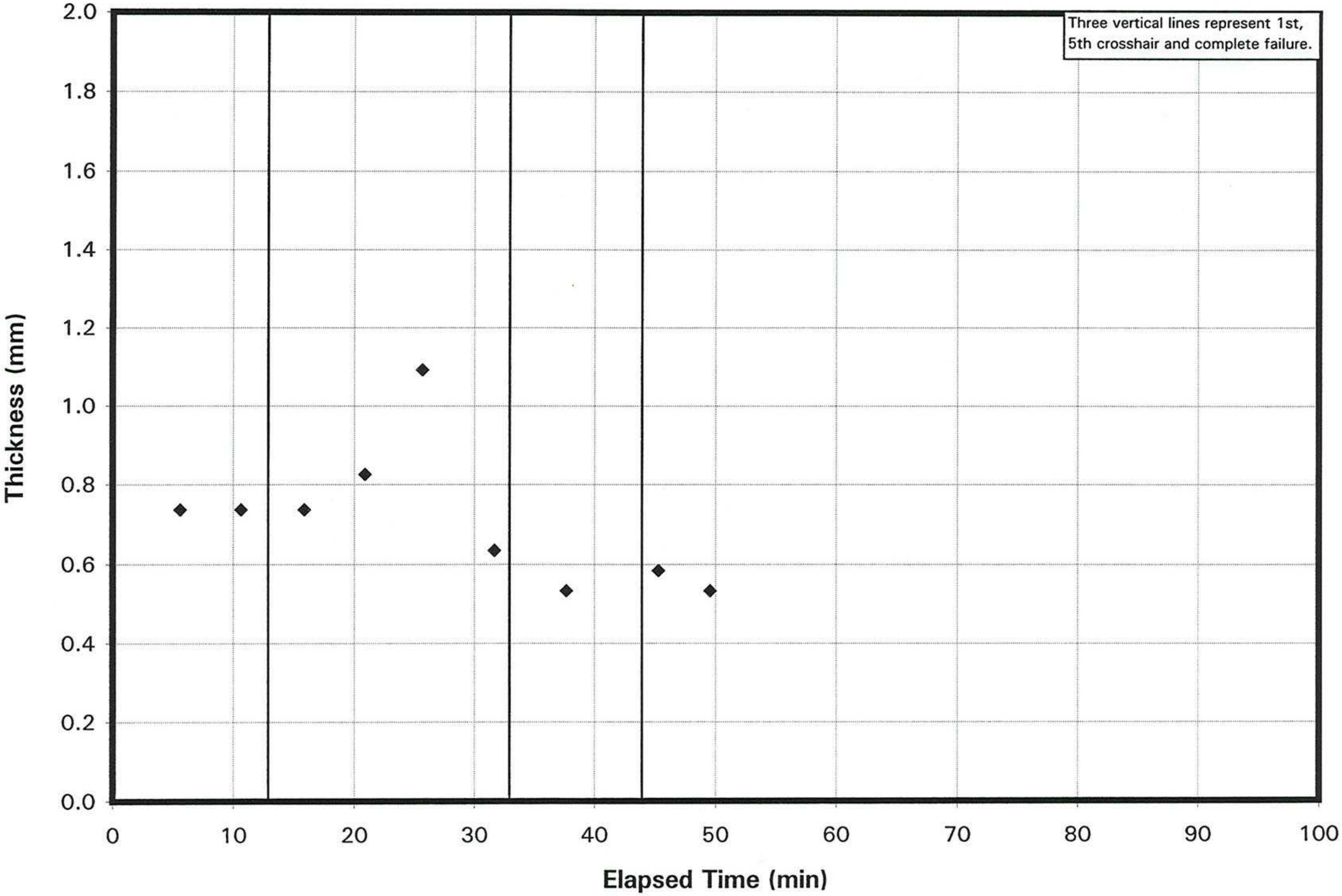
*Gradual transition to smooth surface (lower ½ plate)

Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 2

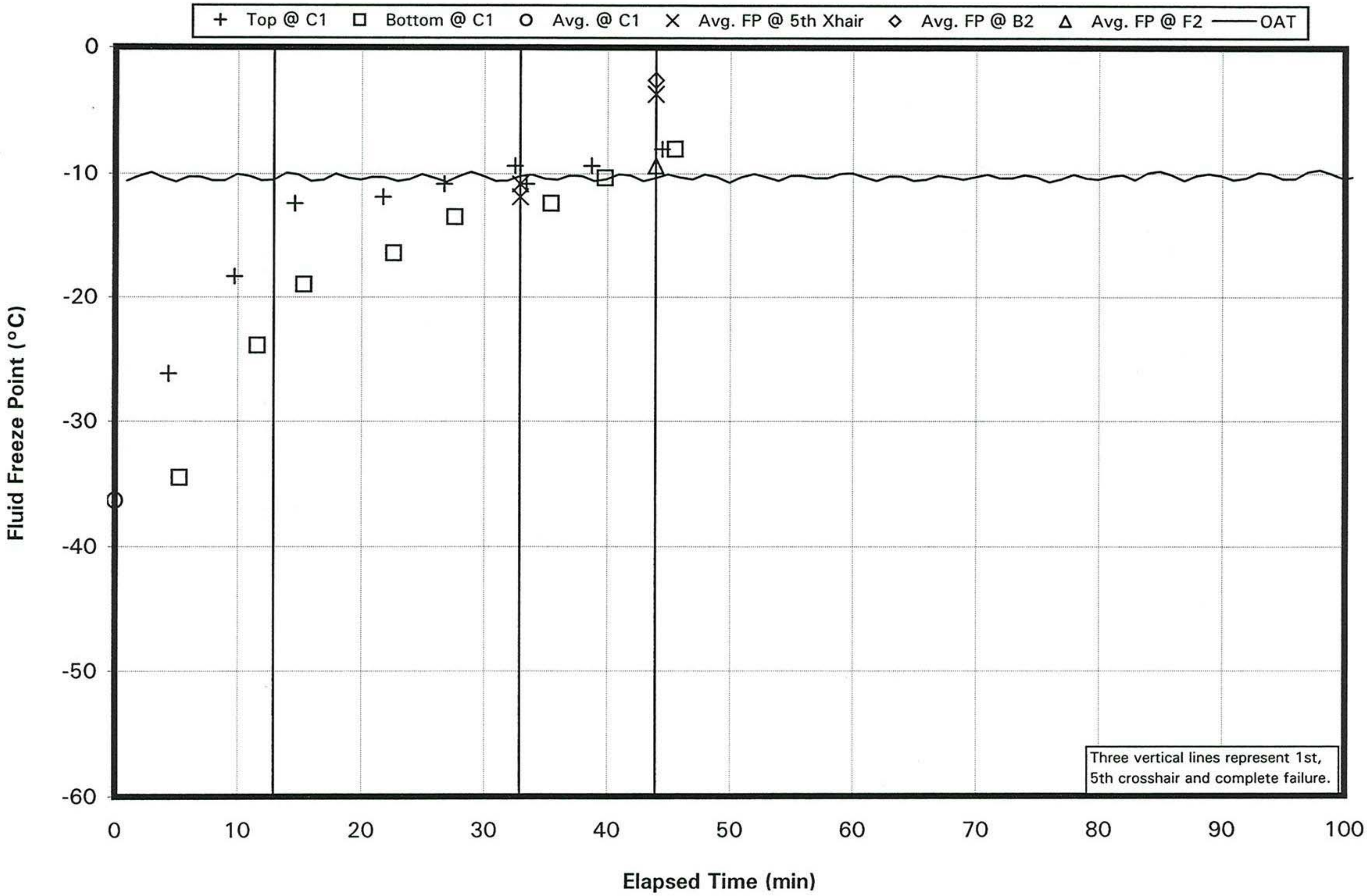


cm1380/analysis/doc_fail/thicknes/Thk_id02
10/14/98, 10:34 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 2

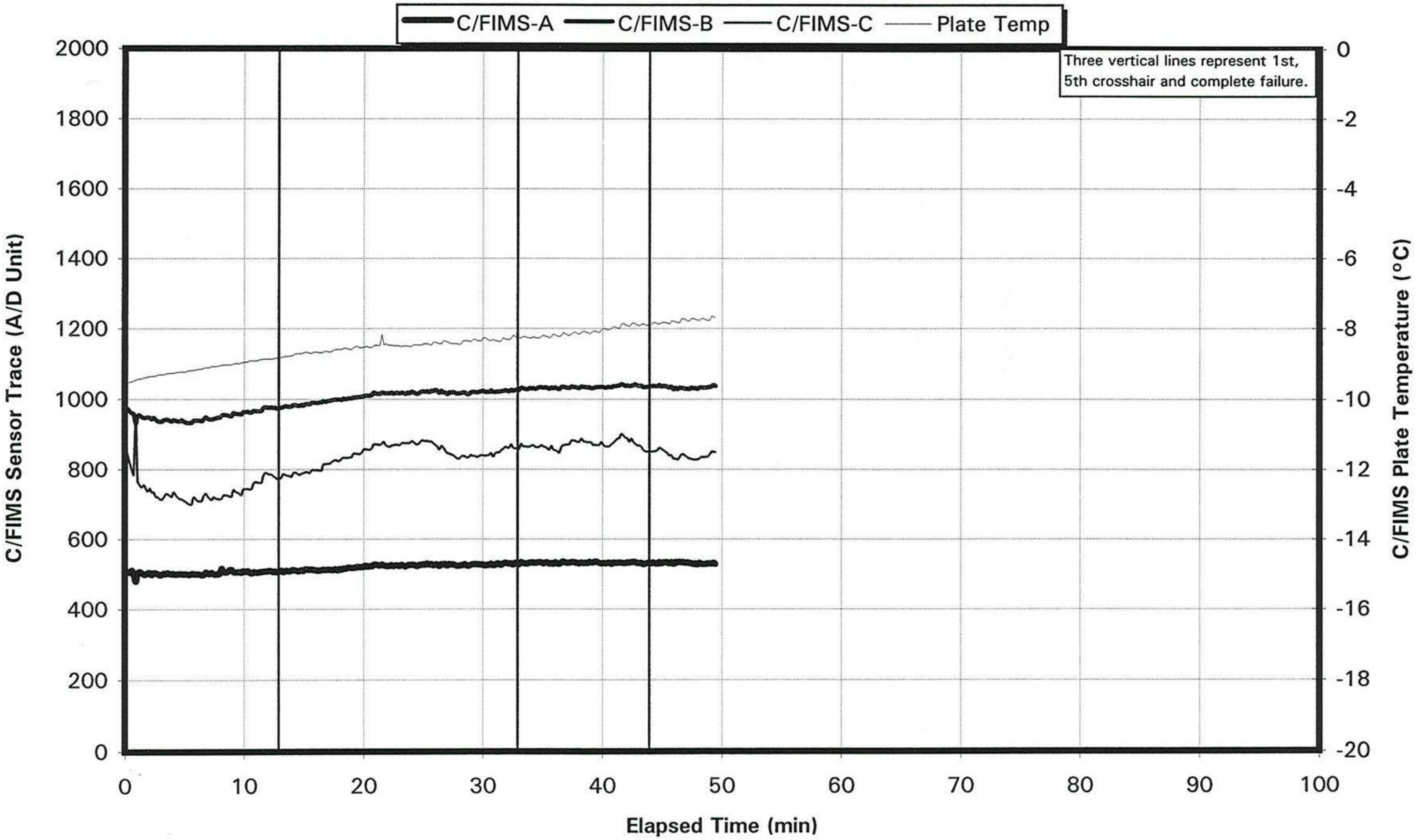


cm1380/analysis/doc_fail/brix/Brx_id02
10/15/98, 9:19 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 2

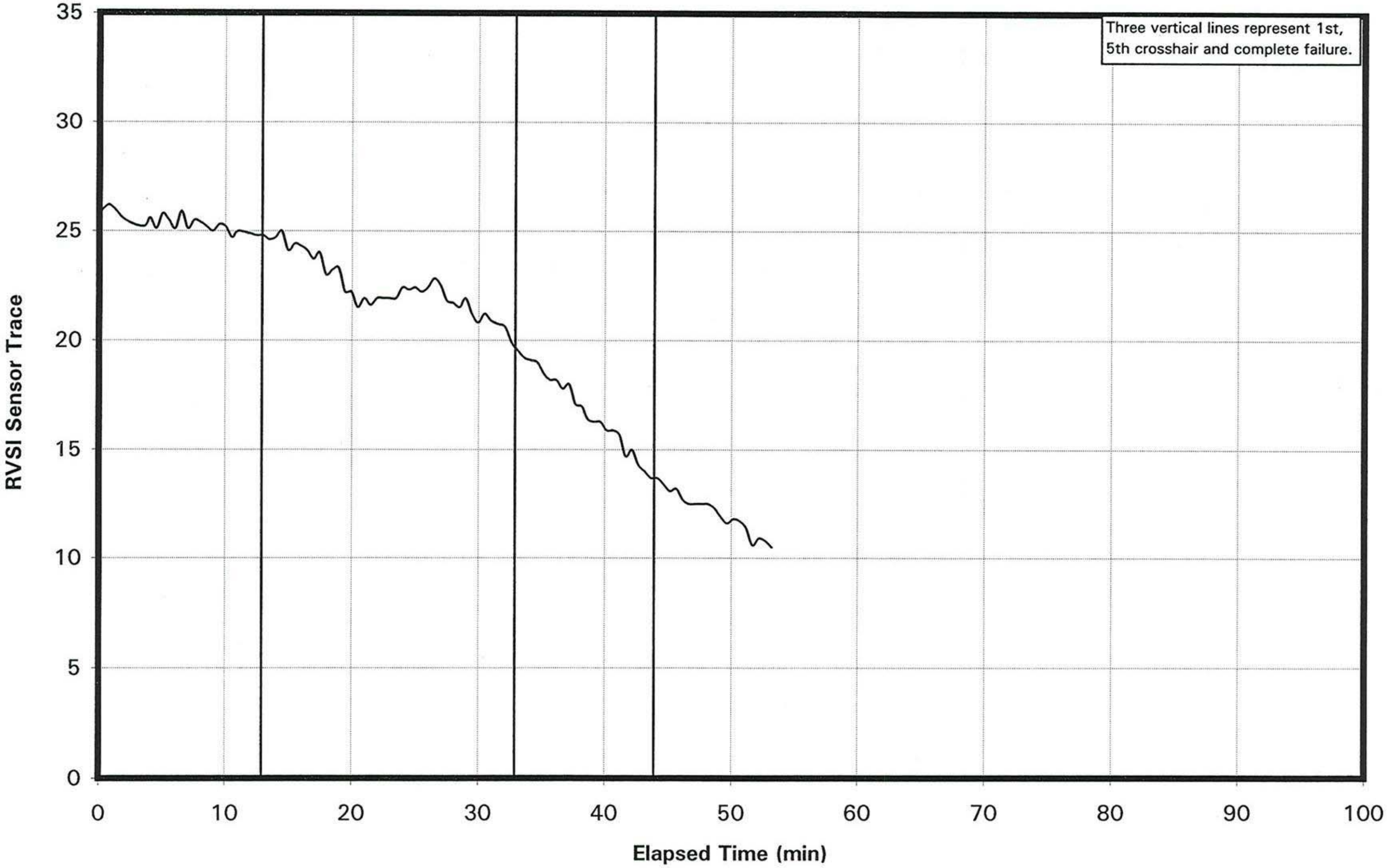


cm1380/analysis/doc_fail/cfims/Cfm_id02
10/15/98, 10:09 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 2

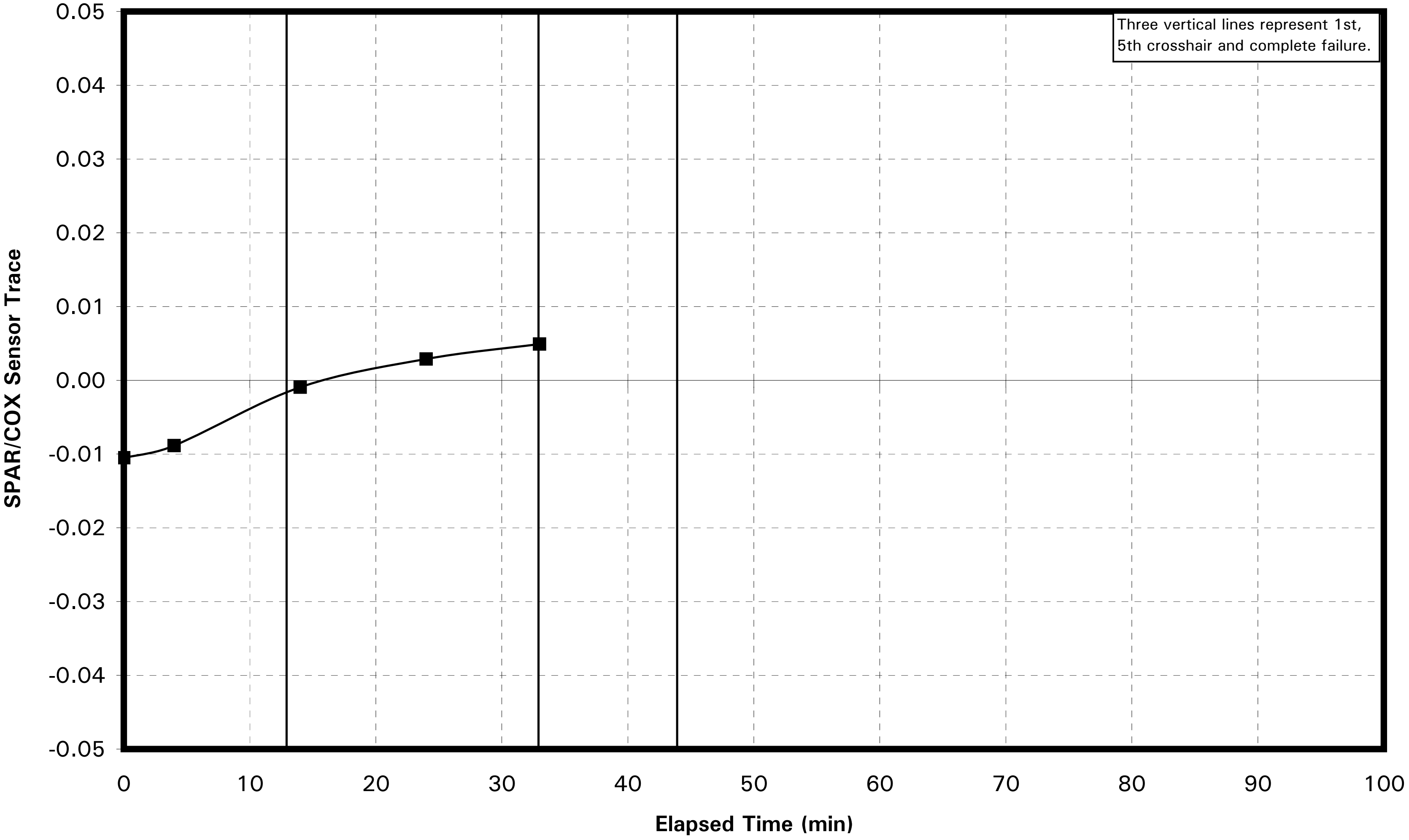


cm1380/analysis/doc_fail/rvsi/Rvs_id02.xls
10/15/98, 11:29 AM

DOCUMENTATION OF FLUID FAILURE

SPAR/COX SENSOR TRACE

ID # 2

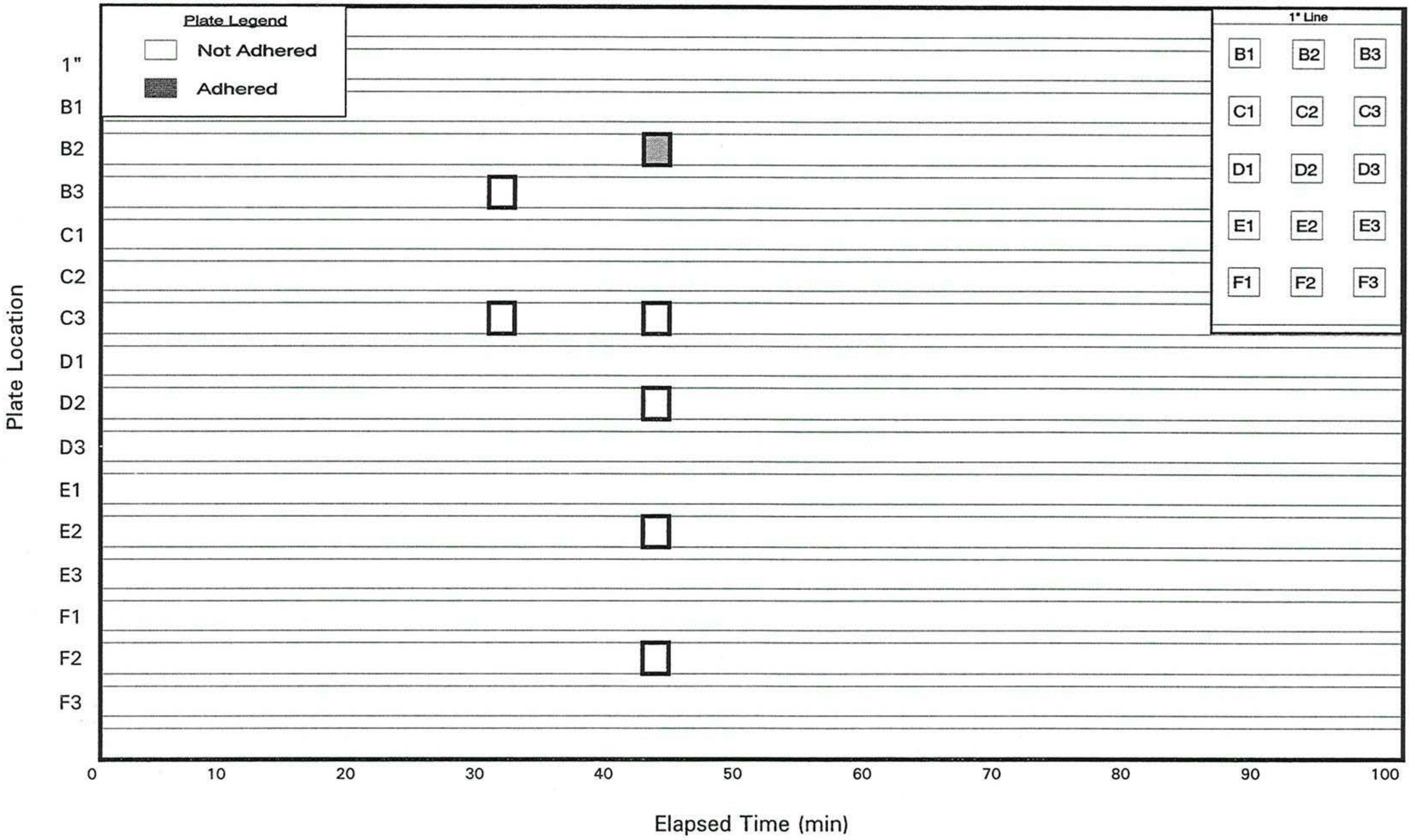


cm1380/analysis/doc_fail/cox/COX_ID02
9/21/2006, 10:39 AM

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 2



cm1380/analysis/doc_fail/Adh_id2
7/28/98, 9:21 AM

GENERAL TEST INFORMATION

ID # 3

July 8, 1998

Ambient Air Temperature: -10.1°C

Precipitation Type: Freezing Drizzle

Rate of Precipitation: 11 g/dm^2/hr

Fluid: OCTAGON

Dilution: Neat

Start of Test: 12:53:45

Failure Mode: 5th X-hair

Failure Location: C1

Failure Time (Standard): 13:33:00

Failure Time (Complete Plate): 13:45:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 3

Photo C3.1 - After Pouring, t = 0 min (Est.)

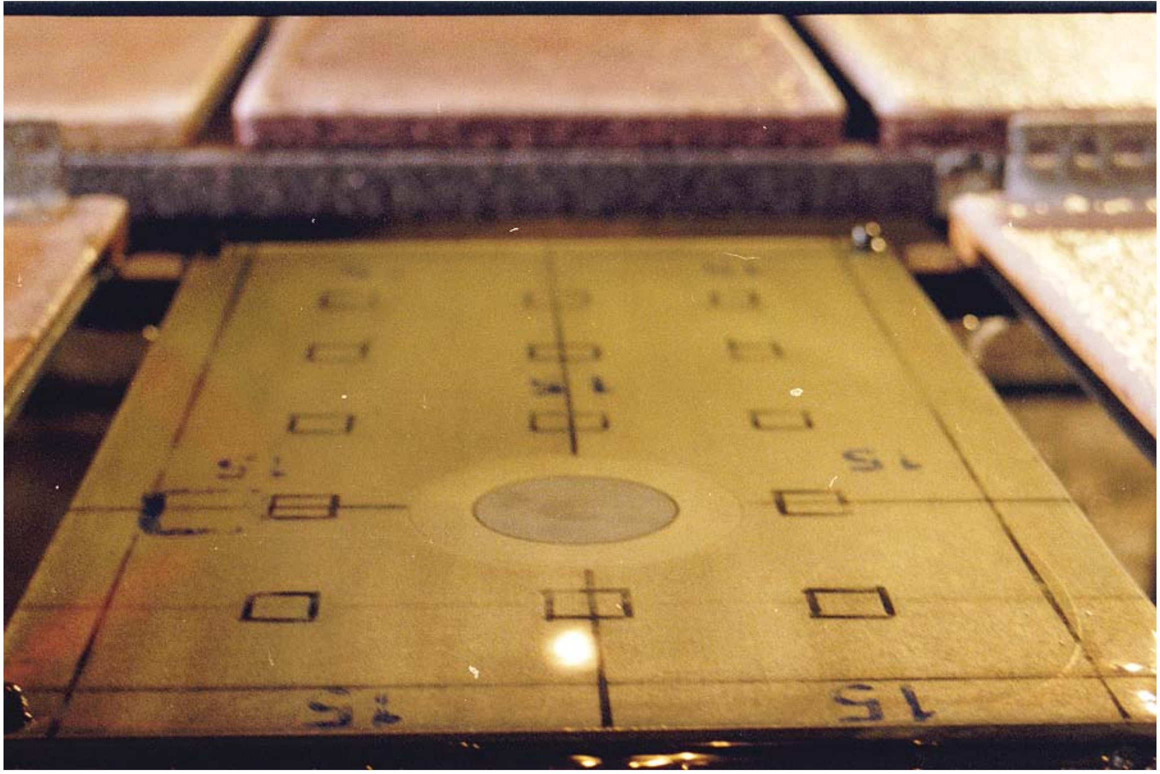
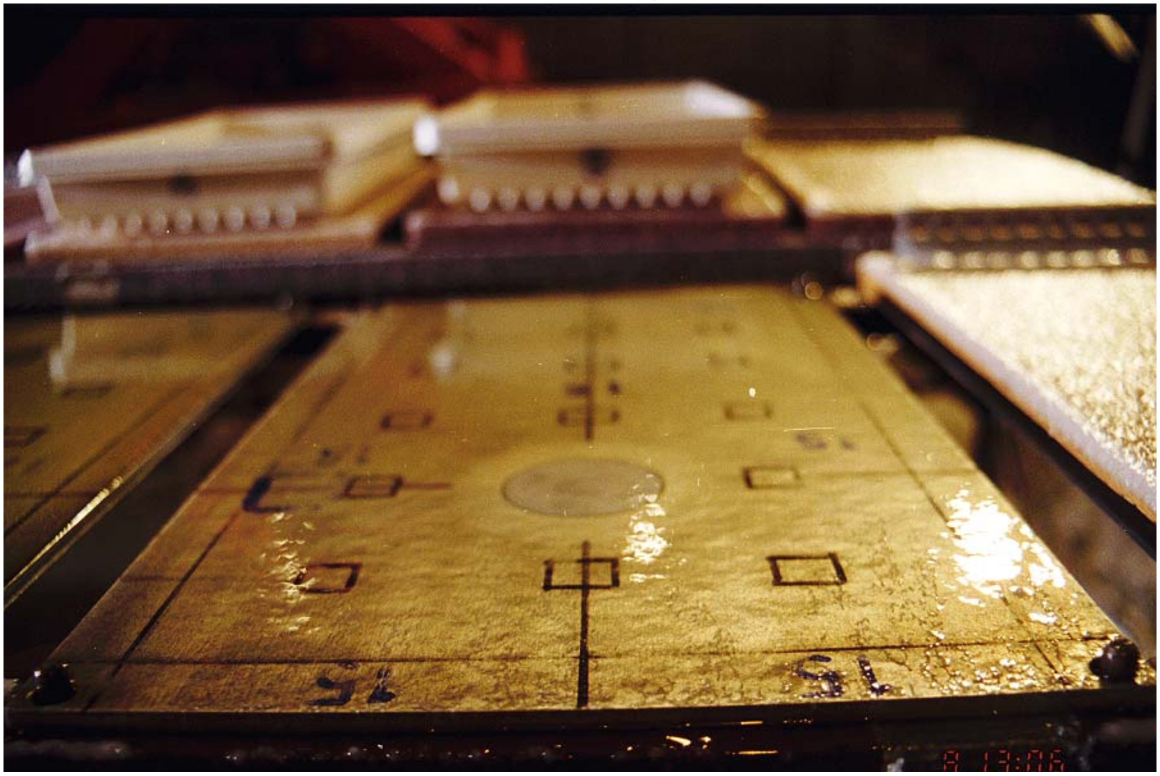


Photo C3.2 - 1st Failure, t = 12 min



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 3

Photo C3.3 - Standard Failure (1/3 or 5th Crosshair), t = 42 min

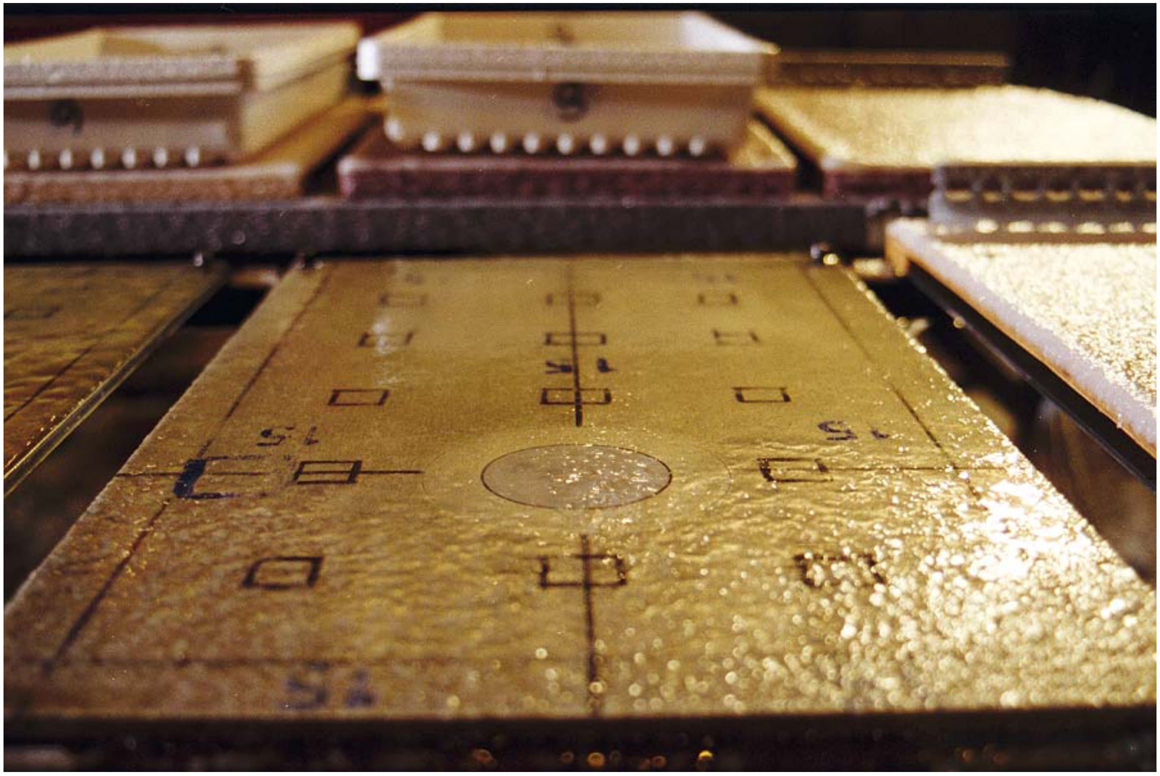
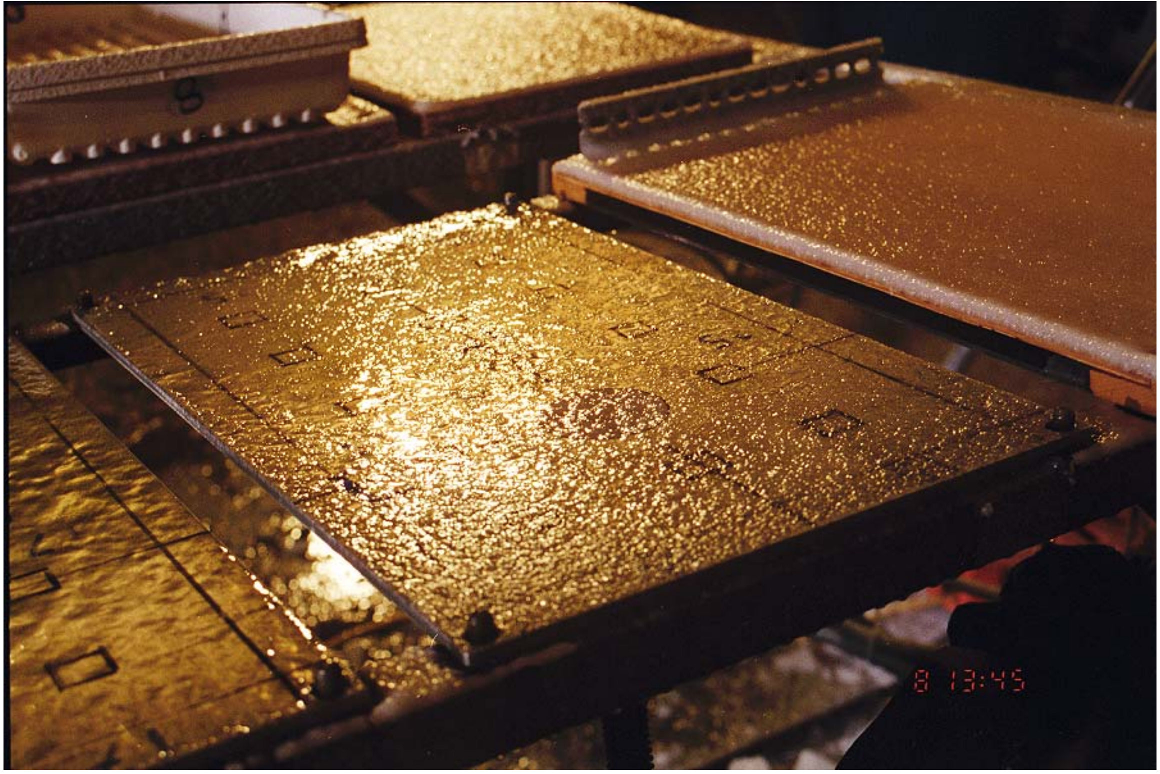


Photo C3.4 - Complete Fluid Failure, t = 51 min



\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAILS\SUBJECTV\SUB_ID03.doc
Last printed 10/13/98 2:45 PM

ID # 3

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08

Time: 1253^{45}

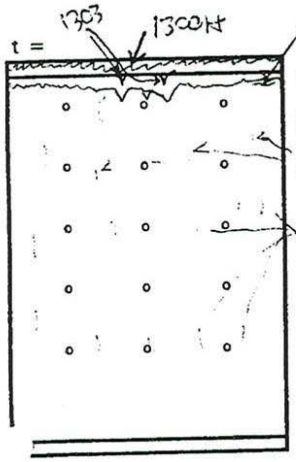
Plate Location: 2

Run #: 3a3

Fluid Name: Oct Max

Fluid Dilution: 100%

t =



Toul: Same as Run 3a2

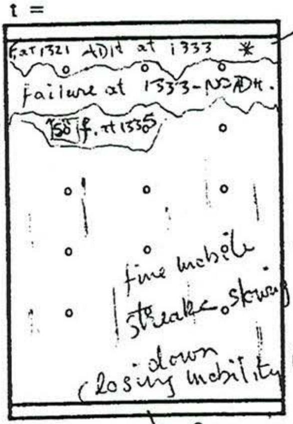
1303 1st failure ~~[illegible]~~ inside 1" line

1305 Freezing streaks of contamination (v. fine + mobile)

1310 fine contamination streaks (solid) distrib evenly over entire fl. surface

1313 failure ½ way to 3" line.

t =



1321 Rough failed surface (wet) + denser streaking of solid streaks of contam over whole plate (NO ADH)

1333 ADH at Rough failed region (area demarcated 1321)

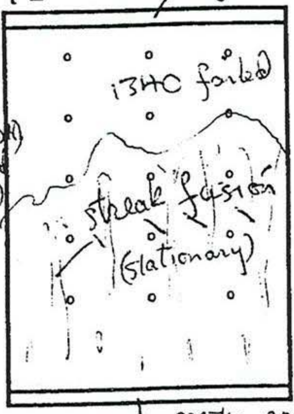
*Top area now thick.

1335 F. at 5th X-Hair "5" ↑ (Sampled at 1337)

Beginning of solid accum. V. light.

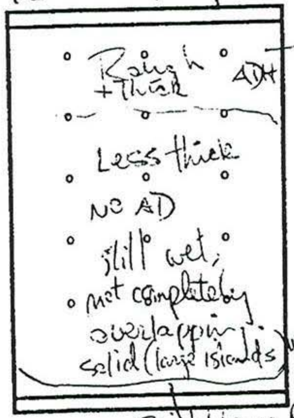
t =

Dry band of failure 0→1" line



greater accum. still light.

t = 1345 full plate failure



almost dry.

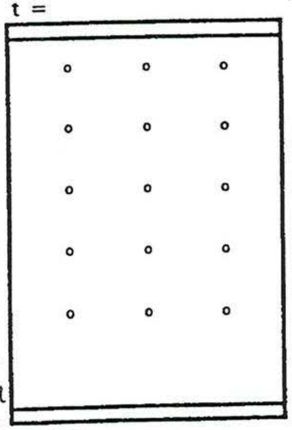
Rough, bumpy ice accumulation

Relatively thick on top of 6" line;

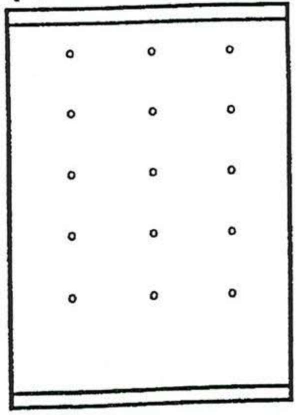
finer and not quite continuous toward lower edge

Solid / Heavy Ridge 1400HRS

t =



t =

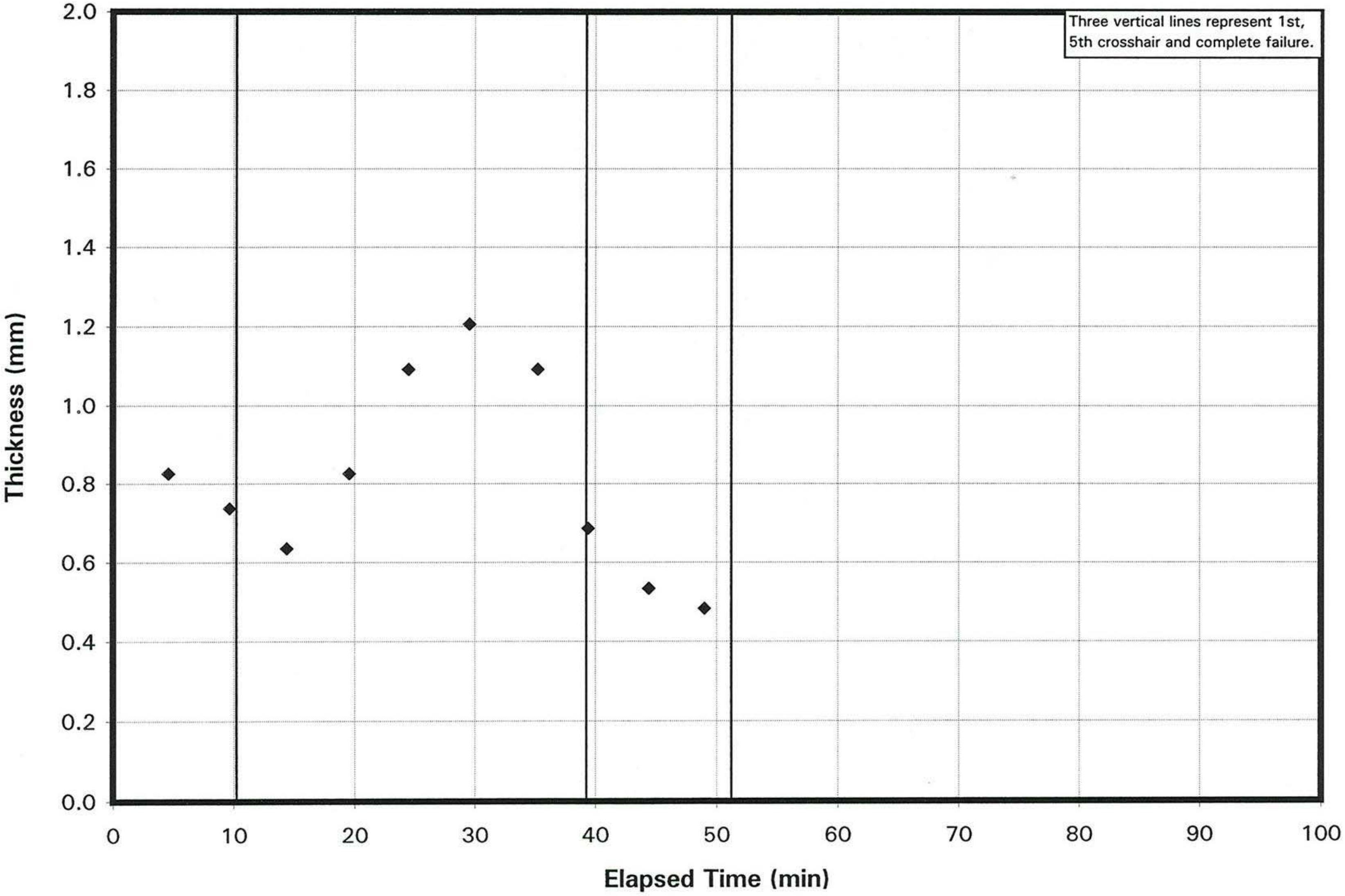


Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 3

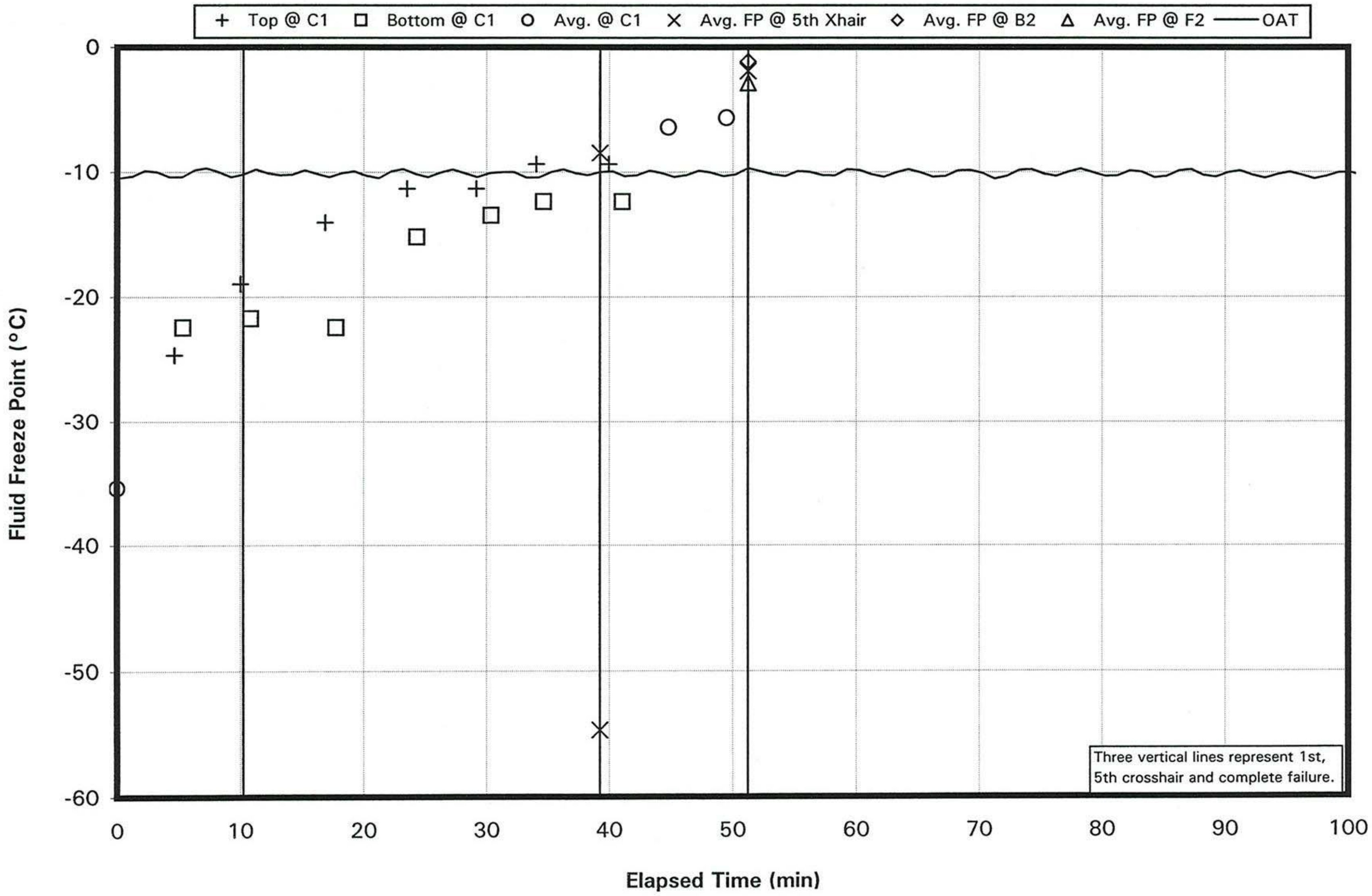


cm1380/analysis/doc_fail/thicknes/Thk_id03
10/14/98, 10:34 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 3



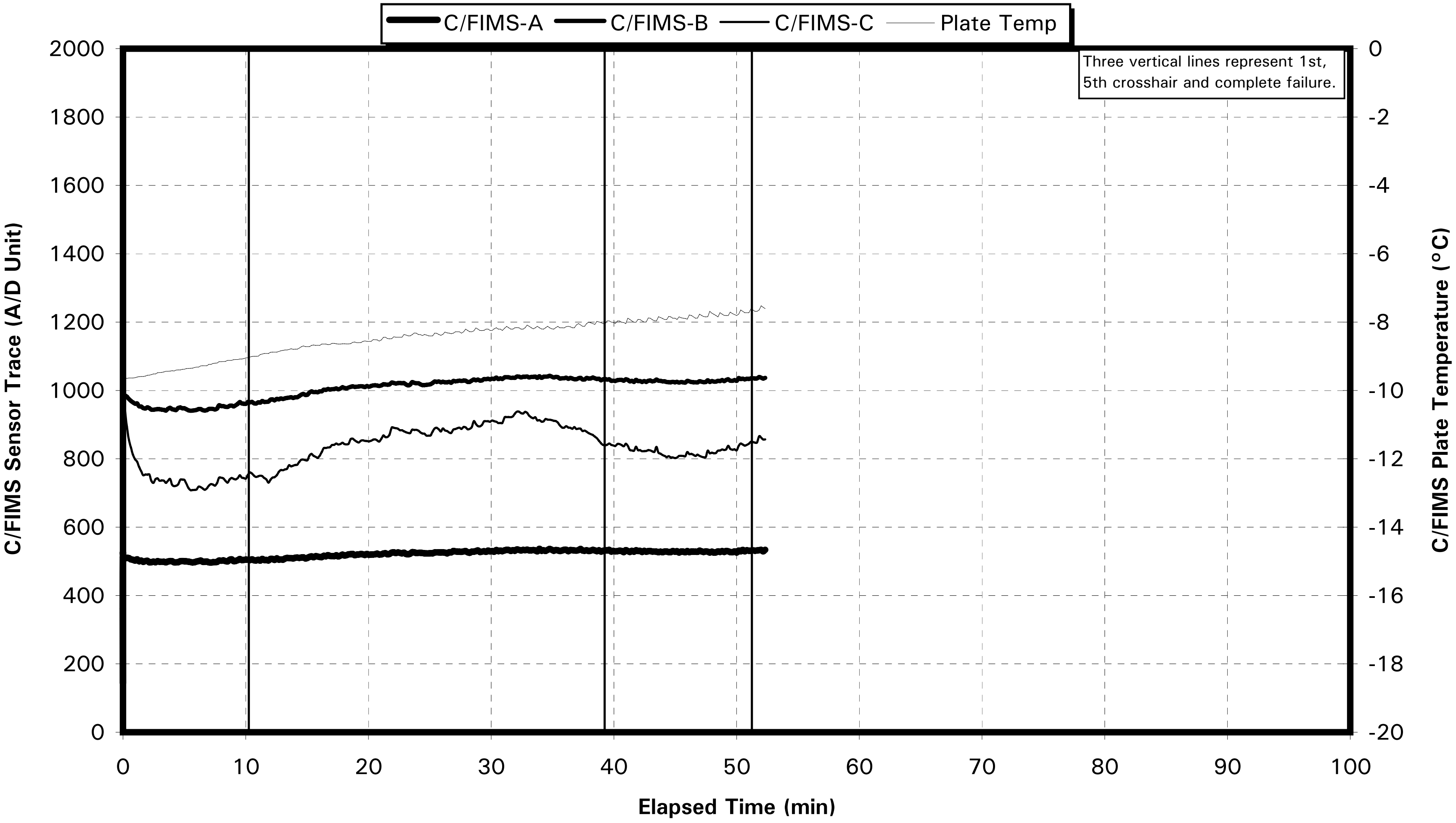
Three vertical lines represent 1st, 5th crosshair and complete failure.

cm1380/analysis/doc_fail/brix/Brx_id03
10/15/98, 9:18 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 3

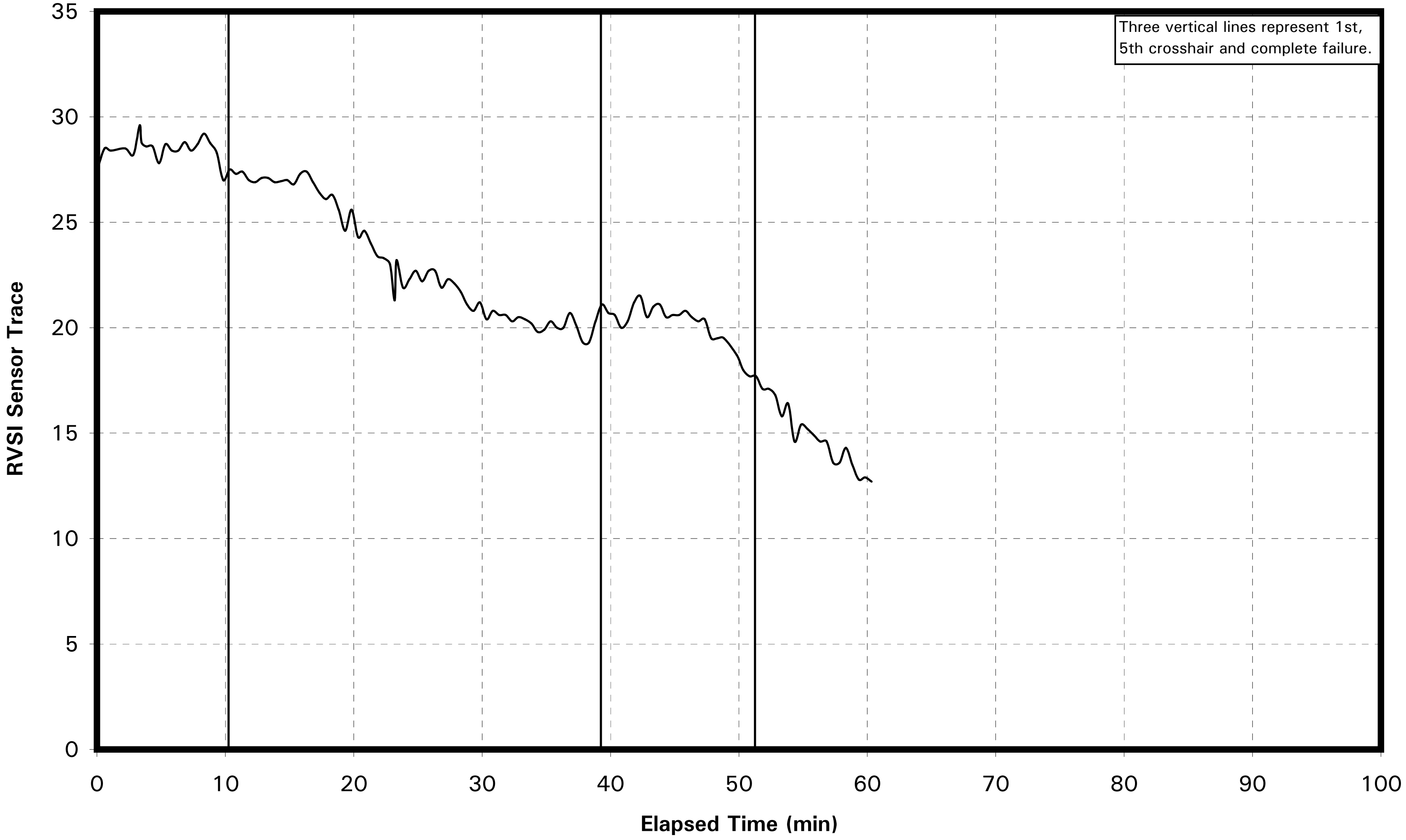


cm1380/analysis/doc_fail/cfims/CFM_ID03
9/21/2006, 10:50 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 3



cm1380/analysis/doc_fail/rvsi/RVS_ID03
9/21/2006, 11:02 AM

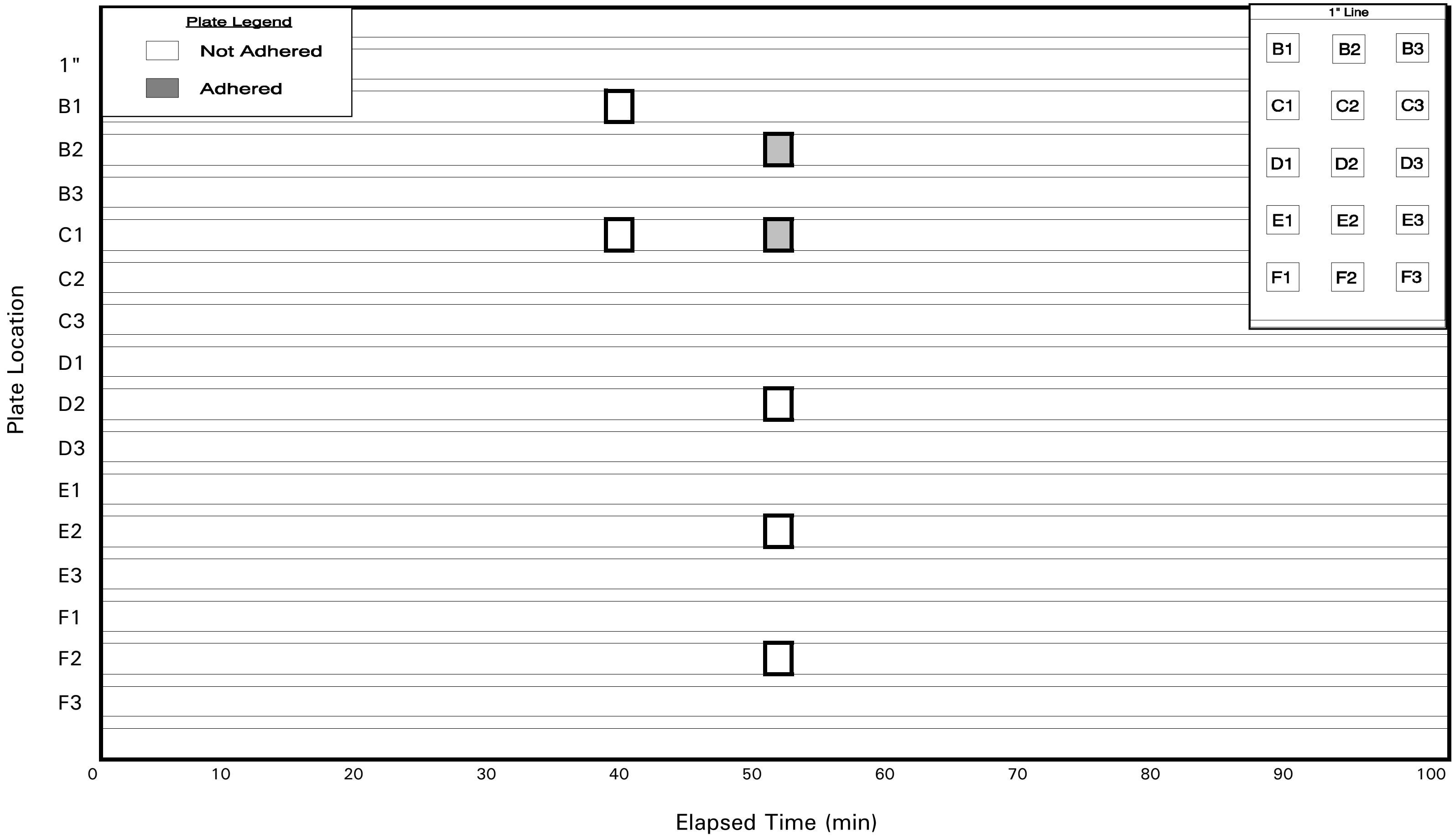
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 3

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 3



cm1380/analysis/doc_fail/ADH_ID03
9/21/2006, 11:06 AM

GENERAL TEST INFORMATION

ID # 4

July 8, 1998

Ambient Air Temperature:	-10.1°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	10.1 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	12:57:05
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	14:01:00
Failure Time (Complete Plate):	14:18:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 4

Photo C4.1 - After Pouring, t = 0 min

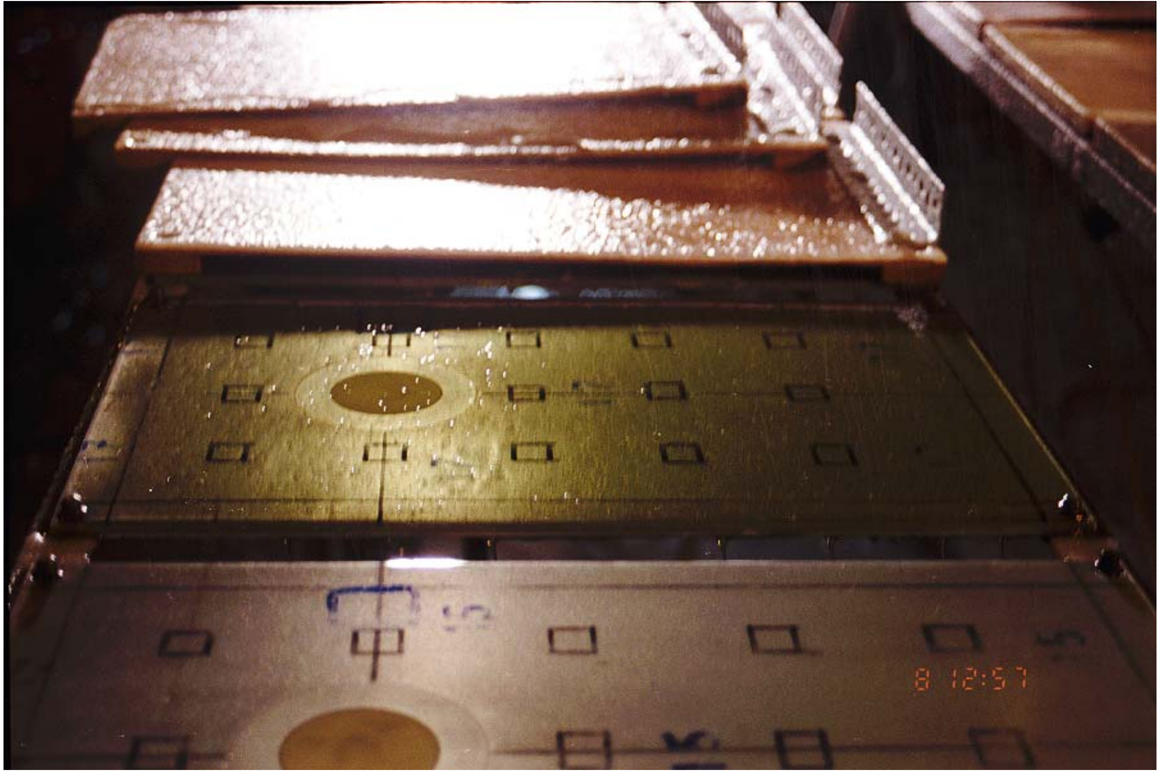
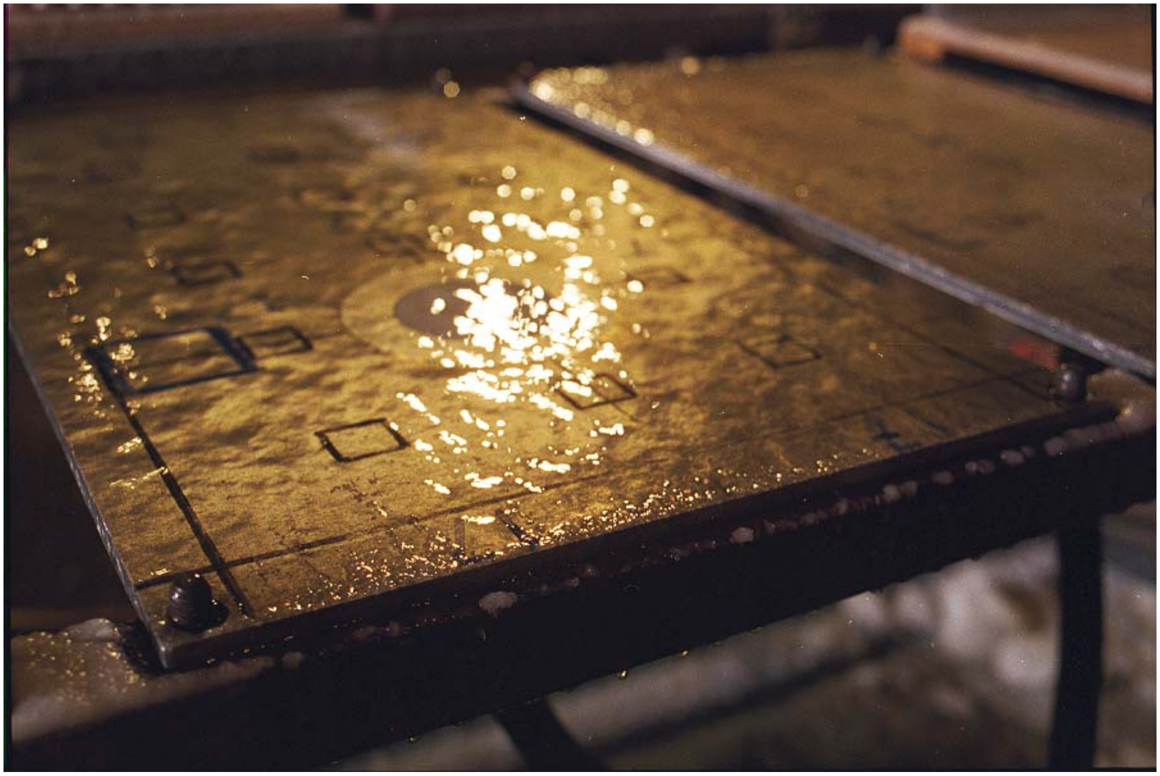


Photo C4.2 - 1st Failure, t = 55 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 4

Photo C4.3 - Standard Failure (1/3 or 5th Crosshair), t = 66 min

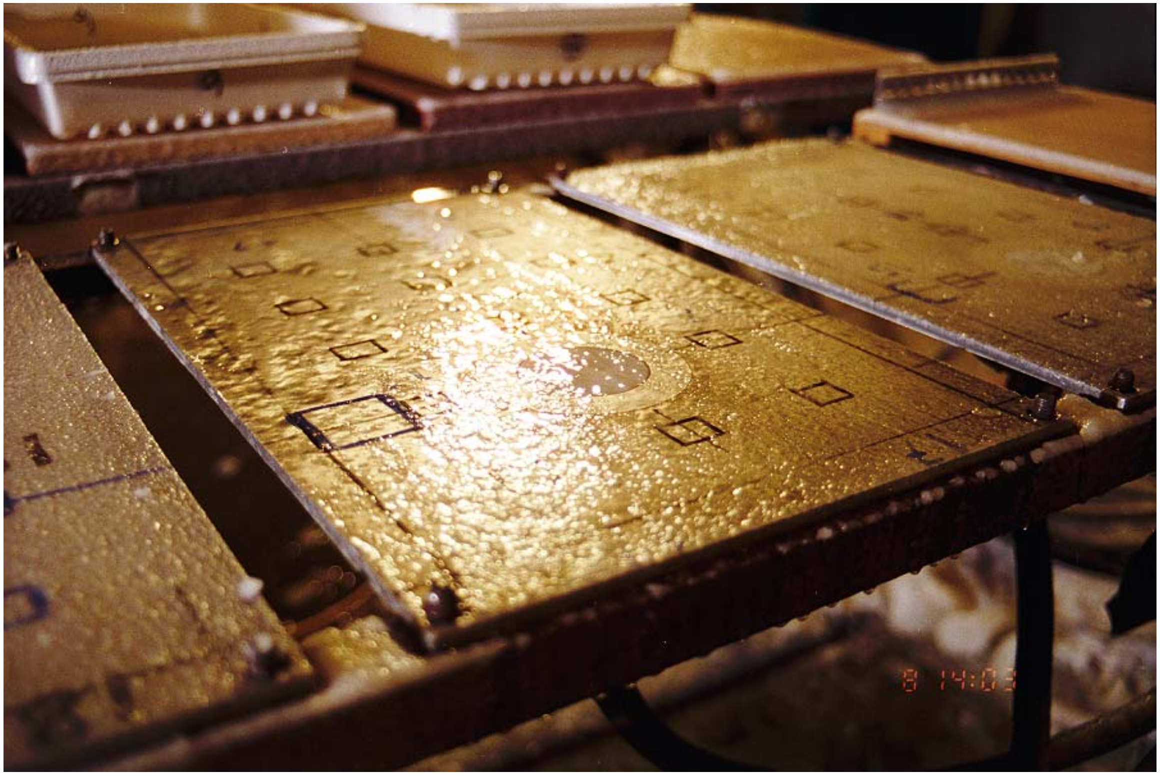


Photo C4.4 - Complete Fluid Failure, t = 81 min (Est.)

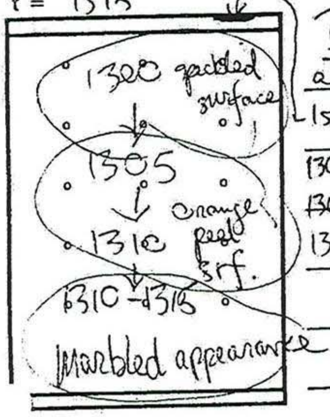
H:\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID04.doc
Last printed 10/13/98 3:33 PM

ID# 4

SUBJECTIVE APPEARANCE OF FLUID FAILURE

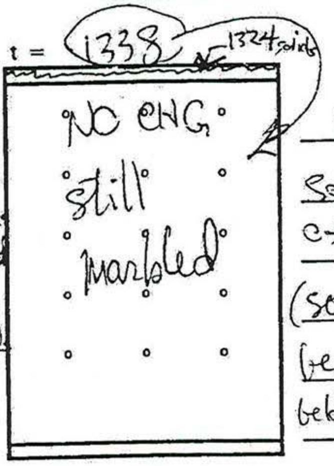
Date: July 08
Time: 1257 ^{00}
Plate Location: 3
Run #: 364
Fluid Name: ULTRA+
Fluid Dilution: 100%

t = 1315



Pour, same as Run 361
1st failure above 1" line
1300 speckled stage; no solids
~~1305-1310 op stage NOSE~~
1315 fully marbled surface, no solids except at top edge of plate.

t = 1338

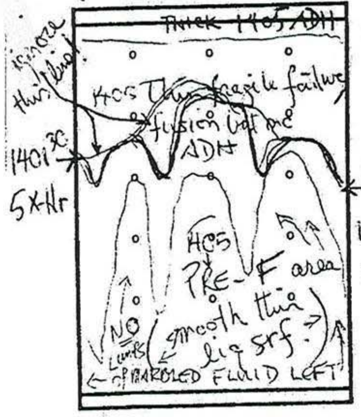


1324 ridge of solid contamination 0->1cm top edge.
(some channelling beginning just below 1" line.)

t = 1342 first failure

1346 fine finger-like formations growing downward
1355 broken marbled area below
- channelling beginning to break up marbled surface
~~[illegible]~~
Thinned fluid (pre failure) condition
~~began~~

t = 1400

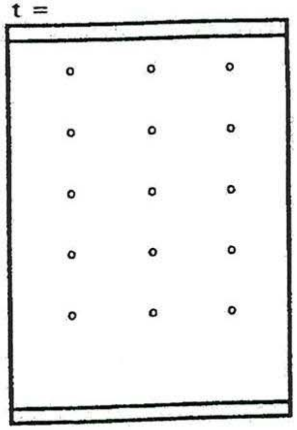


1400 NB channels giveway to failure streaks (large, immobile) which fuse
1401 30 5th X-Hair f'd
1405 No marbled lumps remain

t =

1418 Complete plate failure

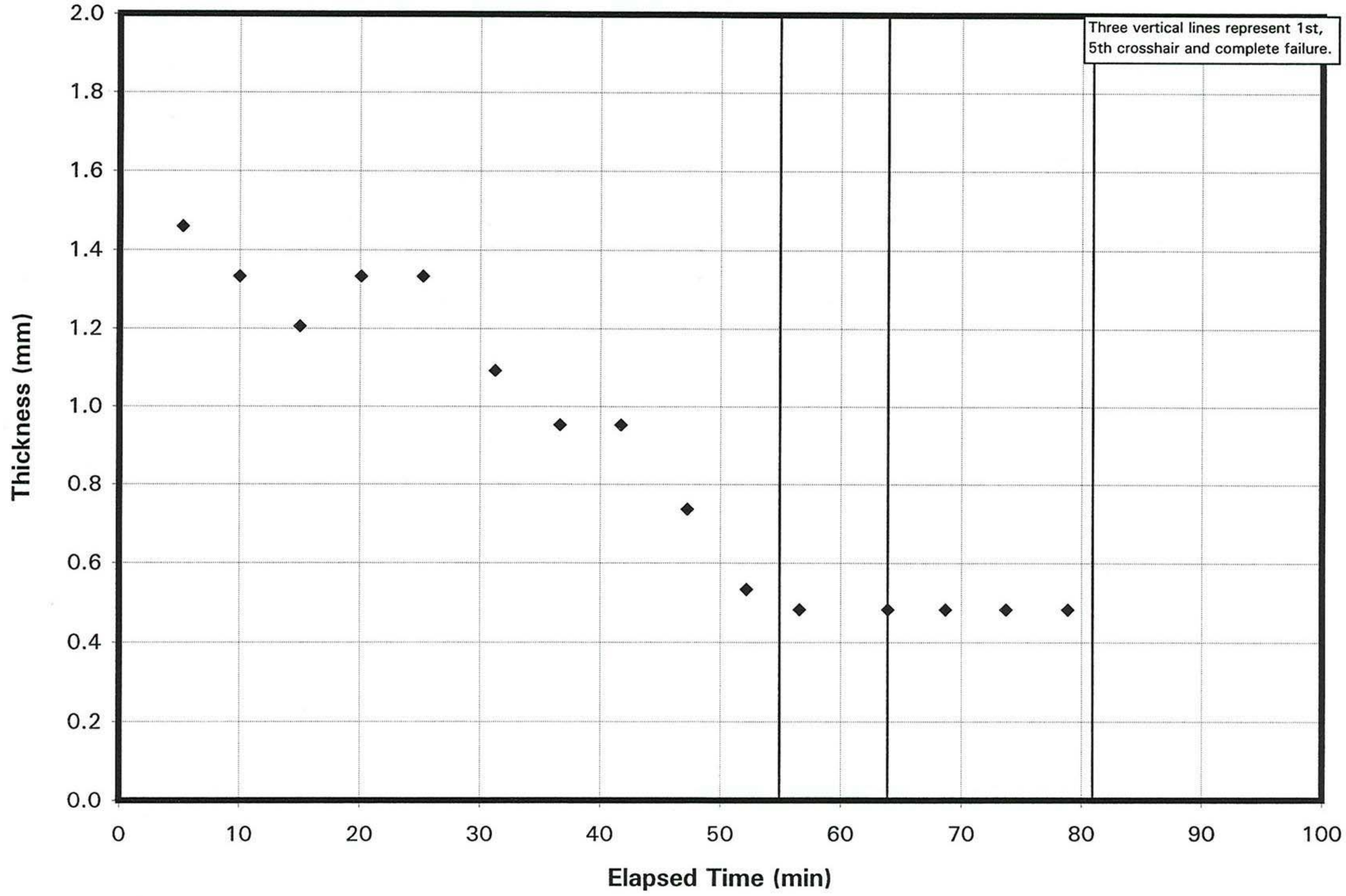
t =



Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

...actually sliding off the surface and extending off surface before breaking off under their own weight -

DOCUMENTATION OF FLUID FAILURE
FLUID THICKNESS TESTS
ID # 4

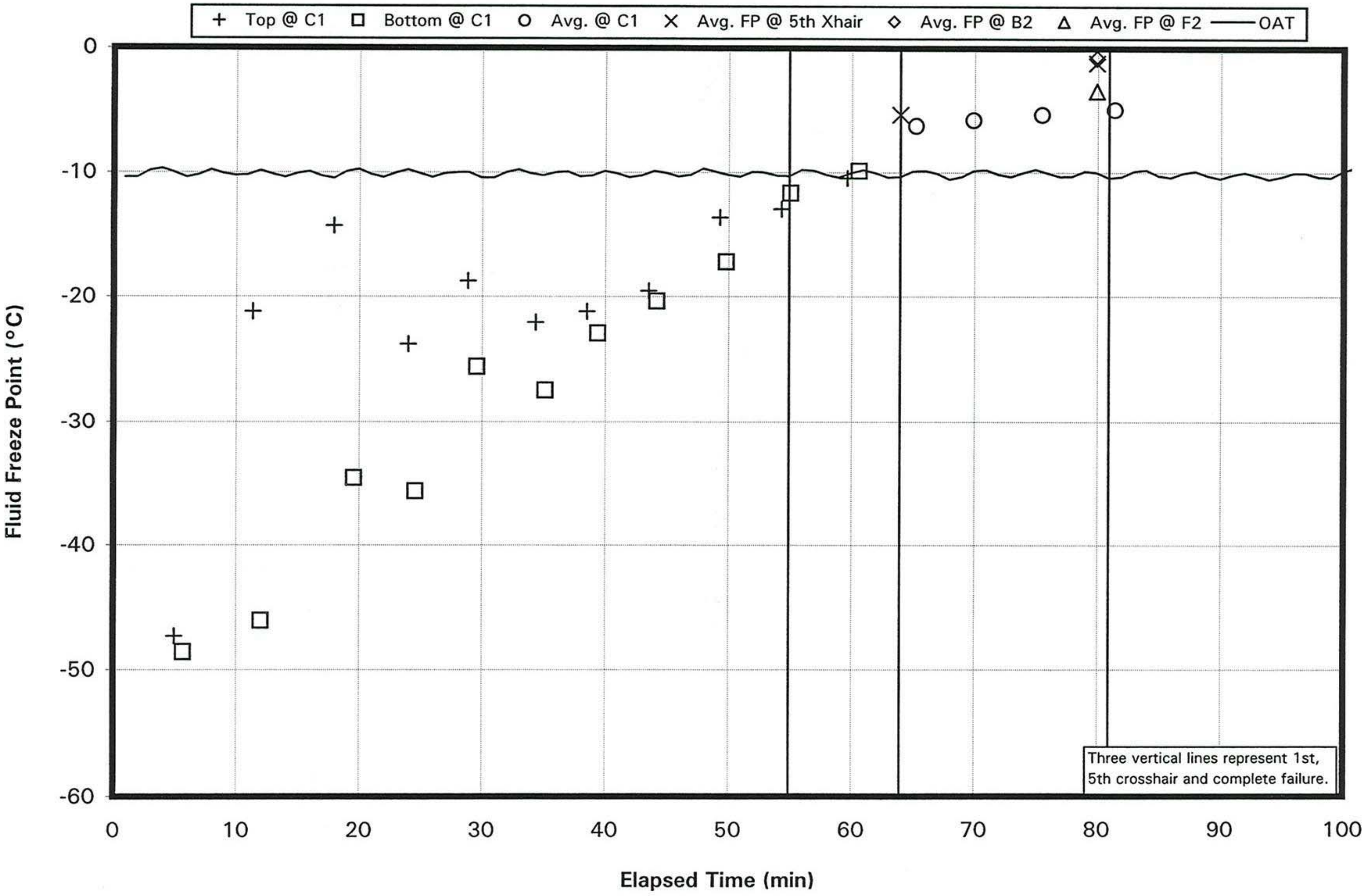


cm1380/analysis/doc_fail/thicknes/Thk_id04
10/14/98, 10:34 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 4

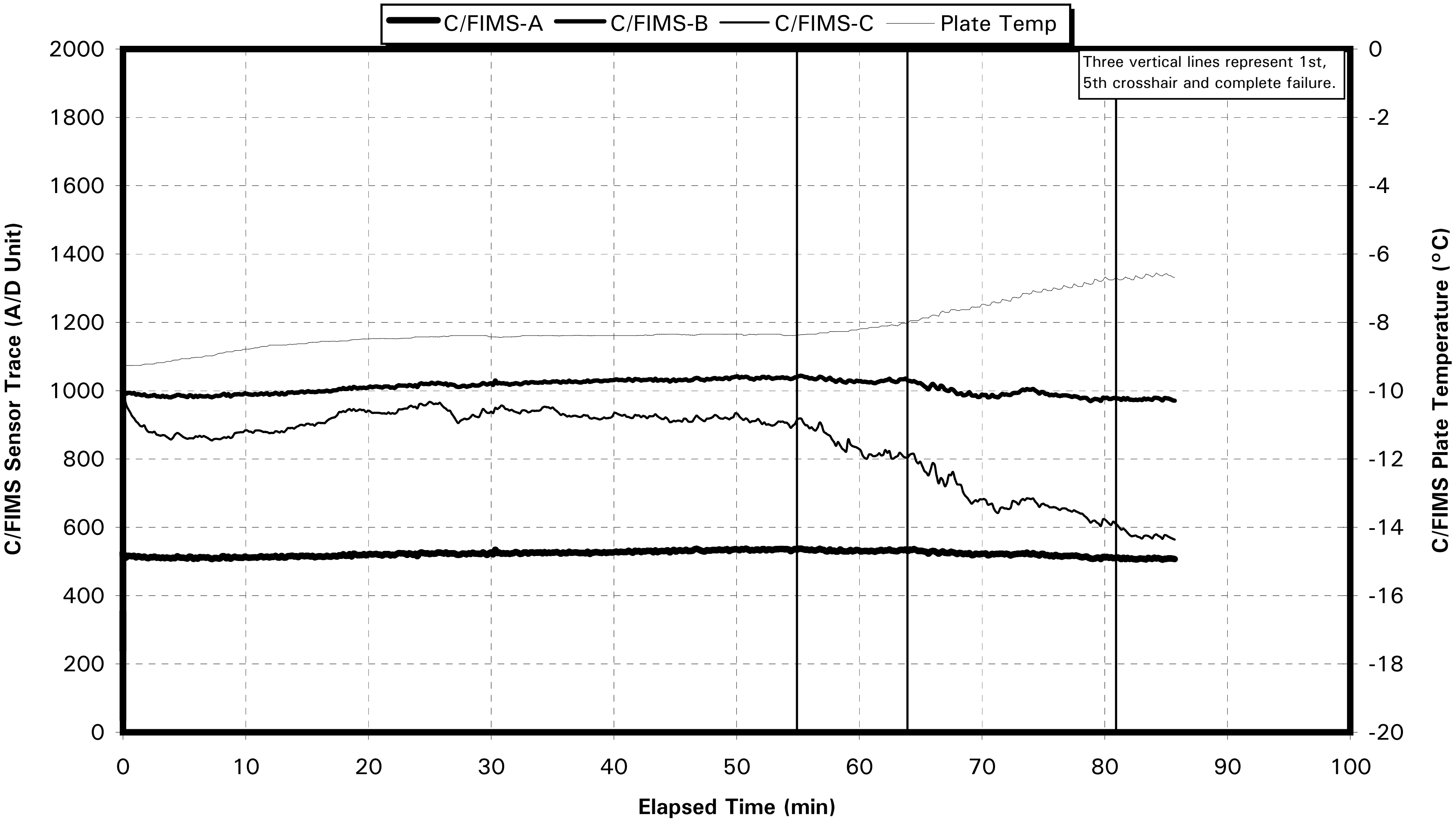


cm1380/analysis/doc_fail/brix/Brx_id04
10/15/98, 9:31 AM

DOCUMENTATION OF FLUID FAILURE

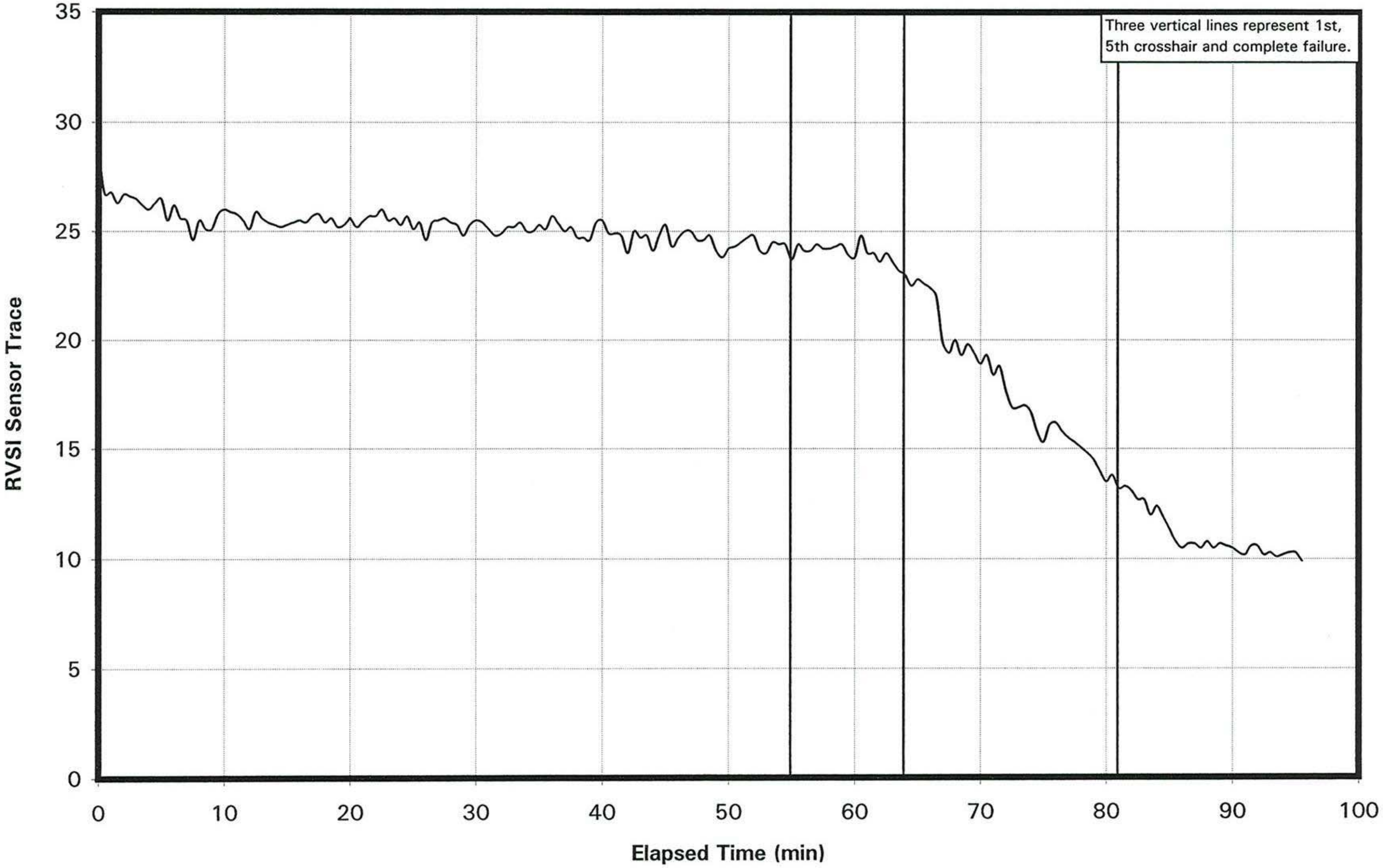
C/FIMS SENSOR TRACE

ID # 4



cm1380/analysis/doc_fail/cfims/CFM_ID04
9/21/2006, 11:20 AM

DOCUMENTATION OF FLUID FAILURE
RVSI SENSOR TRACE
ID # 4



cm1380/analysis/doc_fail/rvsi/Rvs_id04
10/22/98, 7:56 AM

DOCUMENTATION OF FLUID FAILURE

COX/SPAR SENSOR TRACE

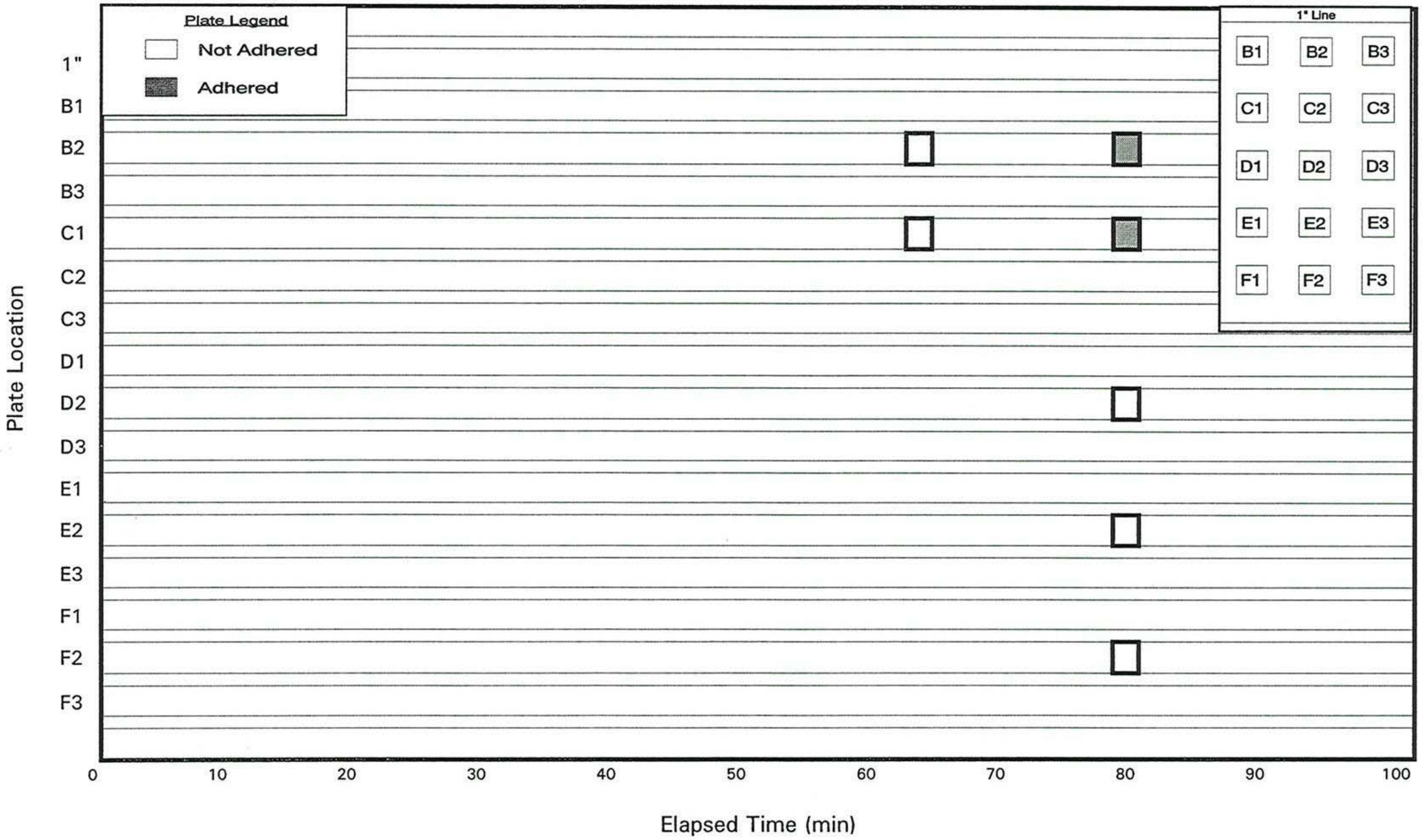
ID # 4

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 4



cm1380/analysis/doc_fail/Adh_id4
7/28/98, 9:31 AM

GENERAL TEST INFORMATION

ID # 5

July 8, 1998

Ambient Air Temperature:	-10.5°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.5 g/dm²/hr
Fluid:	UCAR XL54
Dilution:	Std
Start of Test:	15:38:45
Failure Mode:	5th X-hair
Failure Location:	C1/C2
Failure Time (Standard):	15:43:15
Failure Time (Complete Plate):	15:44:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 5

Photo C5.1 - After Pouring, t = 0 min (Est.)

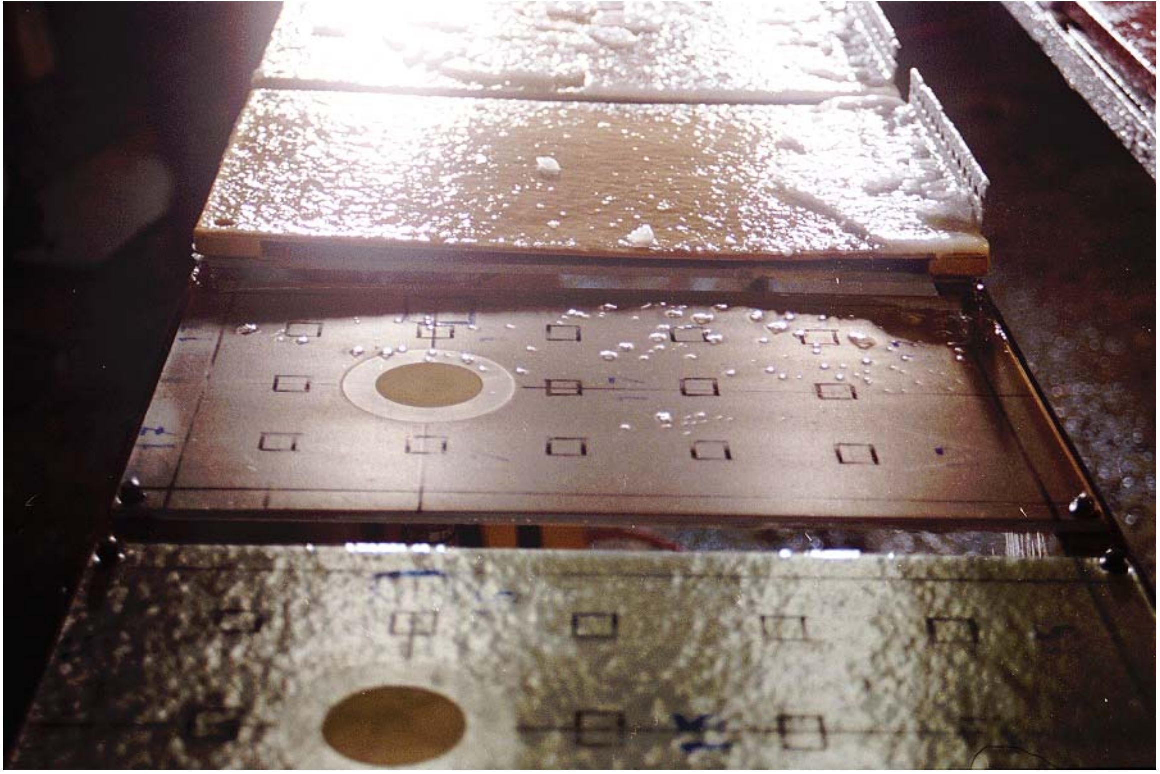
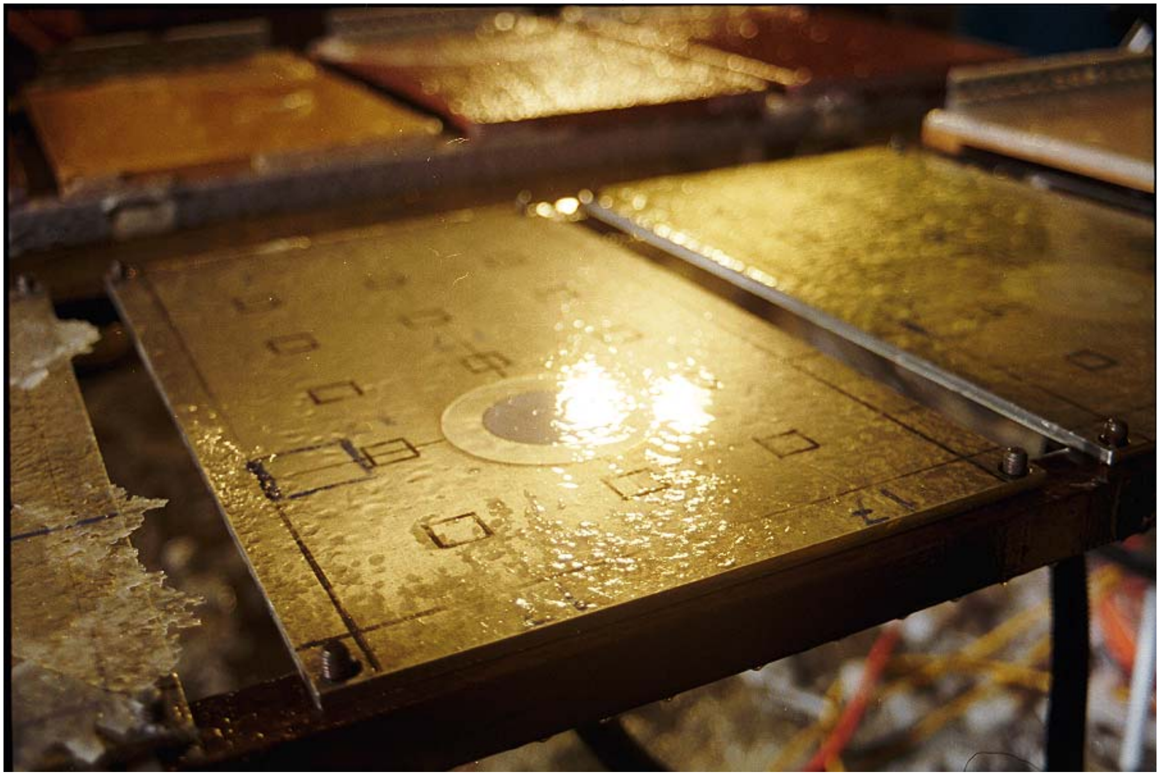


Photo C5.2 - 1st Failure, t = 3 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 5

Photo C5.3 - Standard Failure (1/3 or 5th Crosshair), t = 4 min (Est.)

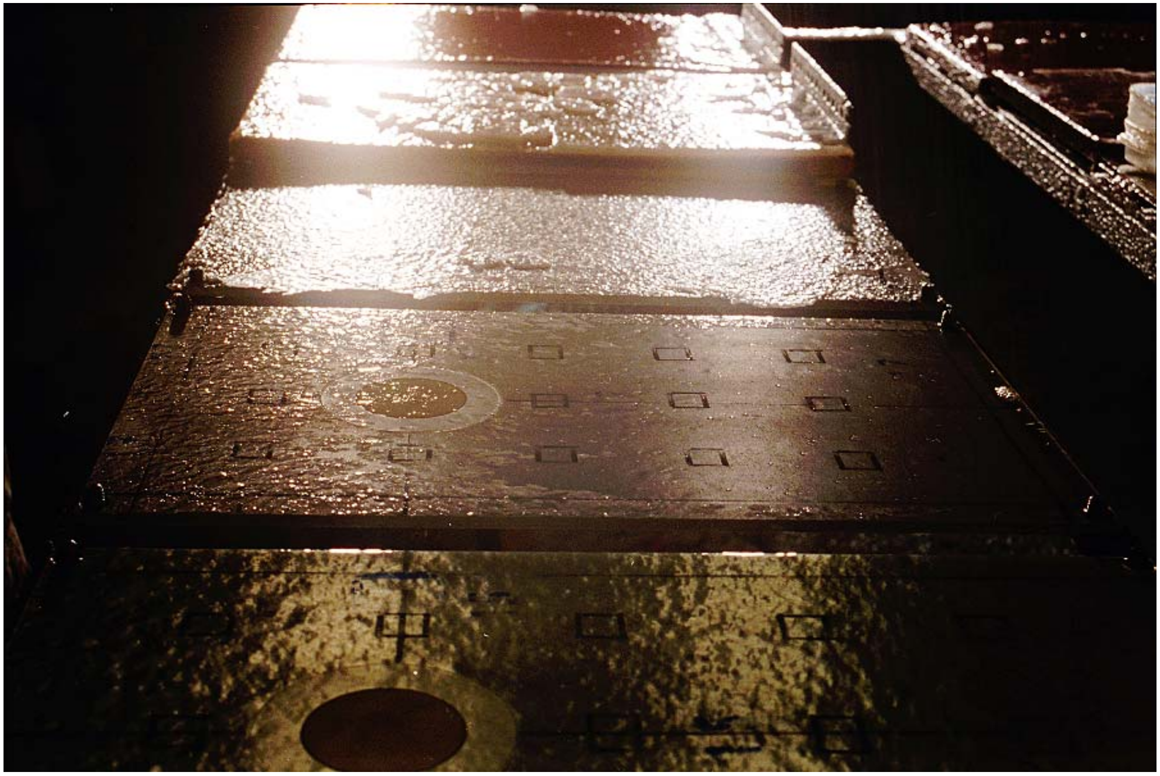
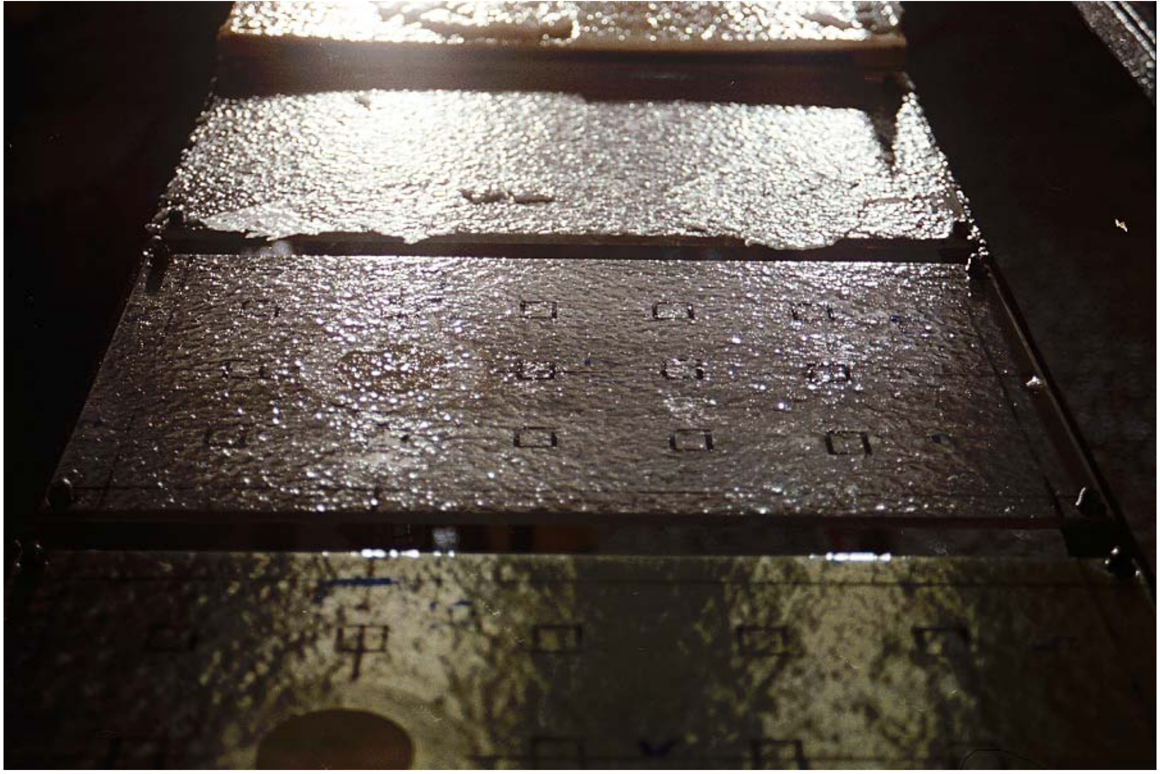


Photo C5.4 - Complete Fluid Failure, t = 5 min (Est.)



ID#5

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08

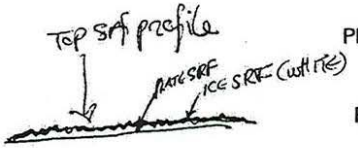
Time: 1538^45

Plate Location: 3

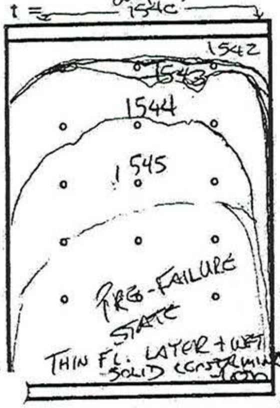
Run #: 4_3

Fluid Name: XL54

Fluid Dilution: STD



t = drying 1540



POUR: 1538^45 same fl. appearance as per Run 4_2

1540 Drying noted on top edge of plate specks on srf at shal. angle views

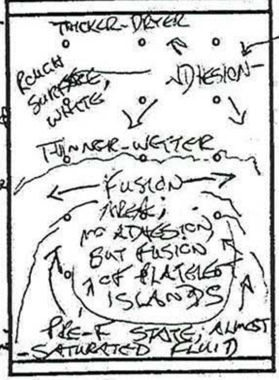
1542 1st failure

1544 5th X-hair

1545 * ADHESION: from 0→6" line

* See NEXT FRAME

t = 1545



ADHESION AREA

THICKER WHITE

BUMPY ICE SURFACE

~~NOT~~ VERY WET.

ADHESION + FUSION V. STRONG

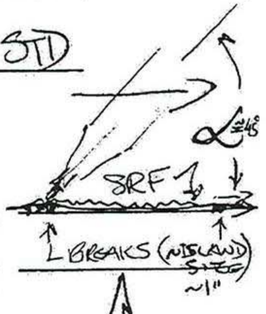
THINNER BUMPY ICE SRF

MORE FRAGILE; ADH. NOT QUITE SET IN

BUT PLATELET ISLANDS FUSE INTO ~1" AREAS

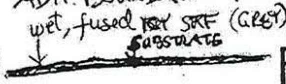
AND ARE EASILY DISLODGED BY DRAGGING A

PENCIL TIP OVER WITH ONLY THE PENCIL'S WEIGHT

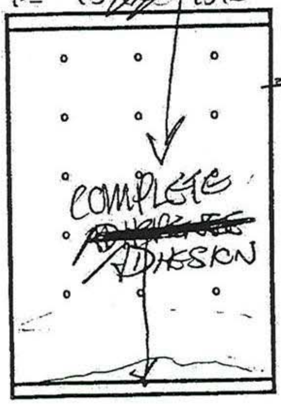


SEE DIAG ABOVE.

ADH. BOUNDARY PROFILE

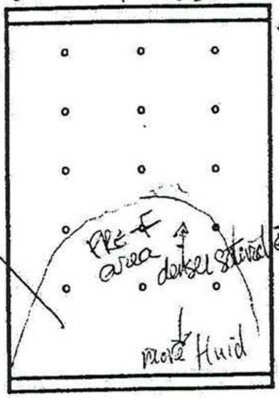


t = ~~1544~~ 1546



FUSION OF SOLID CONTAMINANT PLATELETS

t = 1545



BELOW: PRE-F AREA.

PLATELETS ACCUMULATING

FORMING SAT'D MIXTURE

OF REMAINING FLUID

AND FROZEN CONTAMINATION

~~FUSION RAPIDLY~~ SETS IN TO FORM CONTINUOUSLY ~~FAILED SURFACE~~ WITH.

WITH SUBSEQUENT ADHESION (ALSO RAPID)

FULL PLATE

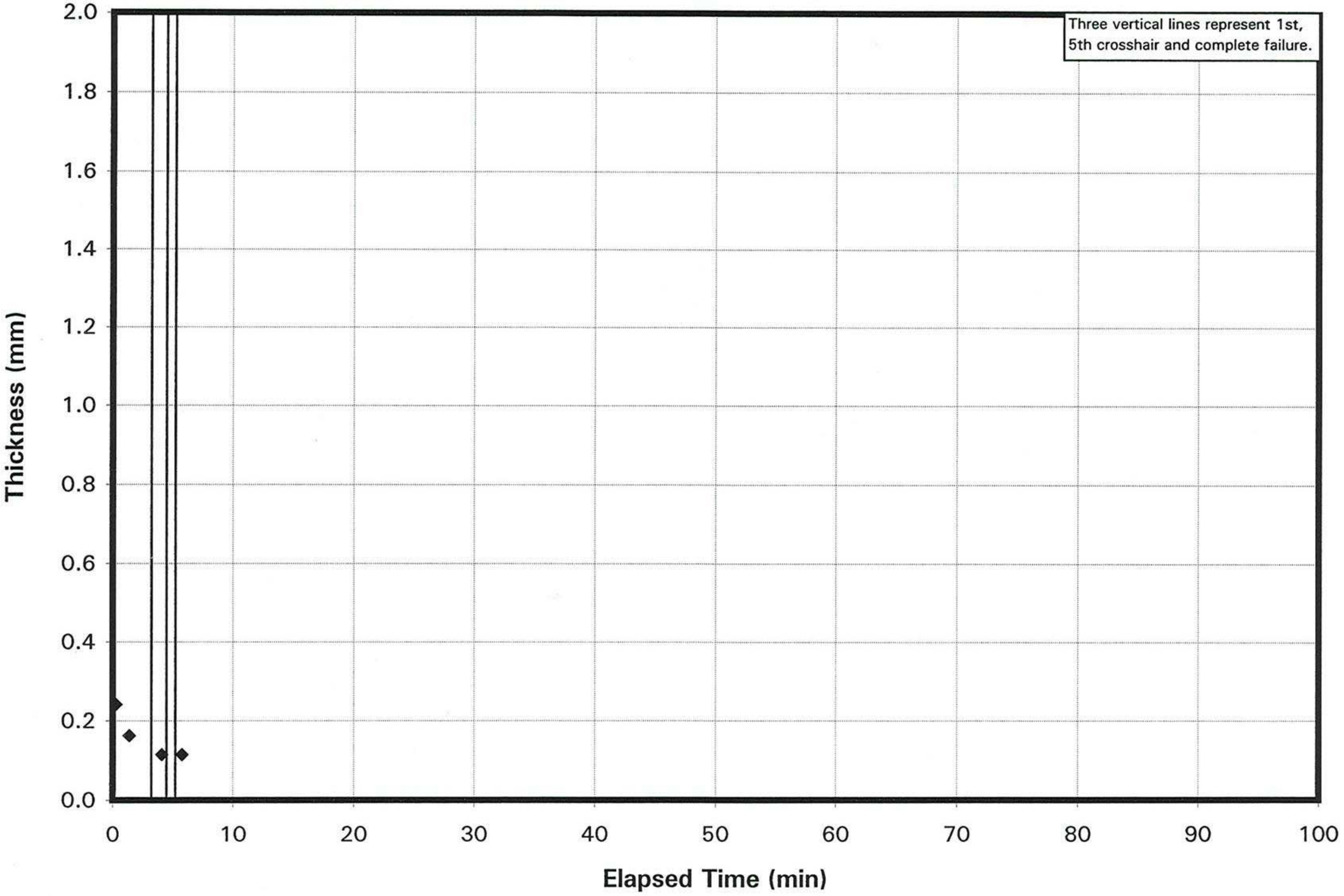
Failure 1546

Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 5

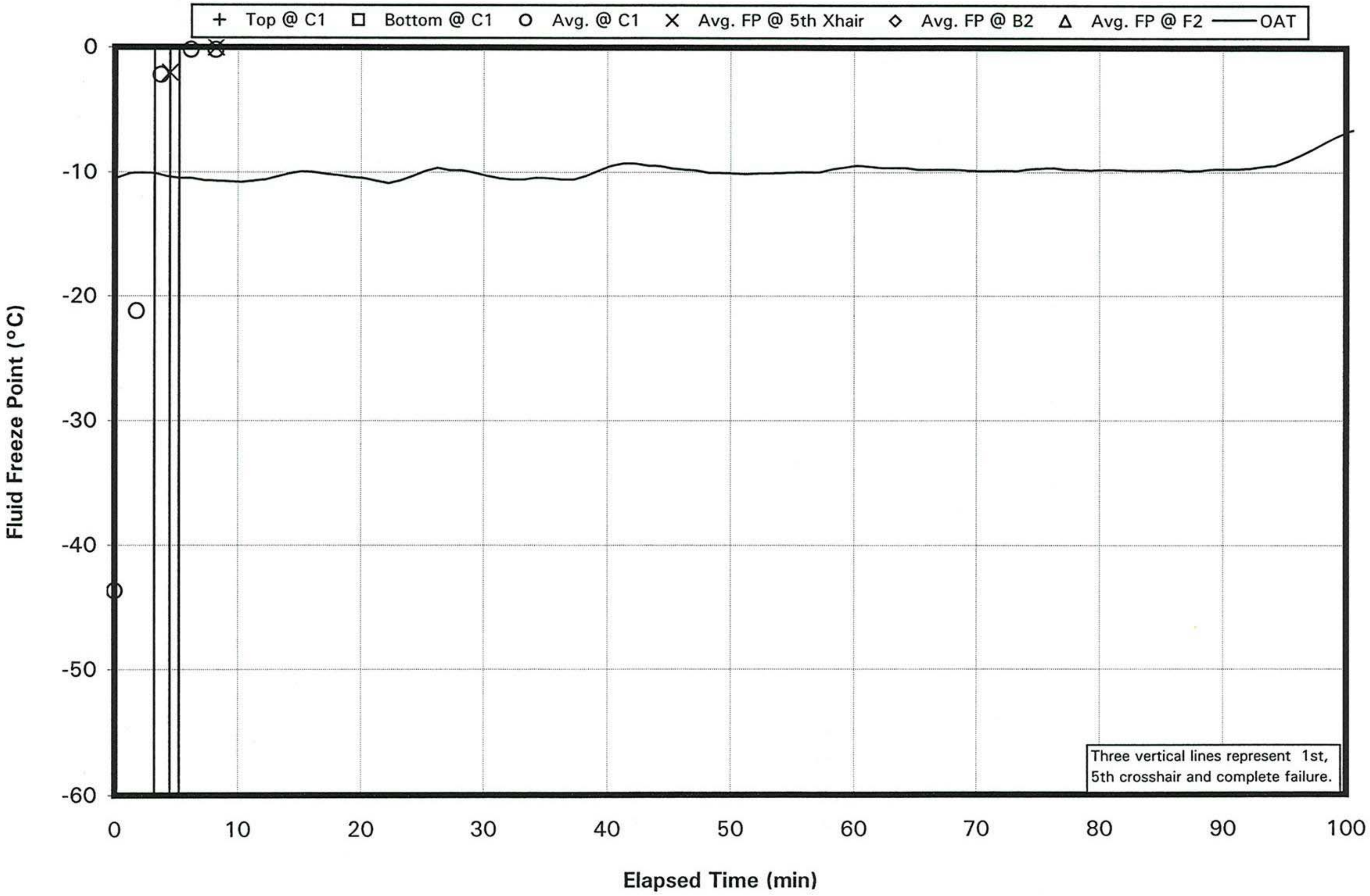


cm1380/analysis/doc_fail/thicknes/Thk_id05.xls
10/15/98, 2:07 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 5



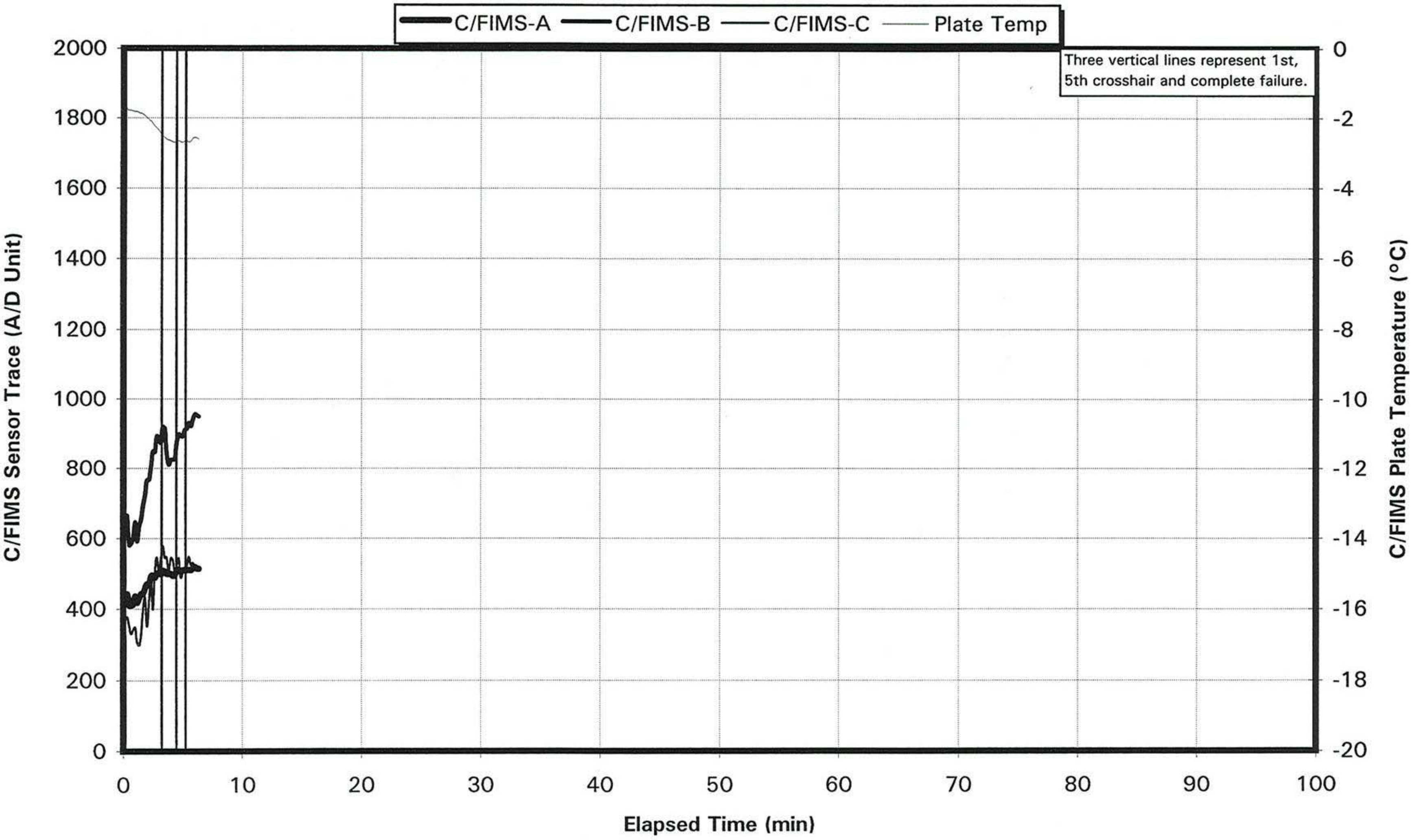
Three vertical lines represent 1st, 5th crosshair and complete failure.

cm1380/analysis/doc_fail/brix/Brx_id05.xls
10/15/98, 2:01 PM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 5

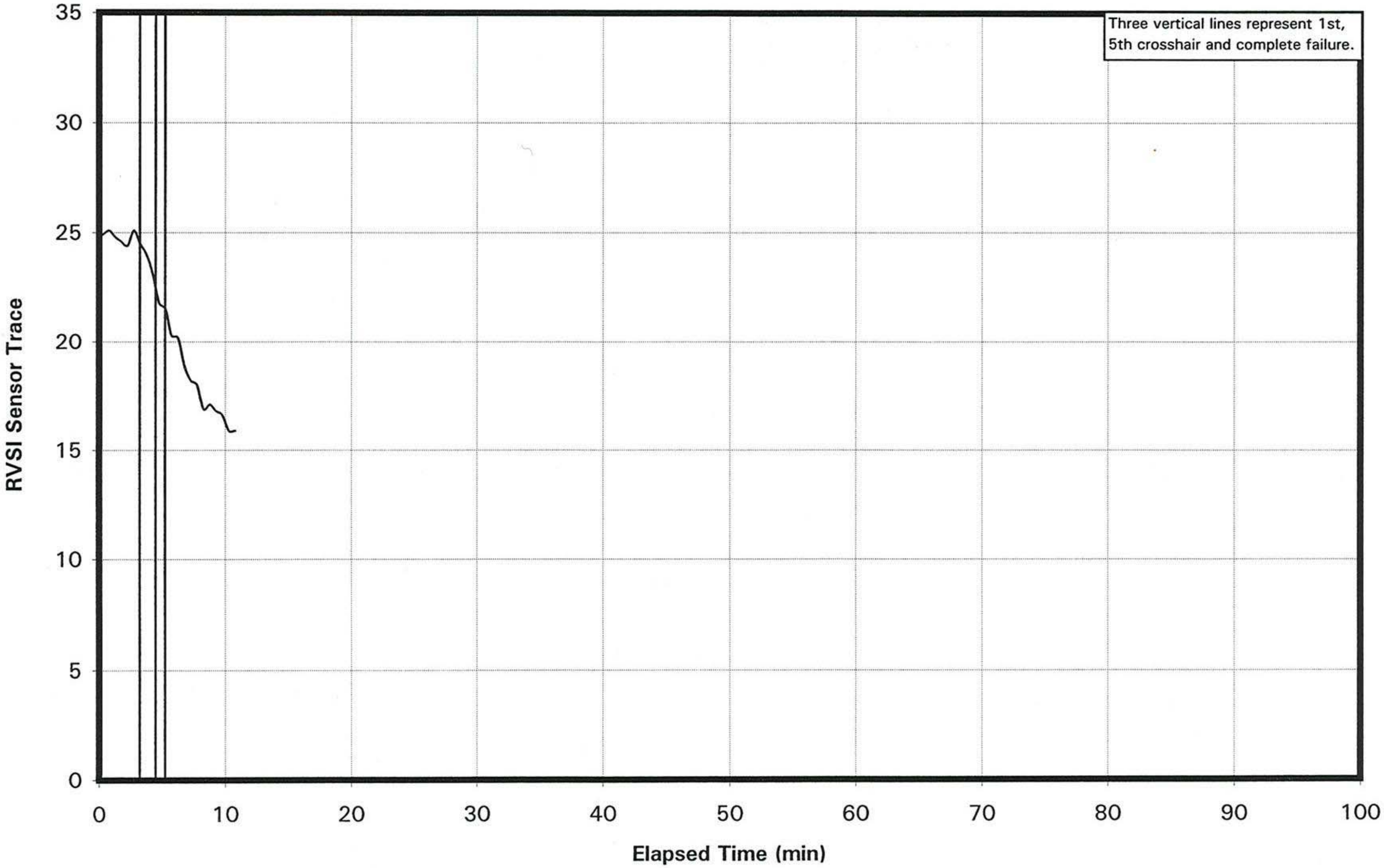


cm1380/analysis/doc_fail/cfims/Cfm_id05.xls
10/15/98, 2:06 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 5



cm1380/analysis/doc_fail/rvsi/Rvs_id05.xls
10/15/98, 2:05 PM

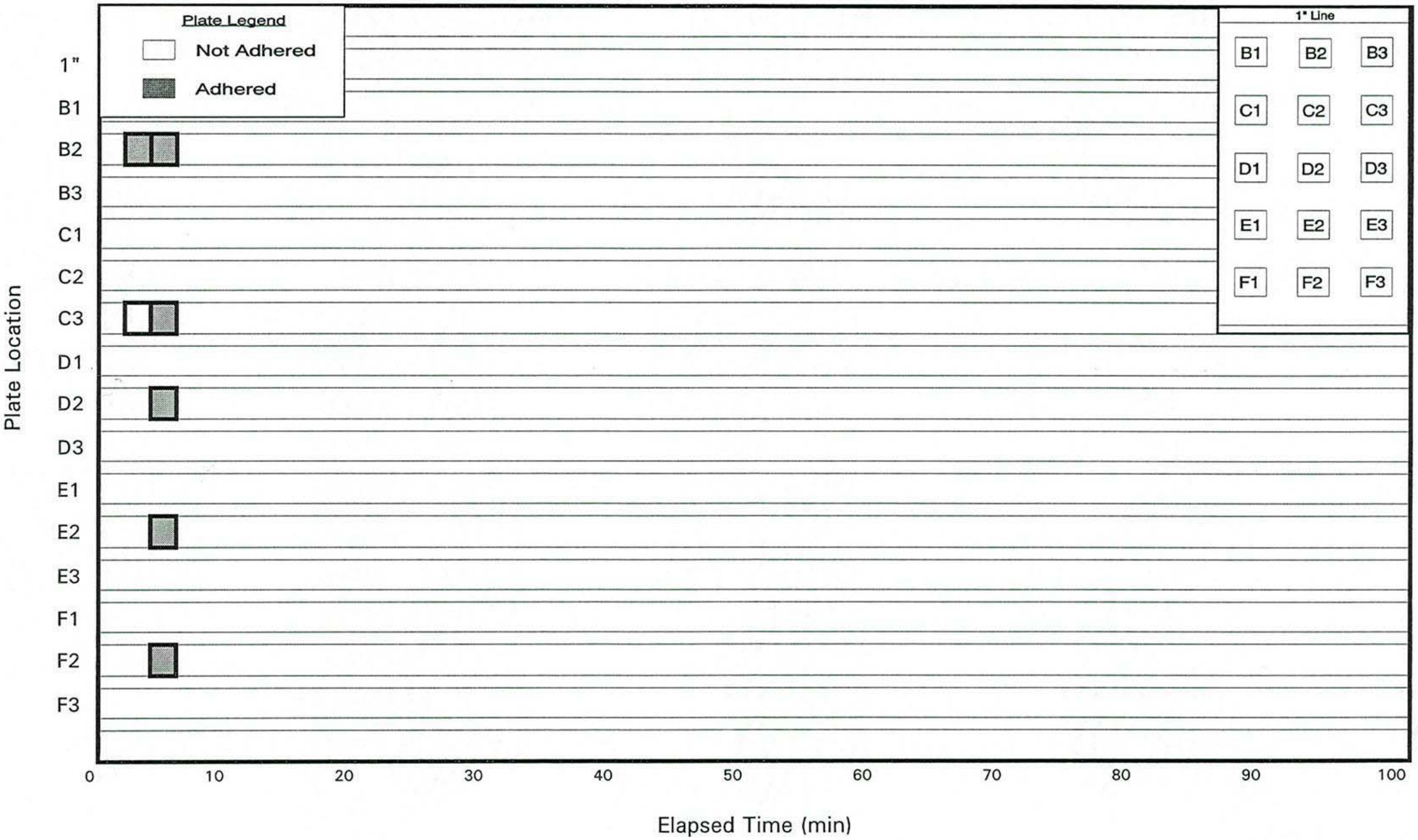
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 5

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 5



cm1380/analysis/doc_fail/Adh_id05
11/24/98, 10:46 AM

GENERAL TEST INFORMATION

ID # 6

July 8, 1998

Ambient Air Temperature:	-10.3°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	25.2 g/dm^2/hr
Fluid:	UCAR ULTRA +
Dilution:	Neat
Start of Test:	15:25:50
Failure Mode:	5th X-hair
Failure Location:	C3
Failure Time (Standard):	15:57:00
Failure Time (Complete Plate):	16:05:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 6

Photo C6.1 - After Pouring, t = 0 min

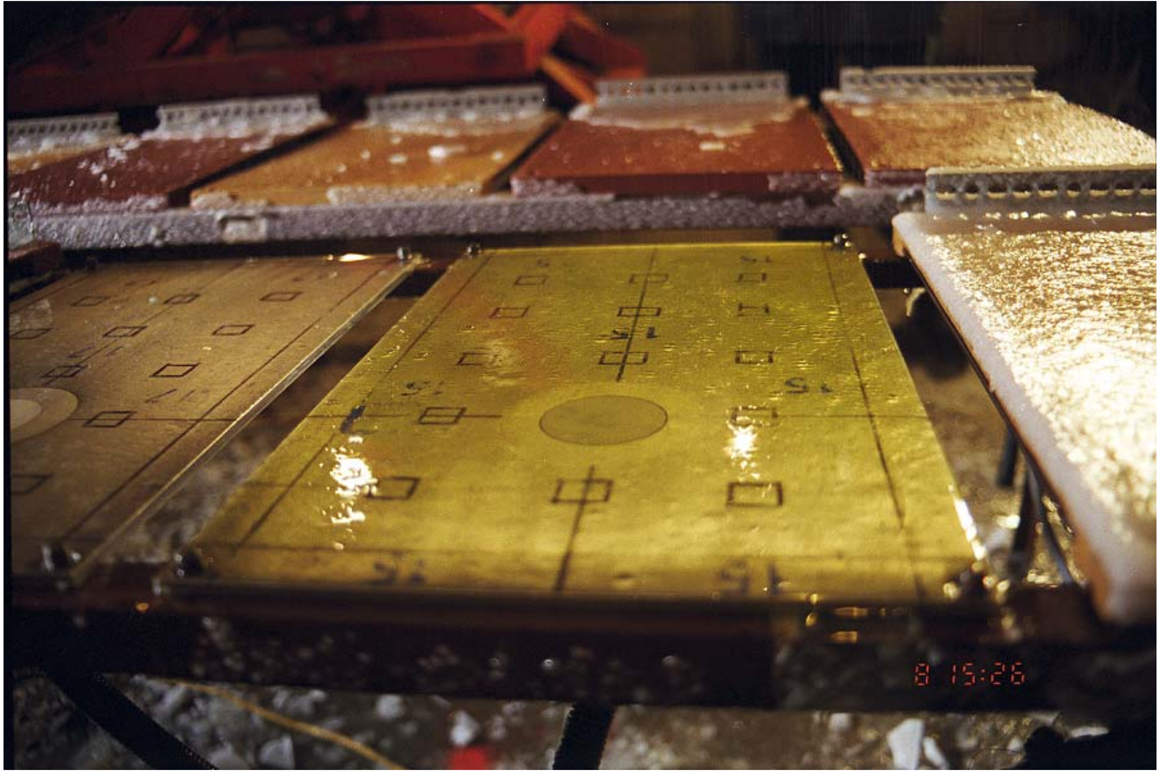
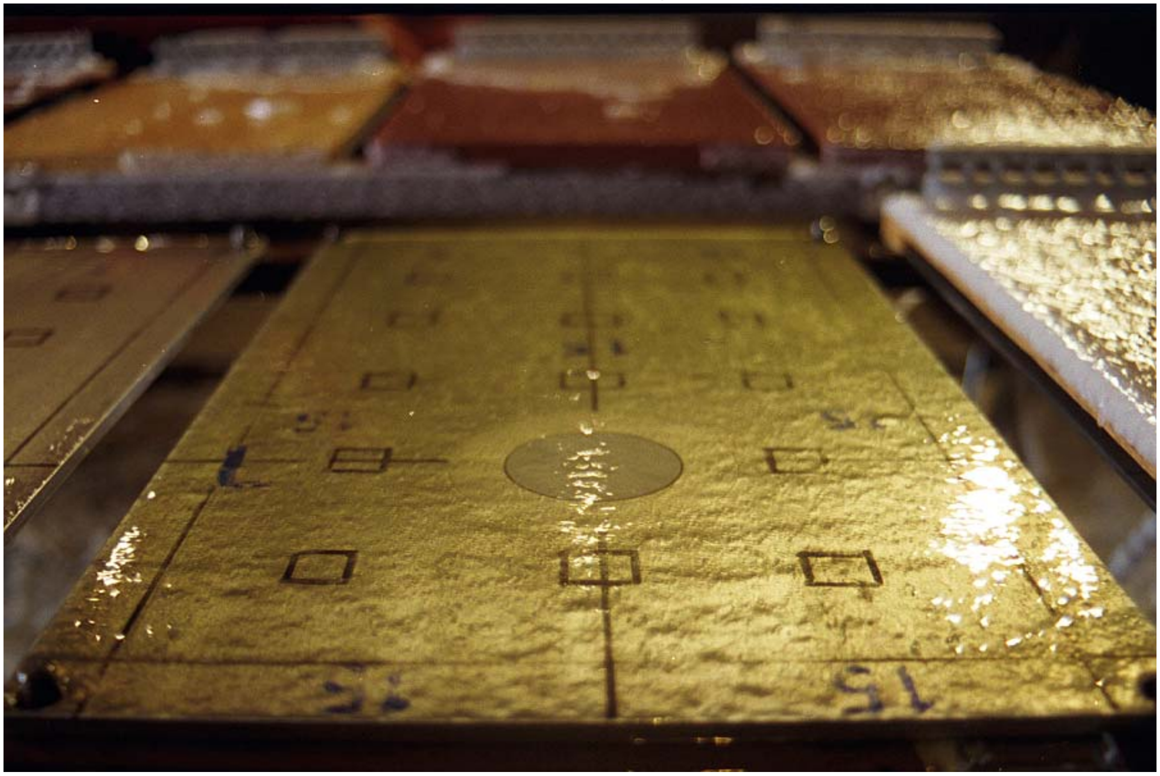


Photo C6.2 - 1st Failure, t = 4 min



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 6

Photo C6.3 - Standard Failure (1/3 or 5th Crosshair), t = 30 min

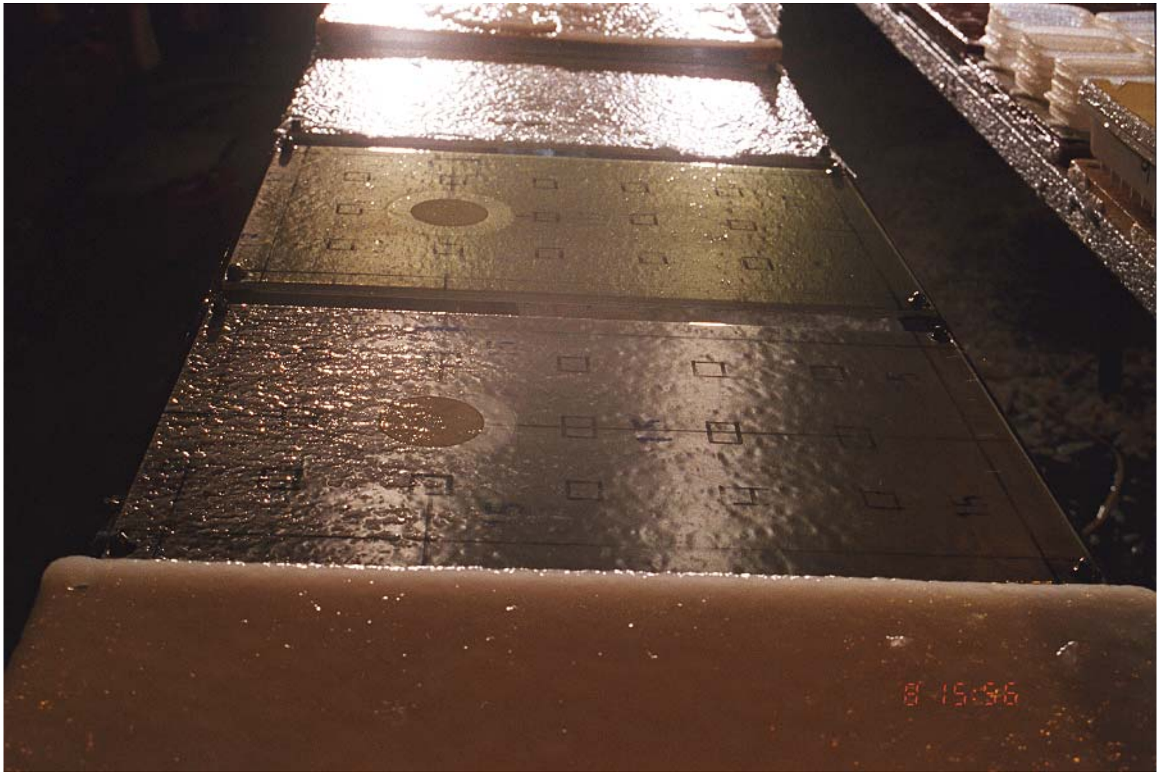
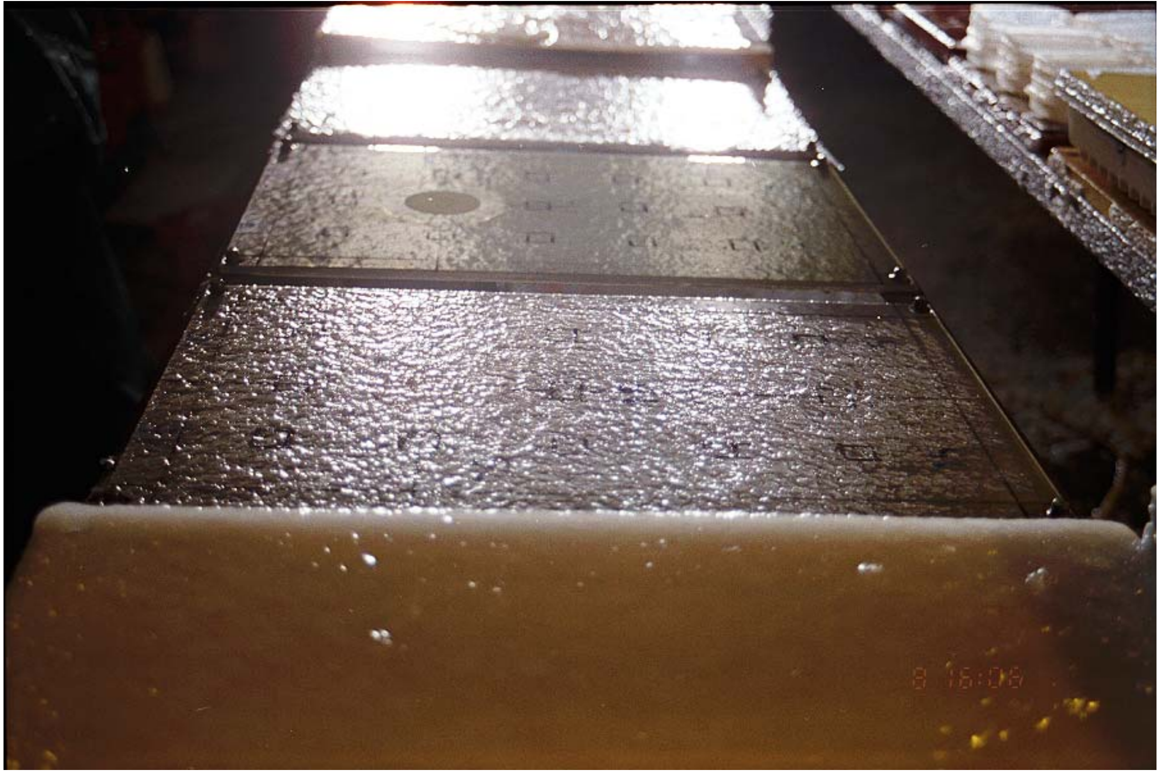


Photo C6.4 - Complete Fluid Failure, t = 40 min



H:\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID06.doc
Last printed 10/14/98 8:30 AM

ID # 6

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08

ZR
TEMP -10°C
R= 25

Time: 1526

Plate Location: 2

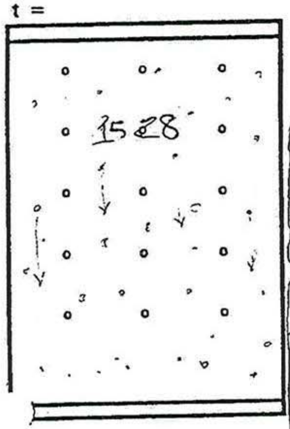
Run #: 4

Fluid Name: ULTRA ⊕

Fluid Dilution: 100%

as per prev. description of ULTRA ⊕ failure.

t =



Pale same as for runs 3b, +3b4

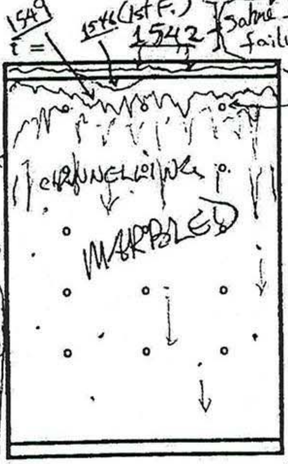
speckle at 1527-1528

op at 1530

Marbled 1540-1542

→ noted fine, evenly distributed, spot-type ~~frozen~~ contamination on entire plate and moving at the rate of flow of fluid off the plate - Primarily in top fl. srf. layer. !

t =



same ~~fine~~ platelet type failure - wet + overlapping but not yet fused together

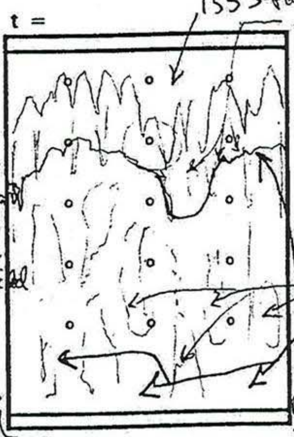
1550 fine finger-type failure propagation beginning. F form below failed region shown at 1549 (V. wet), but not slushy; failures are too large-particled to be slush!

ADHesion extends to 1" line; fusion of platelets close to 3".

- less visible spot failures in marbled state
v. slow flow.

~~---~~ CHANNELLING also breaking up marbled fluid

t =

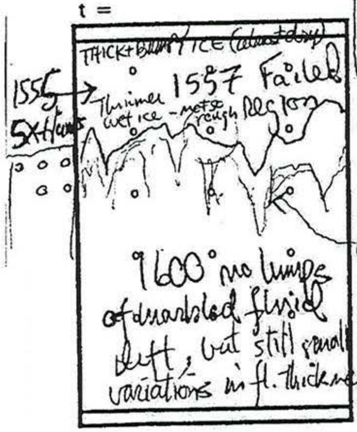


fingers propagating further down plate as failure thickness grows; channelling has ~~be~~ broken up the marbled fluid into lumps and smooth pre-failure areas.

ignore 1557 -

1555 5 X-Hairs!
3₁ 3₂ 3₃
2₂ 2₃

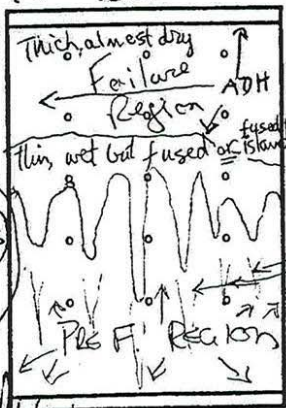
t =



1600° no lumps of marbled fluid left, but still small variations in fl. thickness remains. All this region could be considered to be in a pre-failure condition (ie thin, dil. fl. layer).

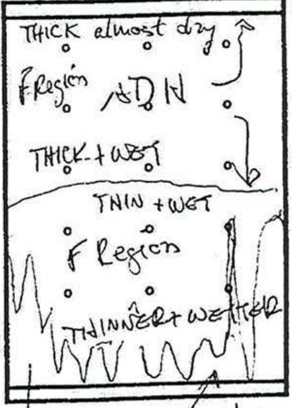
thin failures (fingers) beginning to fuse but still V. wet

t = 1601



wet ~~fiss~~ failings in progress.
(finger propagation

t = 1605



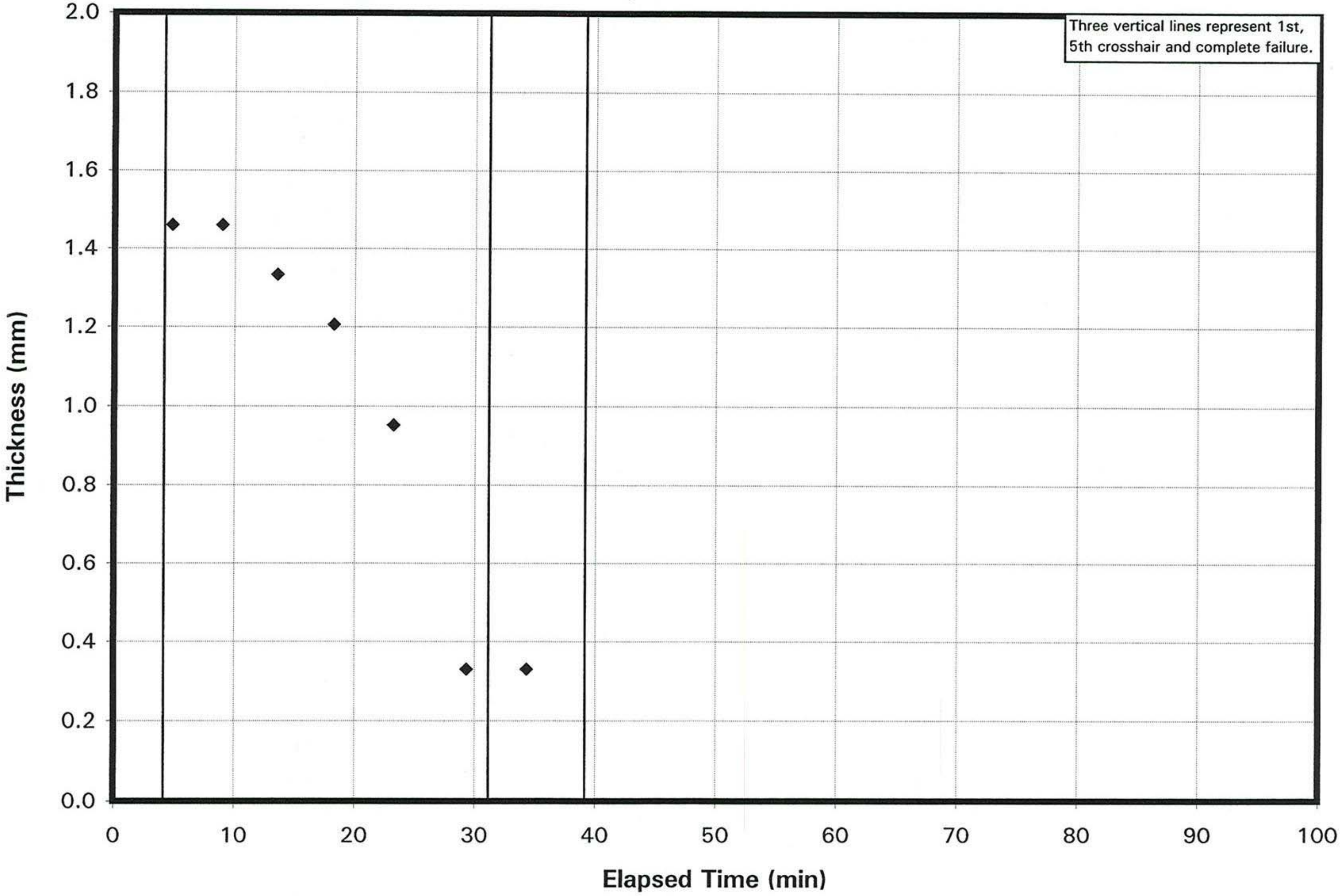
PRE F Region: wet + not yet failed.

Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 6

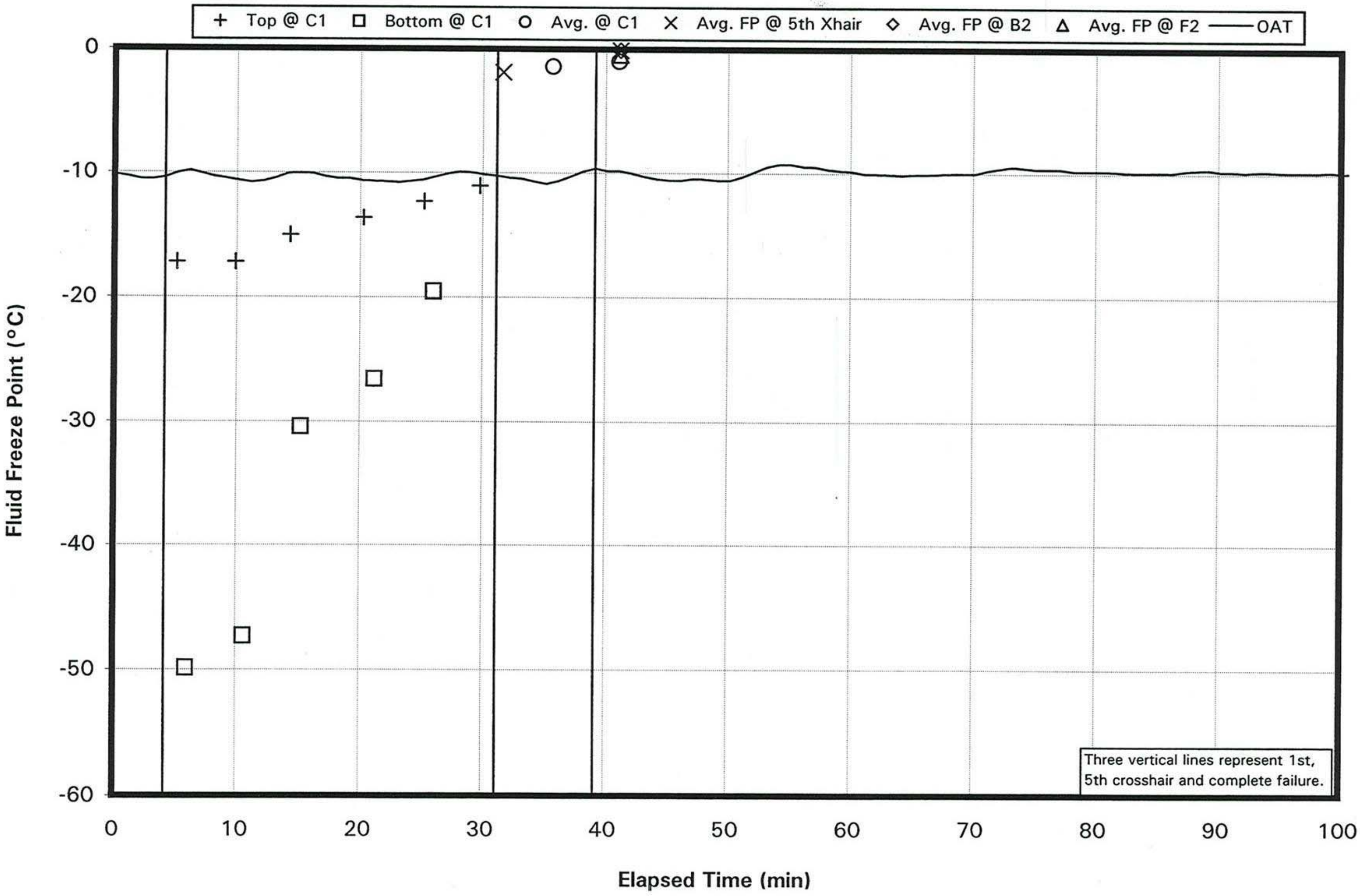


cm1380/analysis/doc_fail/thicknes/Thk_id06
10/22/98, 7:57 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 6

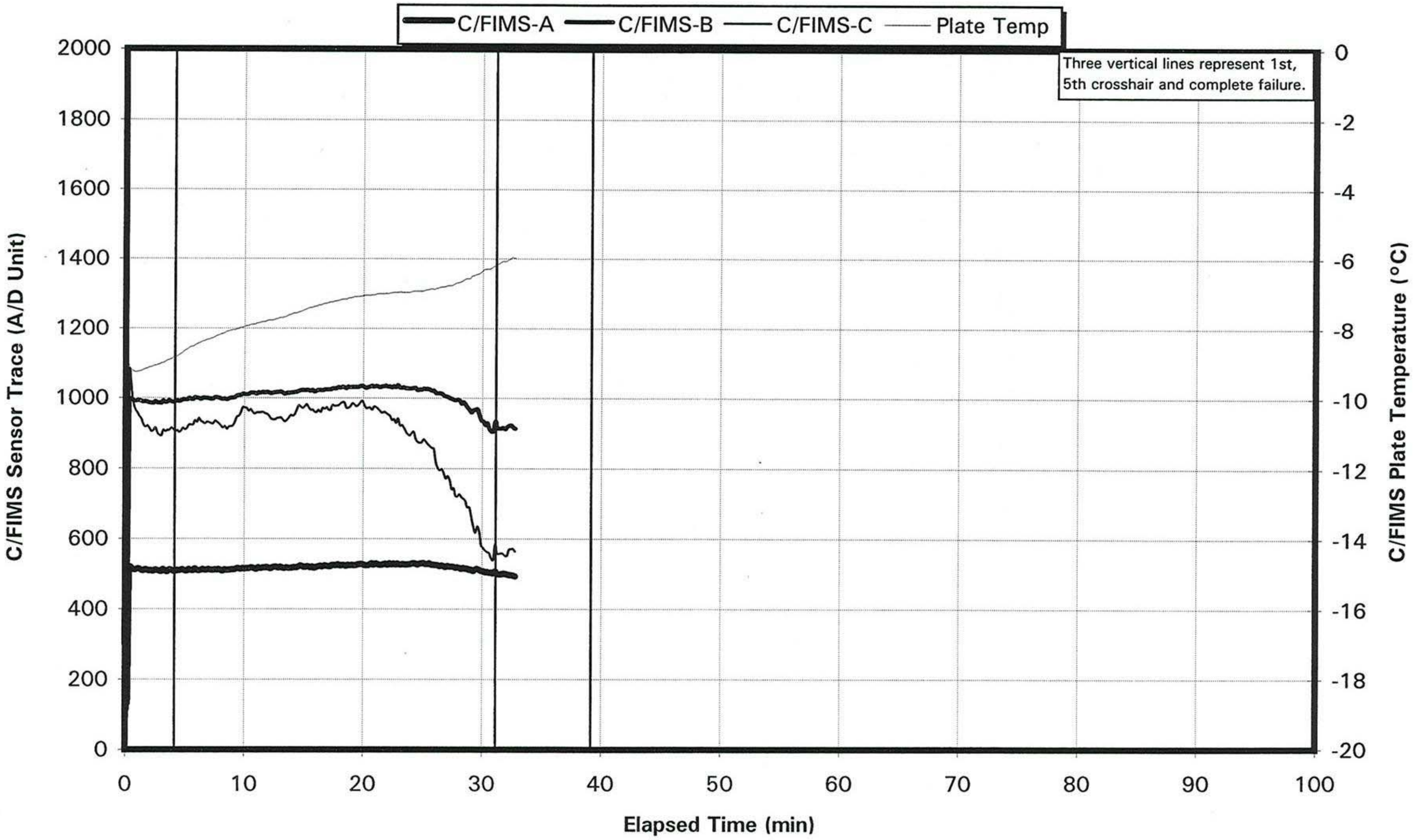


cm1380/analysis/doc_fail/brix/Brx_id06
10/15/98, 9:23 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 6

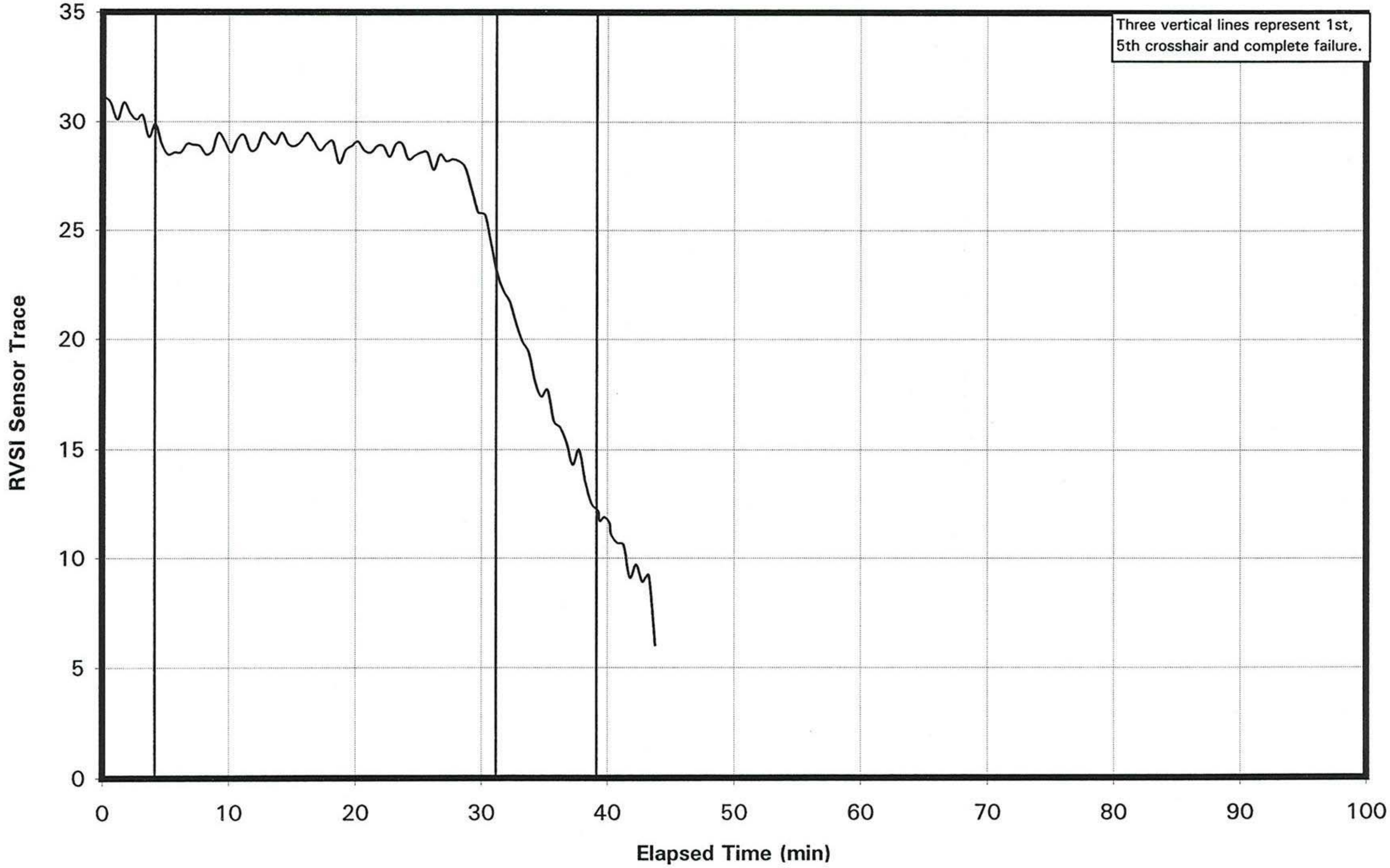


cm1380/analysis/doc_fail/cfims/Cfm_id06
10/15/98, 10:15 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 6



cm1380/analysis/doc_fail/rvsi/Rvs_id06.xls
10/15/98, 11:27 AM

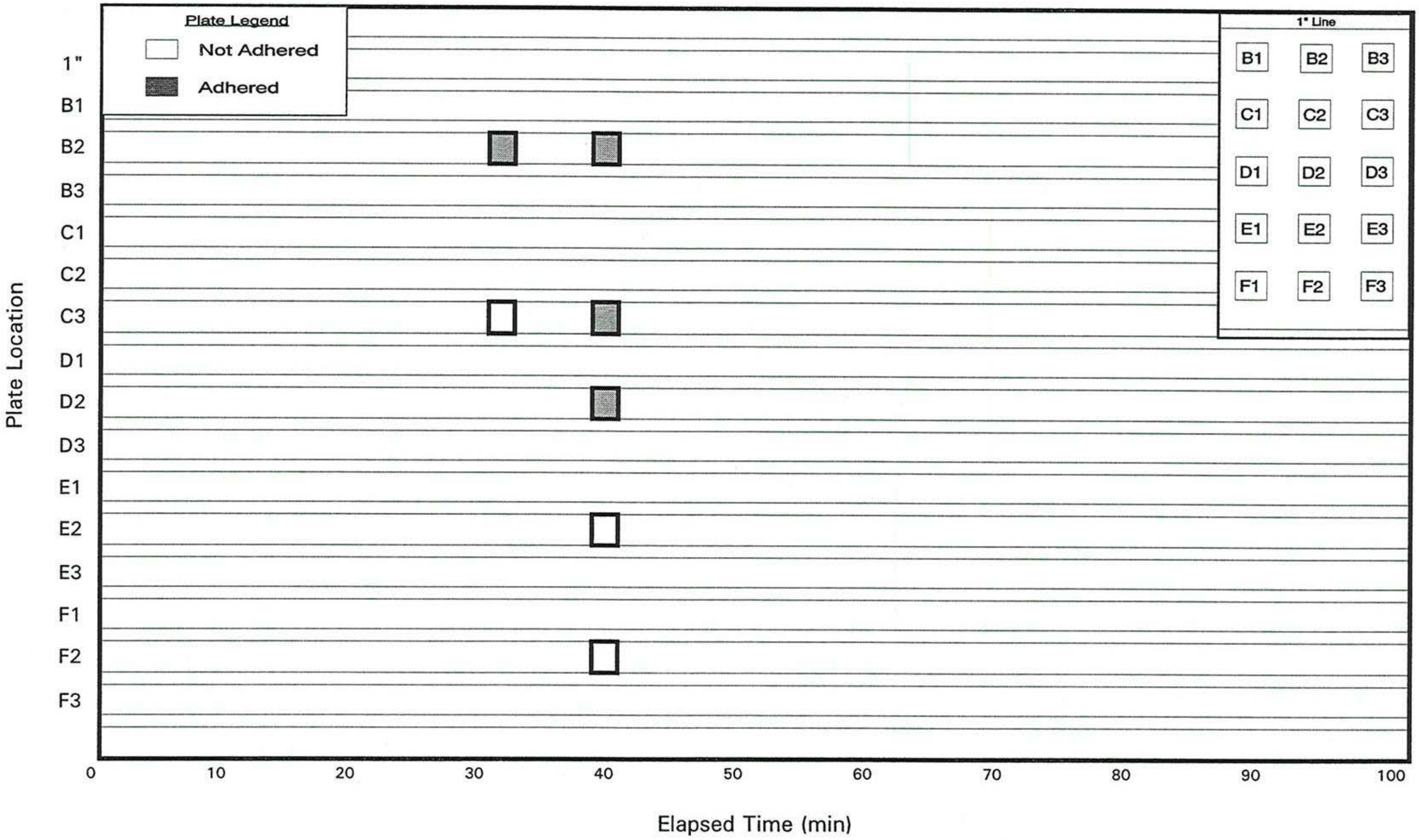
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 6

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 6



cm1380/analysis/doc_fail/Adh_id6
7/28/98, 9:36 AM

GENERAL TEST INFORMATION

ID # 7

July 8, 1998

Ambient Air Temperature: -10.3°C

Precipitation Type: Light Freezing Rain

Rate of Precipitation: 24.5 g/dm²/hr

Fluid: UCAR XL54

Dilution: Std

Start of Test: 15:27:10

Failure Mode: 5th X-hair

Failure Location: C1/C2

Failure Time (Standard): 15:31:00

Failure Time (Complete Plate): 15:32:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 7

Photo C7.1 - After Pouring, t = 0 min

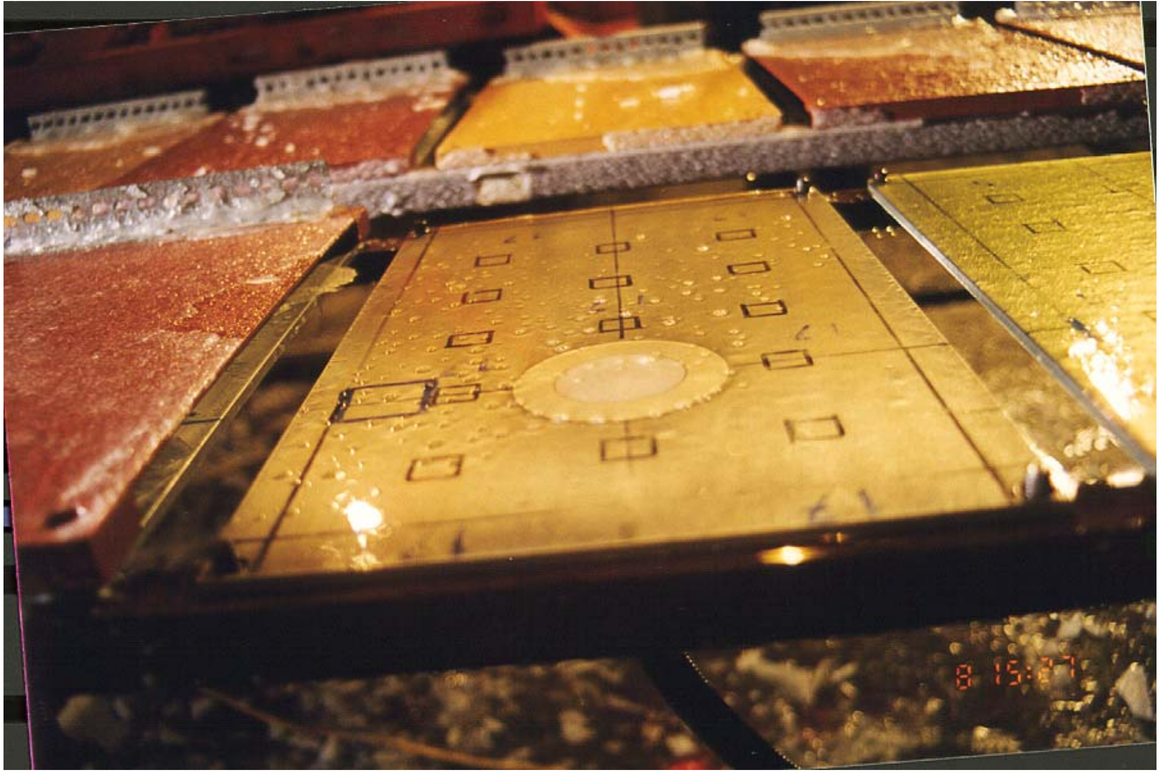
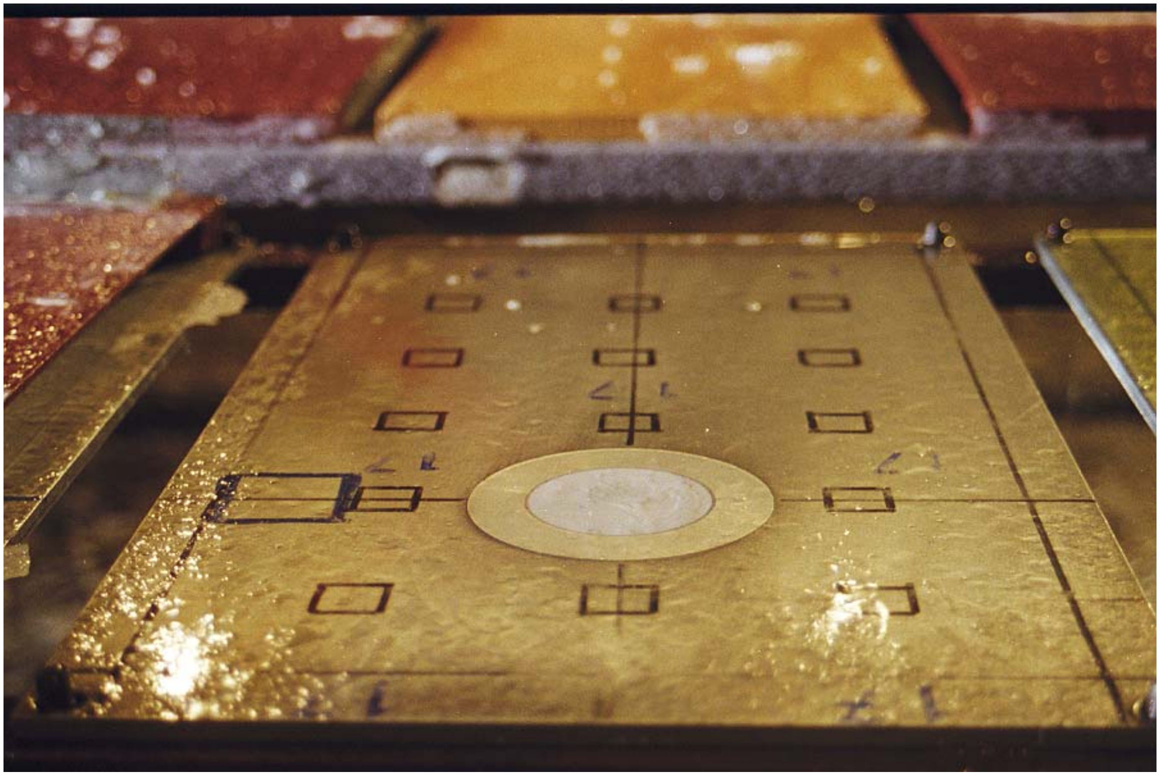


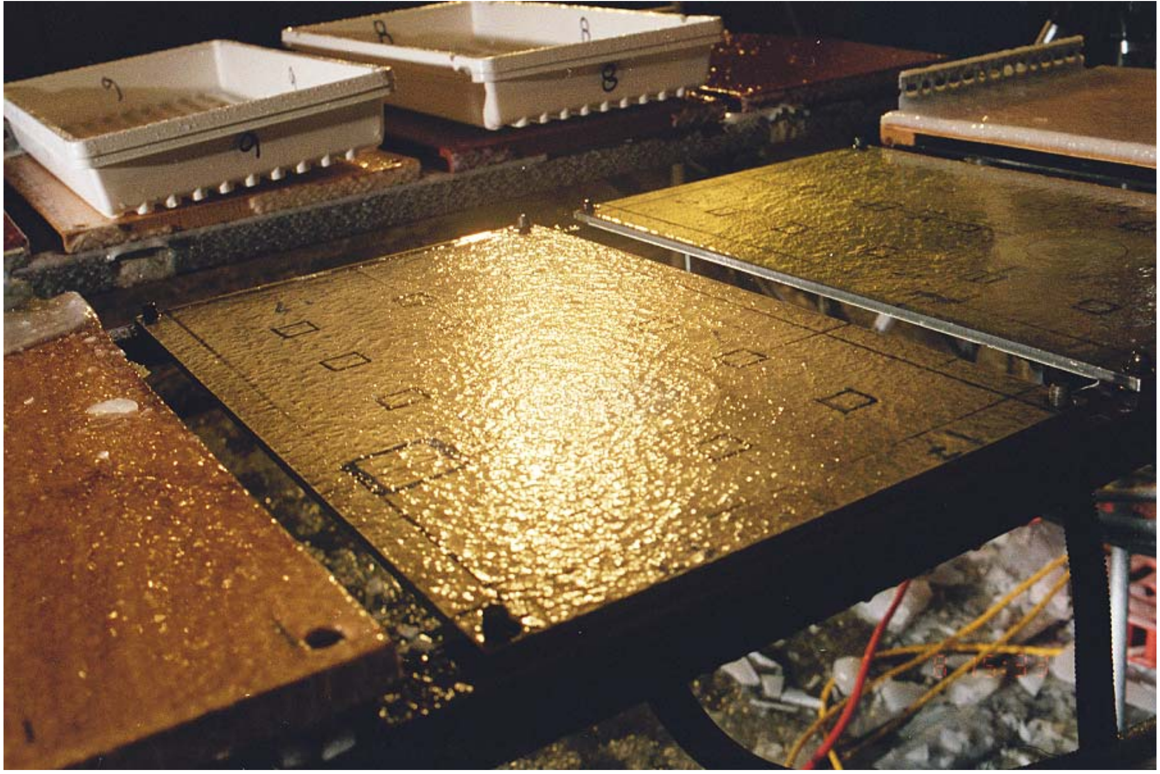
Photo C7.1 - 1st Failure, t = 2 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 7

Photo C7.3 - Standard Failure (1/3 or 5th Crosshair), t = 4 min

Photo C7.4 - Complete Fluid Failure, t = 6 min



ID # 7

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 98

Time: 1527^{10}

Plate Location: 3

Run #: 4$_2$

Fluid Name: XL 54

Fluid Dilution: STD

t = 1528 DRYING of Top edge noted.

fine specks visible from shallow angle top- or side-views of plate.

Pour: 1527^{10} Smooth-surfaced, non-viscous, transparent orange fluid assuming rapid thin layer on plate, some foam bubbles bunched together quickly flow off plate.

1528 some dry or fluidless surface visible on top edge of plate. Specks visible from side of plate, seem to be granules of solid contamination ~~TOP of PLATE BEGINNING~~ to show imminent ~~failure (accum.~~ of wet solids – not yet dense enough for failure call.)

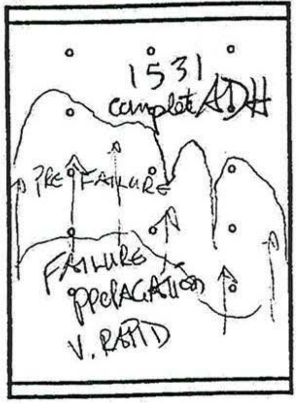
t = 1529

1st failure complete ADH.

Failure is thin but adhesion is strong and failure fusion is ~~almost~~ as fast as failure. ie as soon as an area is failed it fuses + quickly adheres to substrate

Past point of adhesion, thin islands form by dragging pencil tip gently ~~show failure~~ over surface of failure – illustrates fusion but not adhesion. – upper surface of failure is not smooth, but wet and somewhat rough.

t = 1531



t =

t =

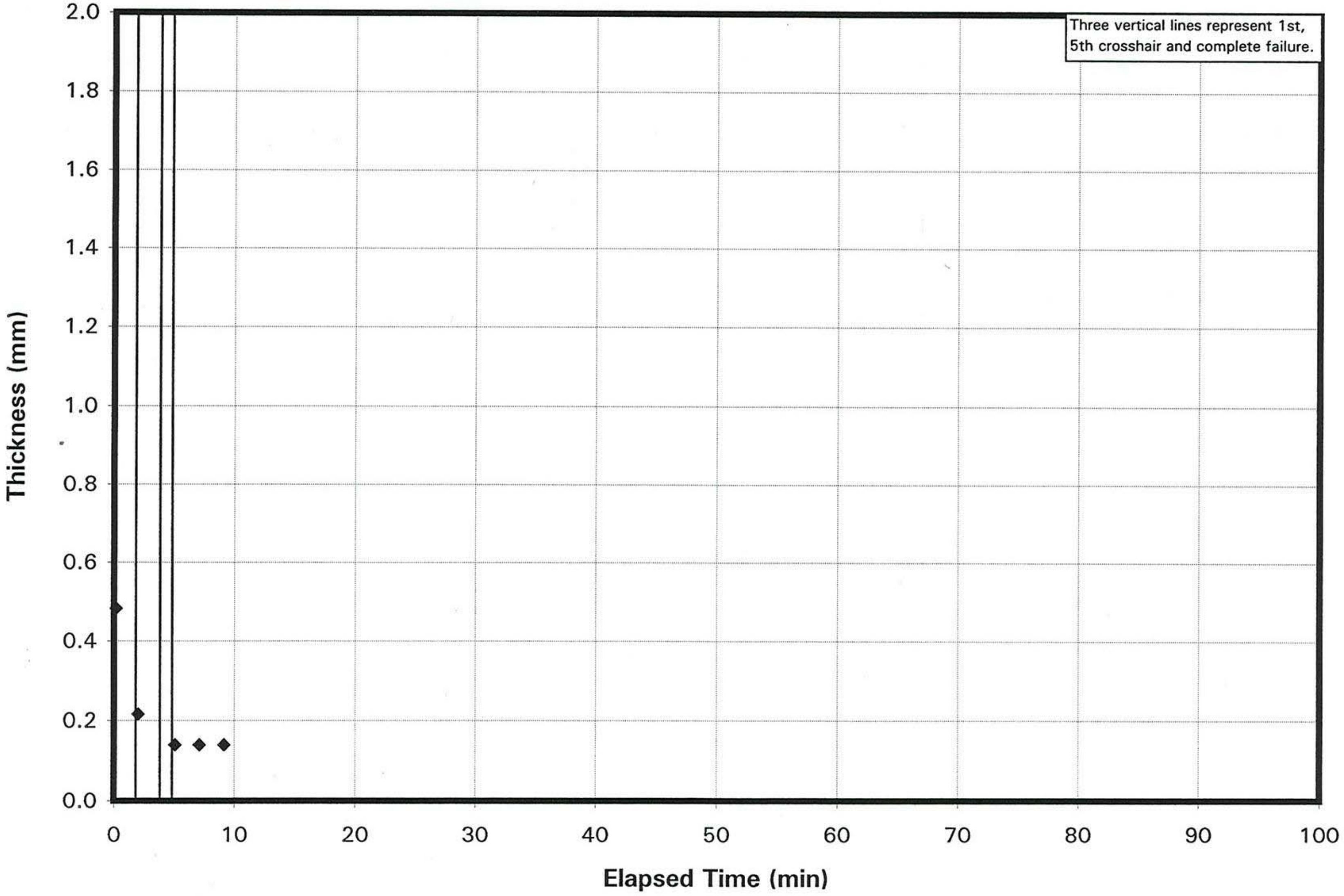
t =

Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 7

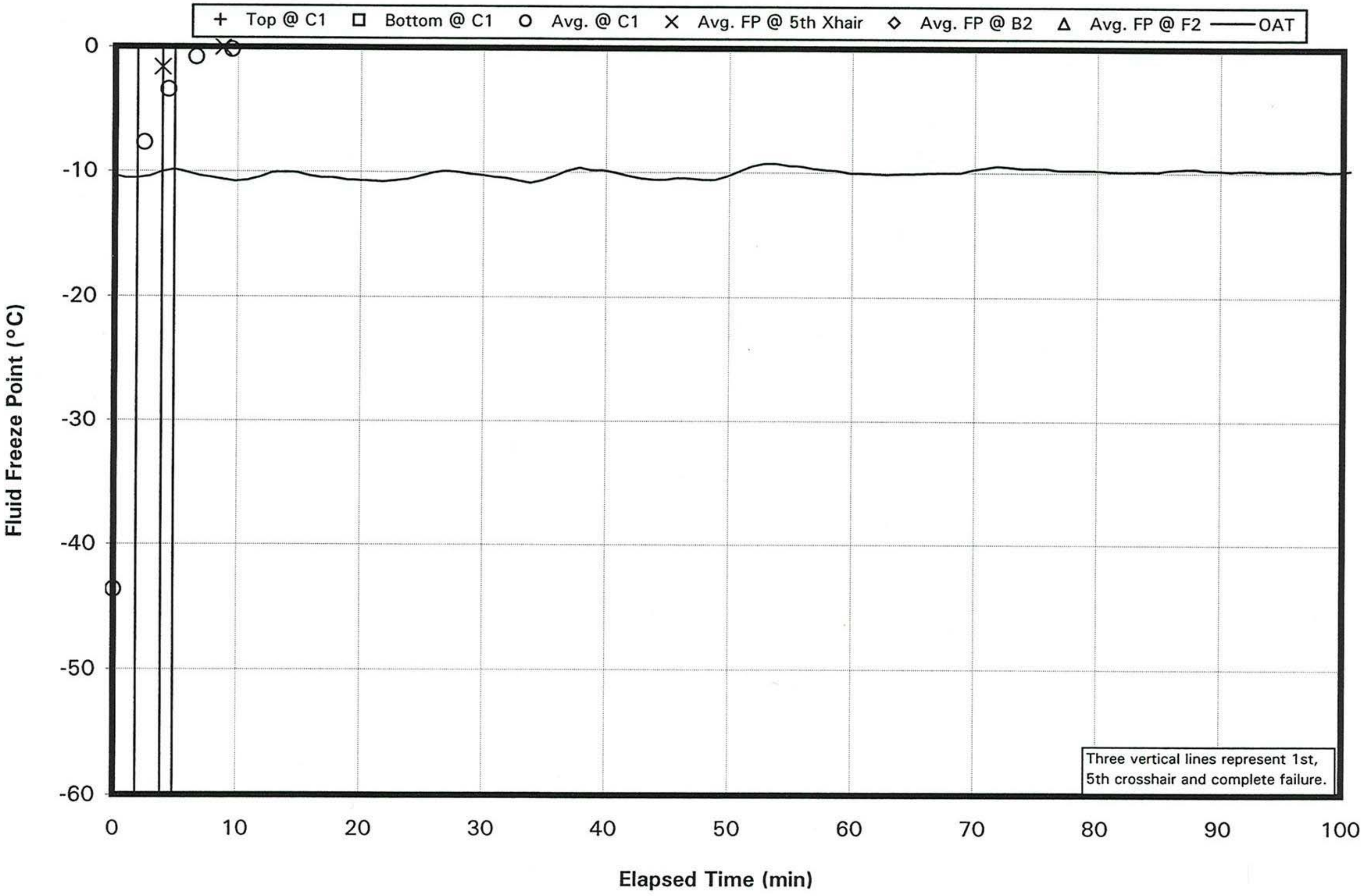


cm1380/analysis/doc_fail/thicknes/Thk_id07
10/14/98, 10:33 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 7

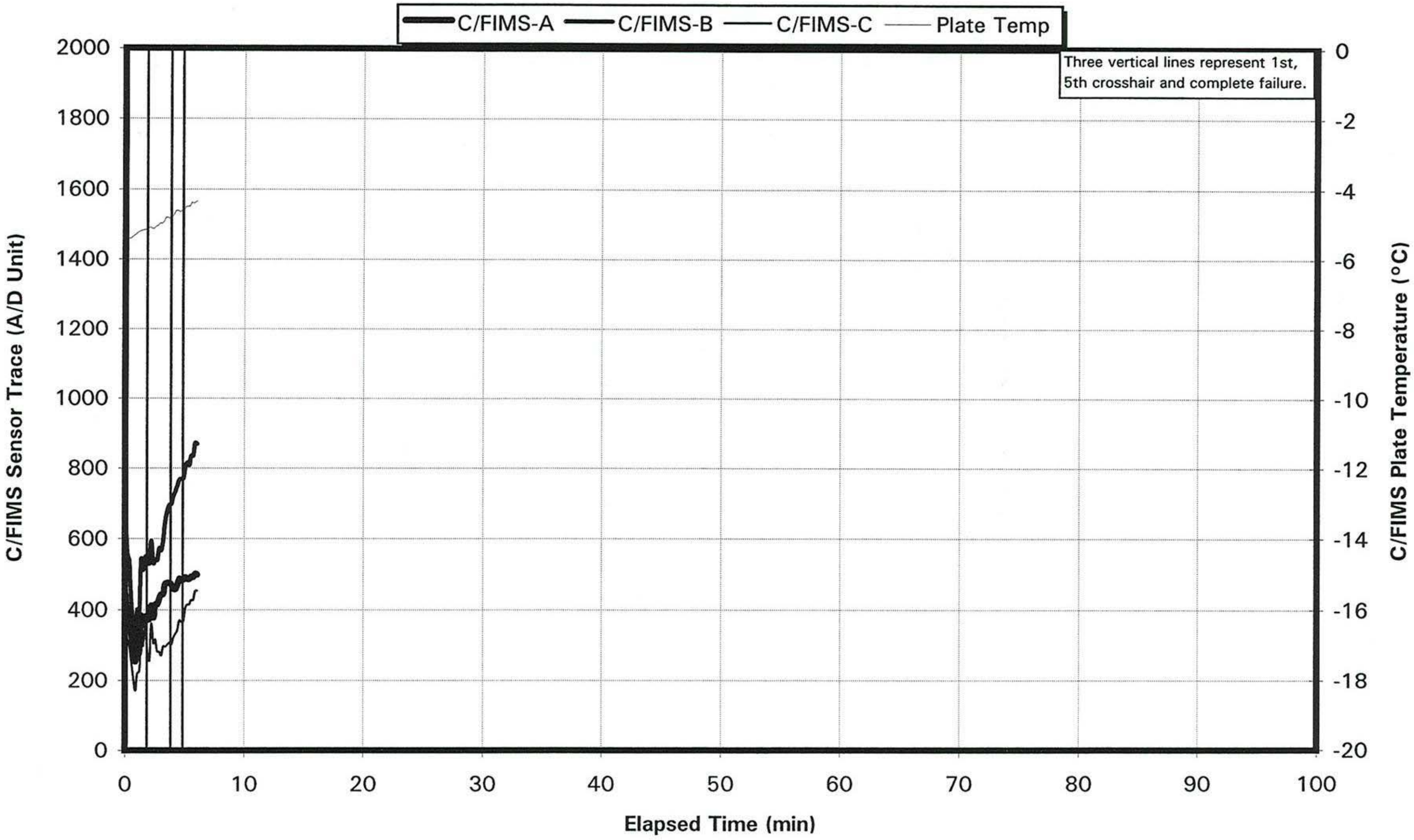


cm1380/analysis/doc_fail/brix/Brx_id07
10/15/98, 9:22 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 7

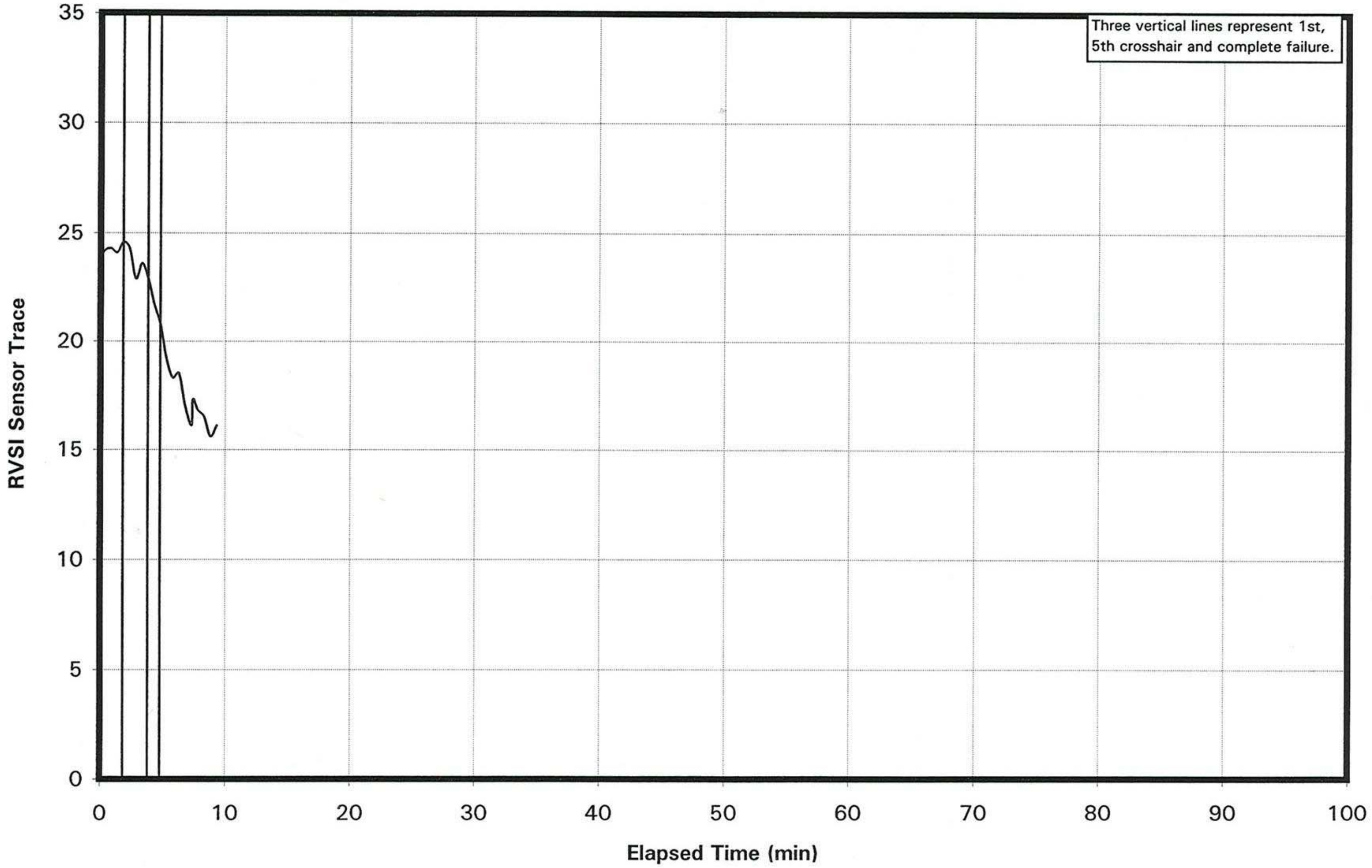


cm1380/analysis/doc_fail/cfims/Cfm_id07
10/15/98, 10:14 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 7

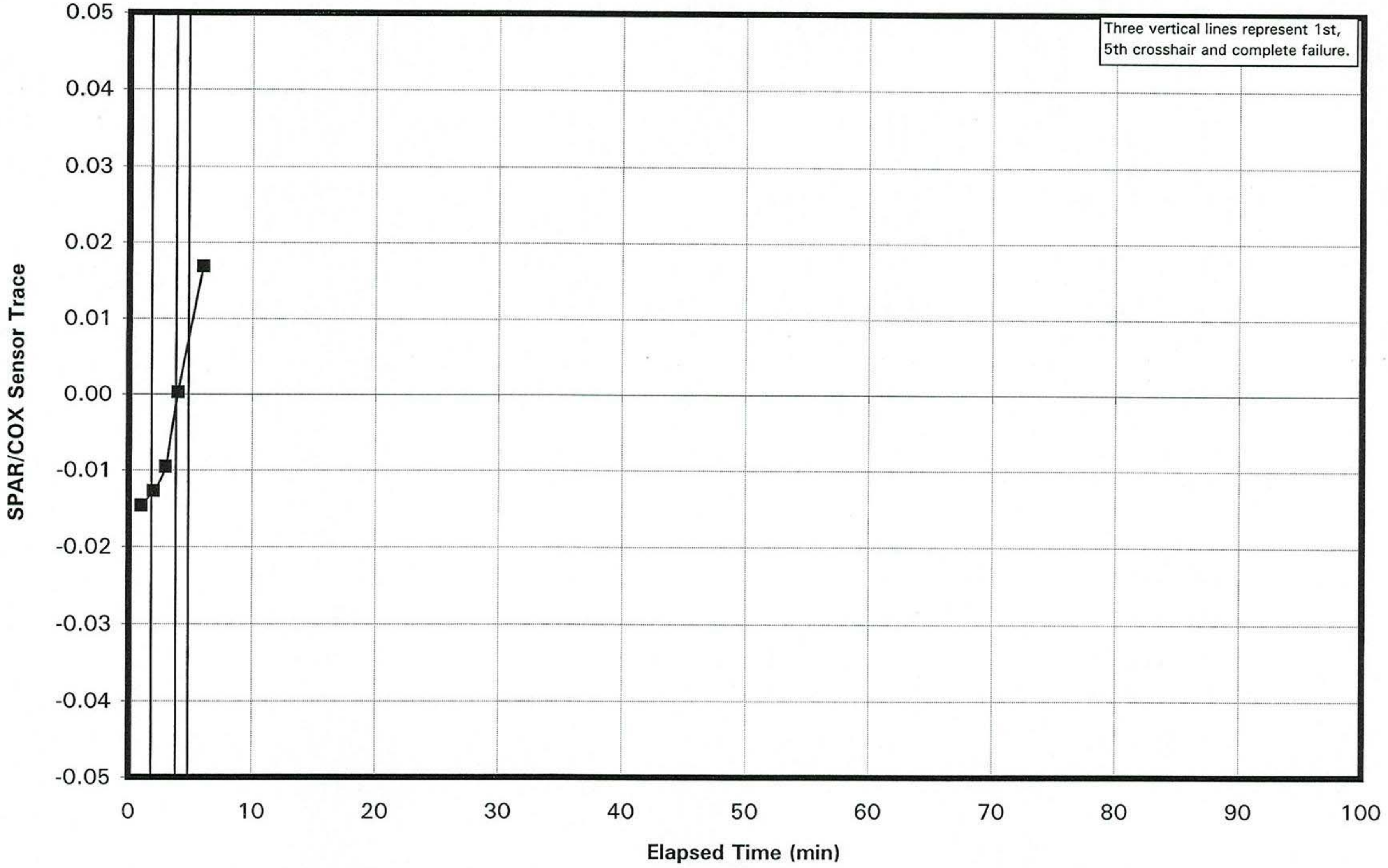


cm1380/analysis/doc_fail/rvsi/Rvs_id07.xls
10/15/98, 11:35 AM

DOCUMENTATION OF FLUID FAILURE

SPAR/COX SENSOR TRACE

ID # 7

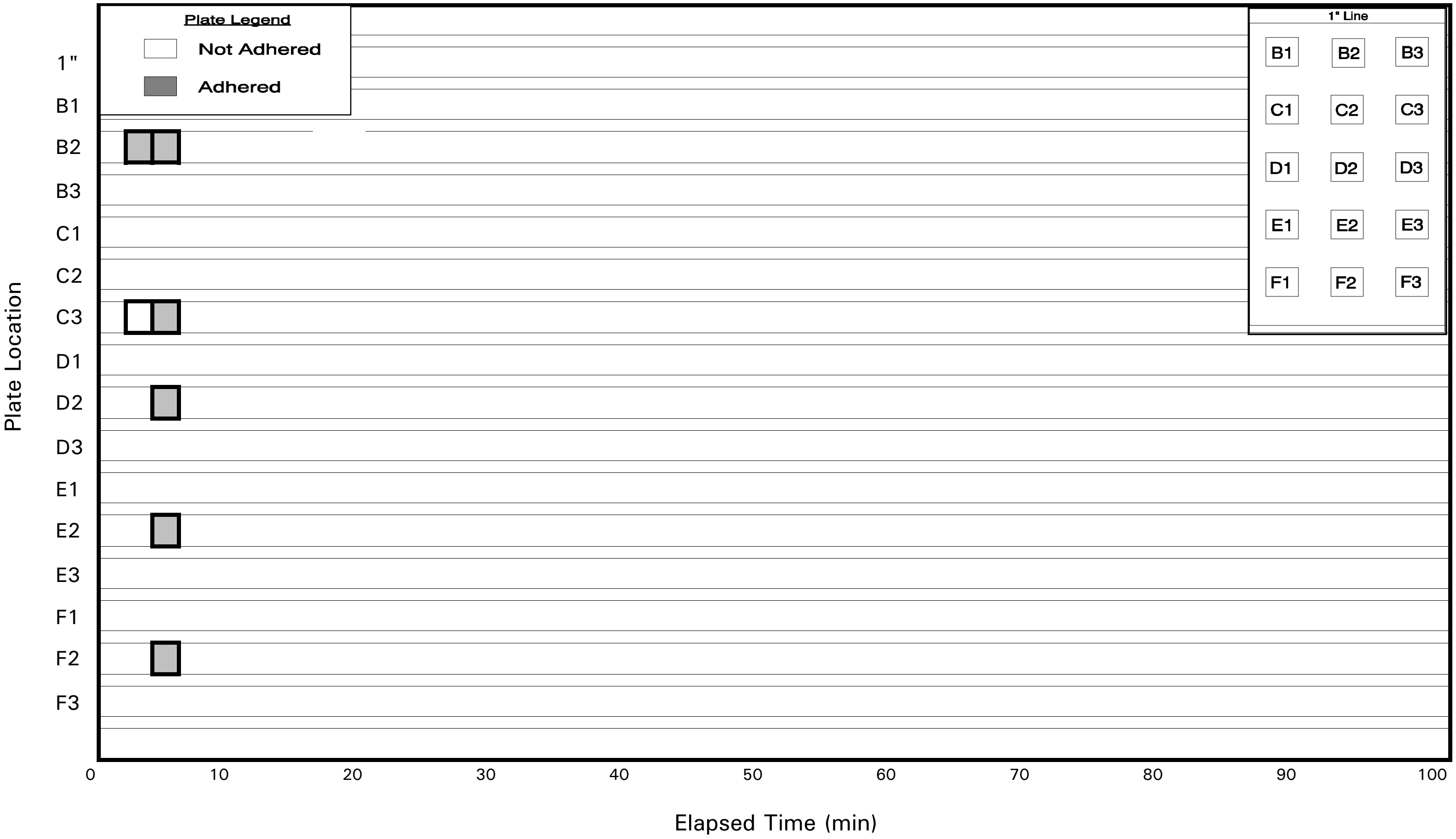


cm1380/analysis/doc_fail/cox/Cox_id07
11/24/98, 10:15 AM

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 7



cm1380/analysis/doc_fail/ADH_ID07
9/21/2006, 11:39 AM

GENERAL TEST INFORMATION

ID # 8

July 8, 1998

Ambient Air Temperature:	-10.5°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	25.2 g/dm²/hr
Fluid:	OCTAGON
Dilution:	Neat
Start of Test:	16:11:00
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	16:33:00
Failure Time (Complete Plate):	16:41:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 8

Photo C8.1 - After Pouring, t = 1min

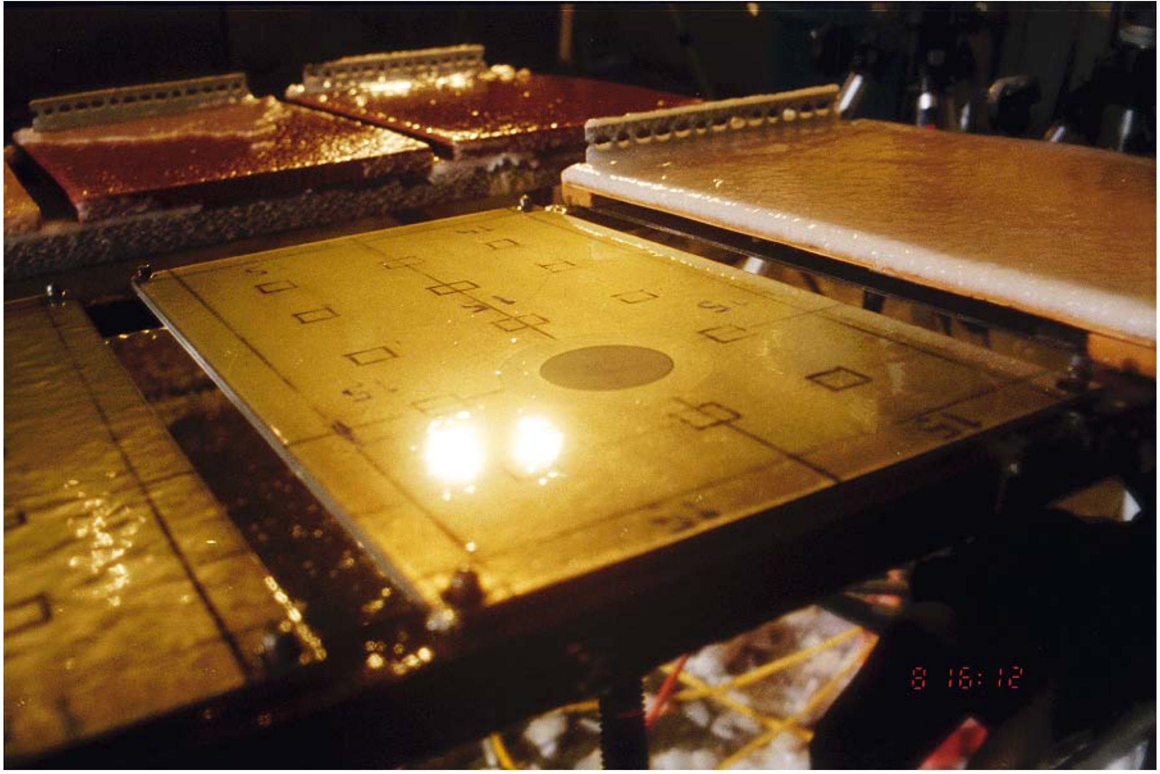
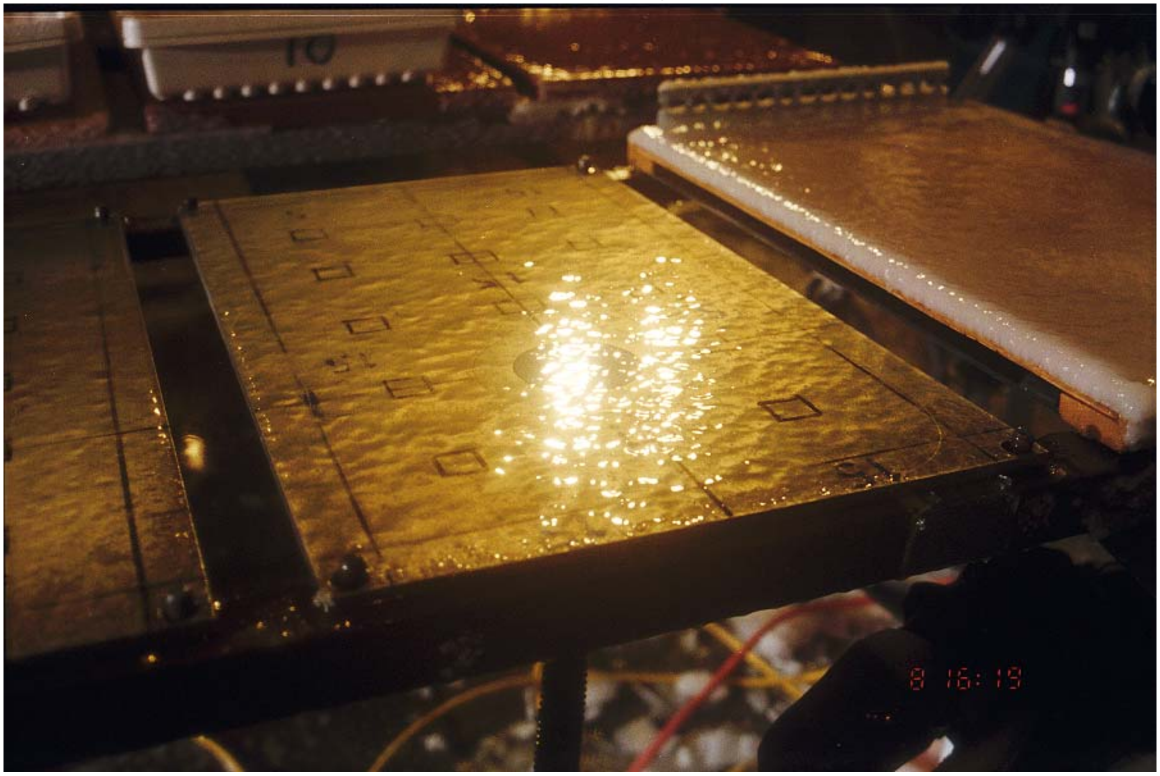


Photo C8.2 - 1st Failure, t = 8 min



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 8

Photo C8.3 - Standard Failure (1/3 or 5th Crosshair), t = 22 min

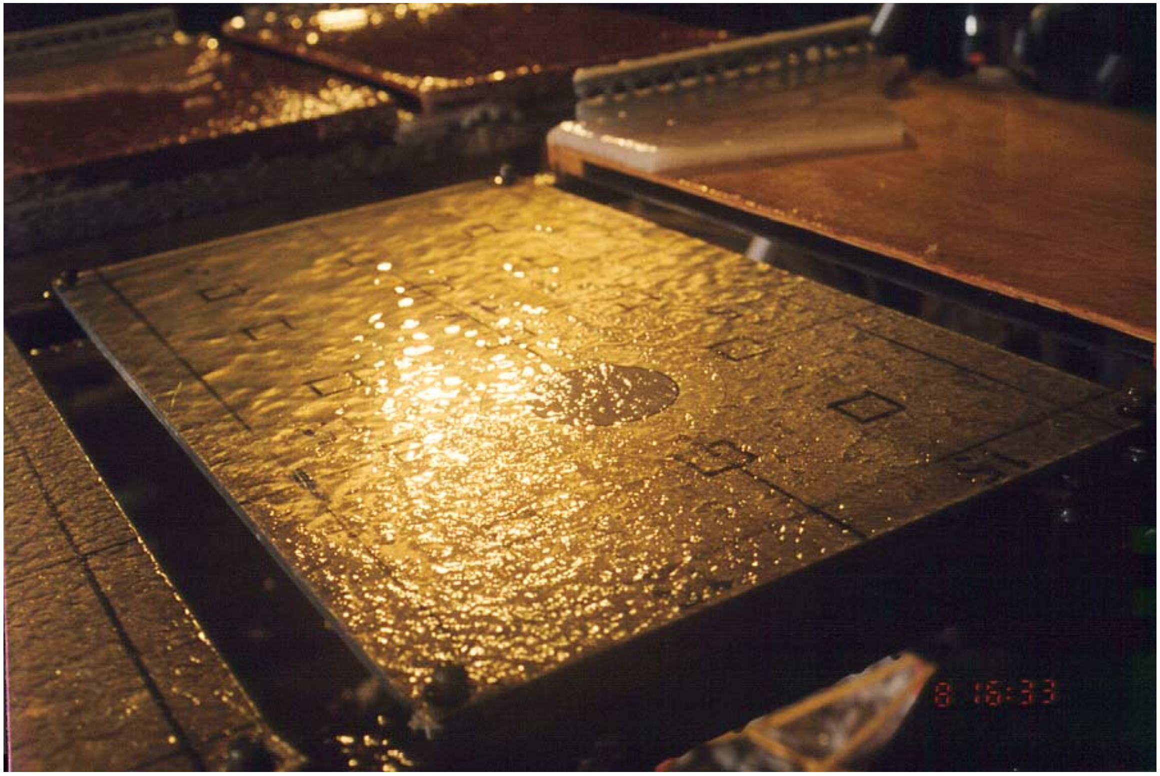
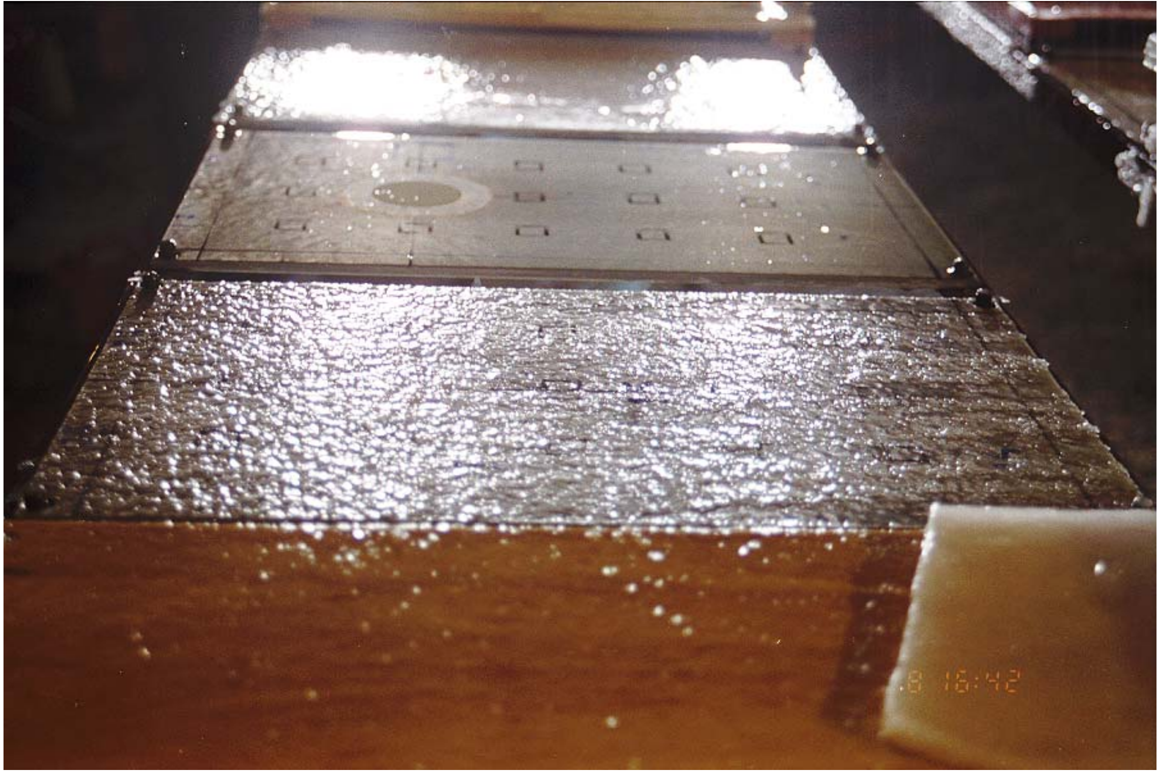


Photo C8.4 - Complete Fluid Failure, t = 31 min



H:\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID08.doc
Last printed 10/14/98 8:35 AM

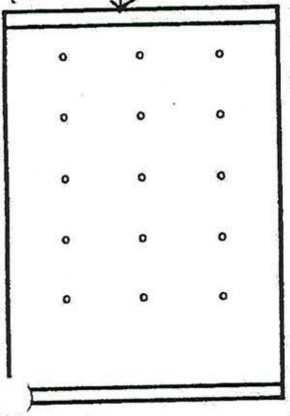
ID # 8

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08
Time: 1611
Plate Location: 2
Run #: 45
Fluid Name: Oct Max
Fluid Dilution: 100%

initial top edge solid contamination begins to accumulate here 1615

t =



Pour:
same as previously ~~described~~ Octmax pours = milky or turbid green and still transparent with no bubbles ~~assumes super~~ smooth, high DOT ~~surface~~ from side view perspective.

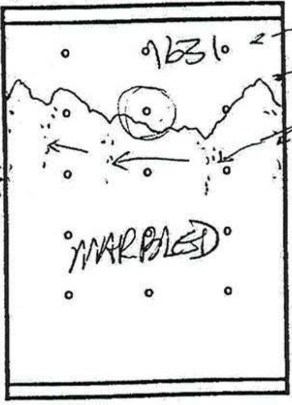
failure has taken a good Foothold from 0 to 21" line.

1st failure 1621

t = 1621

Failure progression at 1628 consisting of fusing platelets of solid contamination. Platelets are too large to produce a slush.

t = 1631



Failure progression

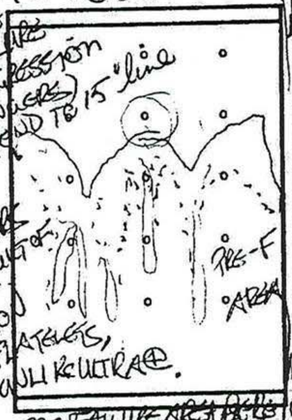
THICKER ADH set in WHITE, BUMPY, LESS WET

THINNER NOT QUITE ADHERING TO PLATE.

fingers emerging along channels in ~~thick fluid.~~ CHANNELS BEGINNING TO BREAK UP THICKER FLUID BELOW.

LARGE STREAK-TYPE FAILURE PROGRESSION (FINGERS) EXTEND TO 15" line

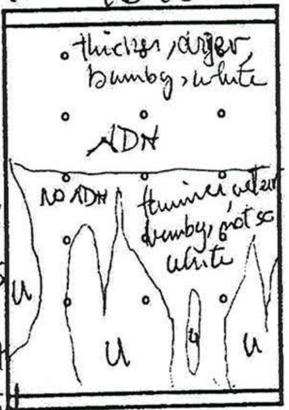
t = 1635



FINGERS A RESULT OF FUSION OF PLATELETS, NOT LIKE ULTRA+. BUT ~~PRE-FAILURE AREA~~ IS NOT SO THIN A FLUID LAYER AS IT IS FOR ULTRA+

from 1615 to ~~1621, fluid taken a gradual marbled appearance, marbled structure size is smaller than in ULTRA+~~ (on average) only slight orange peel texture noted in smooth → marbled transition.

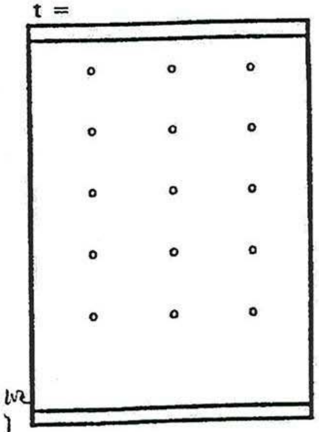
t = 1640



Full plate failure at 164030

u = unfailed area. (pre-failure stage)

t =

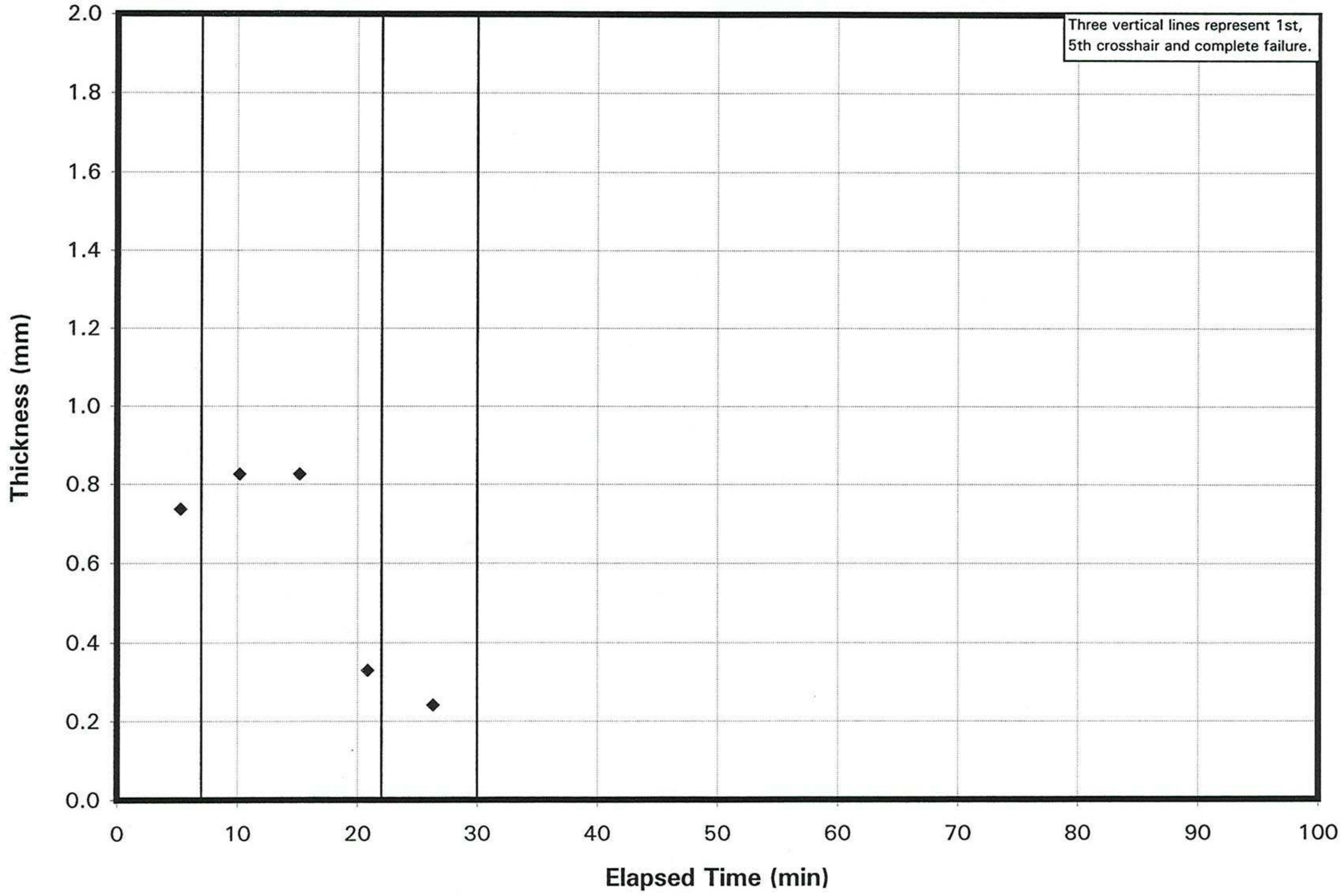


Note: Ensure observations made at t = 0, ... Crosshair ...

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 8

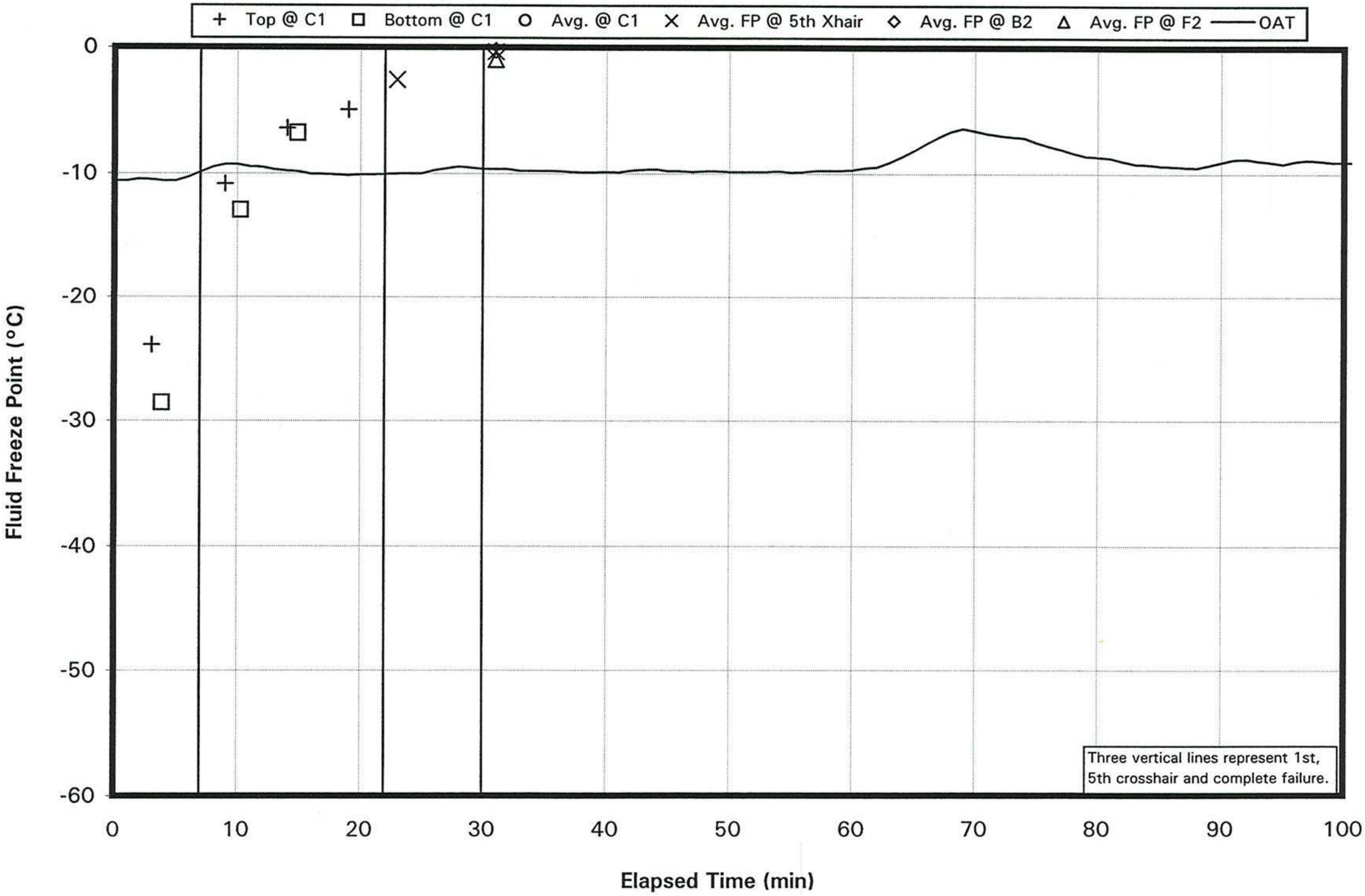


cm1380/analysis/doc_fail/thicknes/Thk_id08
10/14/98, 10:33 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 8

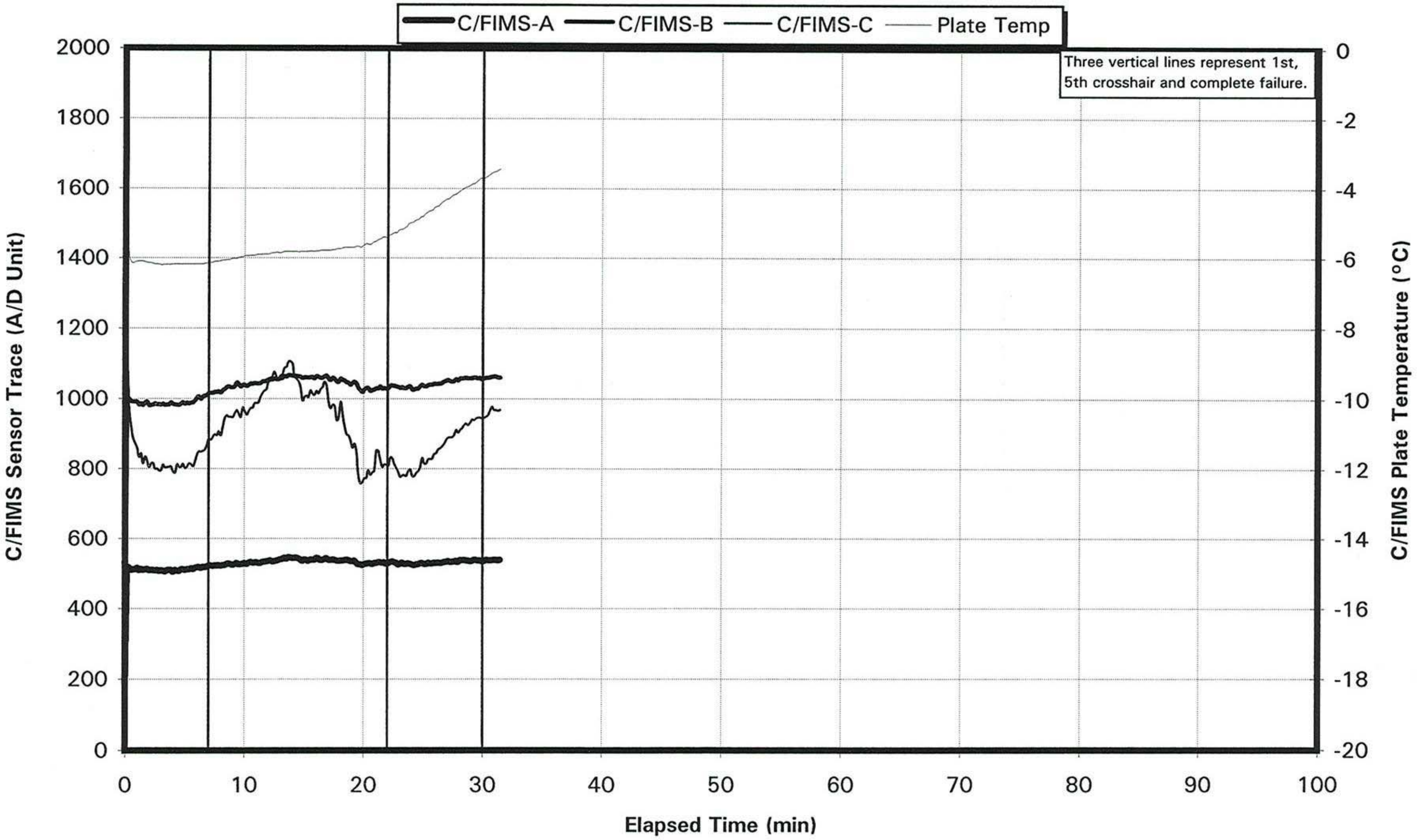


cm1380/analysis/doc_fail/brix/Brx_id08
10/15/98, 9:21 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 8



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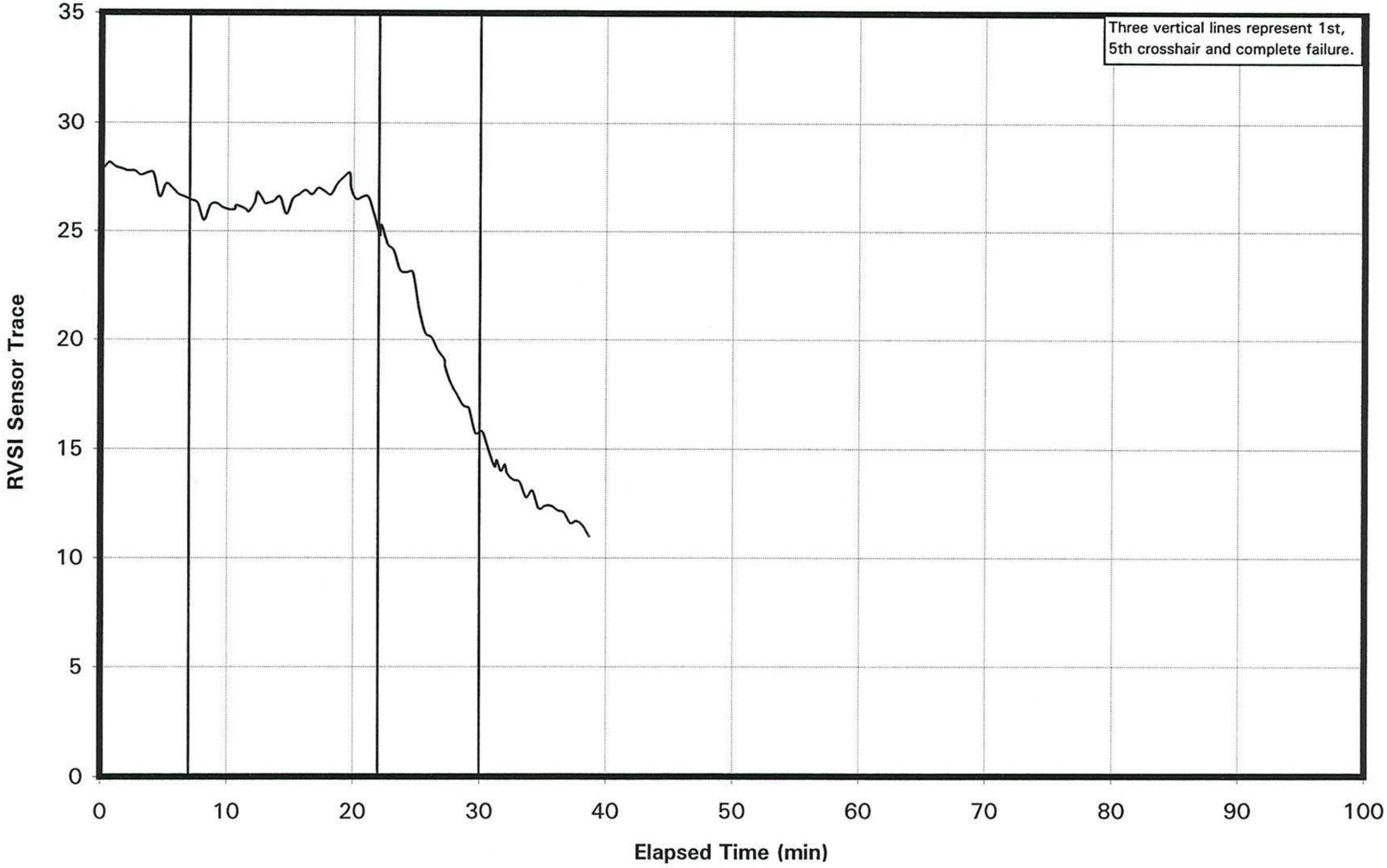
10/15/98, 10:13 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 8



cm1380/analysis/doc_fail/rvsi/Rvs_id08.xls
10/15/98, 11:35 AM

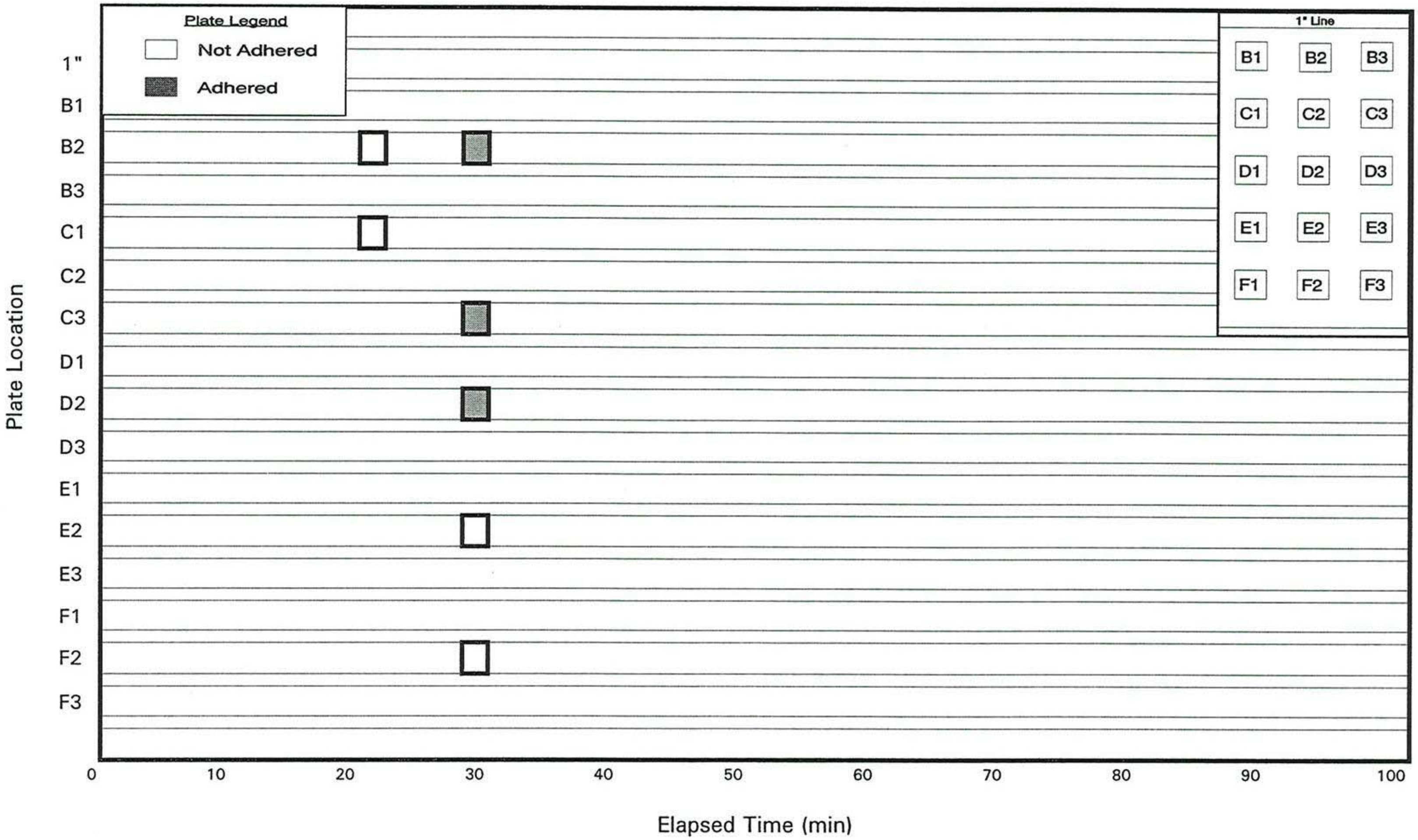
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 8

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 8



cm1380/analysis/doc_fail/Adh_id8
7/28/98, 9:38 AM

GENERAL TEST INFORMATION

ID # 9

July 8, 1998

Ambient Air Temperature:	-10.2°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.5 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	15:54:30
Failure Mode:	5th X-hair
Failure Location:	C3
Failure Time (Standard):	16:23:00
Failure Time (Complete Plate):	16:30:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 9

Photo C9.1 - After Pouring, t = 0 min

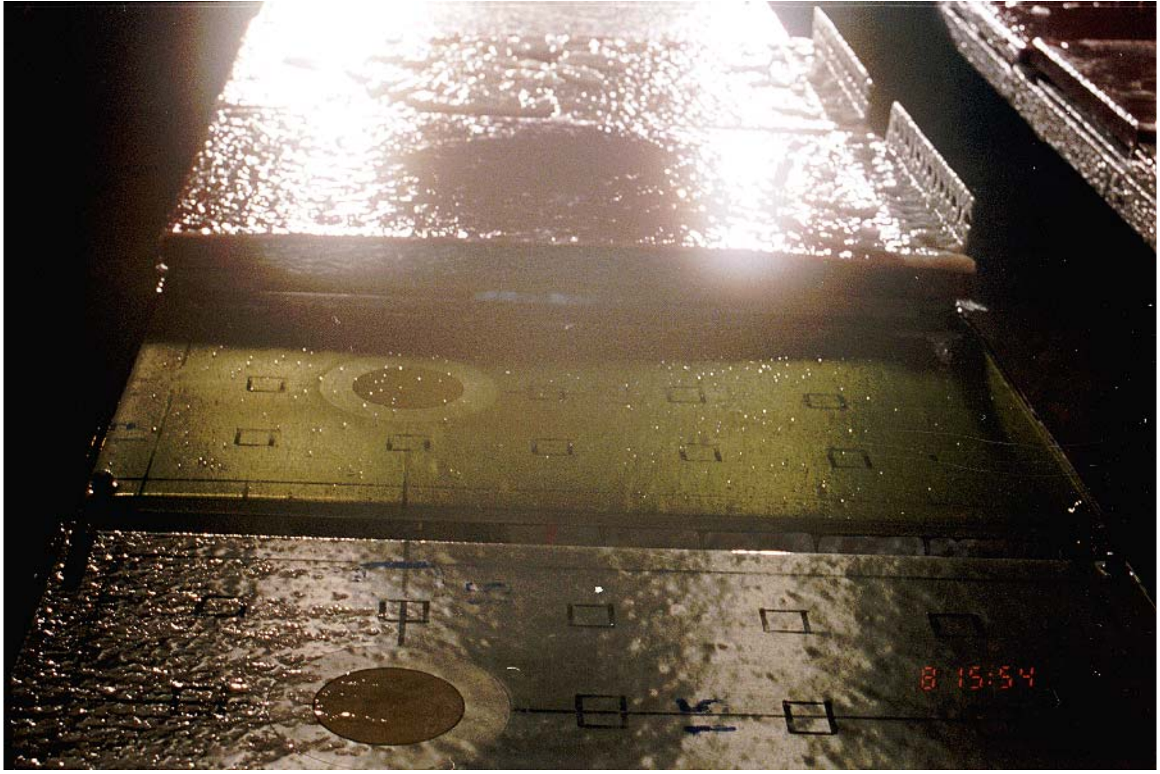
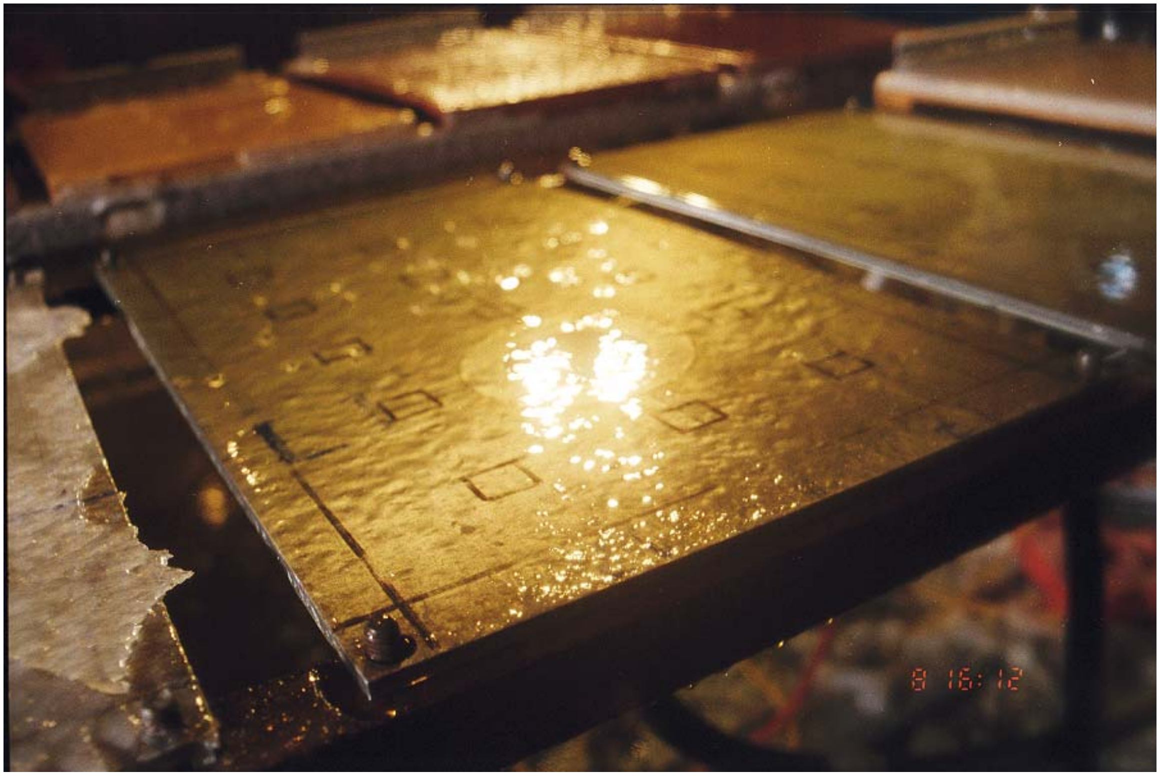


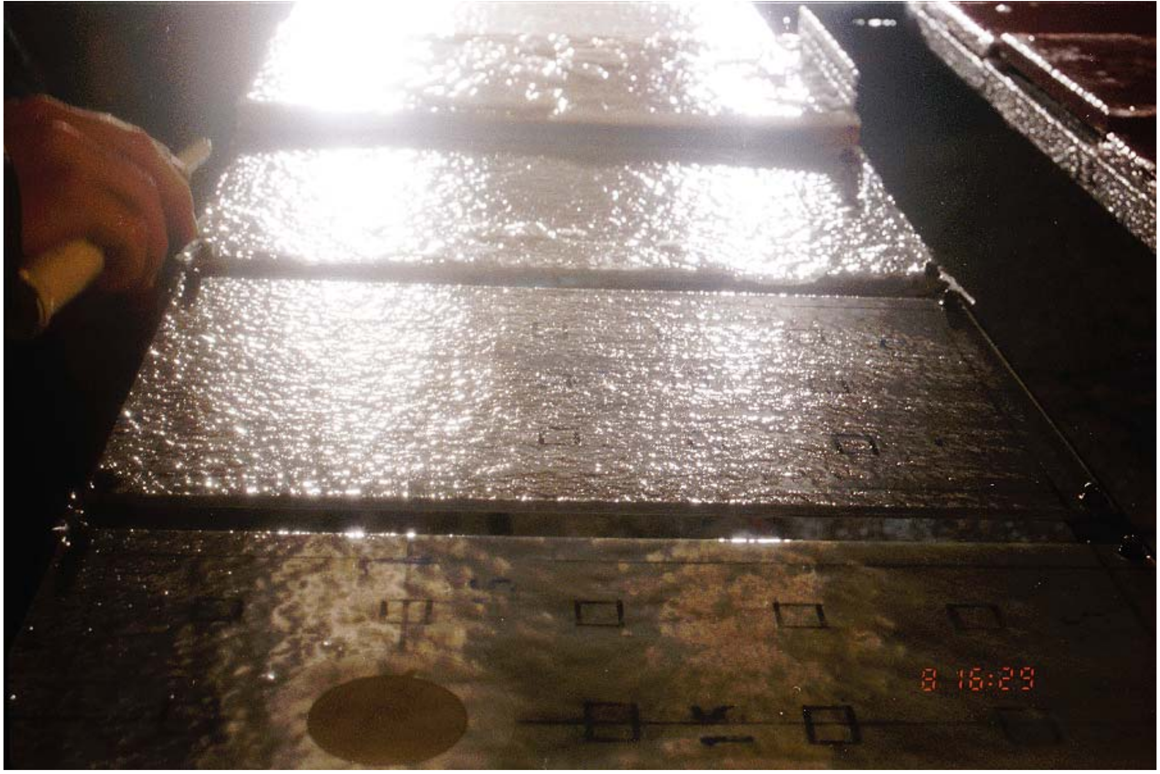
Photo C9.2 - 1st Failure, t = 18 min



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 9

Photo C9.3 - Standard Failure (1/3 or 5th Crosshair), t = 28 min

Photo C9.4 - Complete Fluid Failure, t = 35 min



\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAILS\SUBJECTVISUB_ID09.doc
Last printed 10/14/98 8:41 AM

ID# 9

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08

Time: 1554^{45}

Plate Location: 3

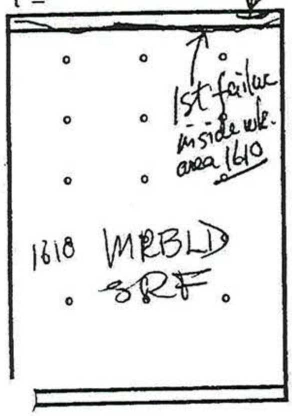
Run #: 4_4

Fluid Name: ULTRA+

Fluid Dilution: 100%

1604 1st failure noted top edge of plate

t =



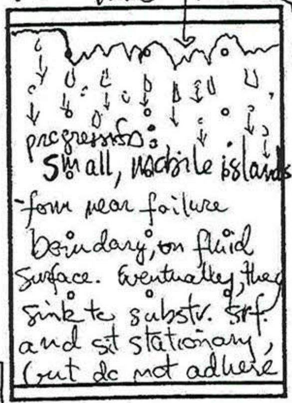
POUR: as per ~~prev. ULTRA RUNS~~ AT EITHER RATE/PPT-TYPE.

1558 speckled appearance assumed by fluid srf.

1601 orange peel texture assumed by fl. srf.

1607 fluid has ~~taken on marbled appearance~~ small dots + streaks ~~specks~~ of solid contamination beginning to persist in fluid

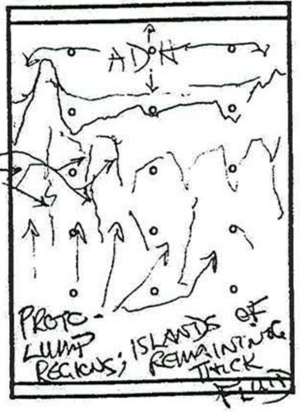
t = 1616 failure; ~~adhesion~~ fully fused, adhesion beginning to set in.



progression: small, mobile islands form near failure boundary, on fluid surface. Eventually, they sink to substr. srf. and sit stationary, (but do not adhere

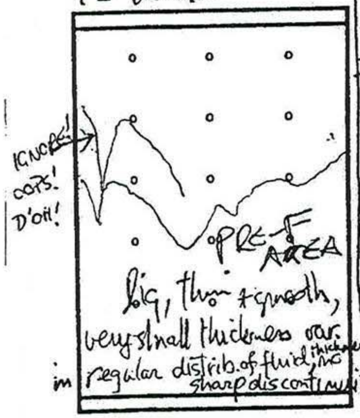
CHANNELLING ~~BREAKING UP MARBLED FLUID INTO DISCRETE~~ LUMPS + PRE-F. AREAS (THIN, DILUTE FLUID)

t = 1622^{30}



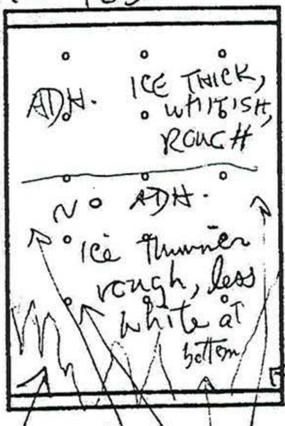
1622^{30} 5X-Hairs ADH almost to 6" line (2X Hairs failed simult.

t = 1626



big, thin + smooth, very small thickness var. irregular distrib. of fluid thickness, no sharp discontinuities in fluid srf.

t = 1630



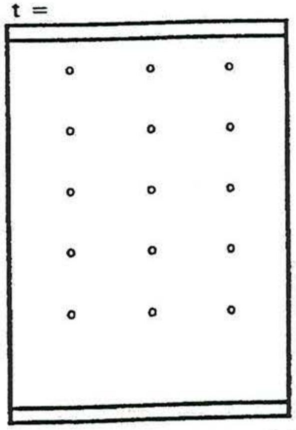
NOT FAILED

NOT FAILED

can be easily broken into islands as prev. described (RUN 4_3)

1629, full plate failure

t =

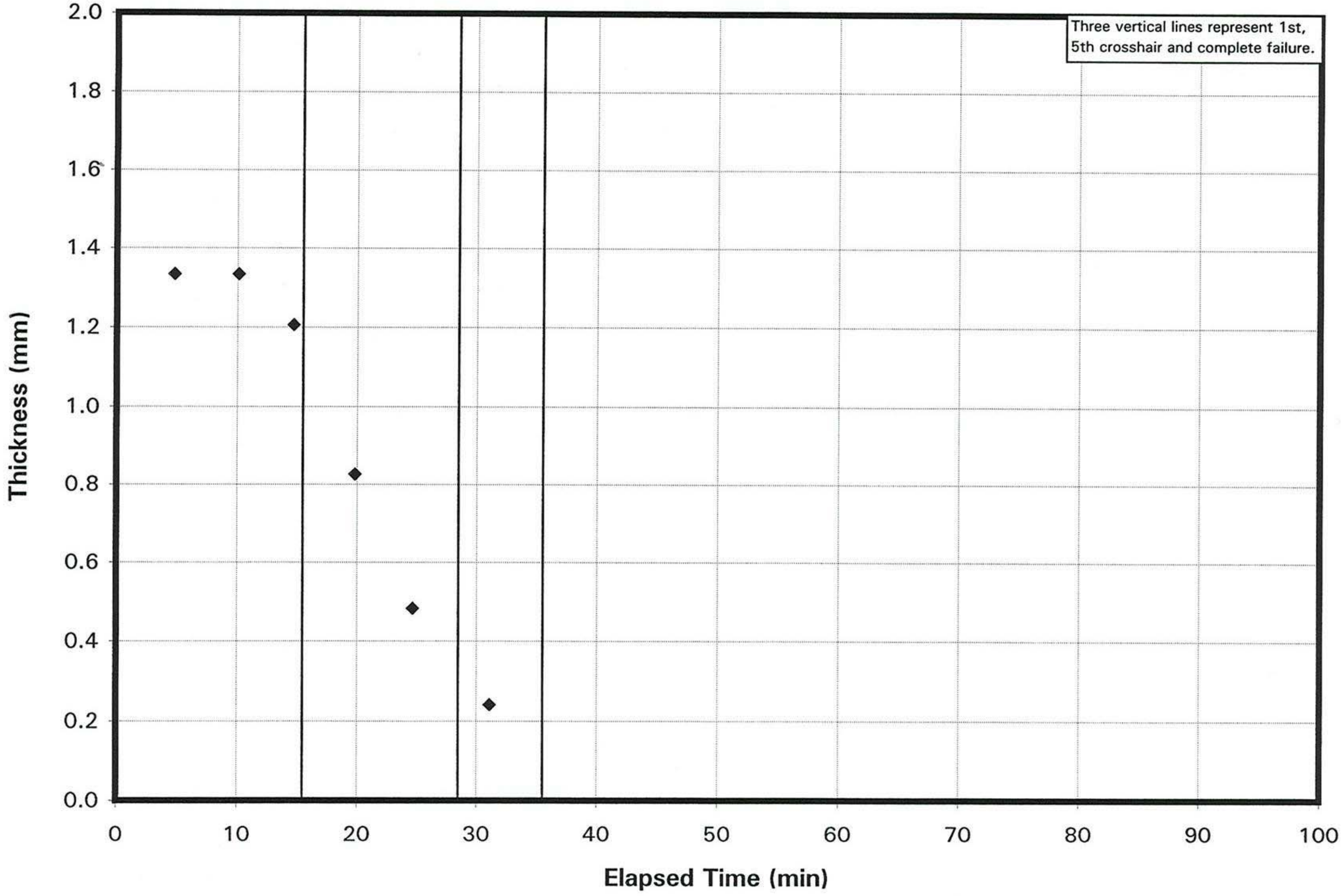


Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 9

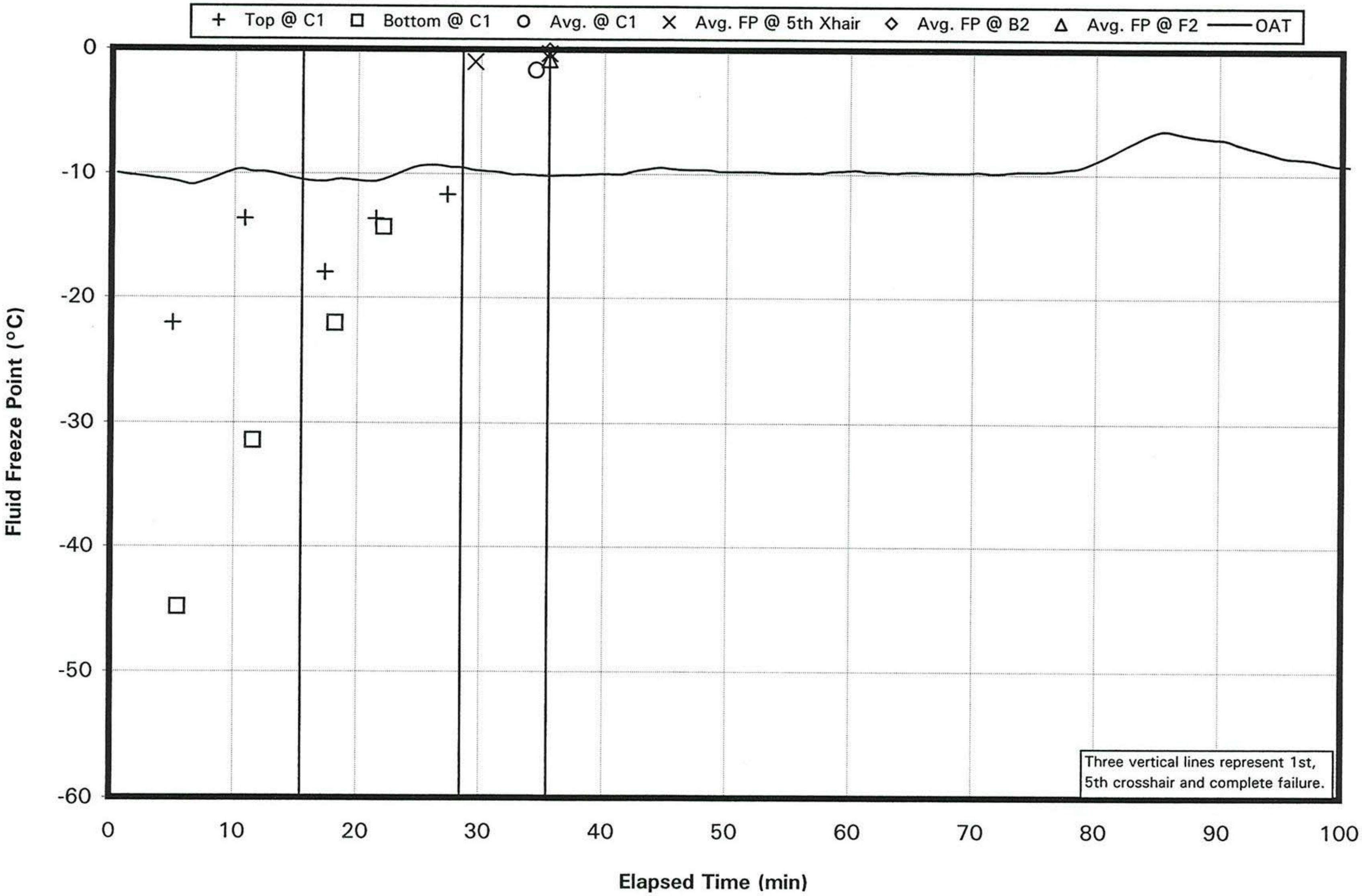


cm1380/analysis/doc_fail/thicknes/Thk_id09
10/14/98, 10:33 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 9

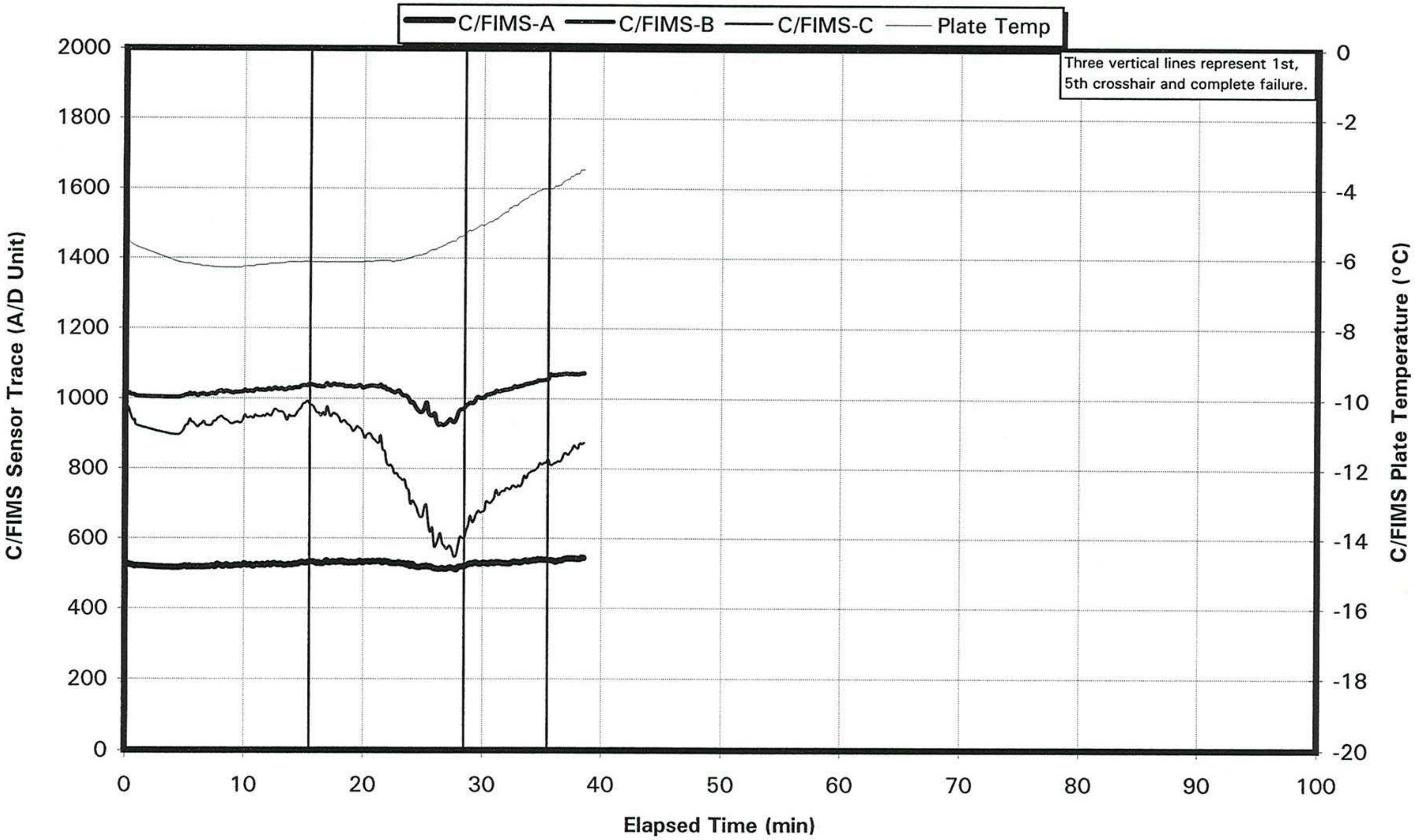


cm1380/analysis/doc_fail/brix/Brx_id09
10/15/98, 9:20 AM

DOCUMENTATION OF FLUID FAILURE

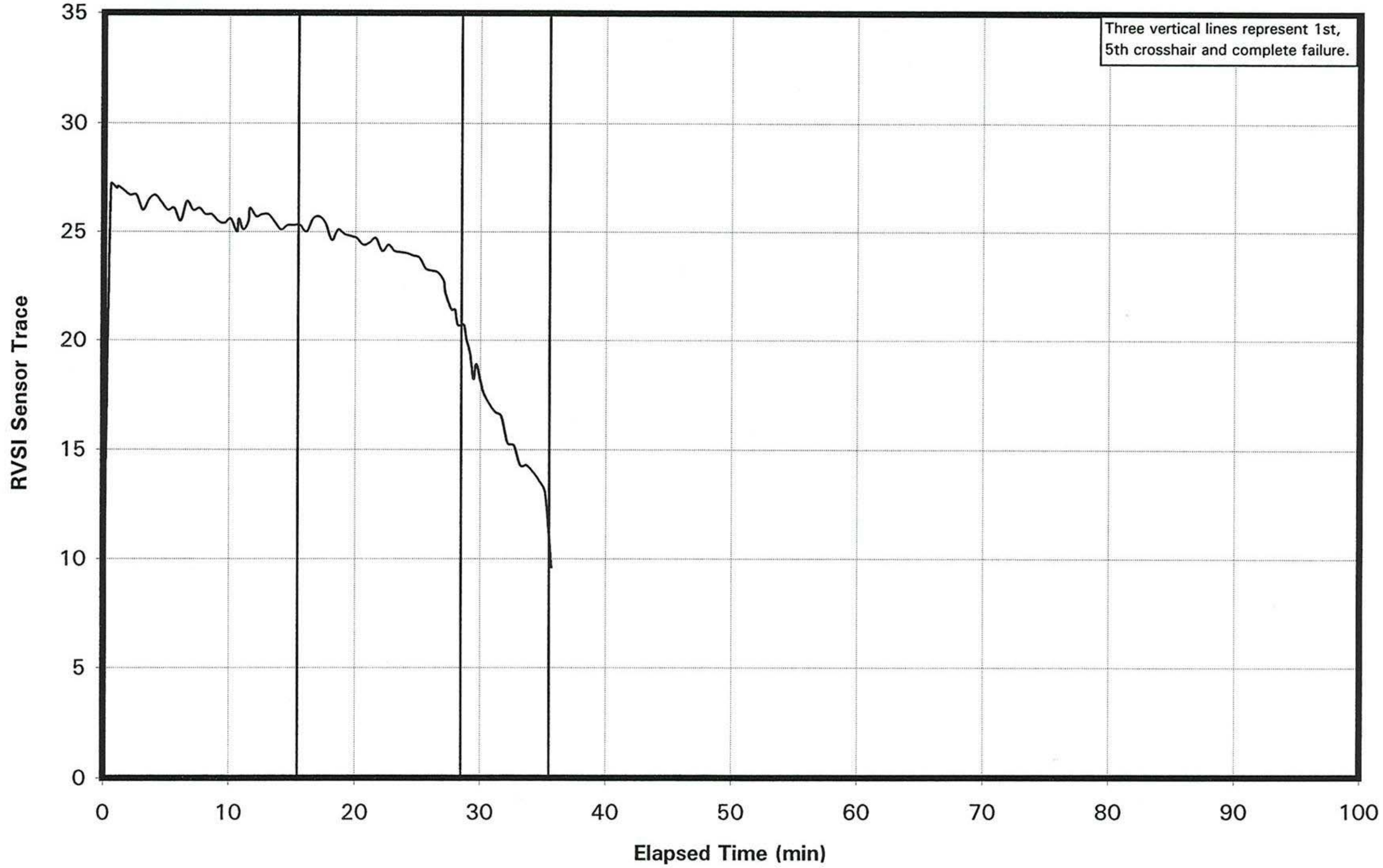
C/FIMS SENSOR TRACE

ID # 9



cm1380/analysis/doc_fail/cfims/Cfm_id09
10/15/98, 10:13 AM

DOCUMENTATION OF FLUID FAILURE
RVSI SENSOR TRACE
ID # 9



cm1380/analysis/doc_fail/rvsi/Rvs_id09.xls
10/15/98, 11:34 AM

DOCUMENTATION OF FLUID FAILURE

COX/SPAR SENSOR TRACE

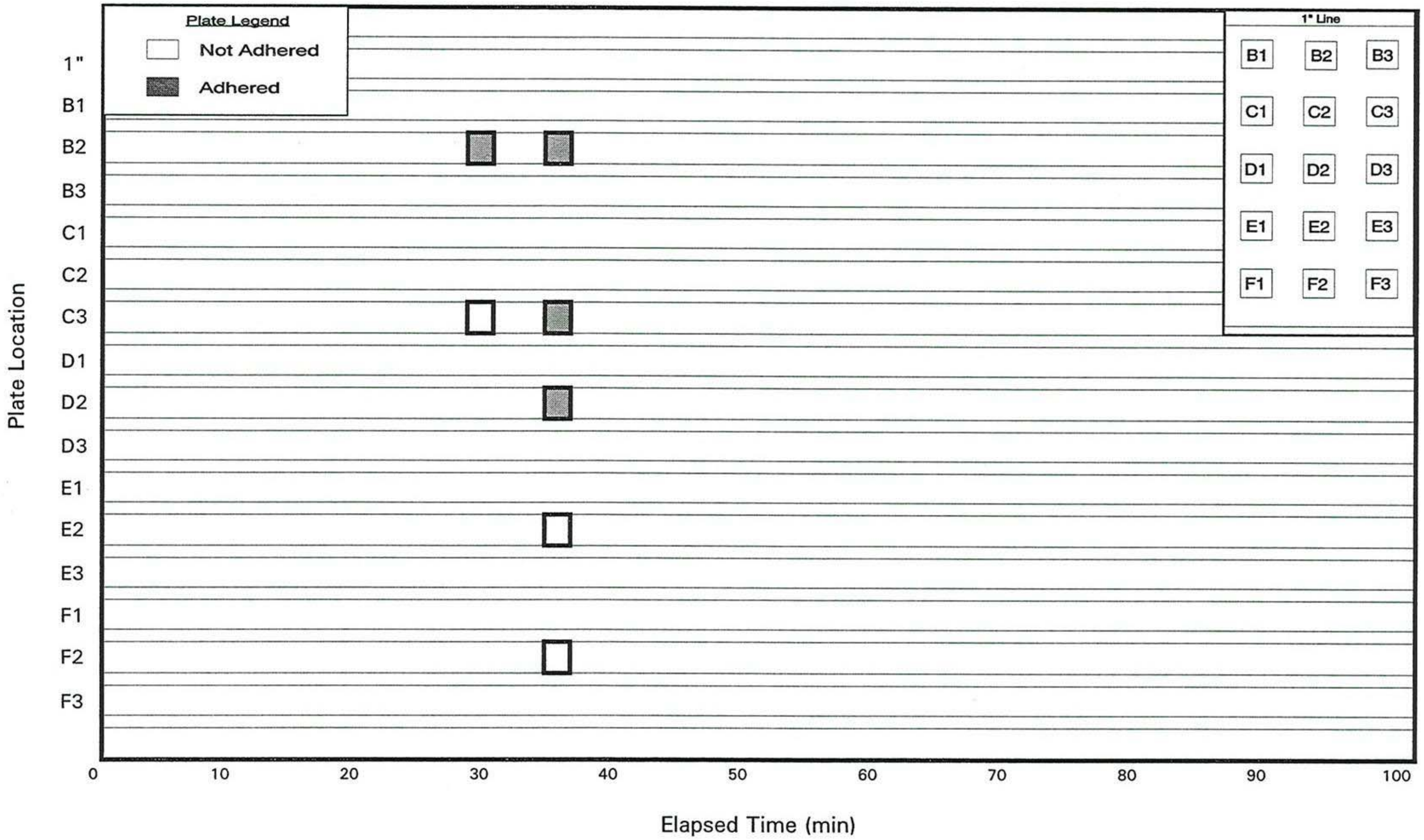
ID # 9

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 9



GENERAL TEST INFORMATION

ID # 10

July 8, 1998

Ambient Air Temperature:	-10.5°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	25.2 g/dm²/hr
Fluid:	KILFROST ABC-S
Dilution:	Neat
Start of Test:	N/A
Failure Mode:	N/A
Failure Location:	N/A
Failure Time (Standard):	N/F
Failure Time (Complete Plate):	N/F

Note: Test stopped after 23 minutes (chamber problem)

PHOTOS OF POUR AND FIRST FAILURE - ID # 10

Photo C10.1 - After Pouring, t = 0 min

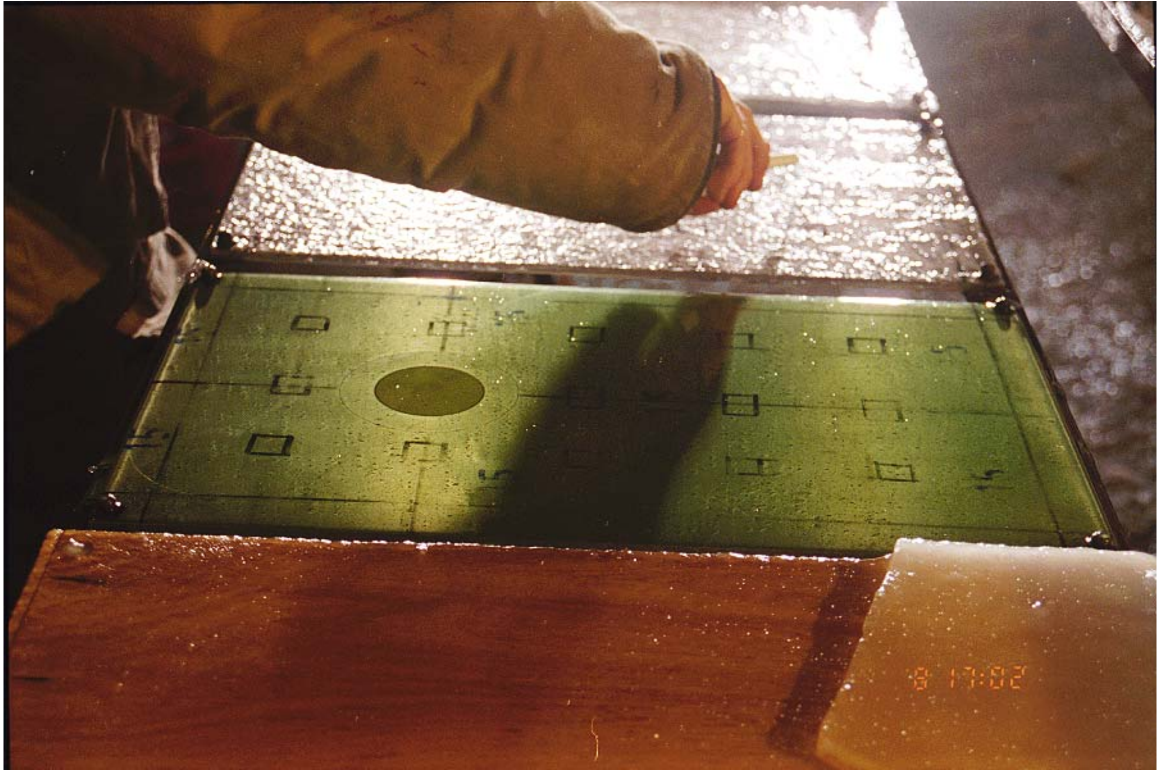
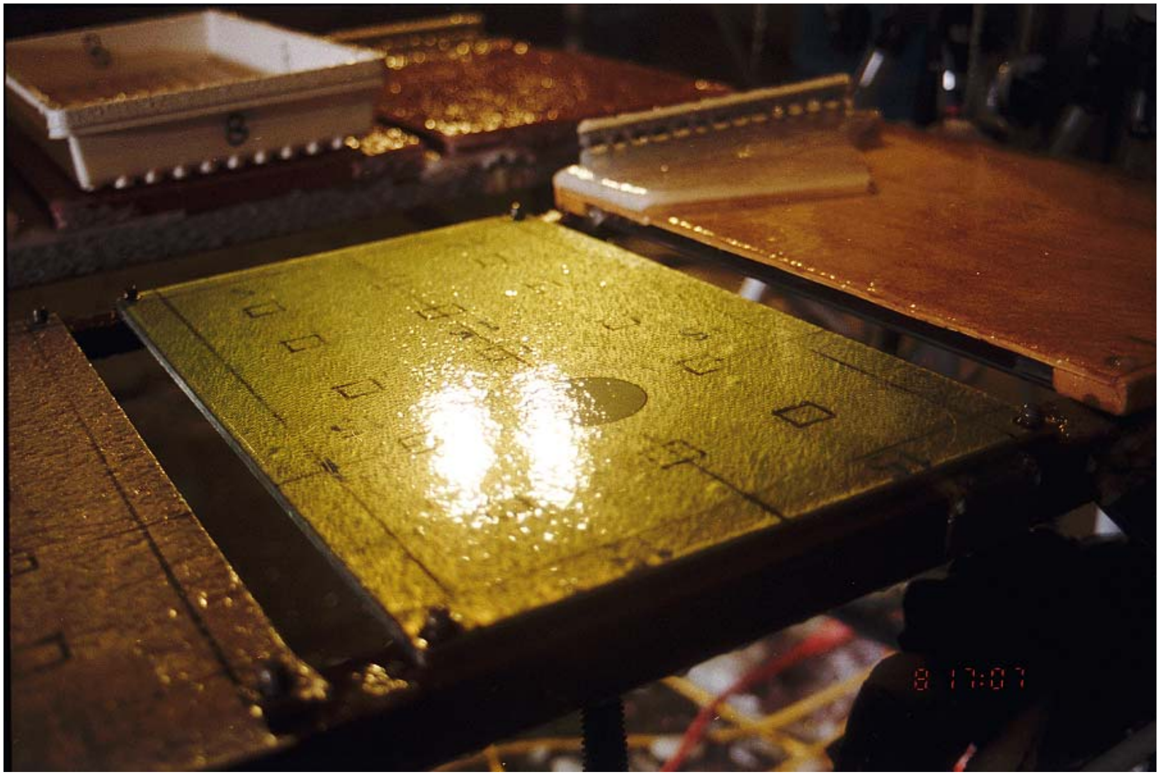


Photo C10.2 - 1st Failure, t = 5 min



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 10

Photo C10.3 - Standard Failure (1/3 or 5th Crosshair), t=xxmin

NOT AVAILABLE
TEST STOPPED AFTER 23 MIN.

Photo C10.4 - Complete Fluid Failure, t = xx min

NOT AVAILABLE
TEST STOPPED AFTER 23 MIN.

ID# 10

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08

Run #: 47

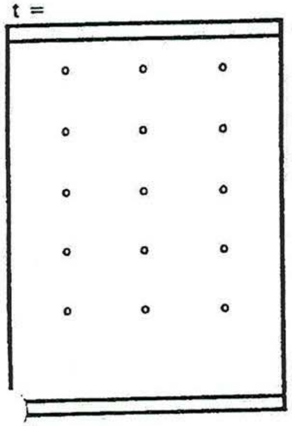
Time: 1701^{50}

Fluid Name: Kilfrost ABG-S

Plate Location: 2

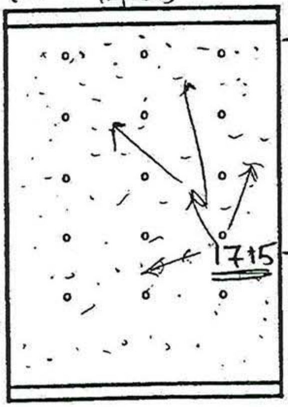
Fluid Dilution: 100%

t =



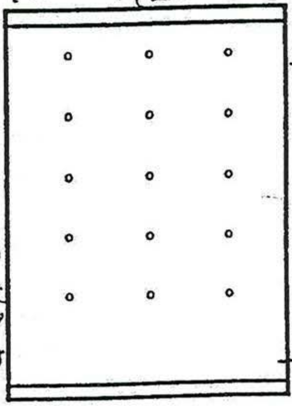
Pour: Thick, clear, green transp liquid w. bubbles embedded into srf of fluid; v. similar to ULTRA+ fluid appearance upon pouring.

t = 1705



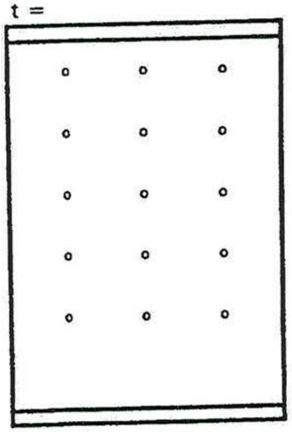
- Very pronounced speckle on surface (distinct circular dots - solid ~~contamination~~)
- very even distrib on fluid surface
- mobile, but v. slow
- Resist mixing into fluid.

t = 1725

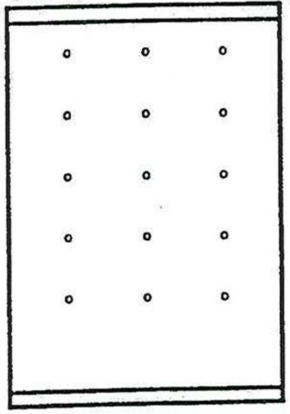


- fluid showing signs of mixing
- ~~low~~ or discrete dot density (almost disappeared)
- Possible chamber problems
- S-canned 1725!

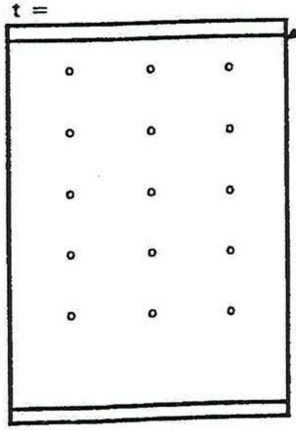
t =



t =



t =

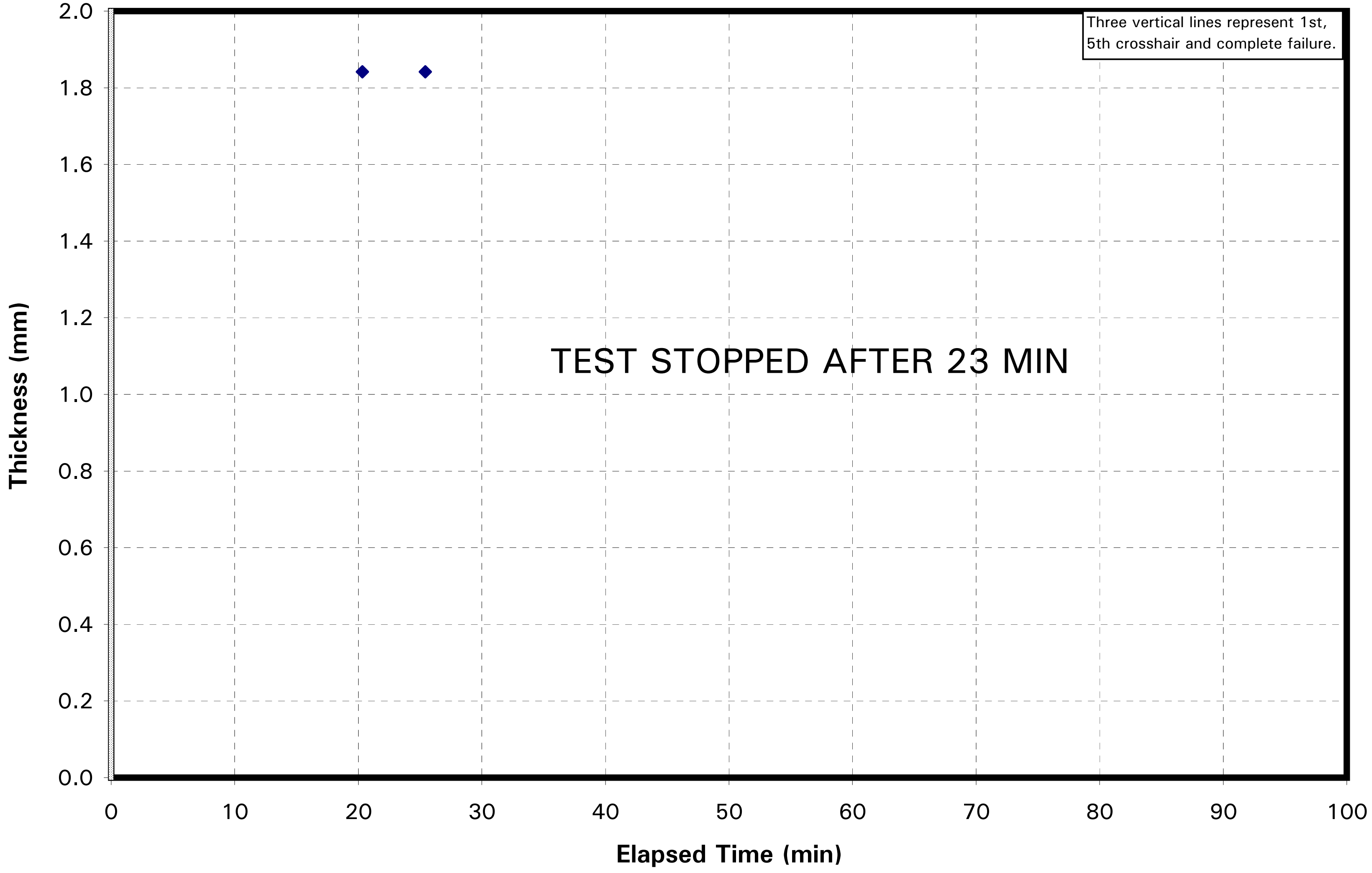


Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 10

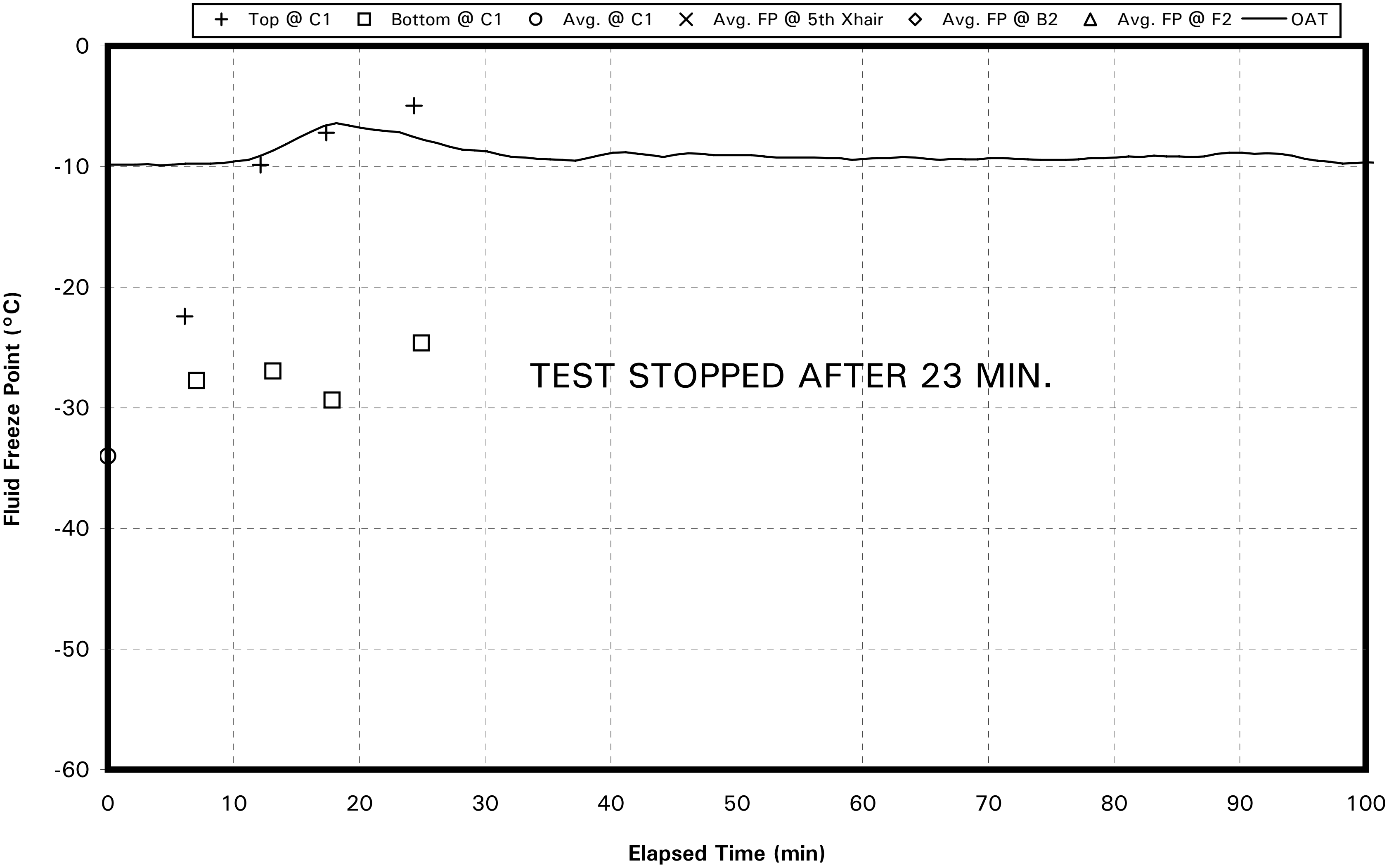


cm1380/analysis/doc_fail/thicknes/THK_ID10
9/21/2006, 12:35 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 10

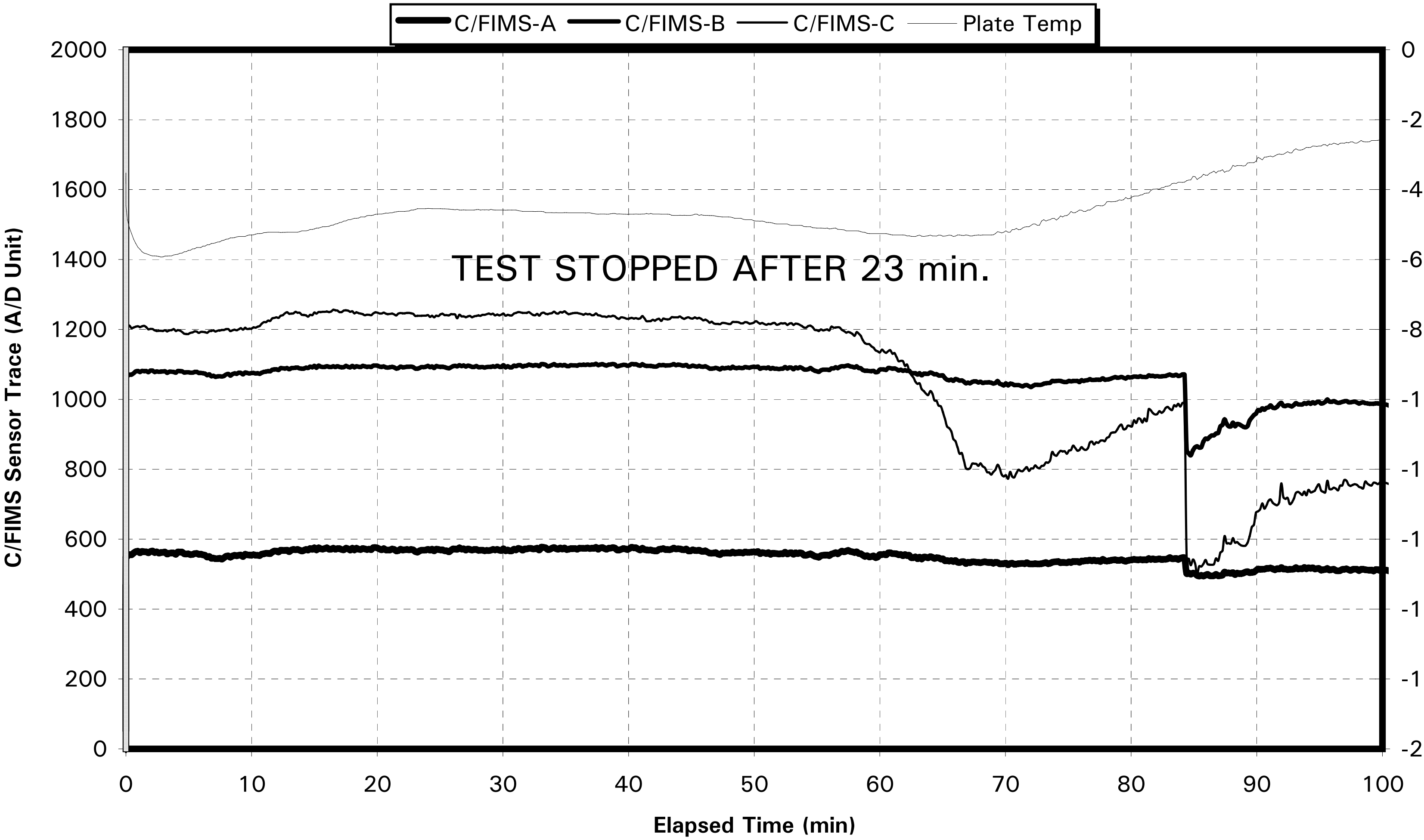


cm1380/analysis/doc_fail/brix/BRX_ID10
9/21/2006, 12:37 PM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 10



cm1380/analysis/doc_fail/cfims/CFM_ID10
9/21/2006, 12:38 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 10

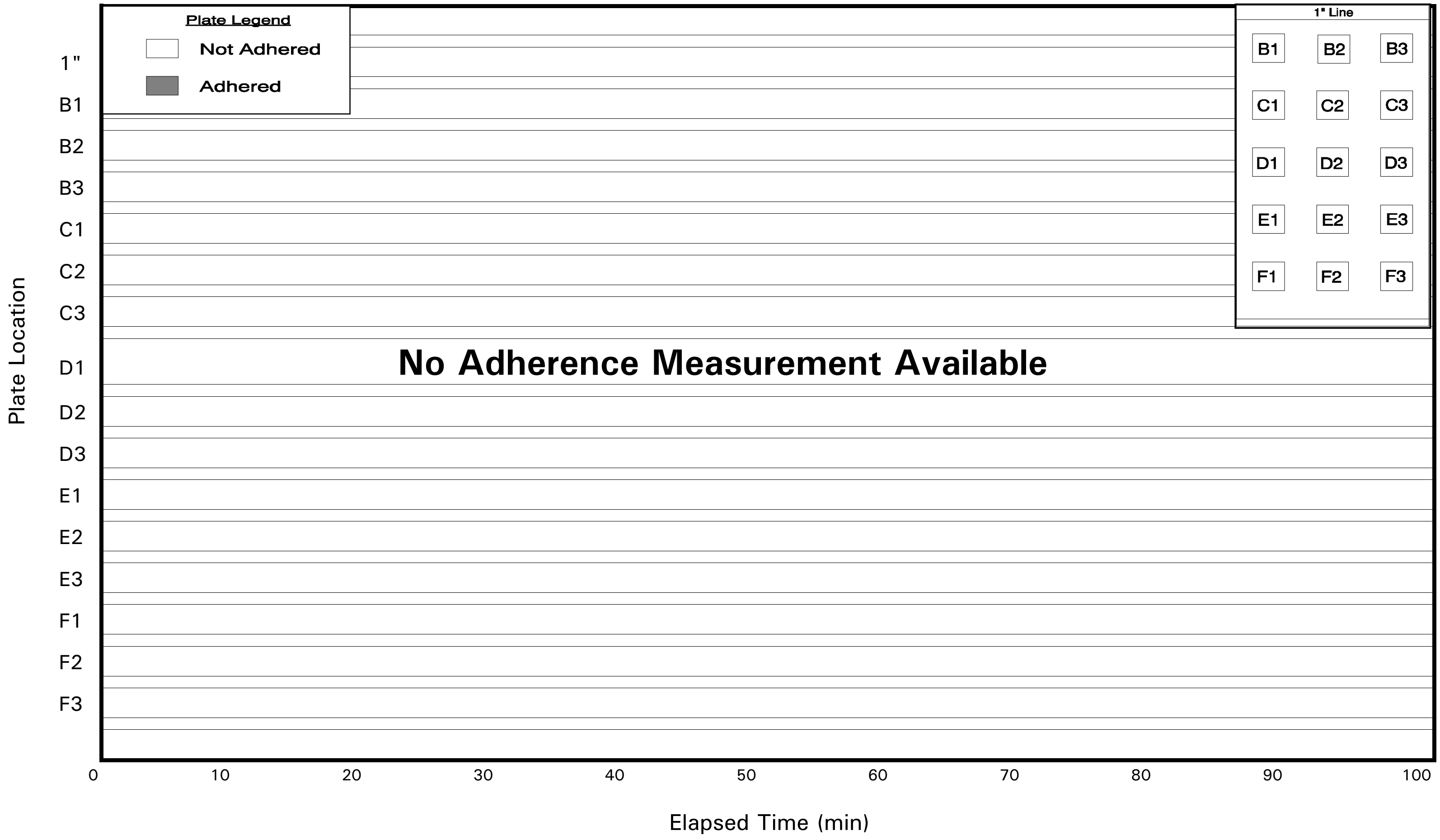
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 10

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 10



cm1380/analysis/doc_fail/ADH_ID10
9/21/2006, 12:40 PM

GENERAL TEST INFORMATION

ID # 11

July 8, 1998

Ambient Air Temperature:	-10.5°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.5 g/dm^2/hr
Fluid:	OCTAGON
Dilution:	Neat
Start of Test:	16:37:20
Failure Mode:	5th X-hair
Failure Location:	C3
Failure Time (Standard):	16:57:00
Failure Time (Complete Plate):	17:02:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 11

Photo C11.1 - After Pouring, t = 0 min

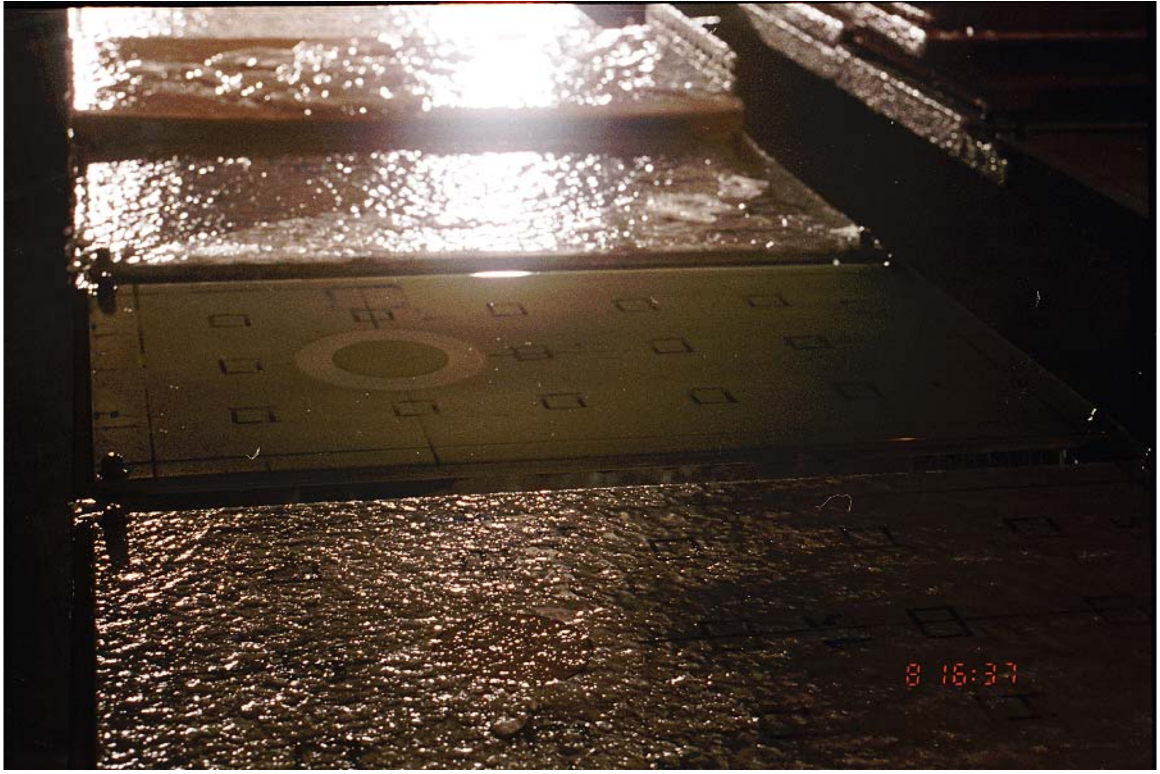
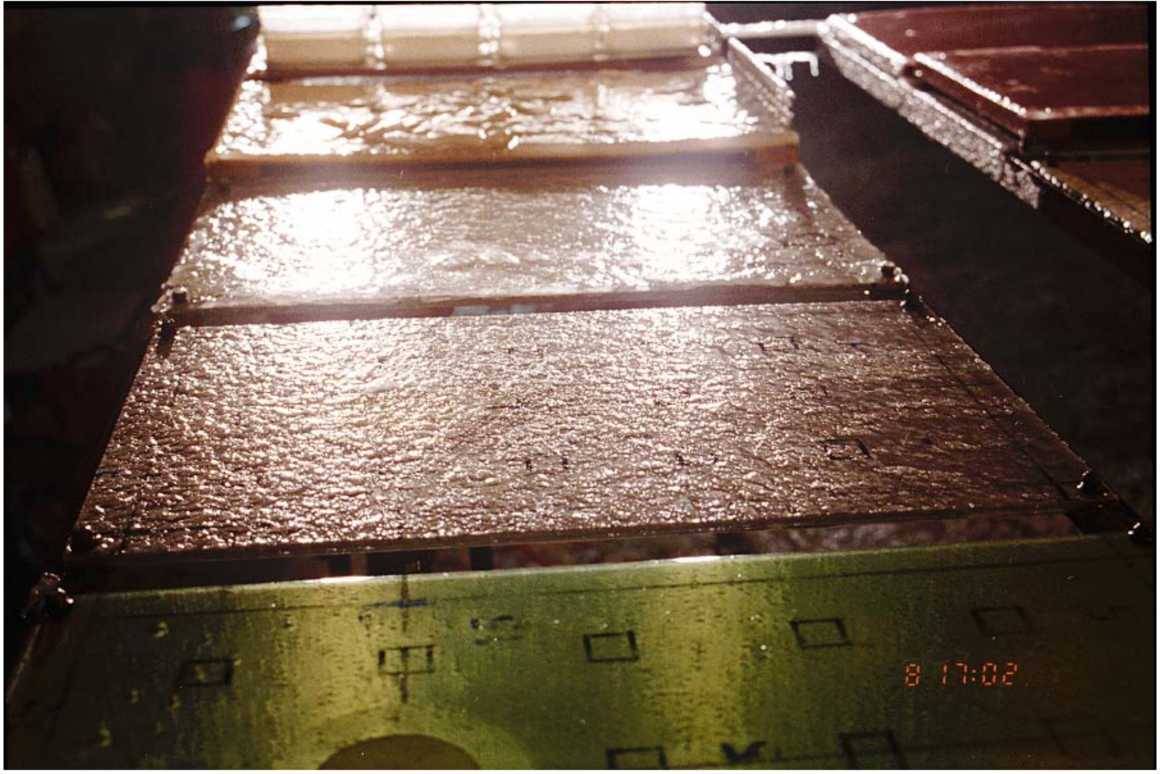


Photo C11.2 - 1st Failure, t = 13 min

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 11

Photo C11.3 - Standard Failure (1/3 or 5th Crosshair), t = 19 min

Photo C11.4 - Complete Fluid Failure, t = 25 min



\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID11.doc
Last printed 10/14/98 8:45 AM

ID# 11

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08

Time: 1657 30

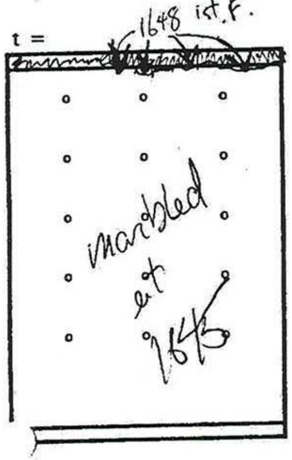
Plate Location: 3

Run #: 4

Fluid Name: Oct Max

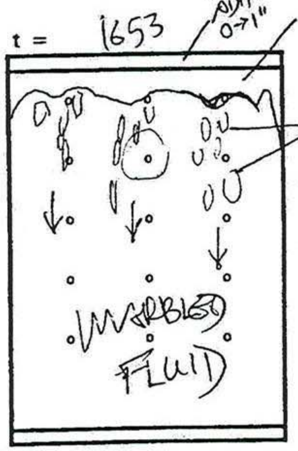
Fluid Dilution: 100%

t =



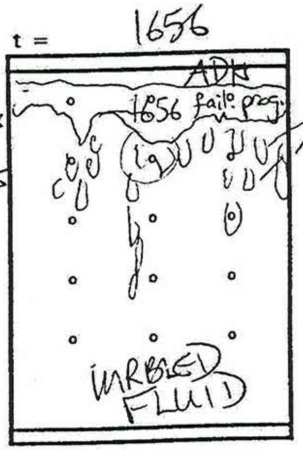
FOUR: same description as last Run 4s
1648 1st failures within wk area

t = 1653



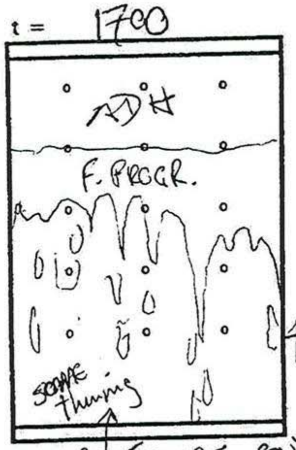
stationary islands forming fingers of failure progression

t = 1656



islands fusing into fingers.
fingers eventually fuse

t = 1700



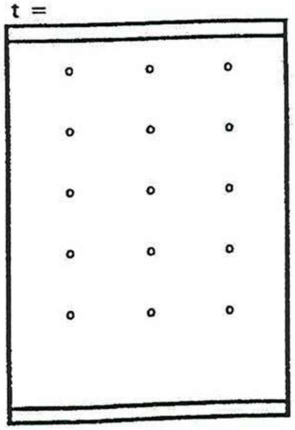
islands continue to fuse, extending to plate bottom edge.

t = 1707

1707 overlapping platelet islands beginning to fuse.

complete plate failure 1707

t =

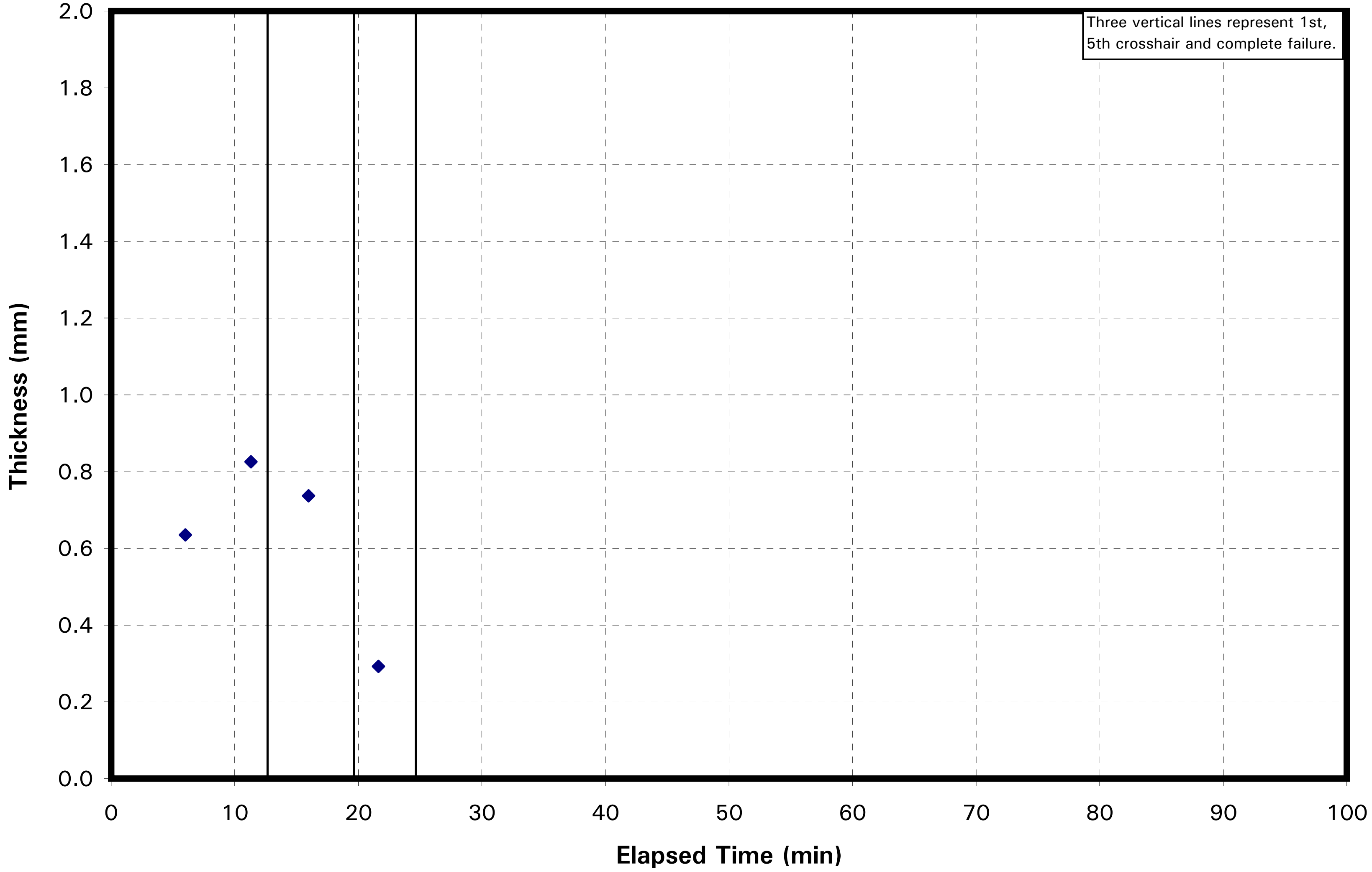


Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 11

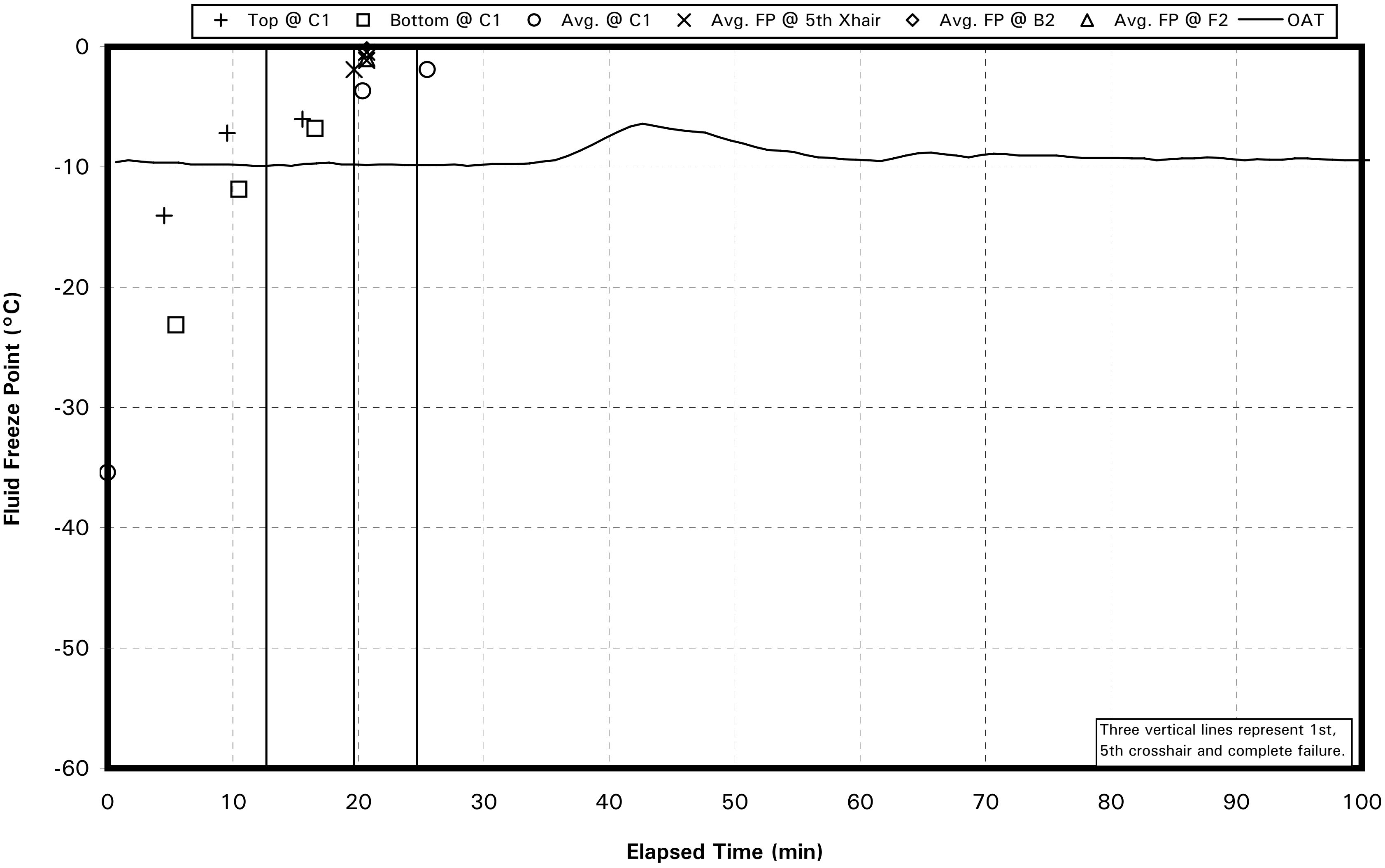


cm1380/analysis/doc_fail/thicknes/THK_ID11
9/21/2006, 12:43 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 11

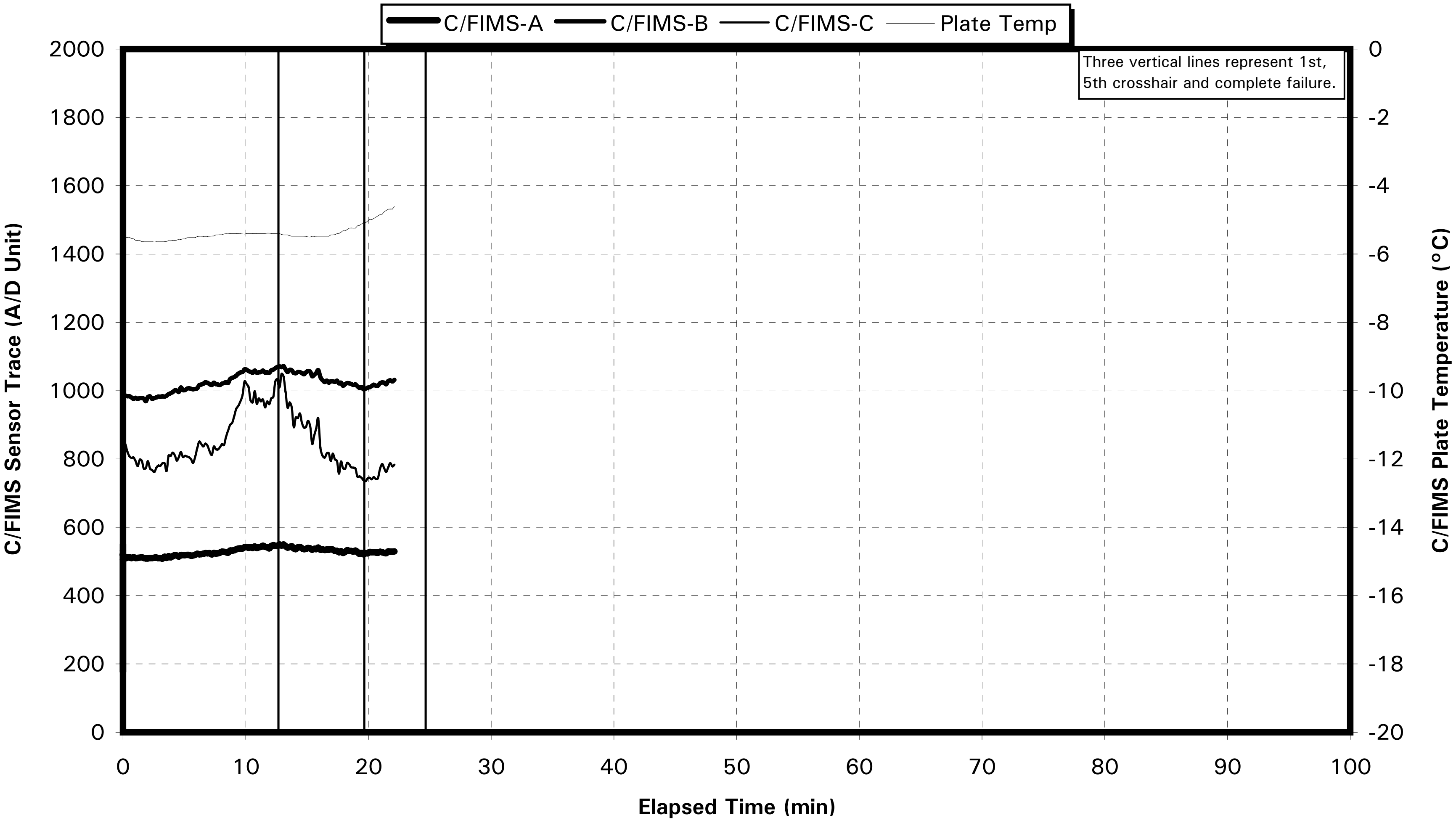


cm1380/analysis/doc_fail/brix/BRX_ID11
9/21/2006, 12:44 PM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 11

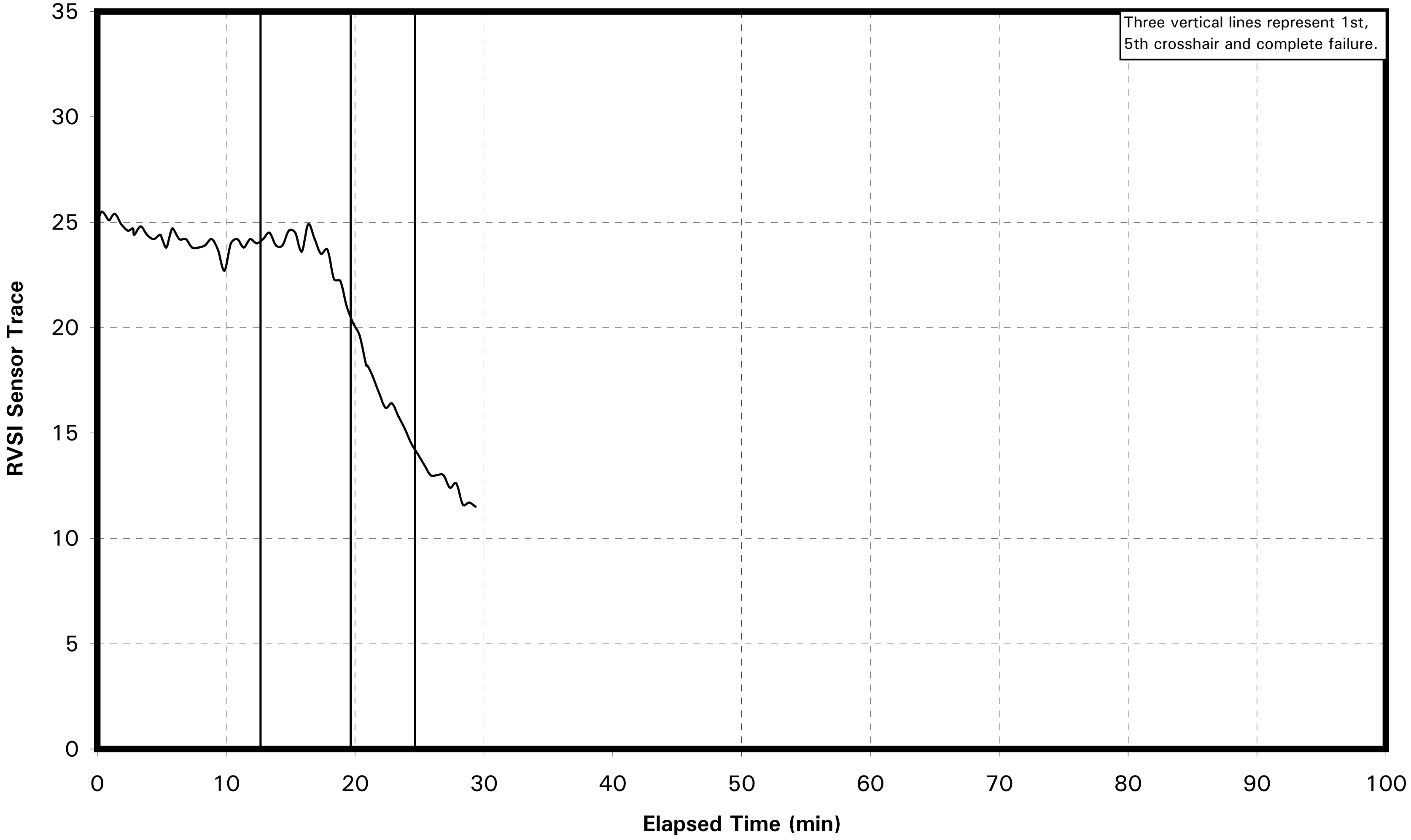


cm1380/analysis/doc_fail/cfims/CFM_ID11
9/21/2006, 12:44 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 11



cm1380/analysis/doc_fail/rvsi/RVS_ID11
9/21/2006, 12:45 PM

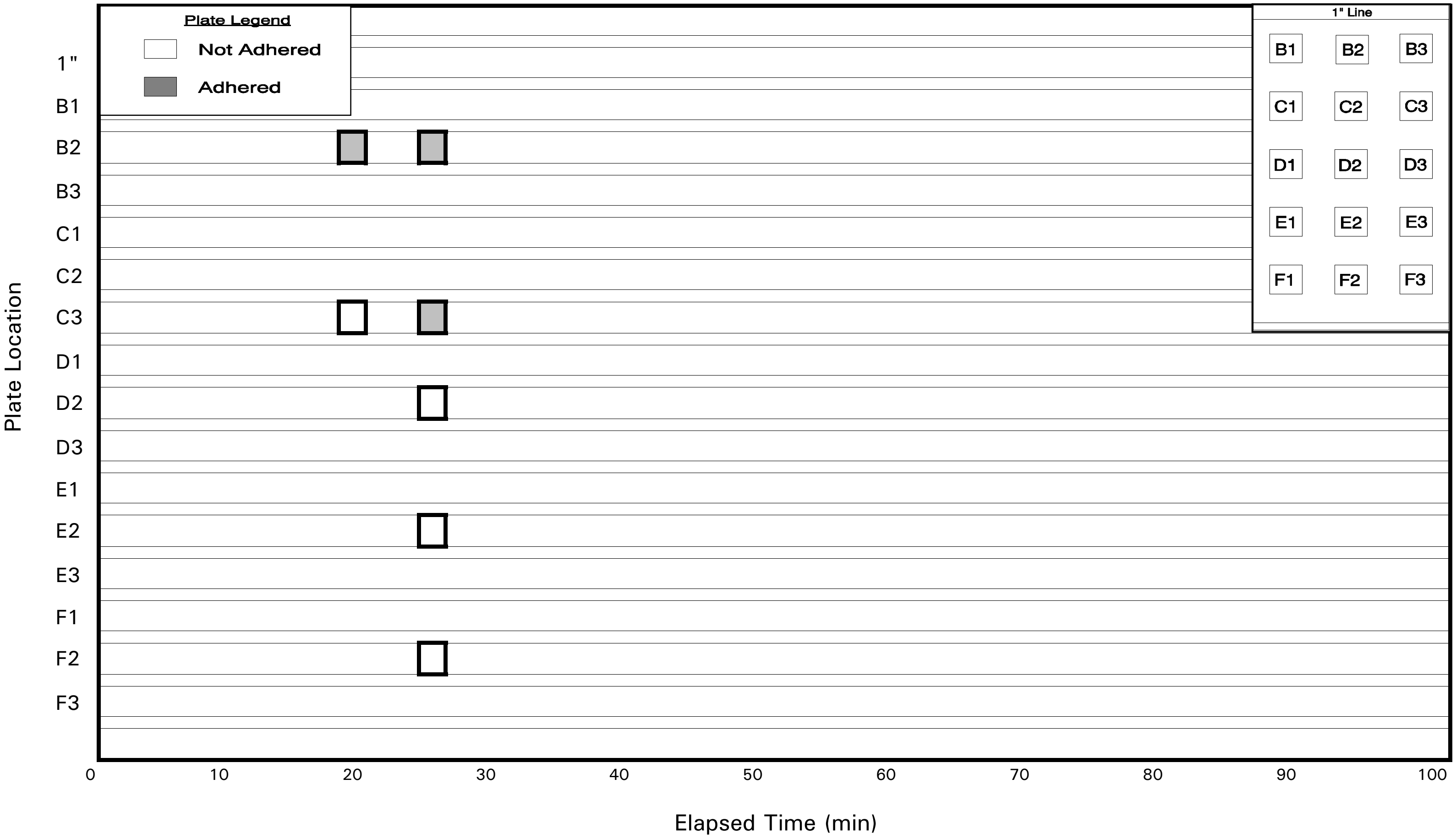
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 11

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 11



cm1380/analysis/doc_fail/ADH_ID11
9/21/2006, 12:59 PM

GENERAL TEST INFORMATION

ID # 12

July 8, 1998

Ambient Air Temperature:	-10.5°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.5 g/dm²/hr
Fluid:	KILFROST ABC-S
Dilution:	Neat
Start of Test:	17:40:50
Failure Mode:	N/A
Failure Location:	N/A
Failure Time (Standard):	N/F
Failure Time (Complete Plate):	N/F

Note: Test stopped after 43 minutes (chamber problem)

PHOTOS OF POUR AND FIRST FAILURE - ID # 12

Photo C12.1 - After Pouring, t = 0 min

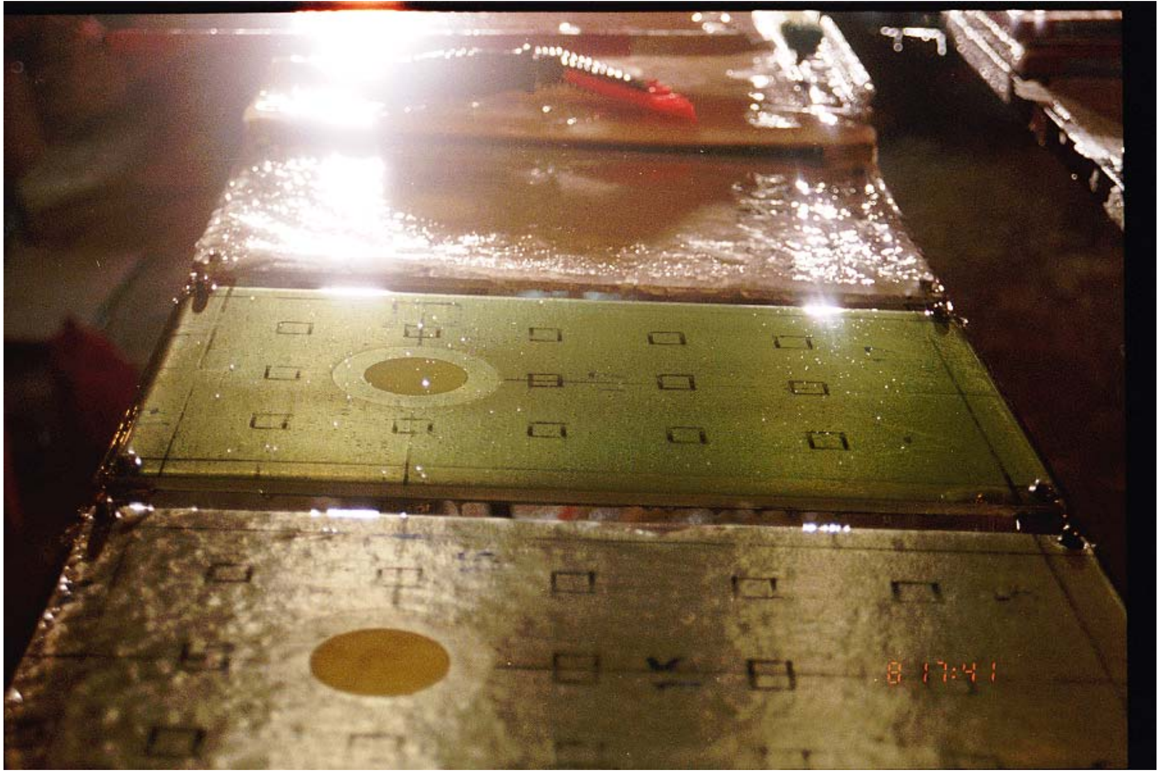


Photo C12.2 - 1st Failure, t = xx min

NOT AVAILABLE
TEST STOPPED AFTER 43 MIN.

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 12

Photo C12.3 - Standard Failure (1/3 or 5th Crosshair), t = xx min

NOT AVAILABLE
TEST STOPPED AFTER 43 MIN.

Photo C12.4 - Complete Fluid Failure, t = xx min

NOT AVAILABLE
TEST STOPPED AFTER 43 MIN.

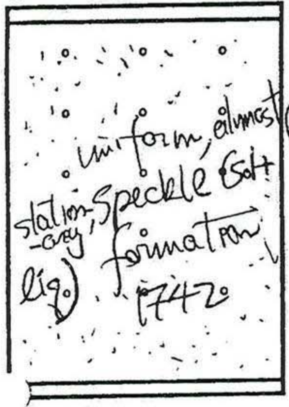
\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAILS\SUBJECTV\SUB_ID12.doc
Last printed 10/14/98 8:47 AM

ID# 12

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08
Time: 1740^{30}
Plate Location: 3
Run #: 4$_{8}$
Fluid Name: Kilfrost ABGS
Fluid Dilution: 100%

t =

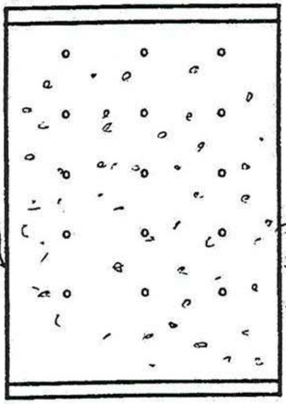


uniform, almost speckle (salt-station-ary, liq.) formation 1742

Pour: same as last description, (Run 4$_{7}$).

1742 Speckle composed of solid + liq. contam. uniformly distrib over entire fluid surf. (hardly moving)

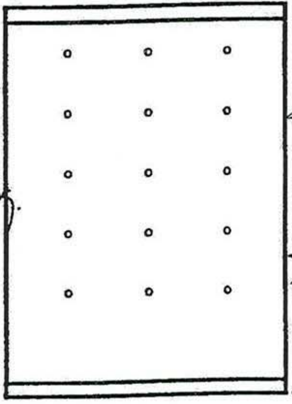
t =



1743 discrete dots of solid contamination which resist mixing.
Distrib evenly over entire plate.

1744 noted some large droplets denting surface as sprayer scanned plate. considerable bounce and run off of impinging droplets

t =

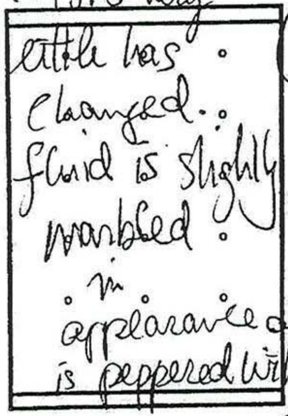


1753 fluid beginning to accept contam. (mixing.)

1800 Contam in. is signif. more mobile ~~[illegible]~~ as ~~[illegible]~~ fluid surface dissolves more contamination.

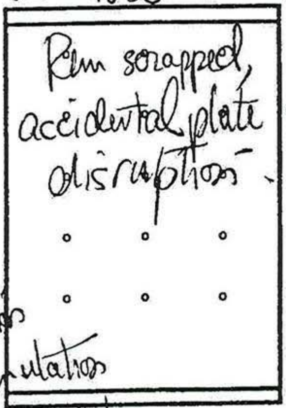
1806 top edge failure (outside "line")

t = 1816 very little has changed.



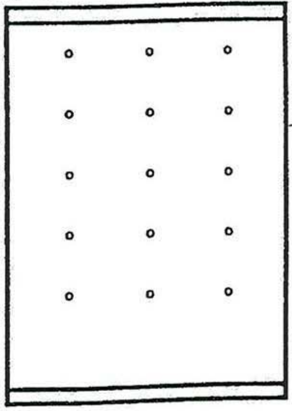
fluid is slightly marbled in appearance and is peppered with mobile round, ~~[illegible]~~ dot-type solid contamination. Some dot accumulation at bottom of plate

t = 1830



Rem scrapped, accidental plate disruption.

t =

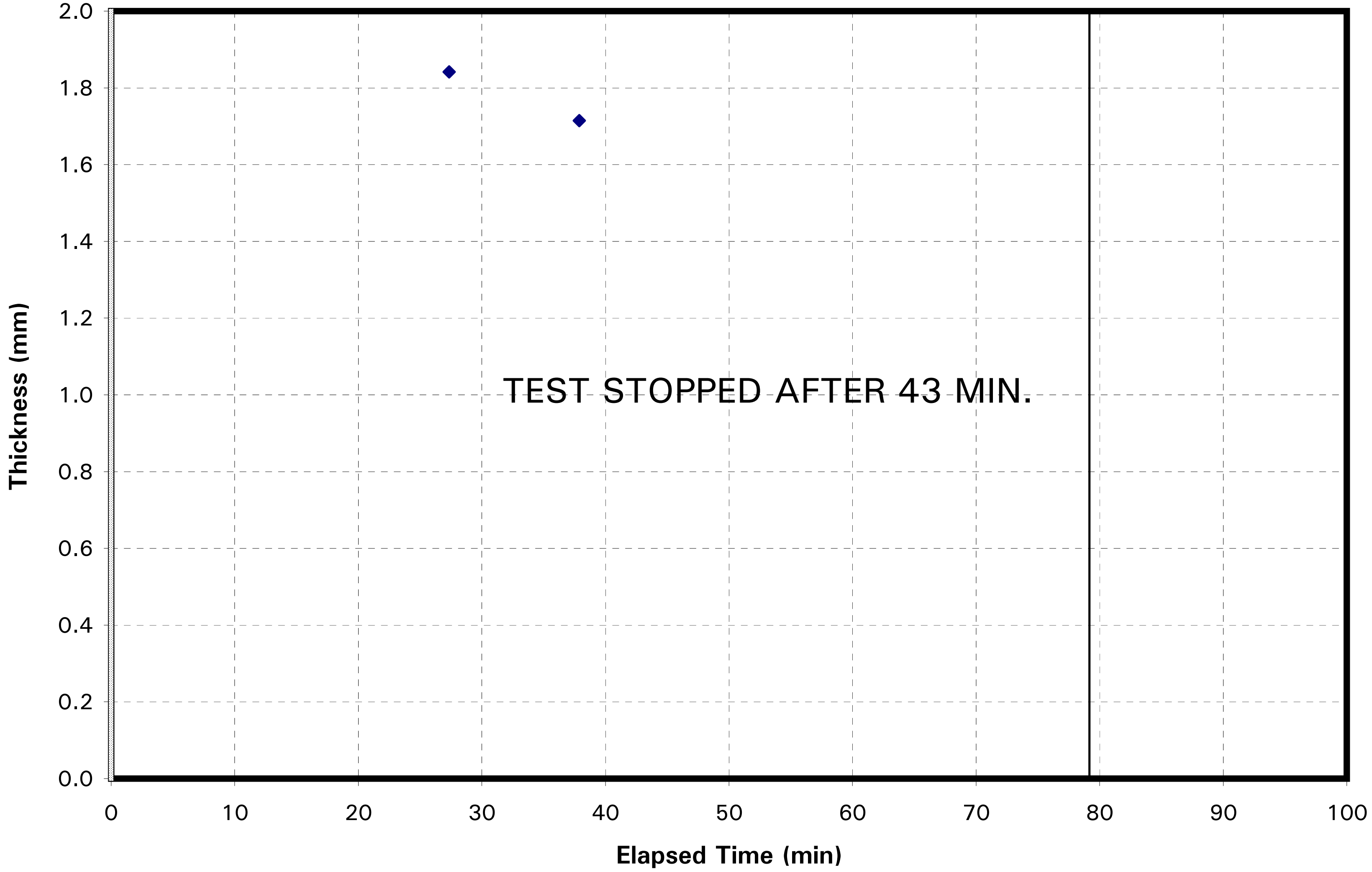


Note: Ensure observations made at t=0, 1st failure, 8th crosst[illegible], wh[illegible] plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 12

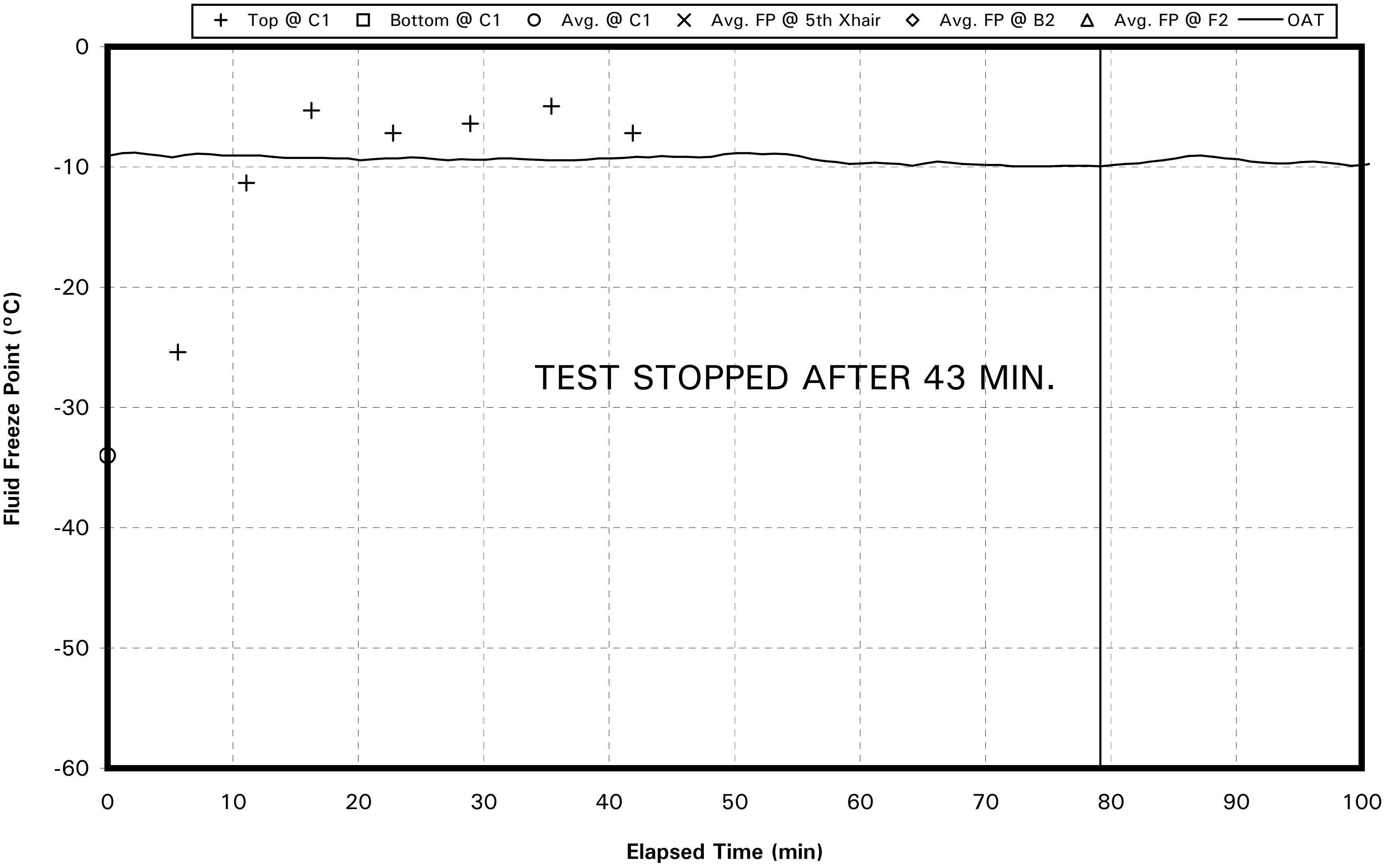


cm1380/analysis/doc_fail/thicknes/THK_ID12
9/21/2006, 1:07 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 12

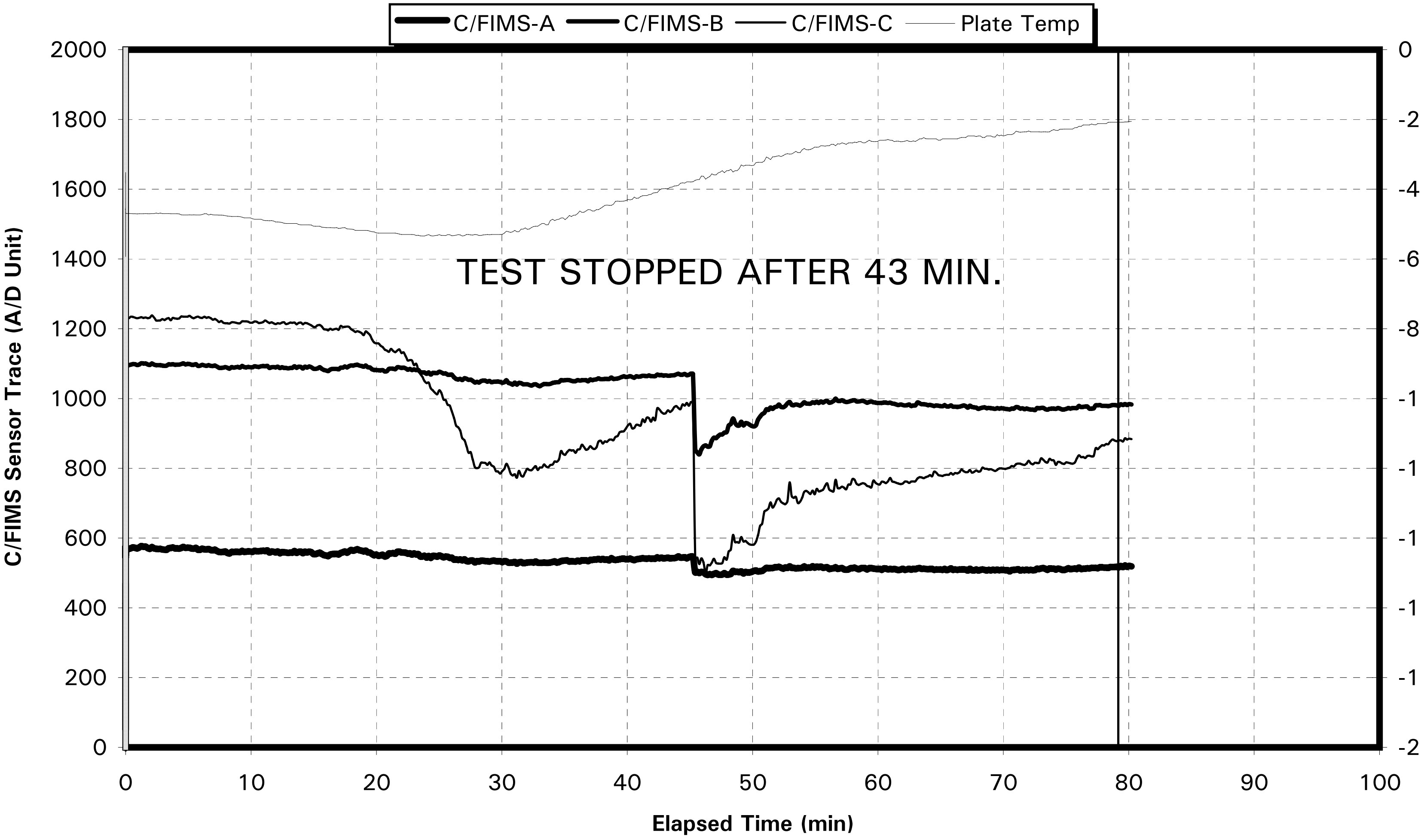


cm1380/analysis/doc_fail/brix/BRX_ID12
9/21/2006, 1:30 PM

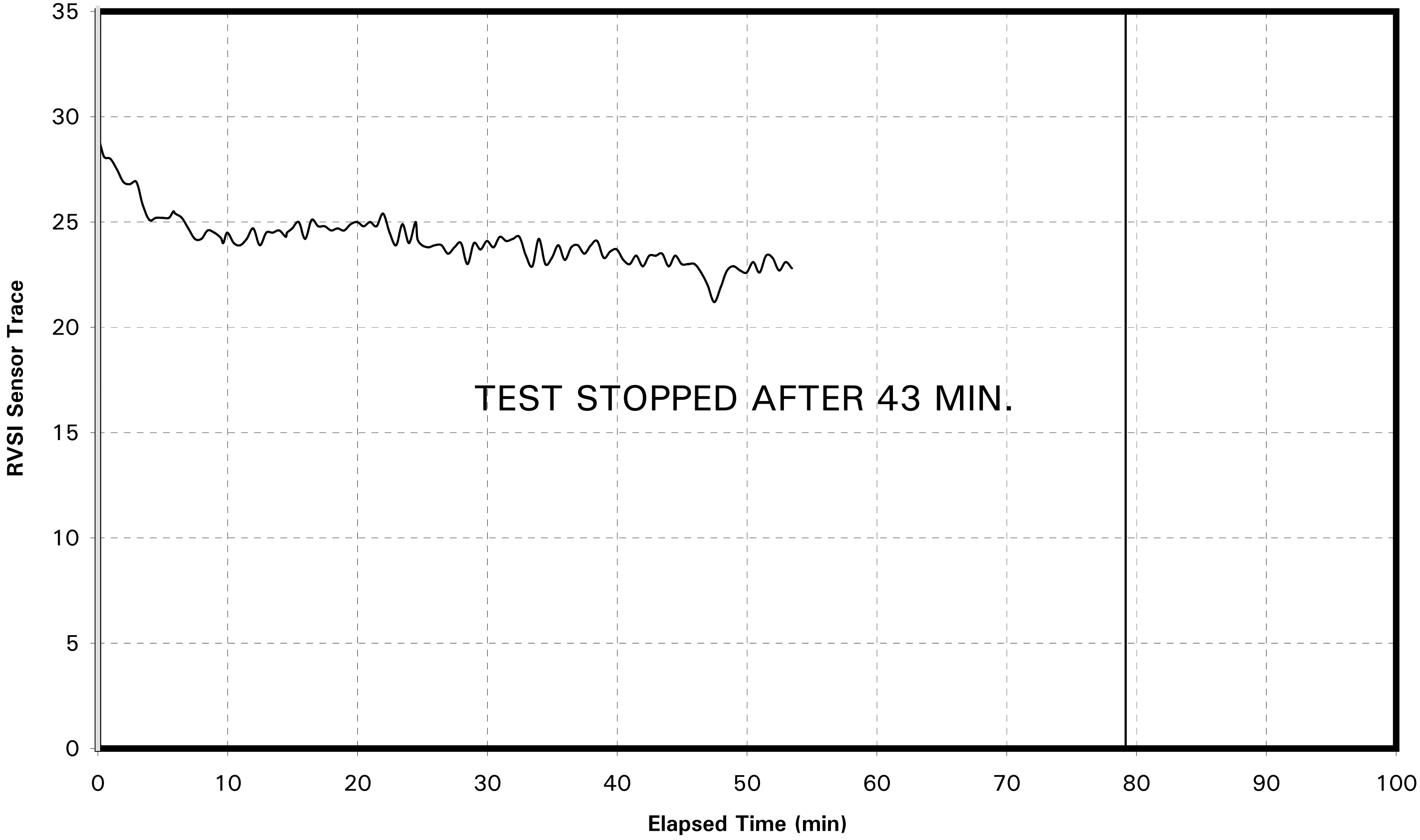
DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 12

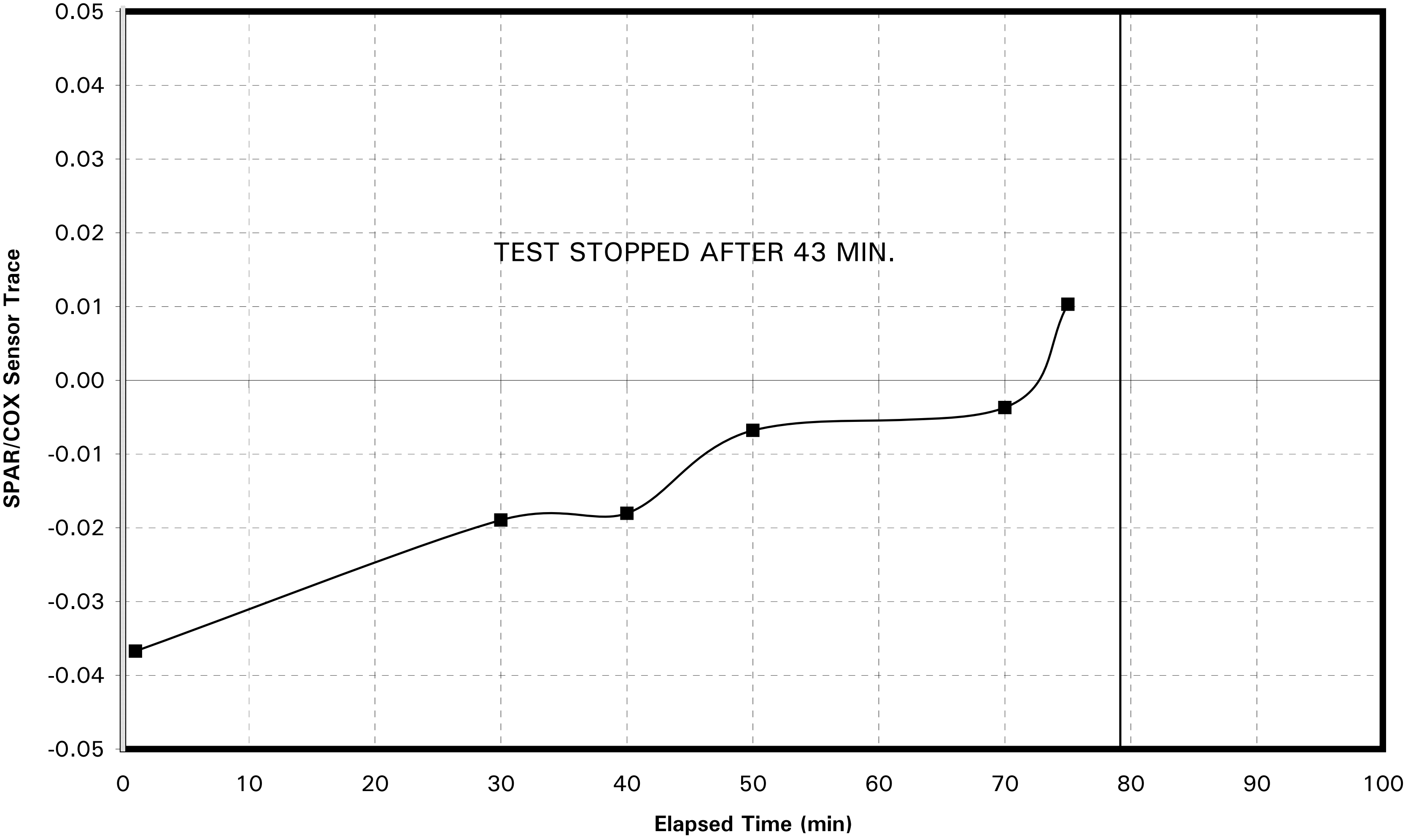


DOCUMENTATION OF FLUID FAILURE
RVSI SENSOR TRACE
ID # 12



cm1380/analysis/doc_fail/rvsi/RVS_ID12
9/21/2006, 1:32 PM

DOCUMENTATION OF FLUID FAILURE
SPAR/COX SENSOR TRACE
ID # 12

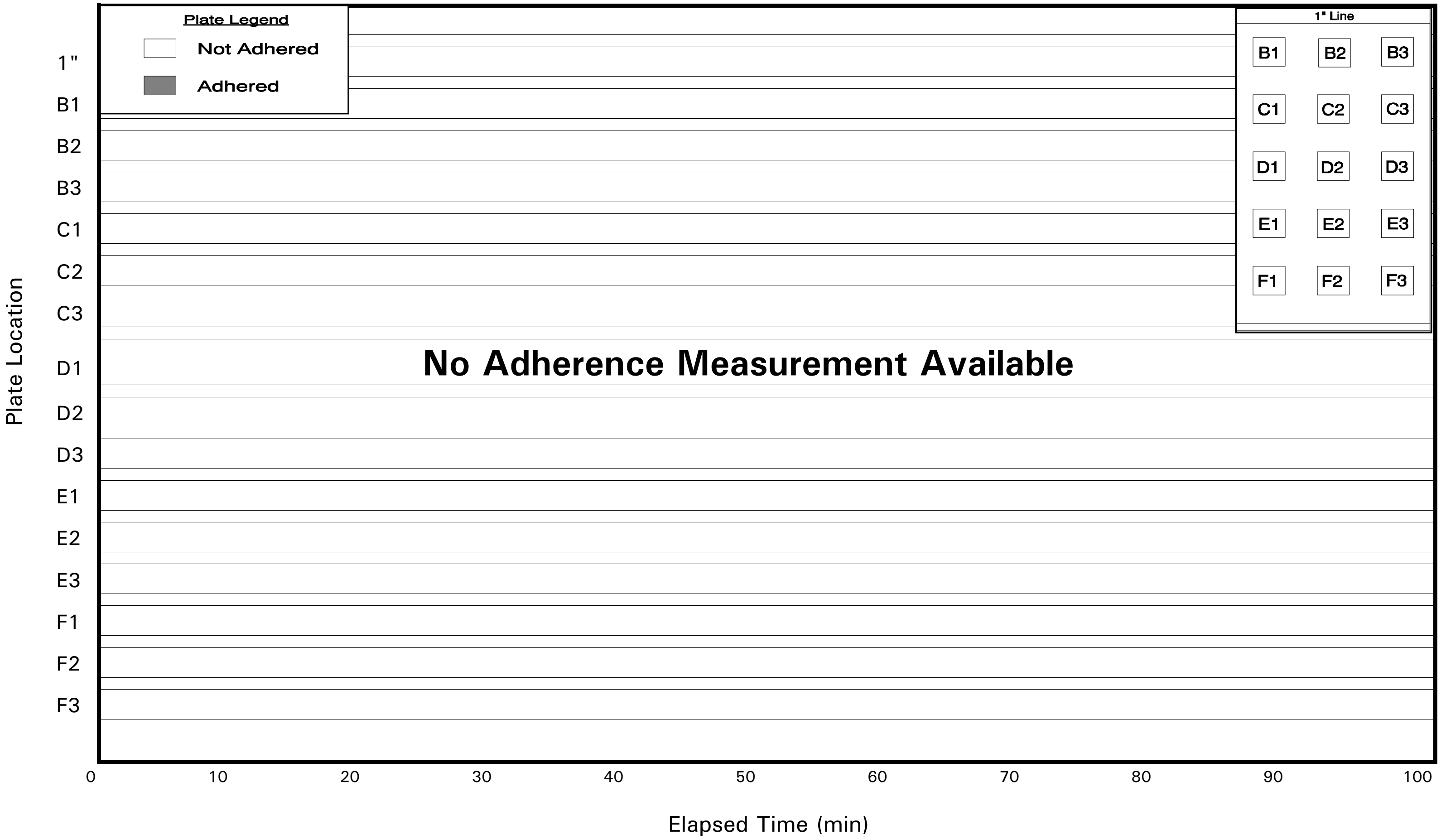


cm1380/analysis/doc_fail/cox/COX_ID12
9/21/2006, 1:34 PM

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 12



GENERAL TEST INFORMATION

ID # 13

July 9, 1998

Ambient Air Temperature:	-3.5°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.1 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	9:13:45
Failure Mode:	5th X-hair
Failure Location:	C3
Failure Time (Standard):	9:49:00
Failure Time (Complete Plate):	9:54:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 13

Photo C13.1 - After Pouring, t = 0 min (Est.)

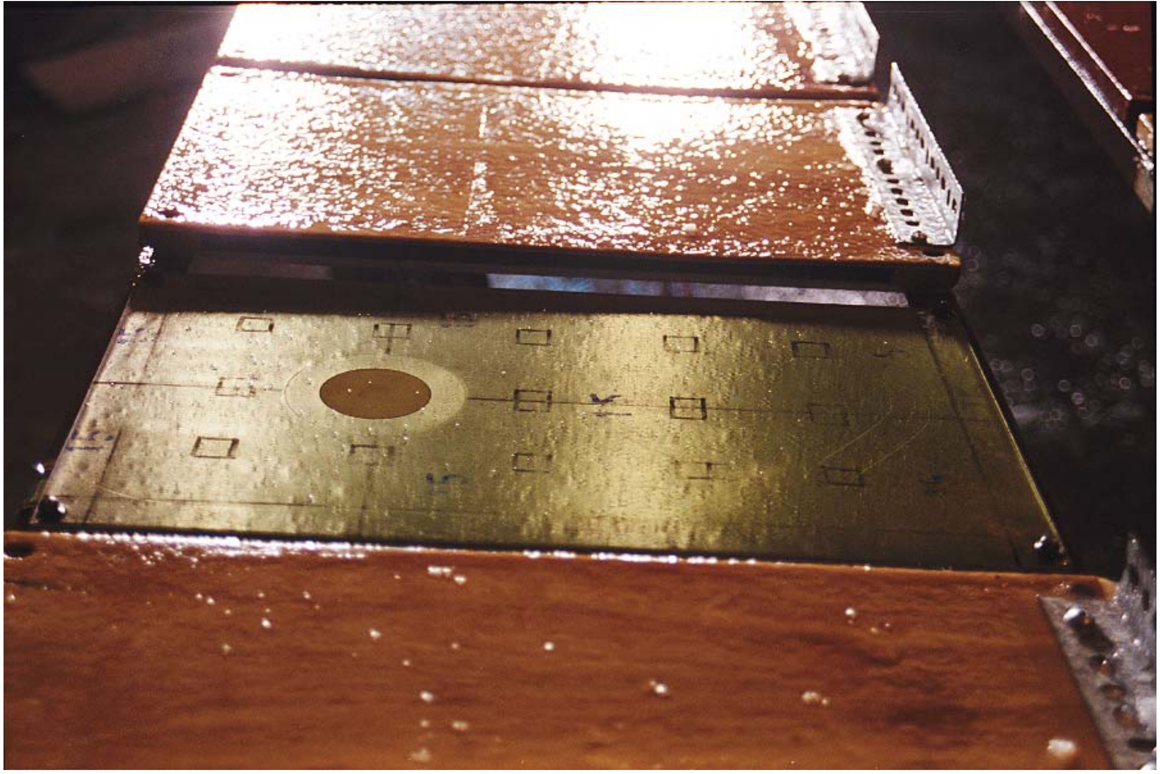


Photo C13.2 - 1st Failure, t = 28 min

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 13

Photo C13.3 - Standard Failure (1/3 or 5th Crosshair), t = 35 min (Est.)

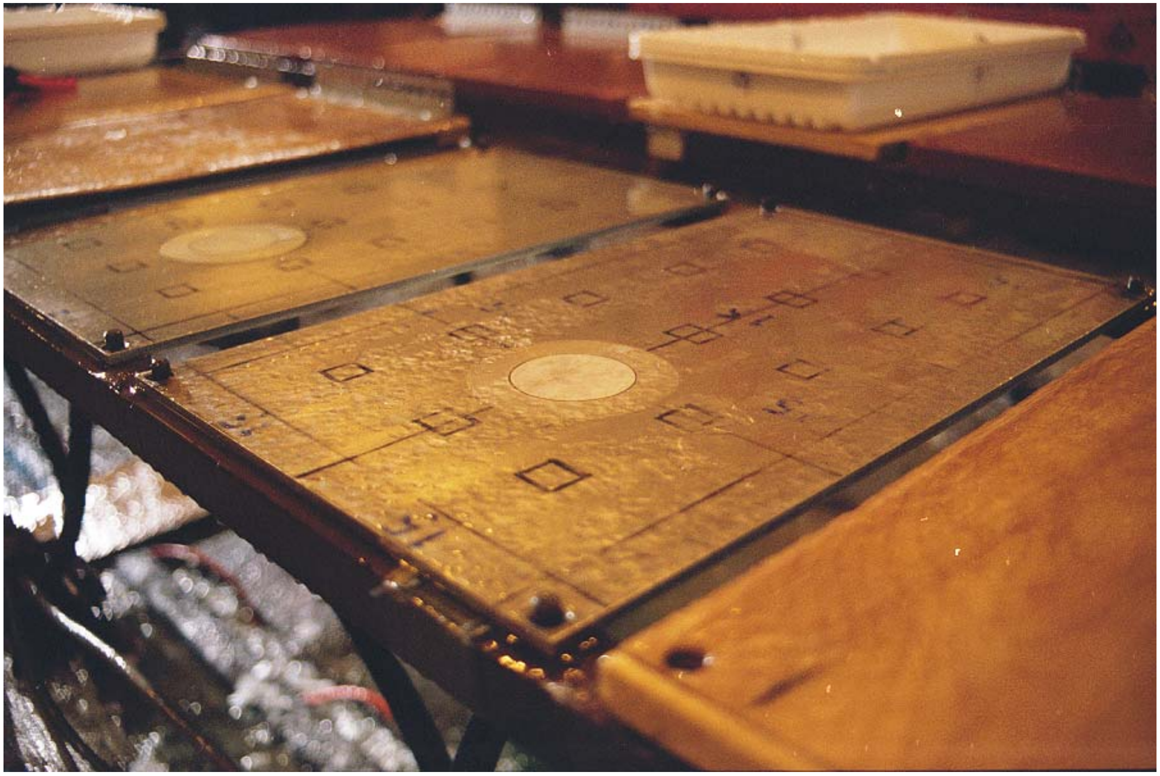
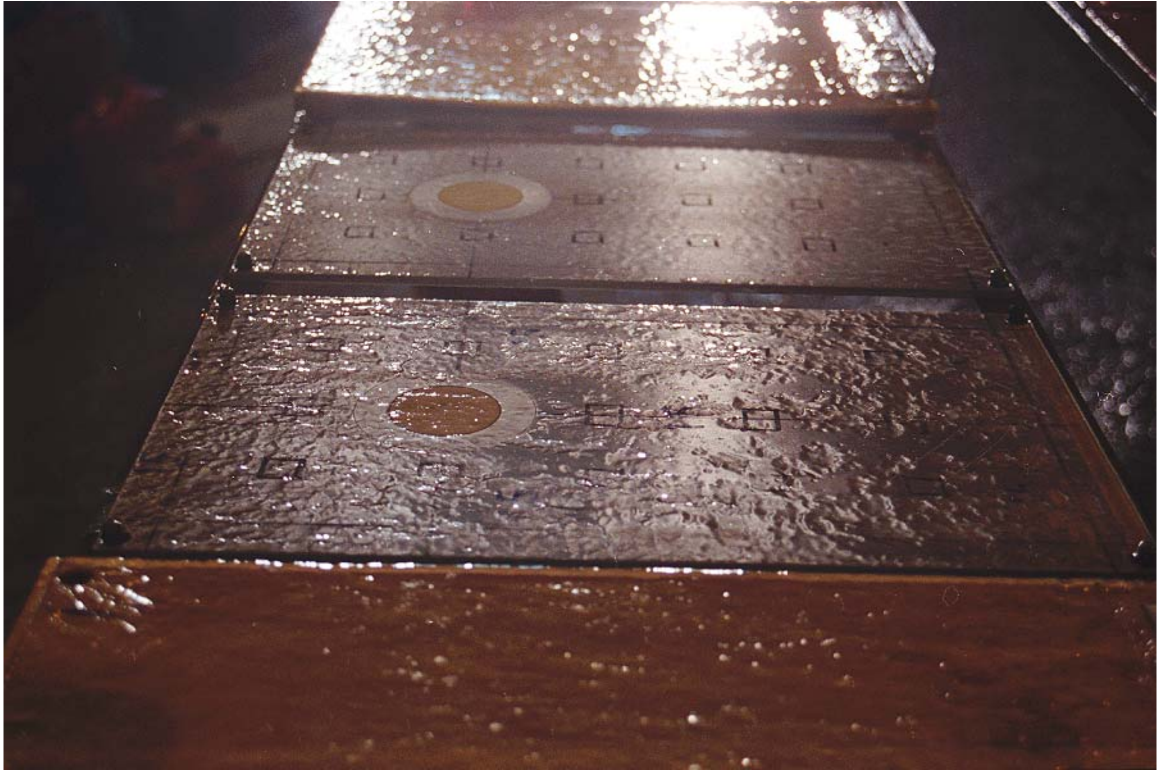


Photo C13.4 - Complete Fluid Failure, t = 40 min (Est.)



ID# 13

SUBJECTIVE APPEARANCE OF FLUID FAILURE

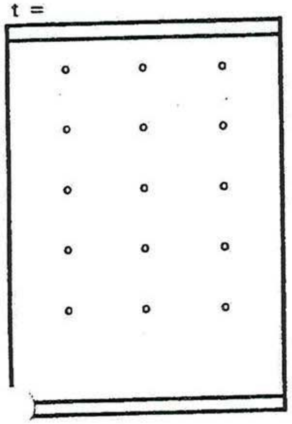
Date: July 09
Run #: 1

R=25
T=-3°C
ZR

Time: 0913^{40}
Fluid Name: ULTRA+

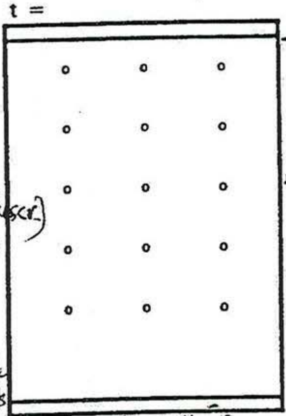
Plate Location: 2
Fluid Dilution: 100%

t =



POUR: ~1 minute
thick green shiny
transparent liquid
with some embedded
air bubbles (as prev. descr.)
0918 Speckle formation
~~no solids~~
0919 O.P. beginning to
set in. Considerable
~~beading of water~~ droplets
with subseq. bounce off
and running off
plate.

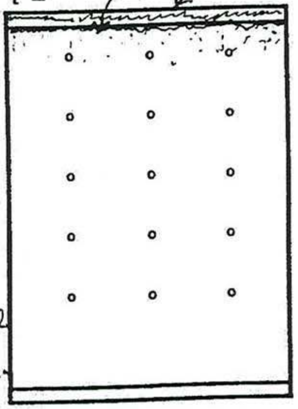
t =



0923 Orange Peel Srf.
droplets beading bounce
~~off~~ and run off plate
past top half of plate,
water beginning to be
more easily accepted
(mixing/dilution)
0930 Marble stage
of fluid setting in.
0935 Marbling of fluid
well developed. Still has
not reached ~~max~~.
extent of marbling

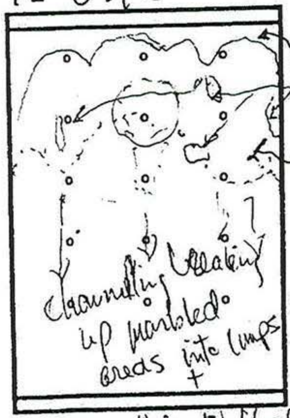
t =

0943



0939 Top edge beginning
to fail, small
apparently (to the naked
eye) solid specks
beginning to form
over 0->3" all
across top of
plate.
0943 1st fail
called

t = 0947

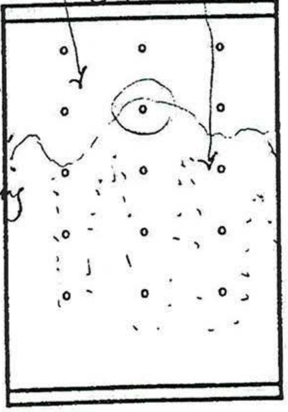


thin dil fluid regions

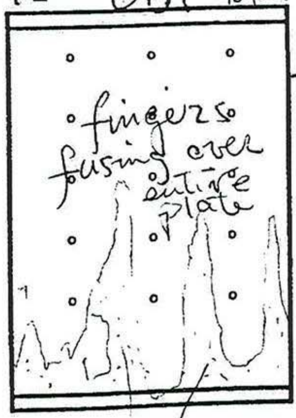
0947 Failure Progress
~~fused platelets; adhesion~~
setting in.
Pre failure region
solid/fluid+water ~50/50
by volume. Overlapping
platelets, not yet
fused. Failed
Islands distributed
~~in this region~~.

0949 5th Xhair

t = 0960 Failure imminent



t = 0957 total plate failure



totally wet
surface.

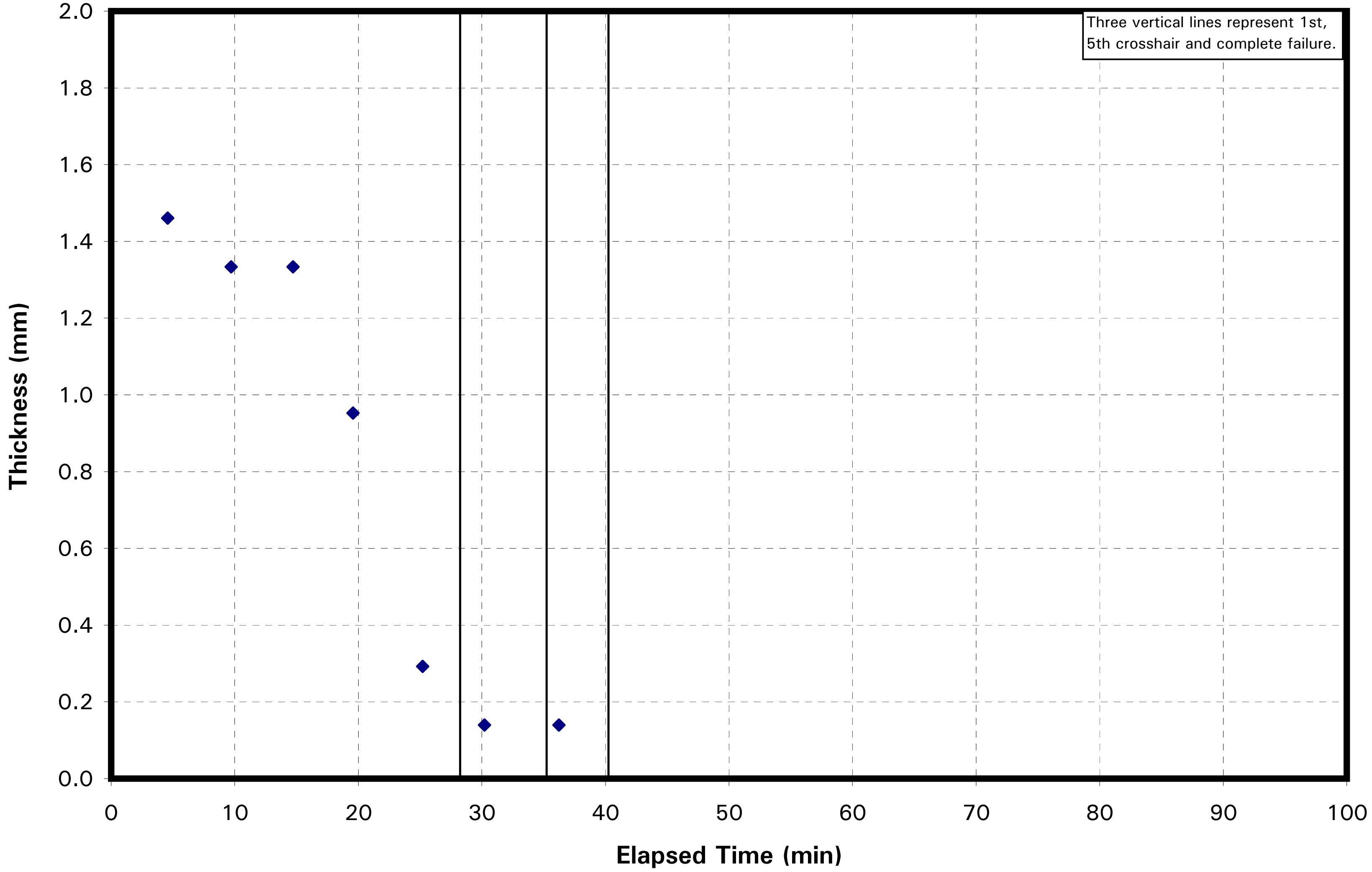
Channels + solid contaminant-
saturated fluid.
(overlapping platelets)

Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 13

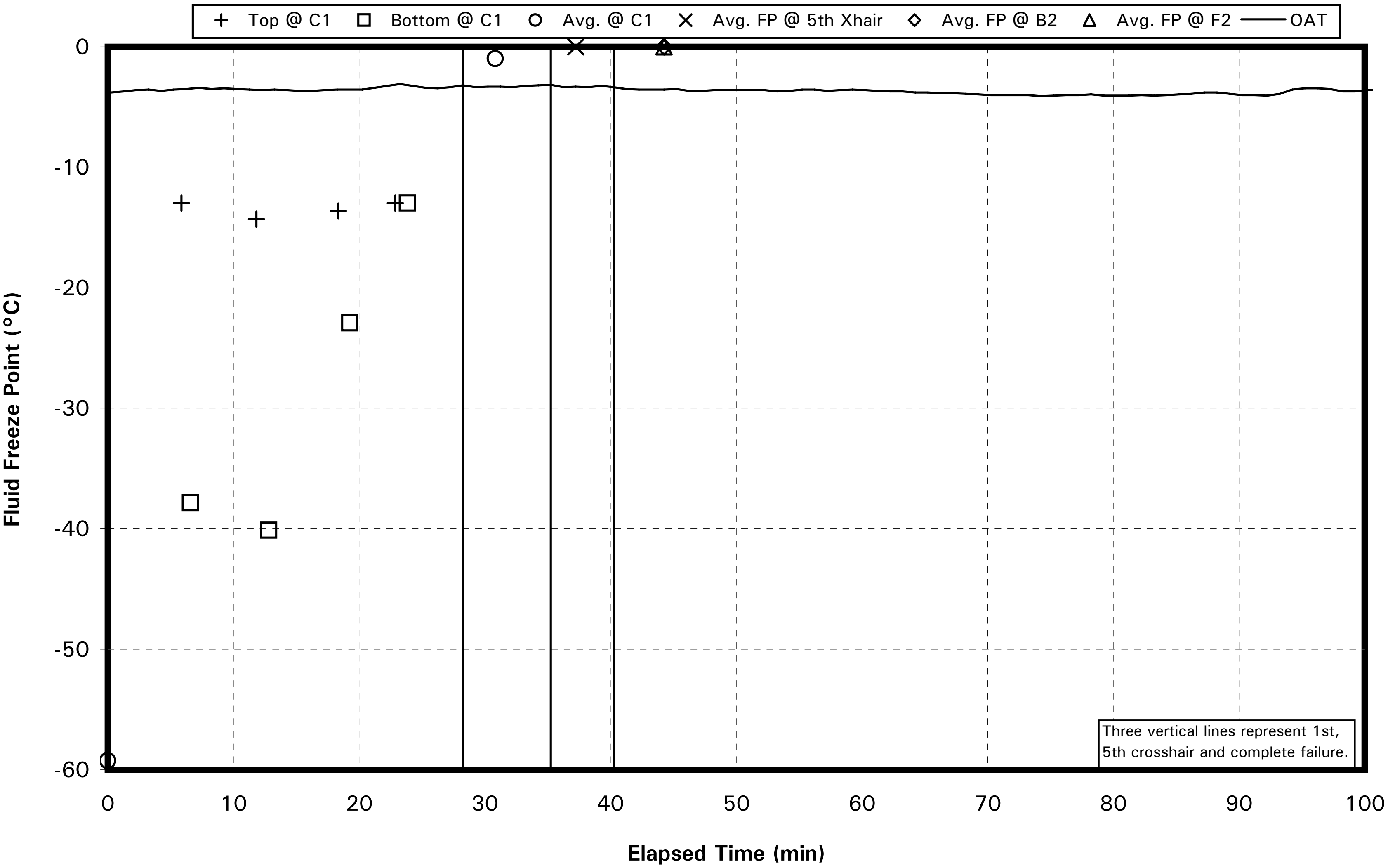


cm1380/analysis/doc_fail/thicknes/THK_ID13
9/21/2006, 1:40 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 13

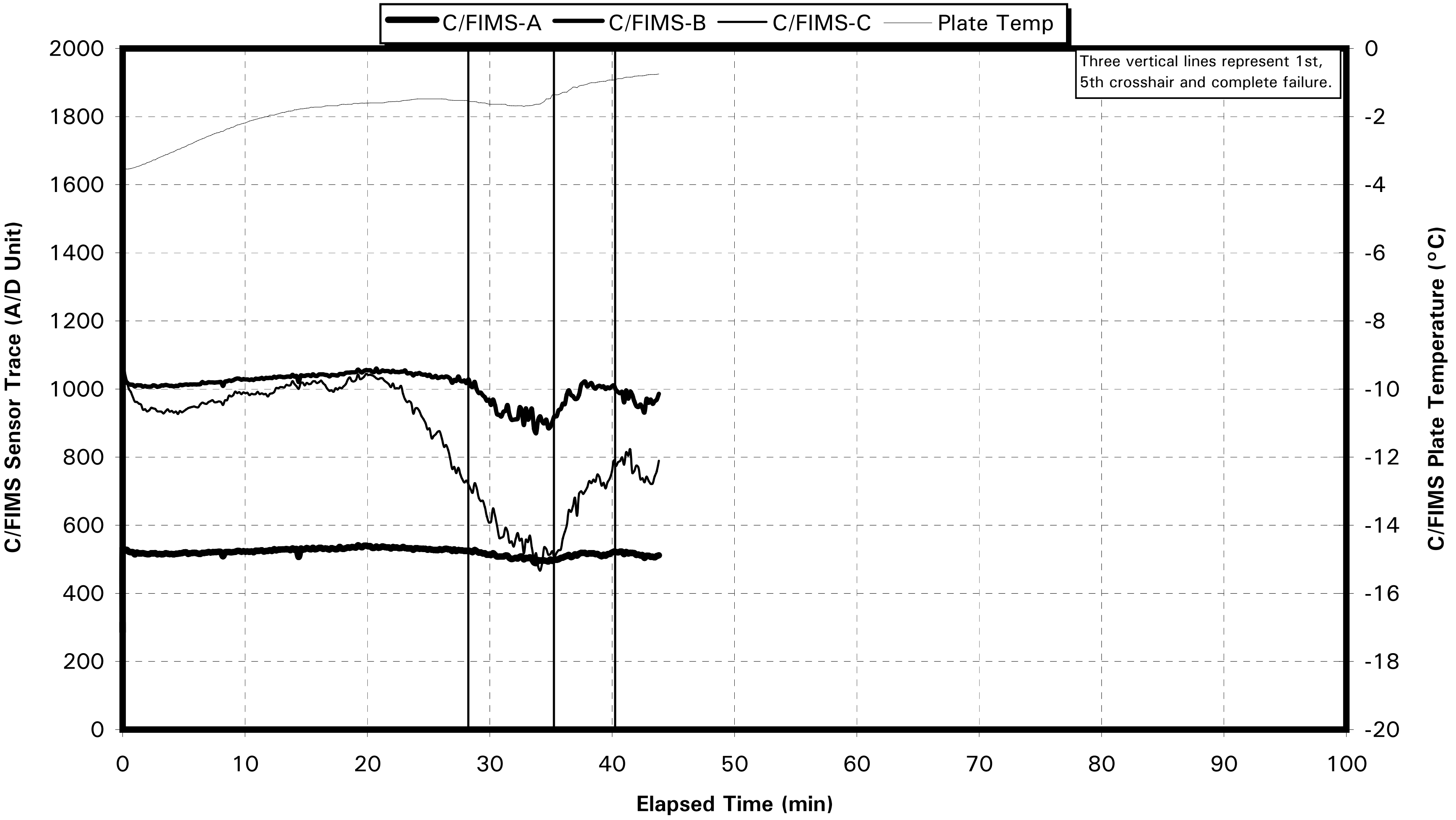


cm1380/analysis/doc_fail/brix/BRX_ID13
9/21/2006, 1:40 PM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 13

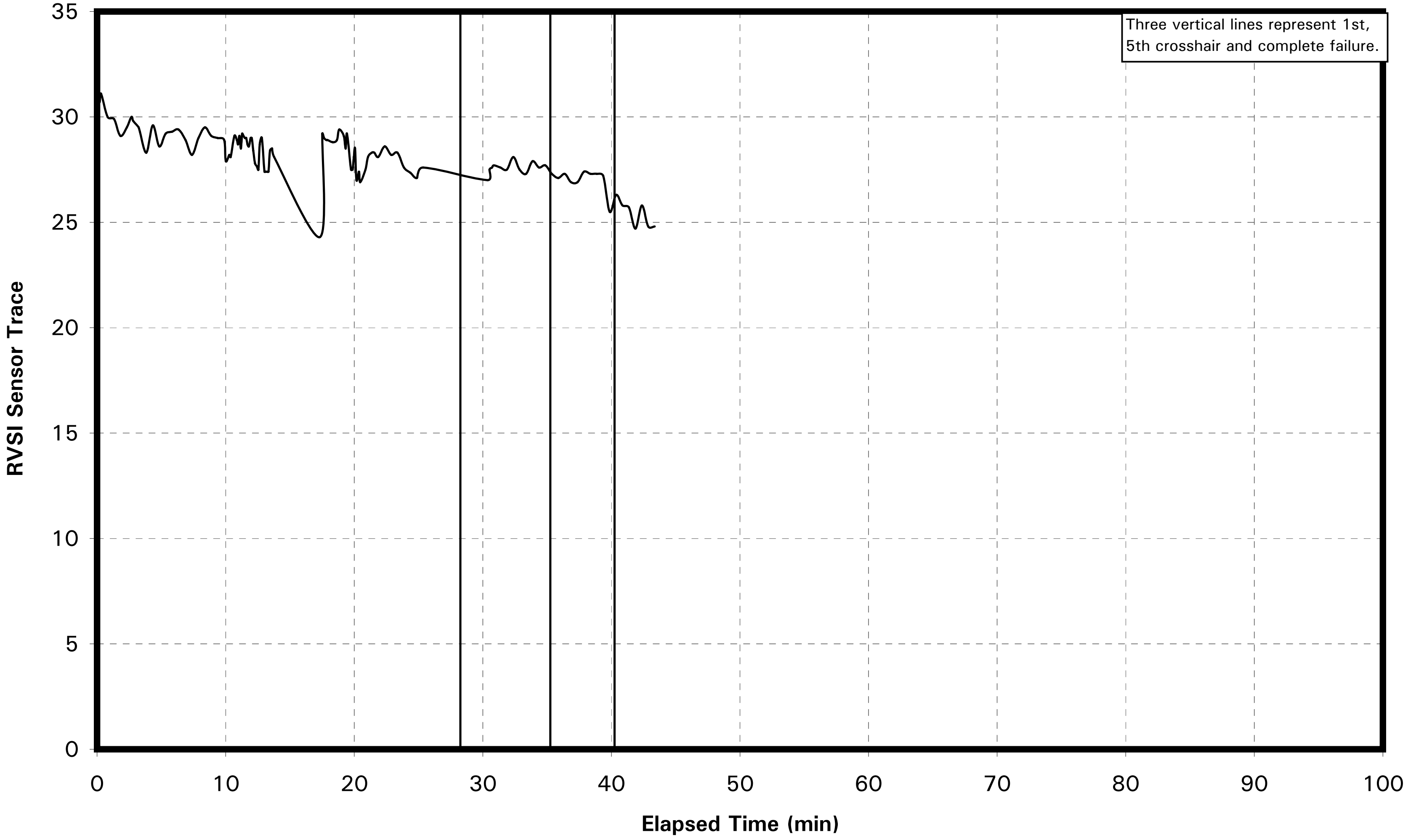


cm1380/analysis/doc_fail/cfims/CFM_ID13
9/21/2006, 1:41 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 13



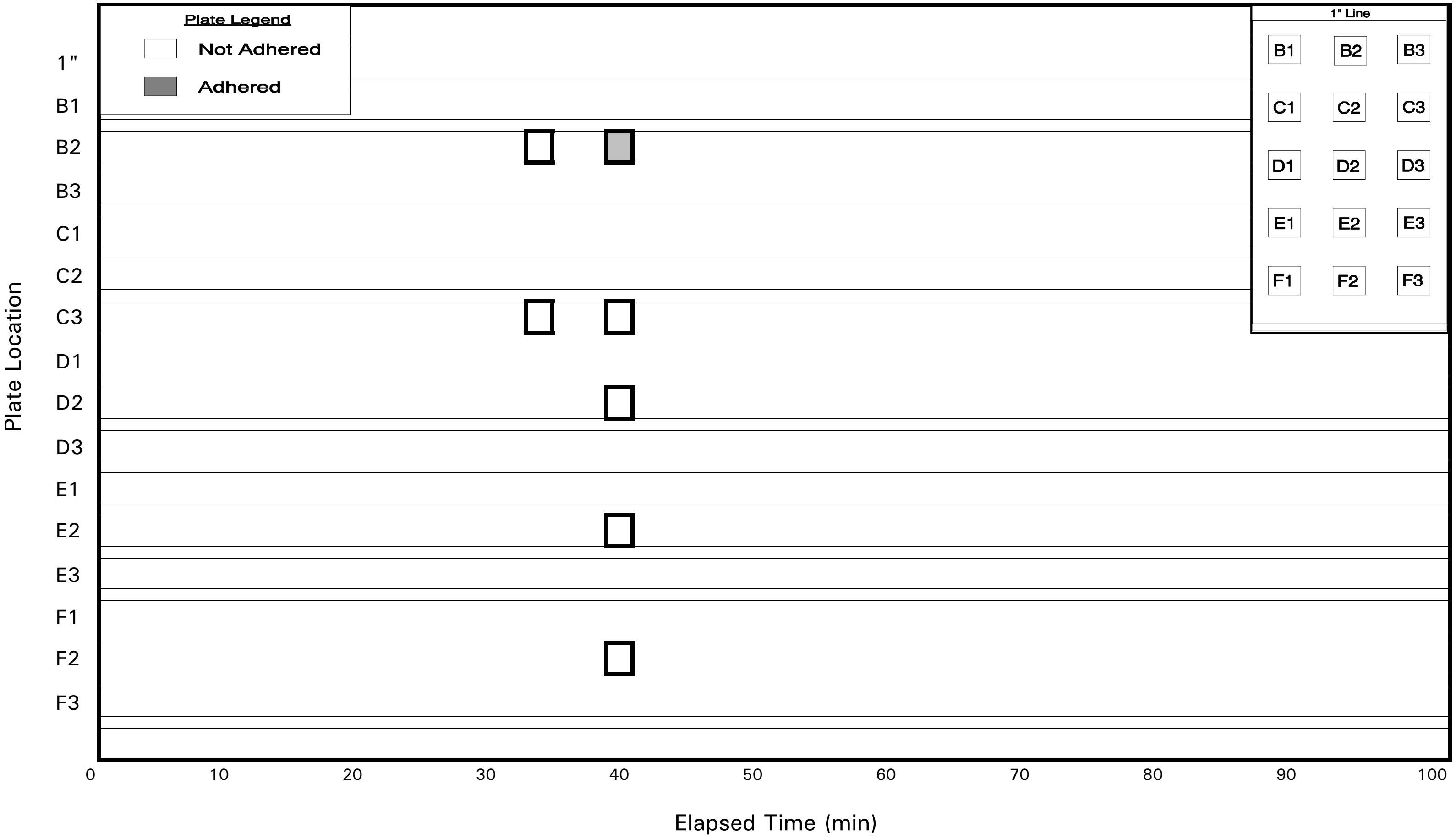
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 13

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 13



cm1380/analysis/doc_fail/ADH_ID13
9/21/2006, 1:44 PM

GENERAL TEST INFORMATION

ID # 14

July 9, 1998

Ambient Air Temperature:	-3.6°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.8 g/dm²/hr
Fluid:	UCAR XL54
Dilution:	Std
Start of Test:	9:16:00
Failure Mode:	5th X-hair
Failure Location:	C2
Failure Time (Standard):	9:27:30
Failure Time (Complete Plate):	9:35:00

Note: Low Initial Brix

PHOTOS OF POUR AND FIRST FAILURE - ID # 14

Photo C14.1 - After Pouring, t = 0 min (Est.)

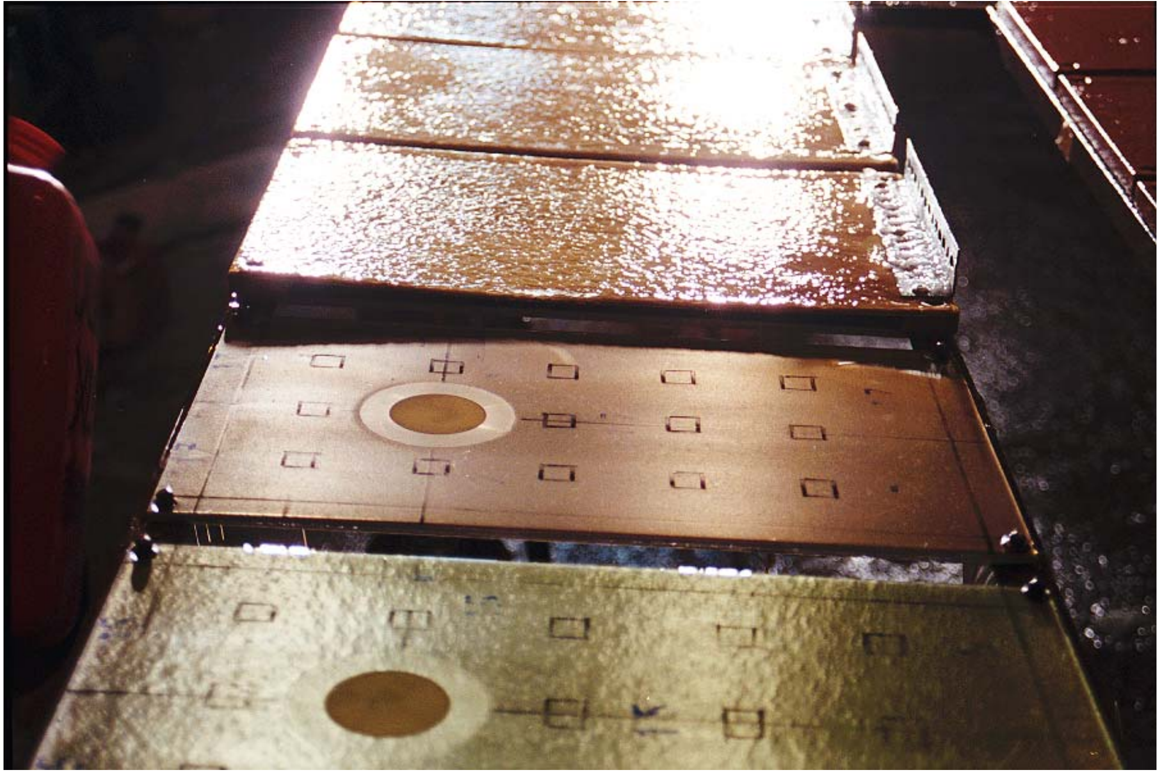
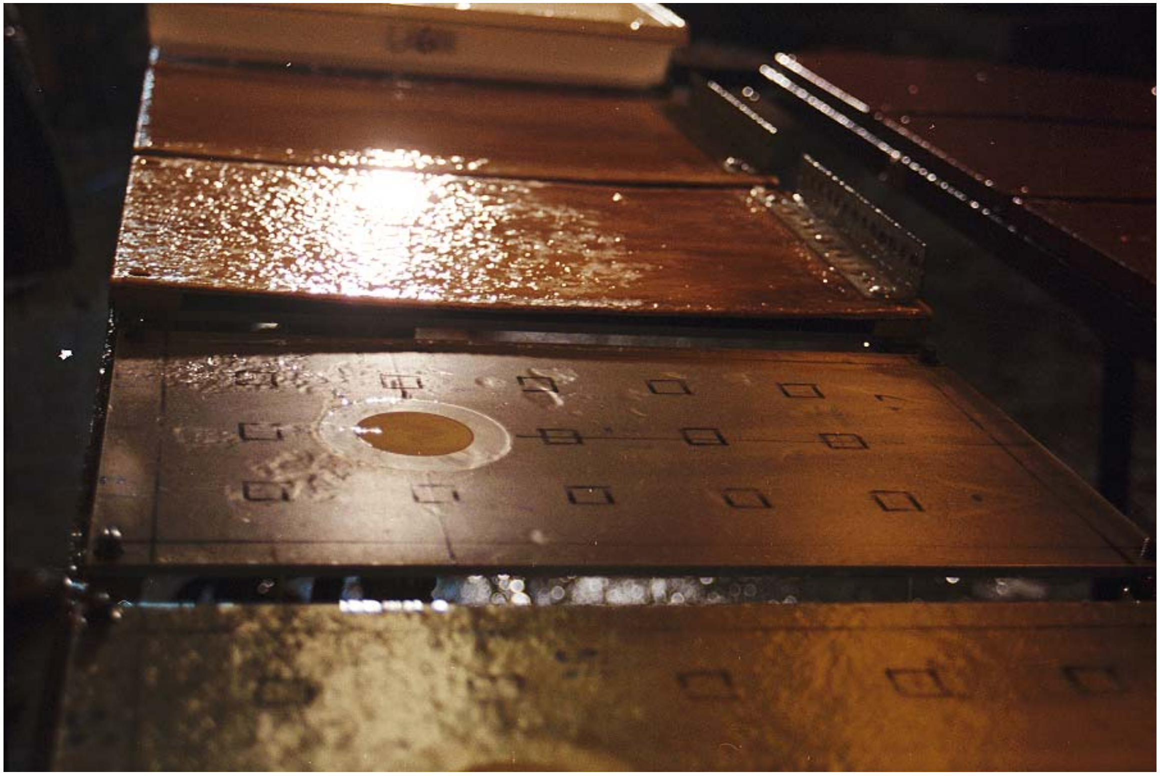


Photo C14.2 - 1st Failure, t = 9 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 14

Photo C14.3 - Standard Failure (1/3 or 5th Crosshair), t = 11 min (Est.)

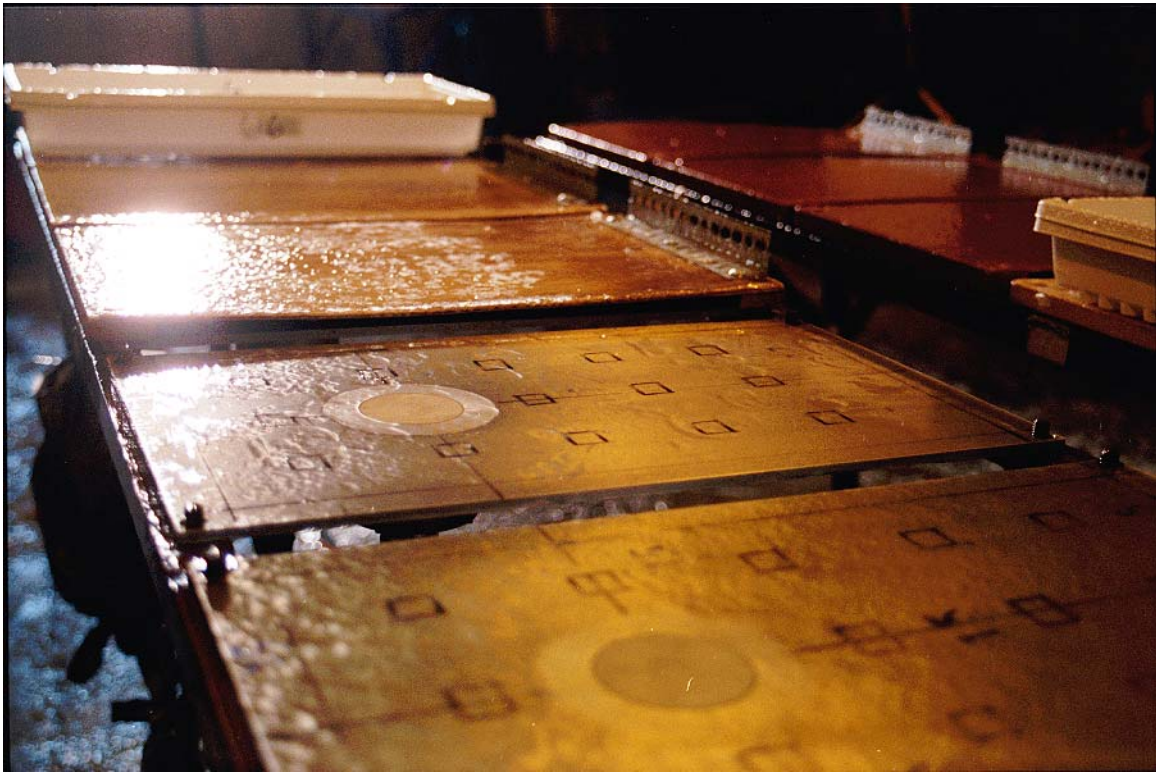
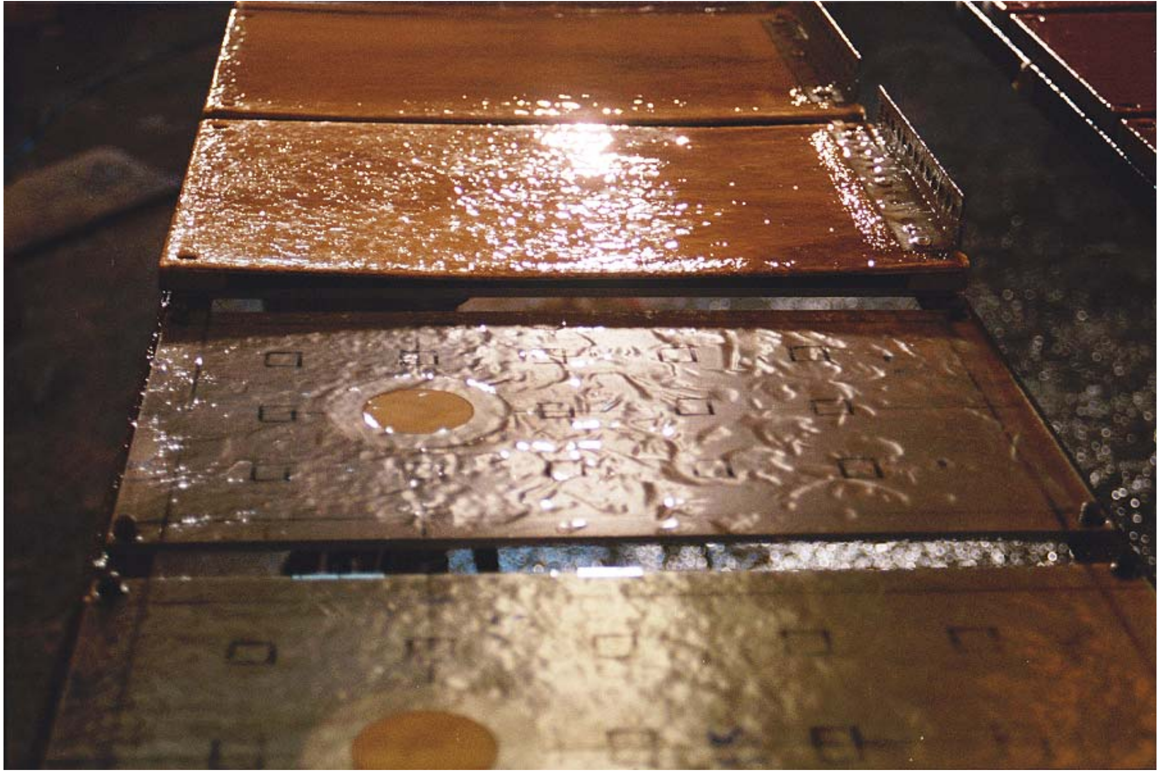


Photo C14.4 - Complete Fluid Failure, t = 19 min (Est.)



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Last printed 10/14/98 8:54 AM

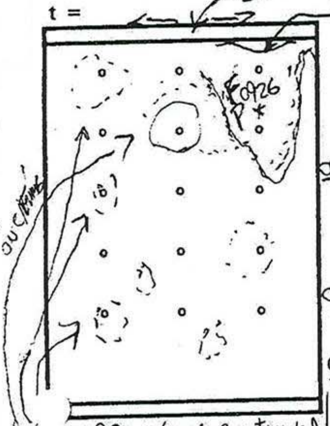
ID# 14

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09
Time: 0916 00
Plate Location: 3
Run #: 1
Fluid Name: XL54
Fluid Dilution: STD

@922 band of solid wet ice.
@925 initial contam

t =



Thin orange transp liquid. V. thin film ~~remains on~~ plate

@917 Showing rapid dilution + drying on top edge of plate.

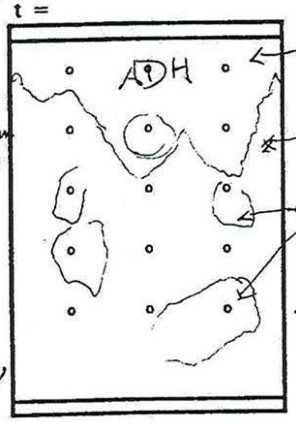
@918 Rivulet formation on top 0->3" line.

@920 Extensive beading, ~~bounce + roll off~~ of ZR upon impact on plate.

(*FP = failure progress)

@926 Intensive saturated fluid island formation on surface.

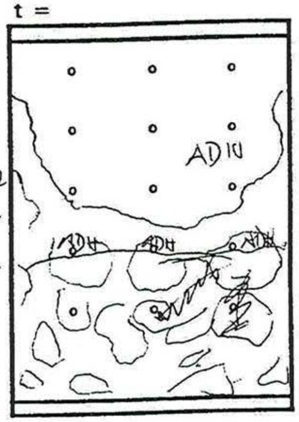
t =



@927 5th X-Hair failure

- clear areas, wet with fluid to surface
- islands of failure ↓ already adhering strongly

t =



@934 30
full plate
failure
ADHESION TO
12" line
Below, islands are fused but do not adhere to substr

t =

t =

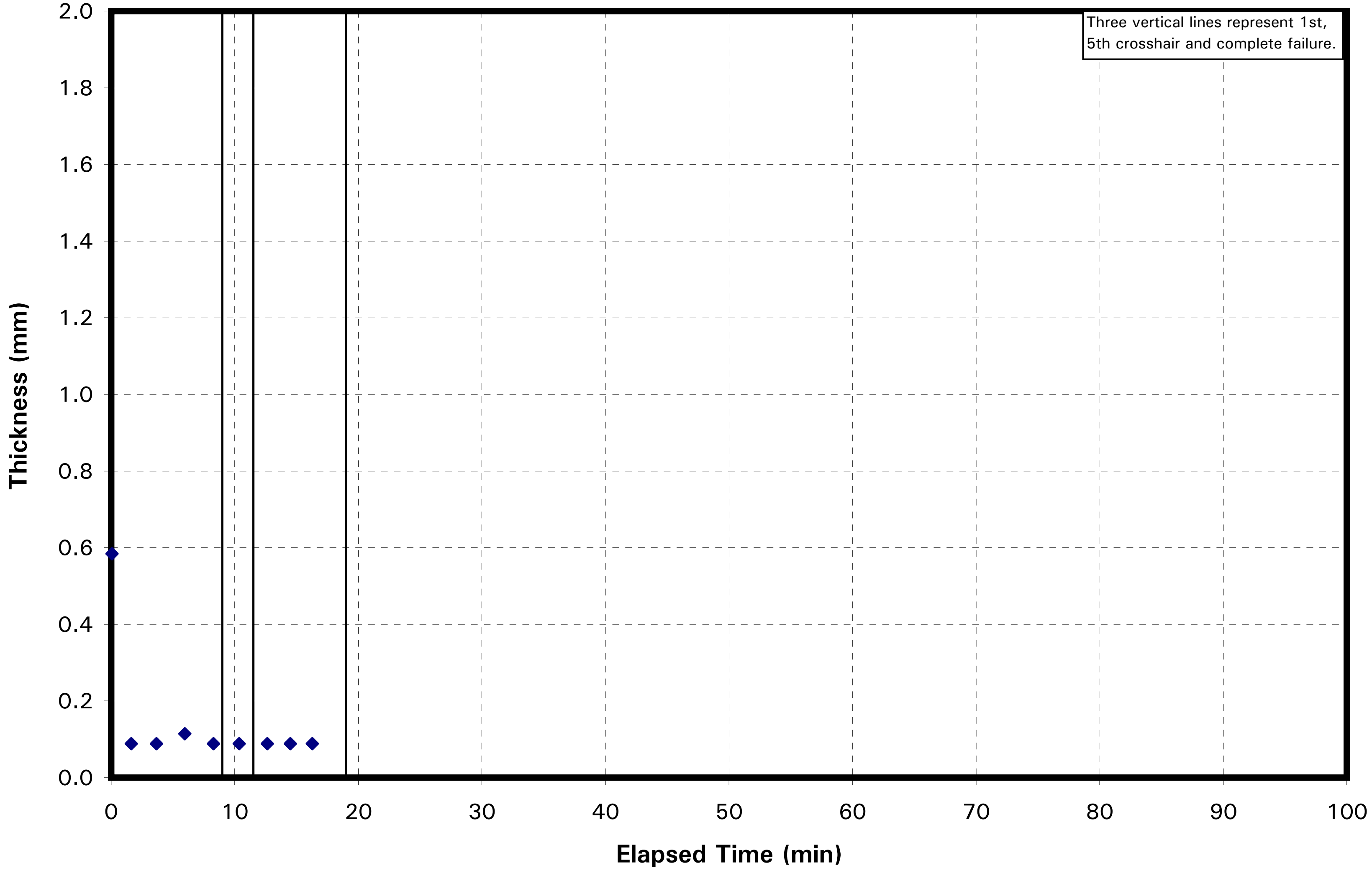
t =

Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

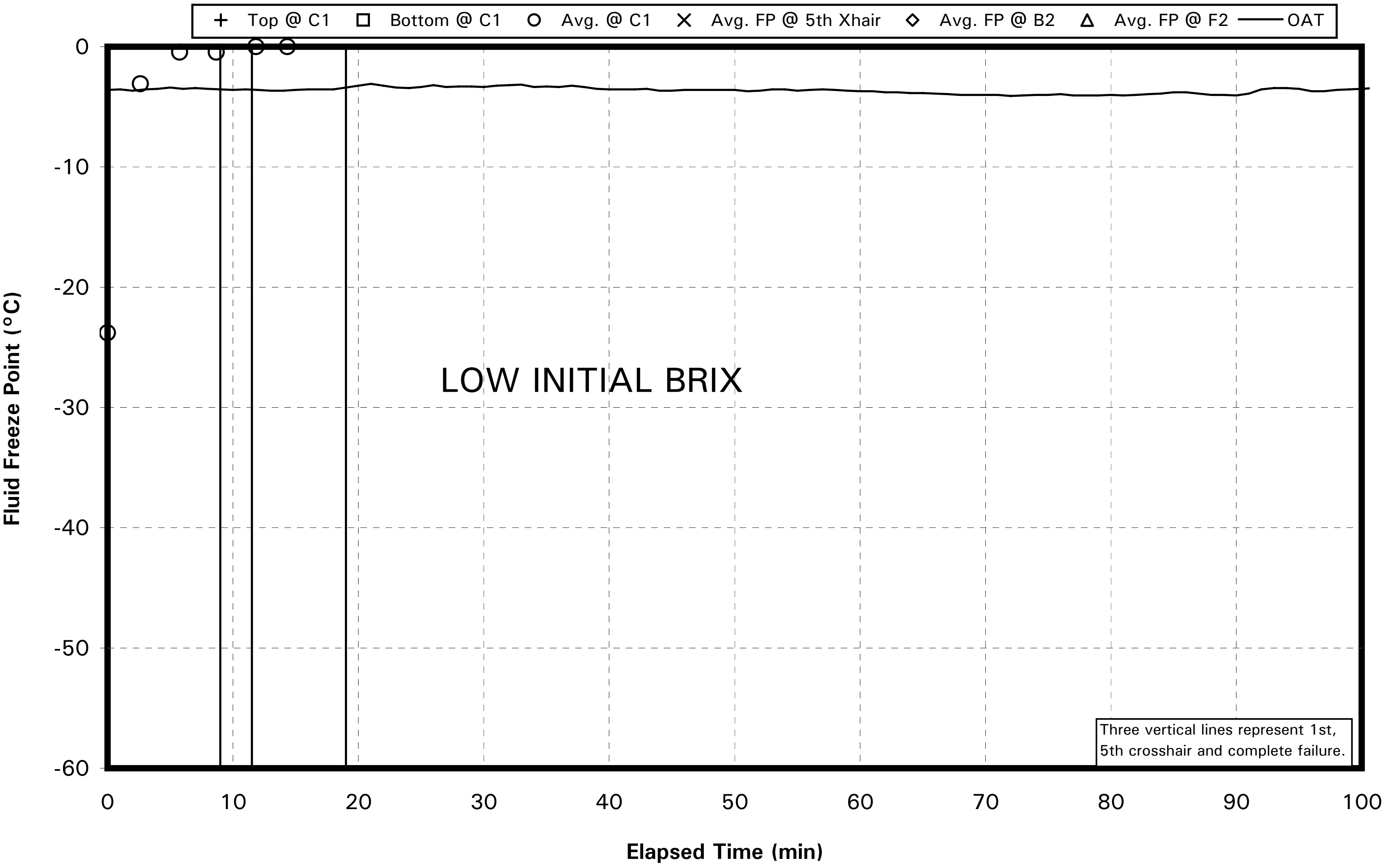
ID # 14



DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 14

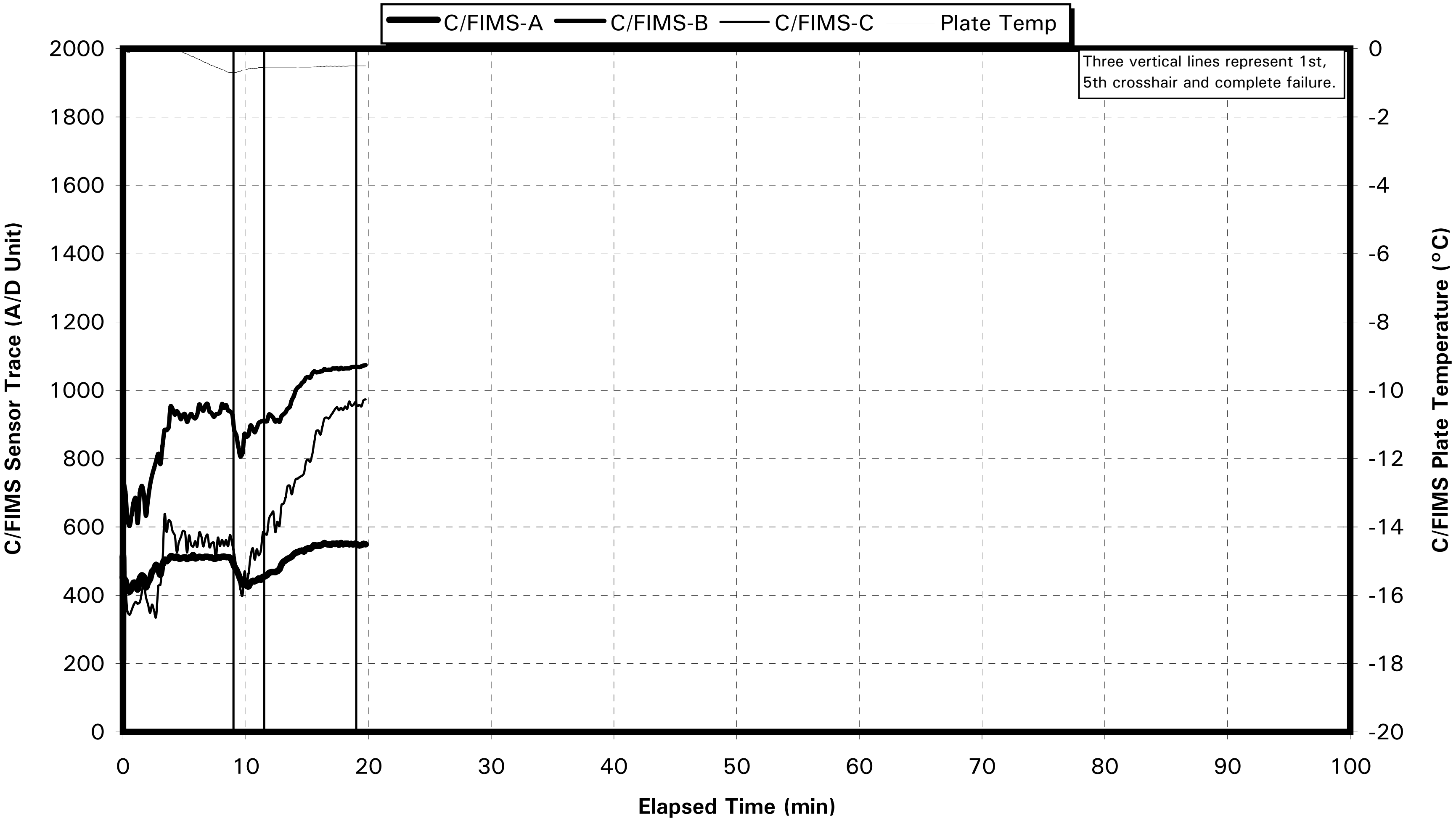


cm1380/analysis/doc_fail/brix/BRX_ID14
9/21/2006, 1:49 PM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 14

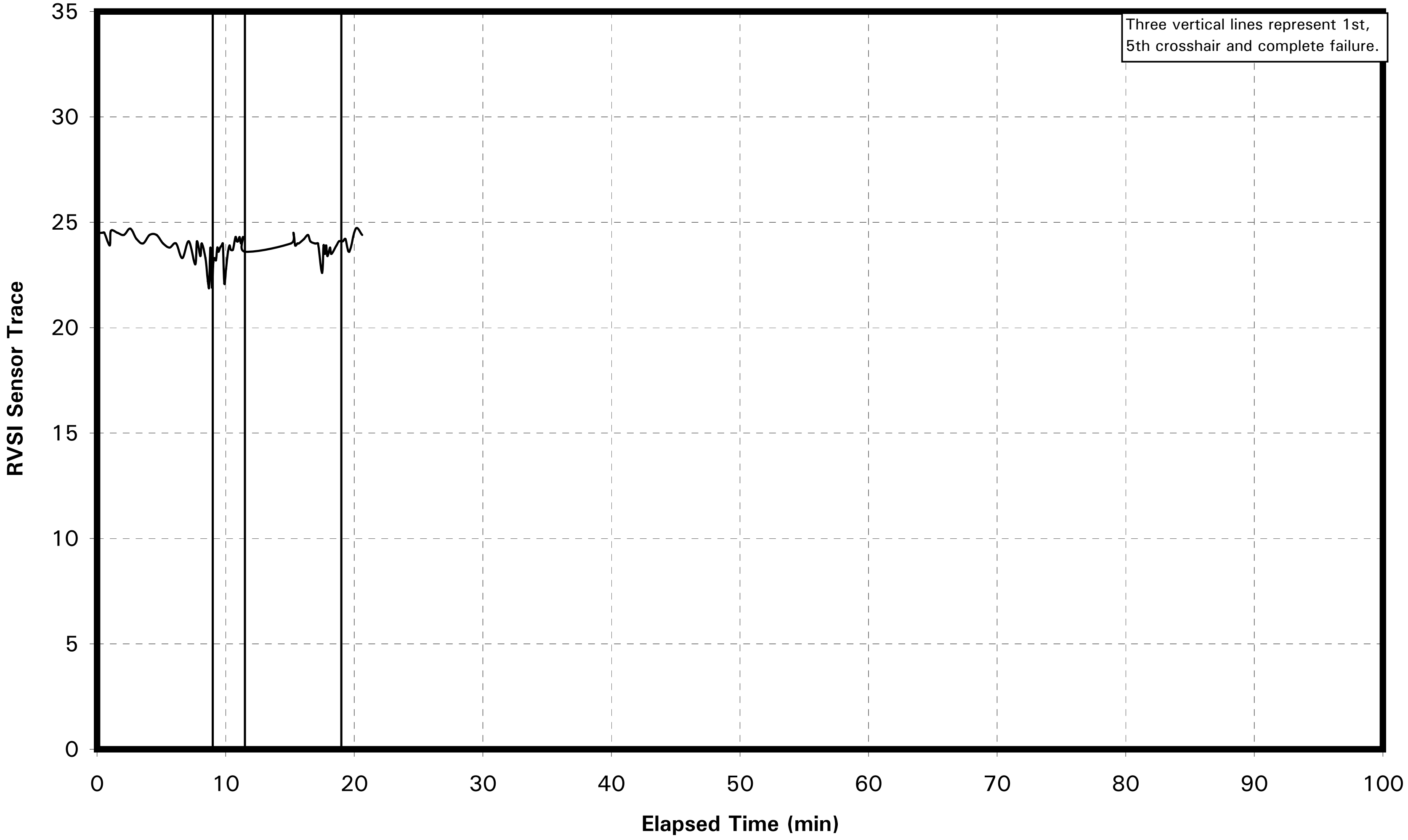


cm1380/analysis/doc_fail/cfims/CFM_ID14
9/21/2006, 1:51 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 14



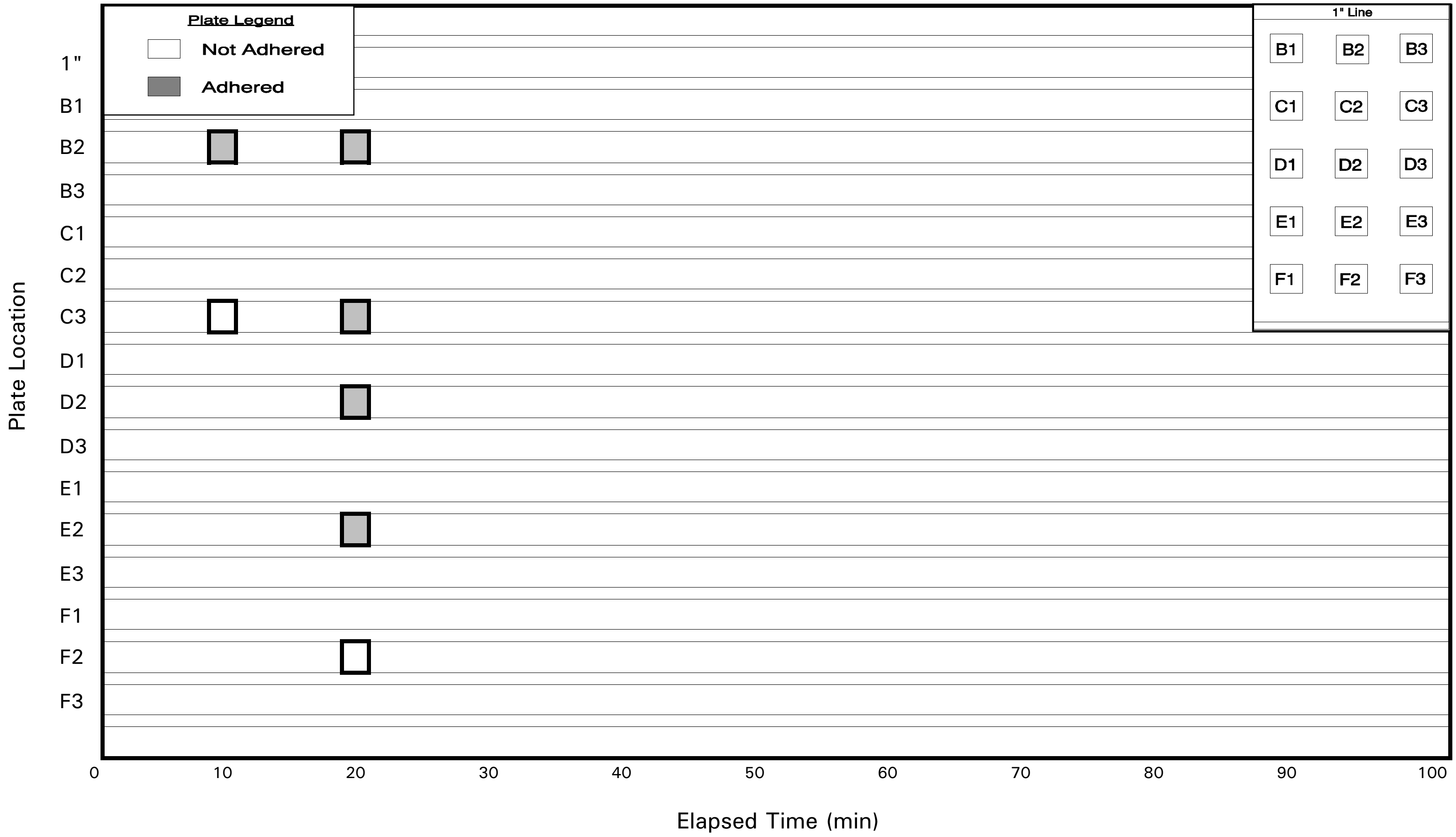
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 14

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 14



cm1380/analysis/doc_fail/ADH_ID14
9/21/2006, 1:53 PM

GENERAL TEST INFORMATION

ID # 15

July 9, 1998

Ambient Air Temperature:	-3.3°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.8 g/dm²/hr
Fluid:	SPCA AD-480
Dilution:	50%
Start of Test:	9:41:15
Failure Mode:	5th X-hair
Failure Location:	C3
Failure Time (Standard):	9:57:00
Failure Time (Complete Plate):	9:59:00

cm1380/analysis/doc_fail/GEN_INFO
At: 15
9/21/2006, 1:54 PM

PHOTOS OF POUR AND FIRST FAILURE - ID # 15

Photo C15.1 - After Pouring, t = 0 min (Est.)

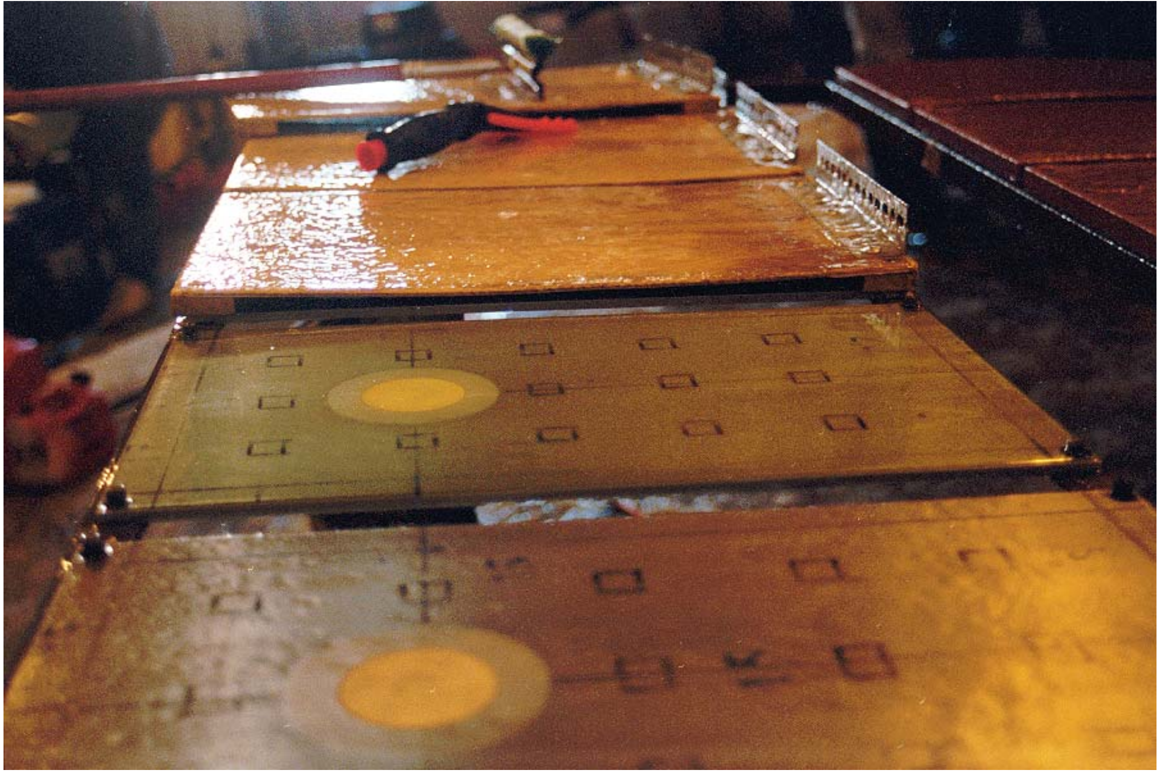
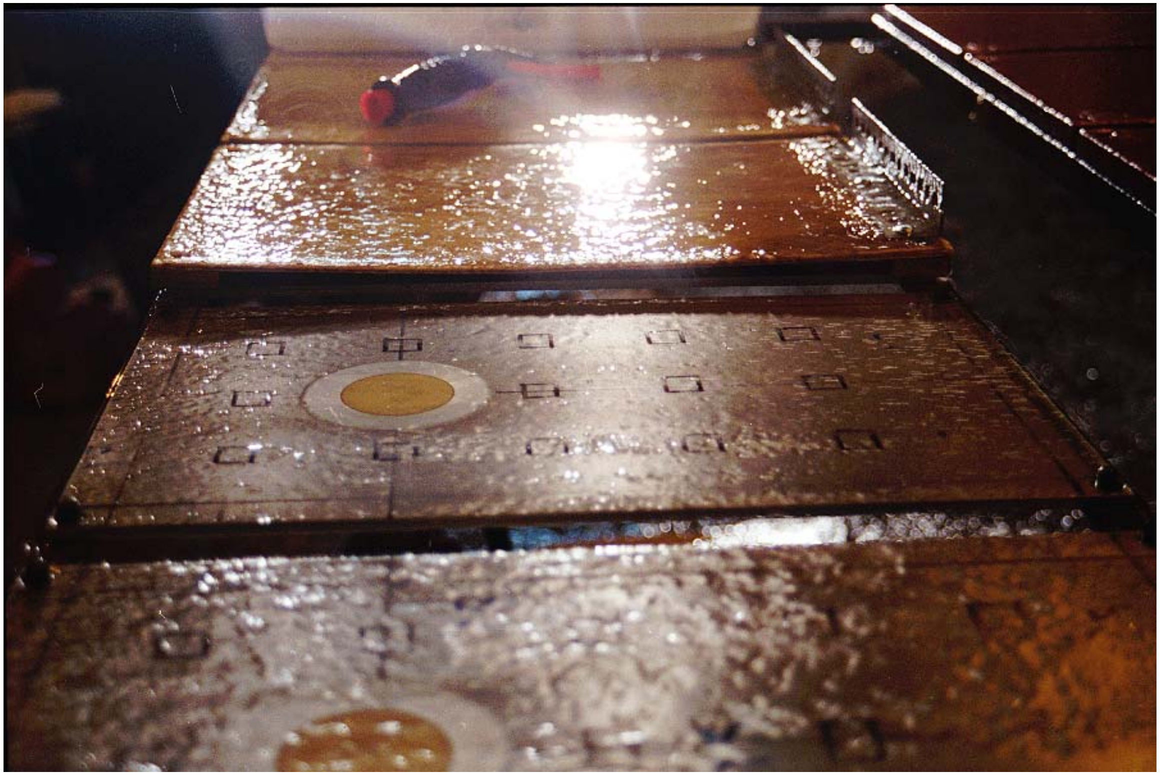


Photo C15.2 - 1st Failure, t = 14 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 15

Photo C15.3 - Standard Failure (1/3 or 5th Crosshair), t = 16 min (Est.)

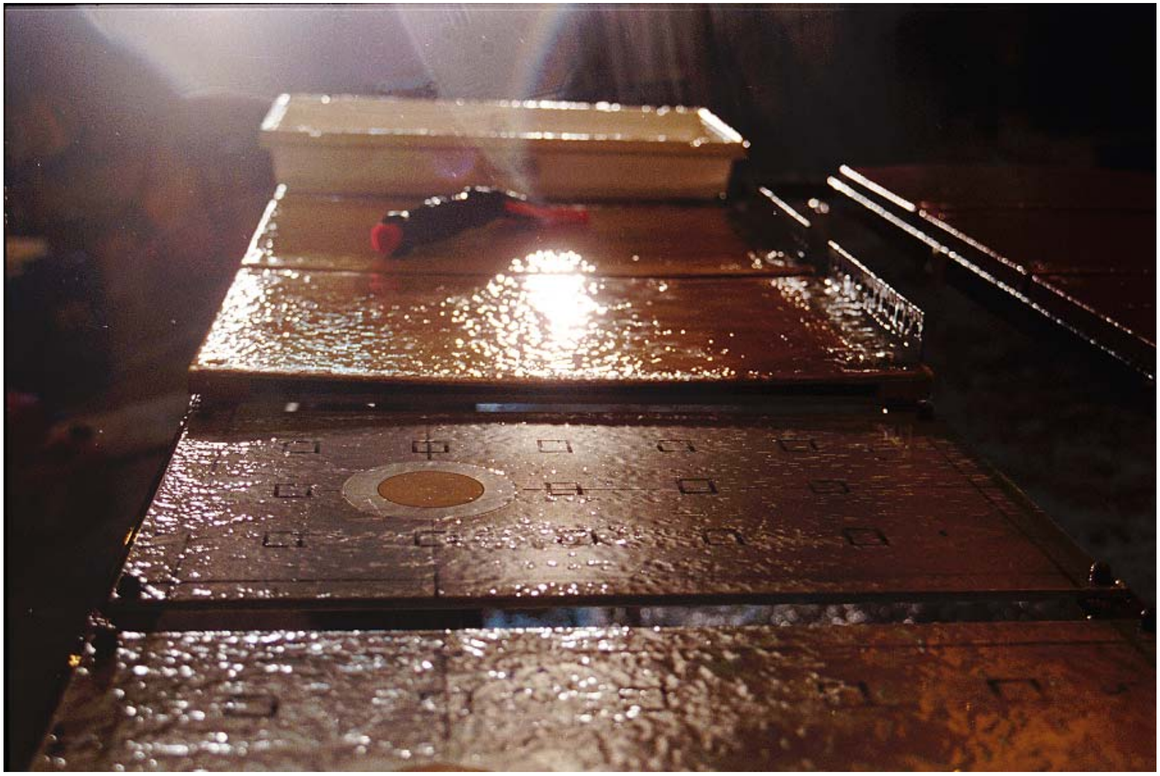
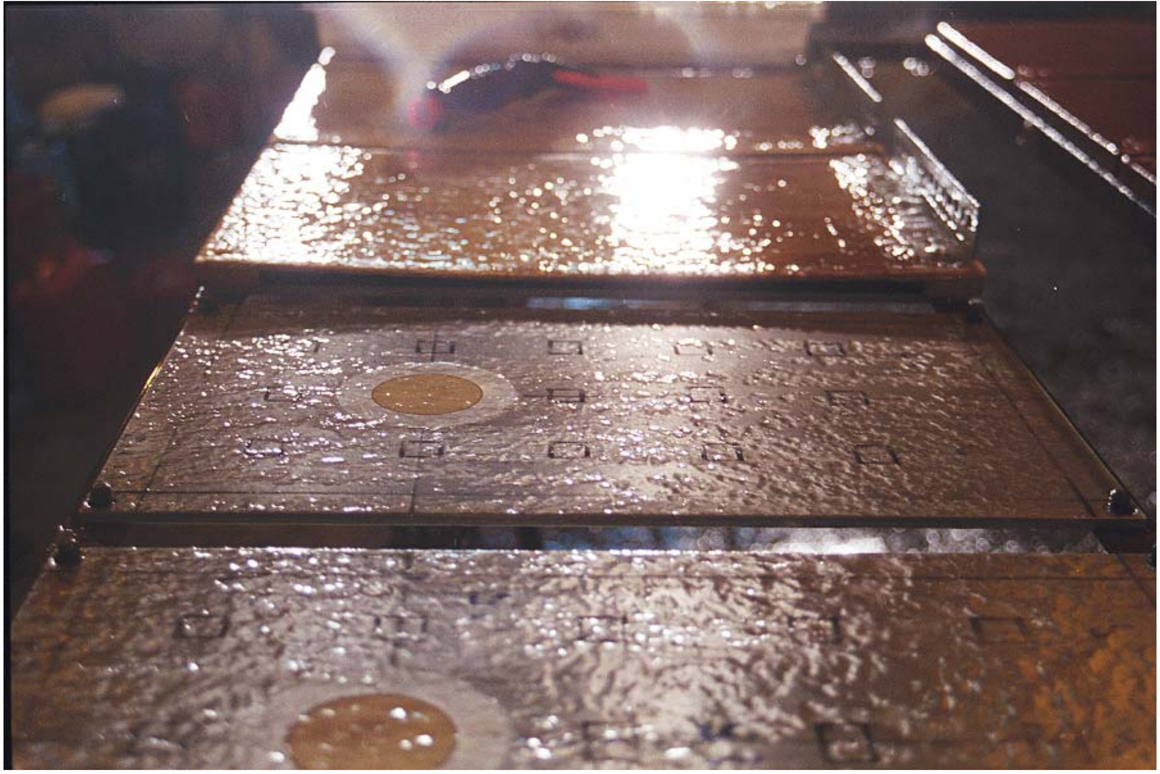


Photo C15.4 - Complete Fluid Failure, t = 18 min



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ID # 15

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09

Time: 0941

Plate Location: 3

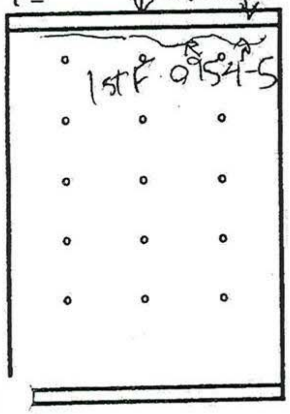
Run #: L3 (75)

Fluid Name: S480

Fluid Dilution: 50/50

Top edge failure 0952-53

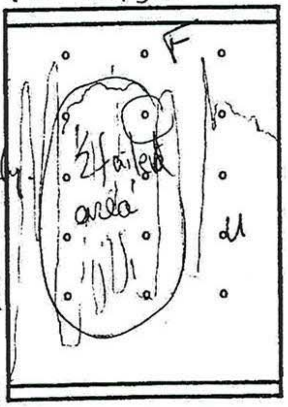
t =



Pour:
Clear green transp. fluid, still rel. thick
Accepts rain easily and immediately.

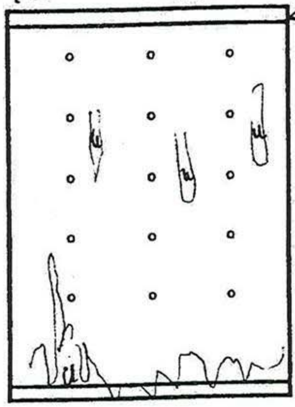
0952 orange peel srf. well developed in fluid (dilution)
Side view shows still plenty of bead, bounce, and roll-off of precip.
0954-5 1st failure

t = 0956



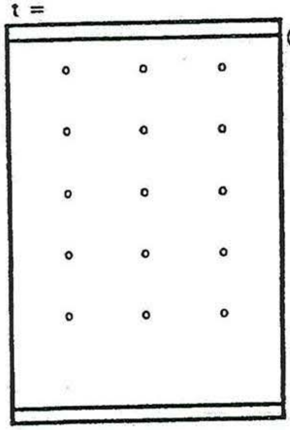
0957 5th xhair
F= failed
U= unfailed
3" line fails almost simultaneously.
fingers composed of fine overlapping unfused platelets

t = 0959

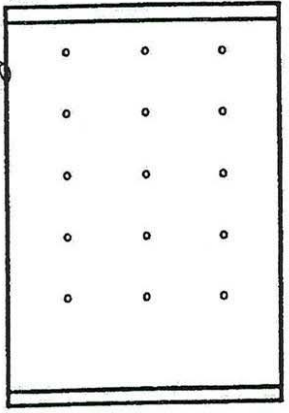


ADHESION above 1" line only.
full plate failure
U= not failed regions
F-regions remain very wet, no ADH within work area.

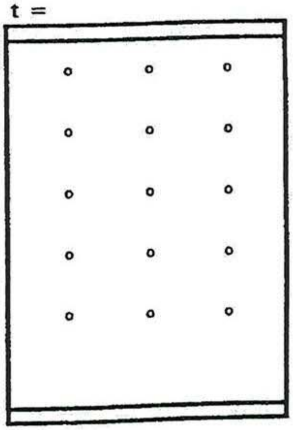
t =



t =



t =

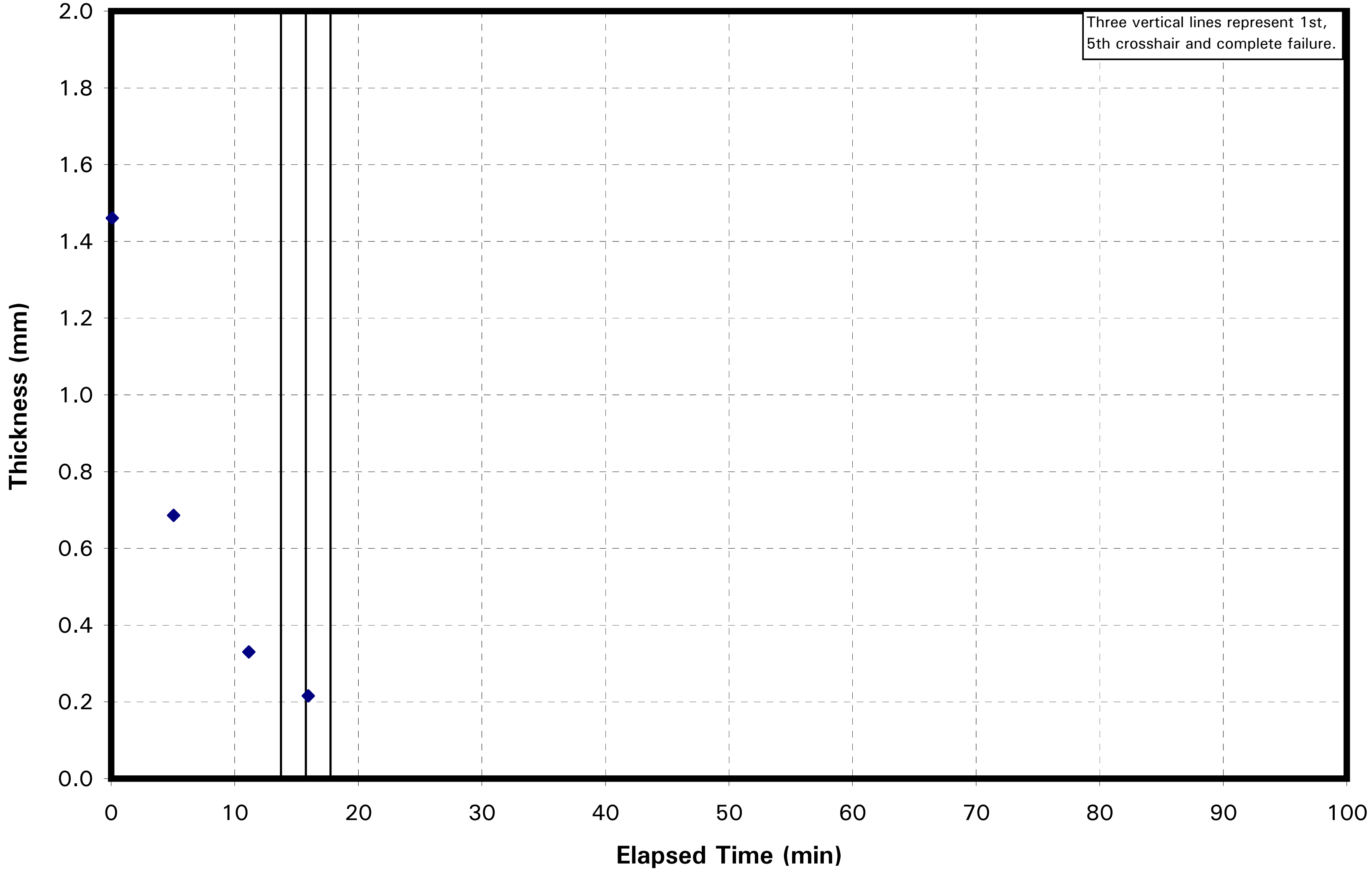


Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 15

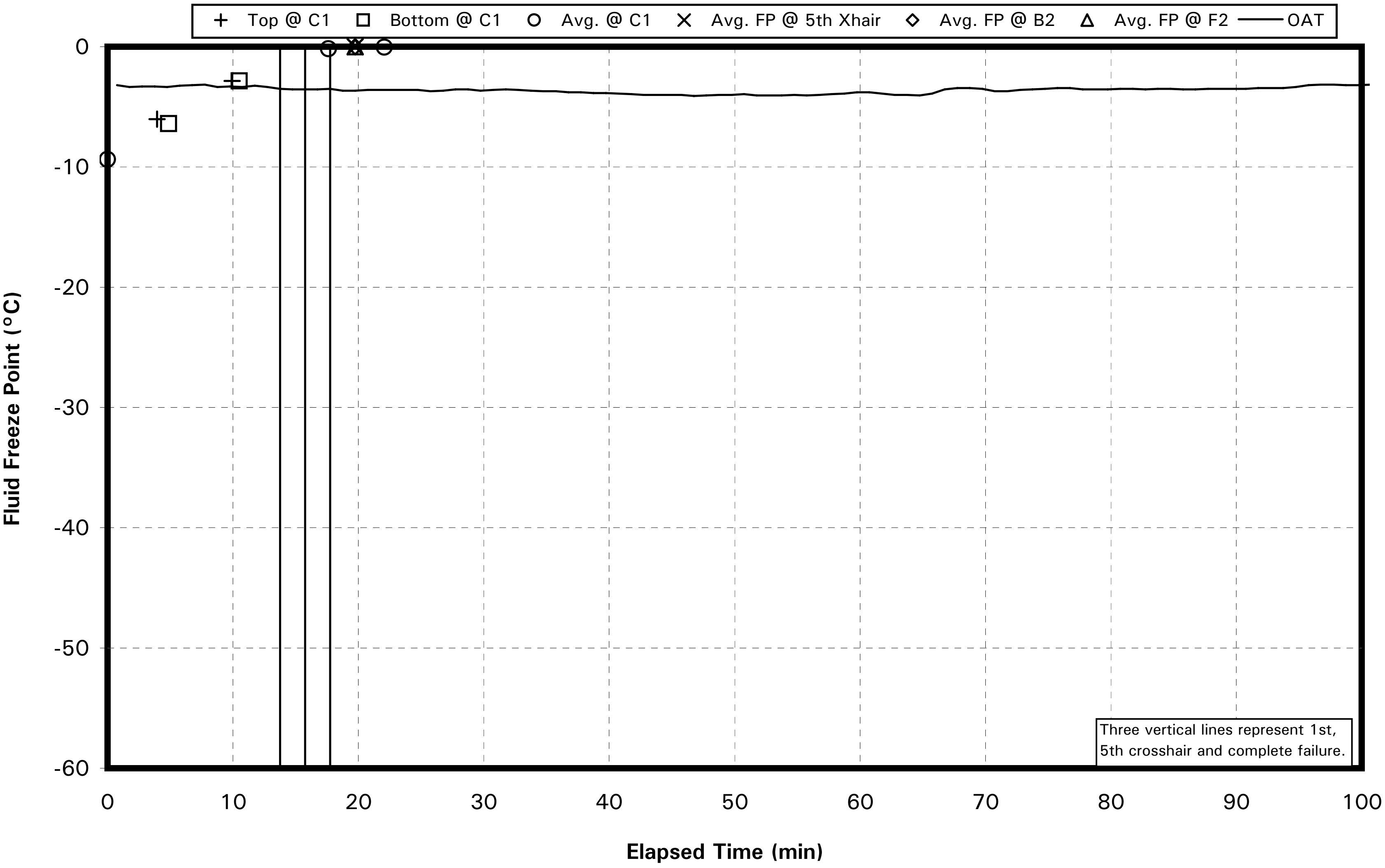


cm1380/analysis/doc_fail/thicknes/THK_ID15
9/21/2006, 1:56 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 15

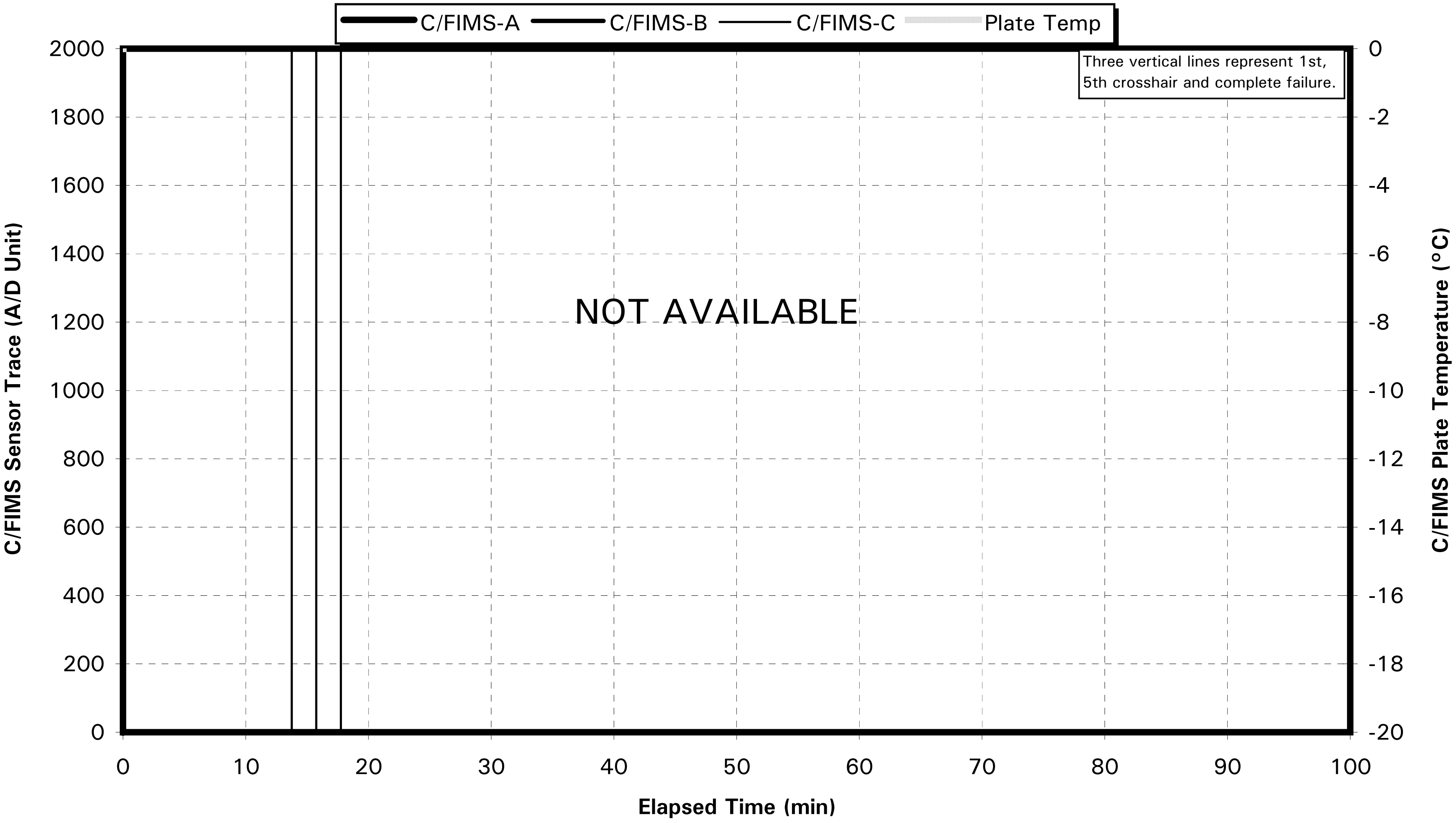


cm1380/analysis/doc_fail/brix/BRX_ID15
9/21/2006, 1:56 PM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 15



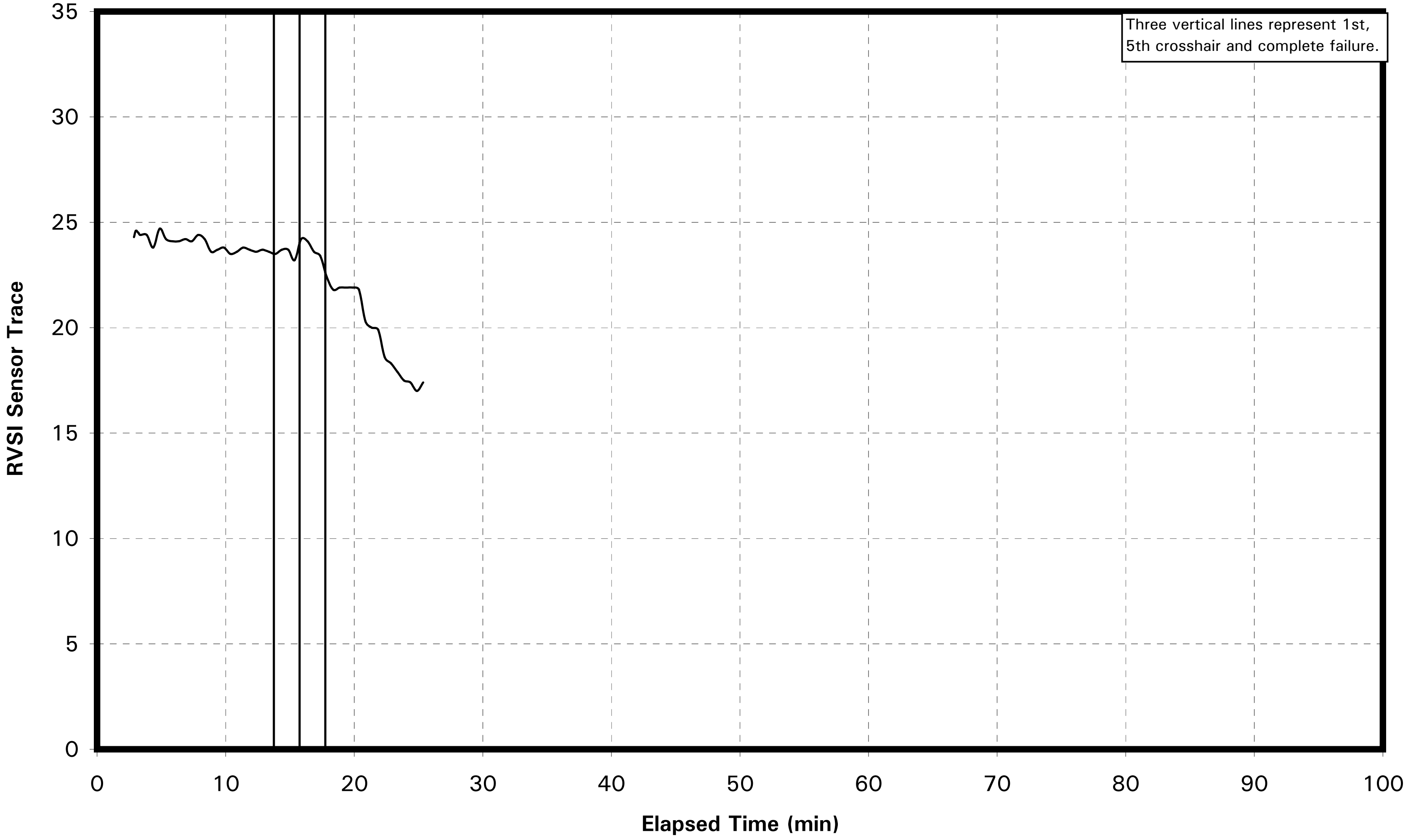
Three vertical lines represent 1st, 5th crosshair and complete failure.

cm1380/analysis/doc_fail/cfims/CFM_ID15
9/21/2006, 1:57 PM

DOCUMENTATION OF FLUID FAILURE

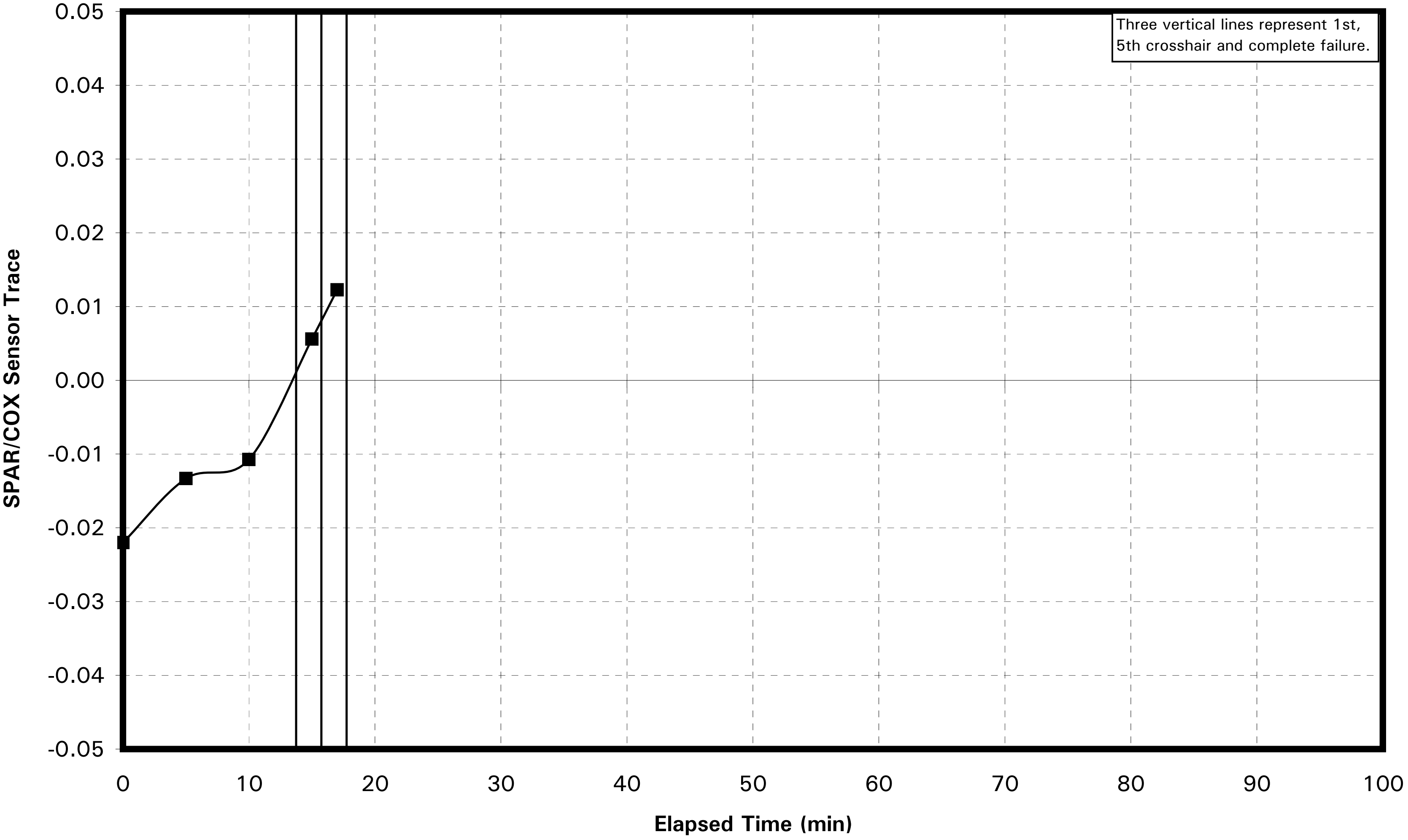
RVSI SENSOR TRACE

ID # 15



cm1380/analysis/doc_fail/rvsi/RVS_ID15
9/21/2006, 1:59 PM

DOCUMENTATION OF FLUID FAILURE
SPAR/COX SENSOR TRACE
ID # 15

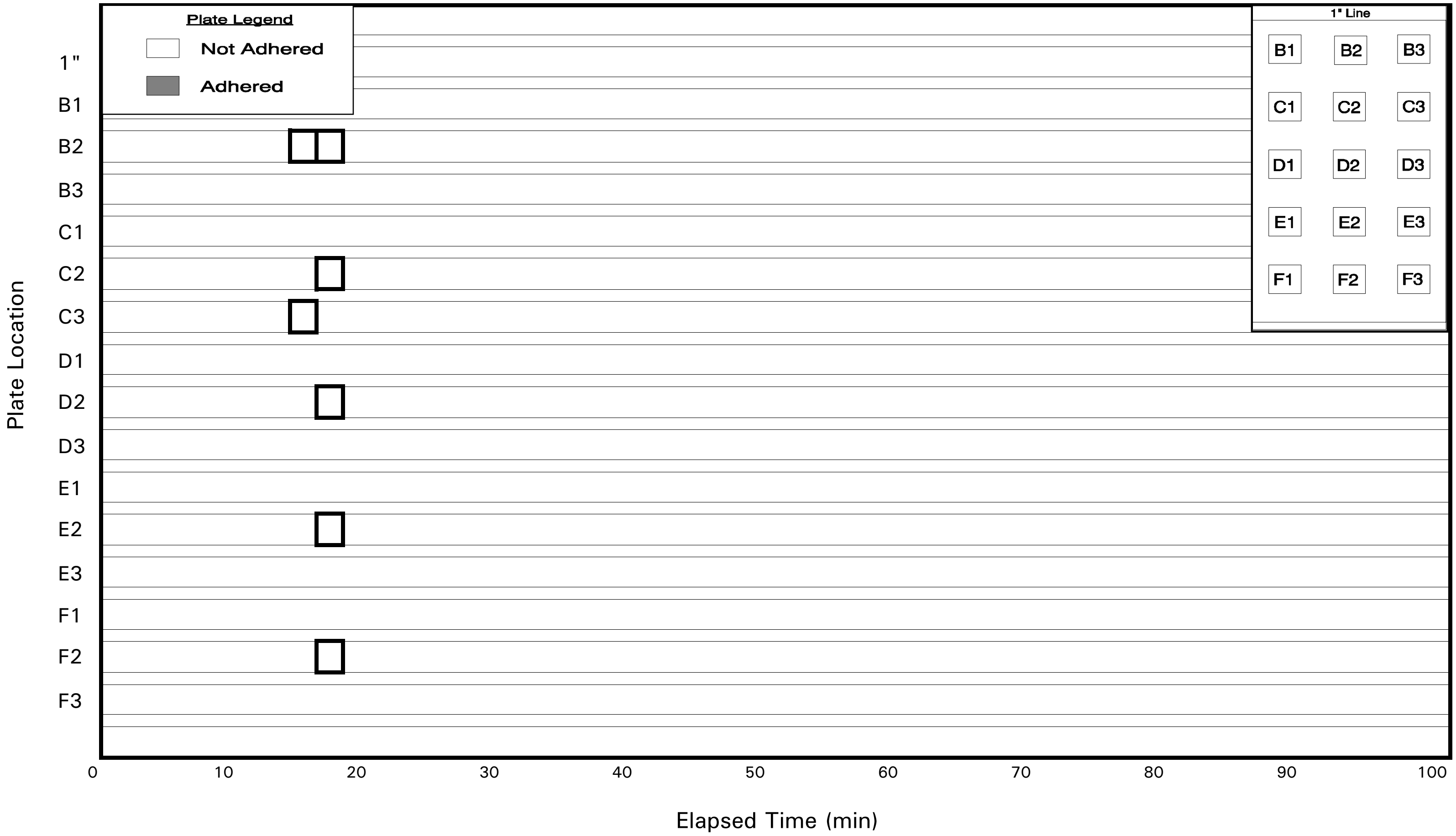


cm1380/analysis/doc_fail/cox/COX_ID15
9/21/2006, 2:00 PM

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 15



cm1380/analysis/doc_fail/ADH_ID15
9/21/2006, 2:01 PM

GENERAL TEST INFORMATION

ID # 16

July 9, 1998

Ambient Air Temperature:	-3.7°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.1 g/dm²/hr
Fluid:	OCTAGON
Dilution:	Neat
Start of Test:	10:02:40
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	10:25:00
Failure Time (Complete Plate):	10:27:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 16

Photo C16.1 - After Pouring, t = 0 min

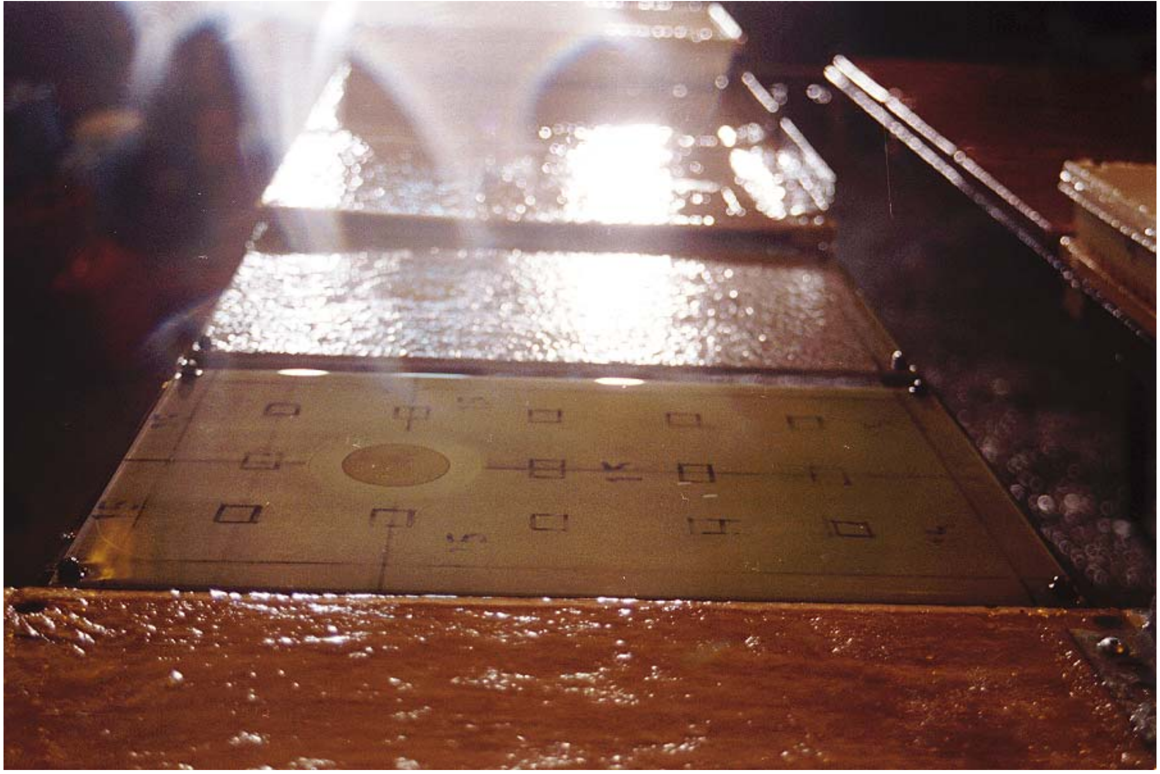
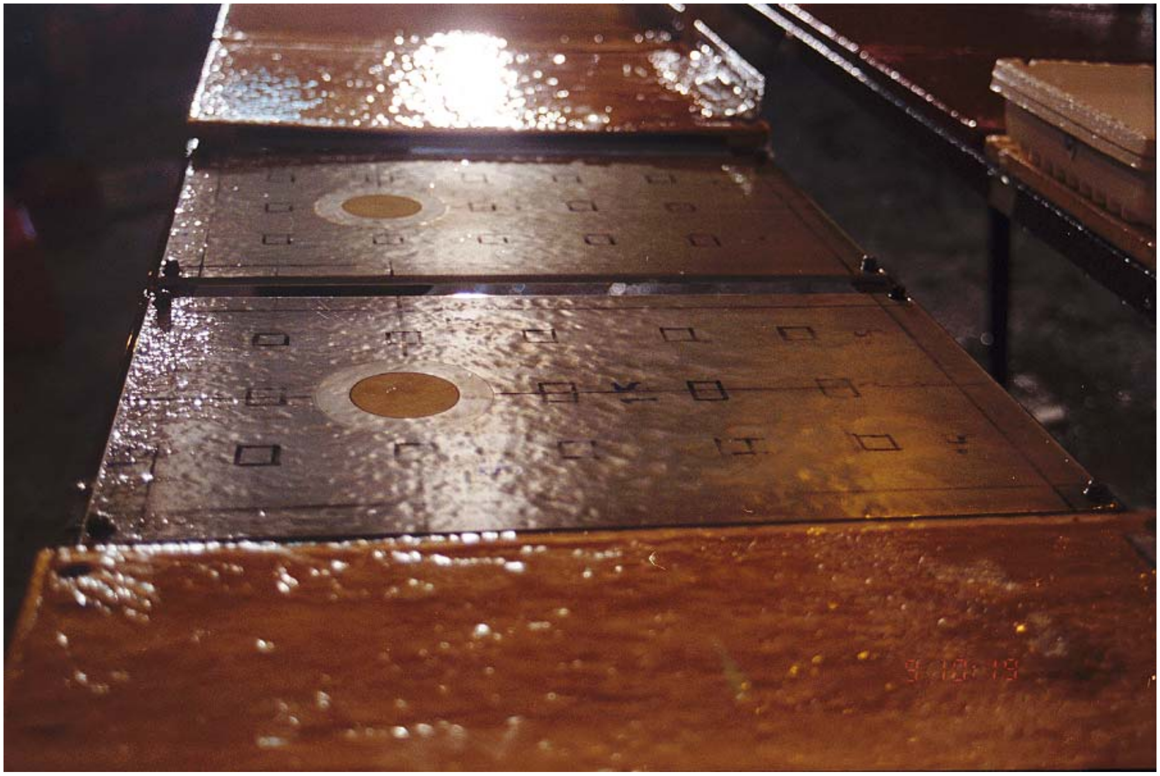


Photo C16.2 - 1st Failure, t = 14 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 16

Photo C16.3 - Standard Failure (1/3 or 5th Crosshair), t = 21 min

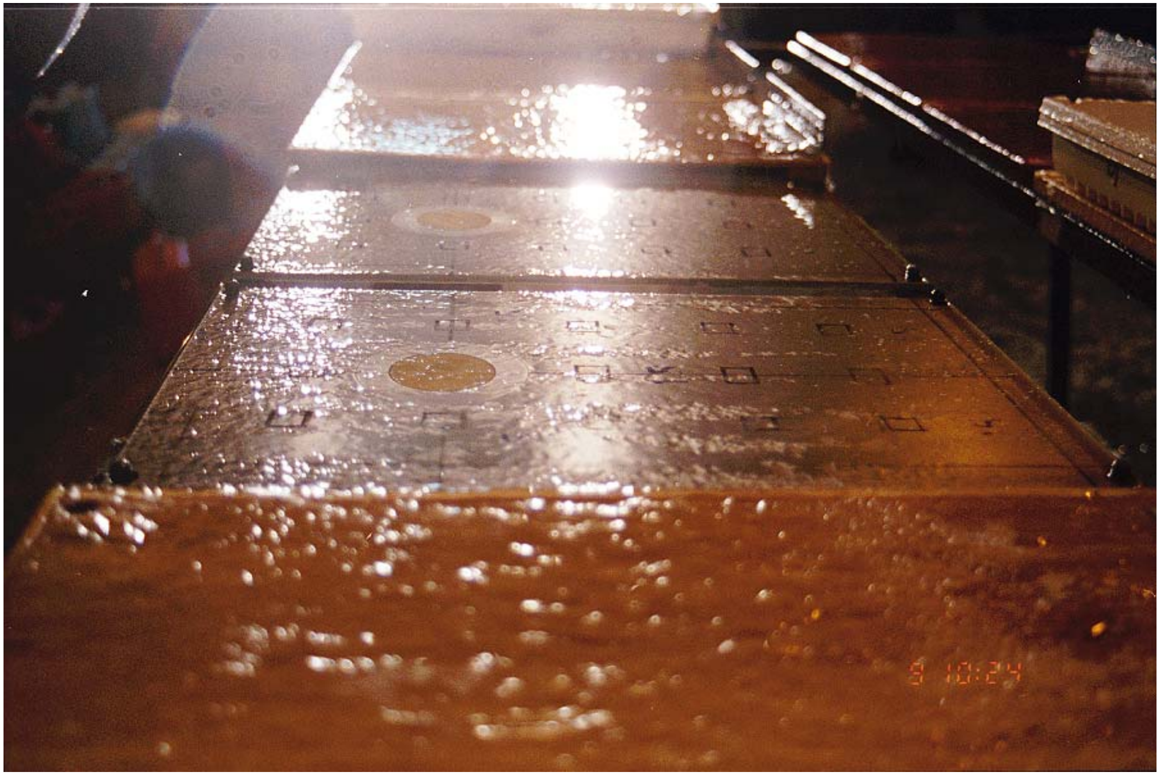
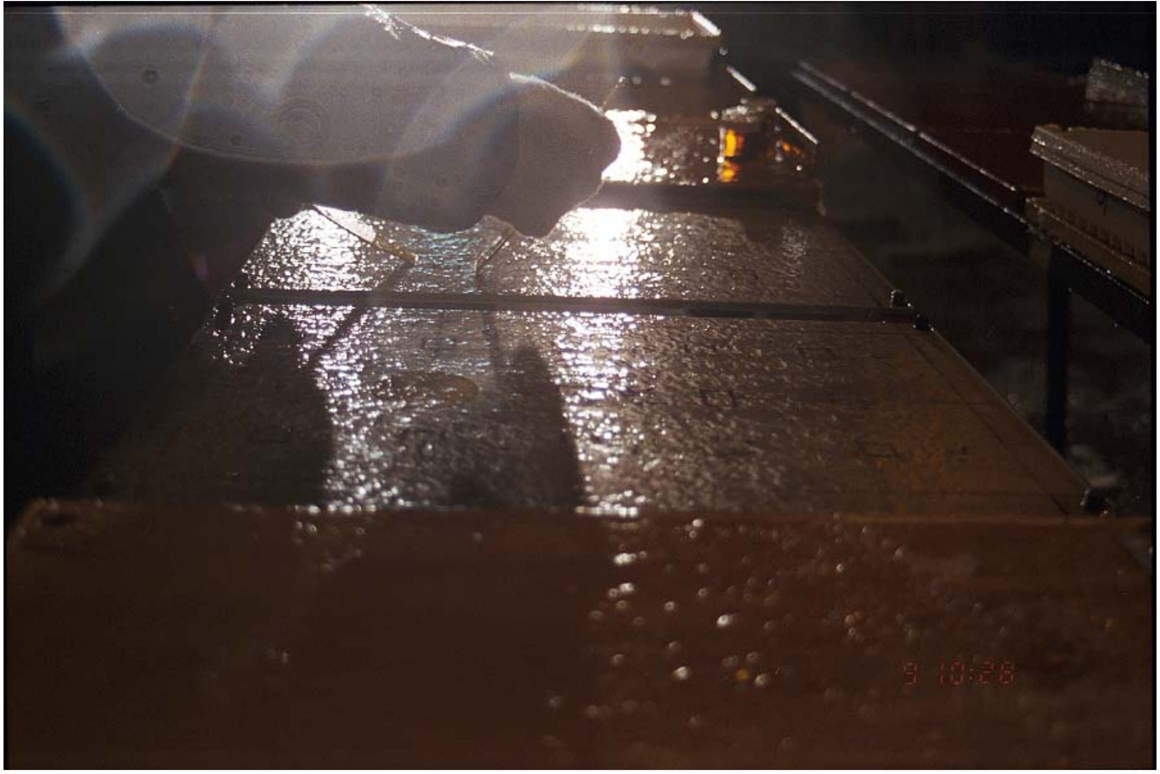


Photo C16.4 - Complete Fluid Failure, t = 25 min



IP# 16

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09

Time: 1002^{40}

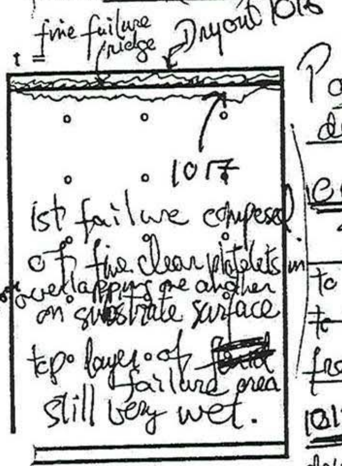
Plate Location: 2

Run #: 14 (5?)

Fluid Name: Oct May

Fluid Dilution: 100%

t =



1st failure composed of fine clear platelets in close contact overlapping one another on substrate surface top layers of failure area still very wet.

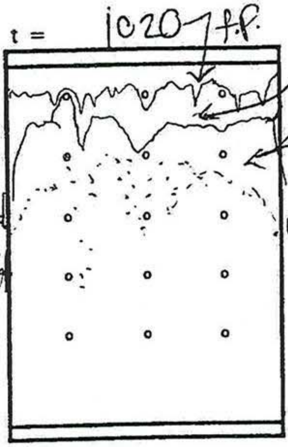
Pour: as prev. described.

1006 Orange Peel Surface well developed to 6" line. Falls off to smoother surface from 6->12" line

1012 Marbled surface developing 0->6" line O.P. well developed 6->12" line

1015 Dryout at top edge of plate.

t = 1020 f.p.

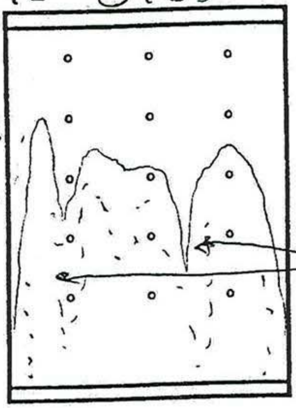


fingers of solid contam sat'd fluid begin to emerge.

No adh.

at 1023 f-region adhesion < 3" line

t = 0925



0925 5th X-Hair

all happens quite suddenly wet fingers continued to extend to bottom of plate.

0927 full plate failure

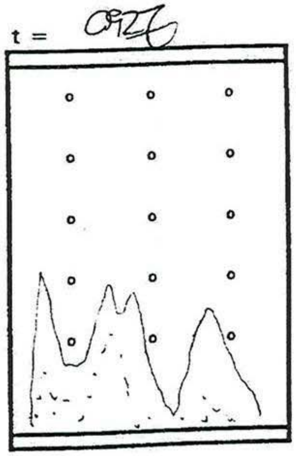
/ ADH at 6" line

Remaining unfailed area is ready to go, (pre-failure condition).

t =

t =

t = 0926

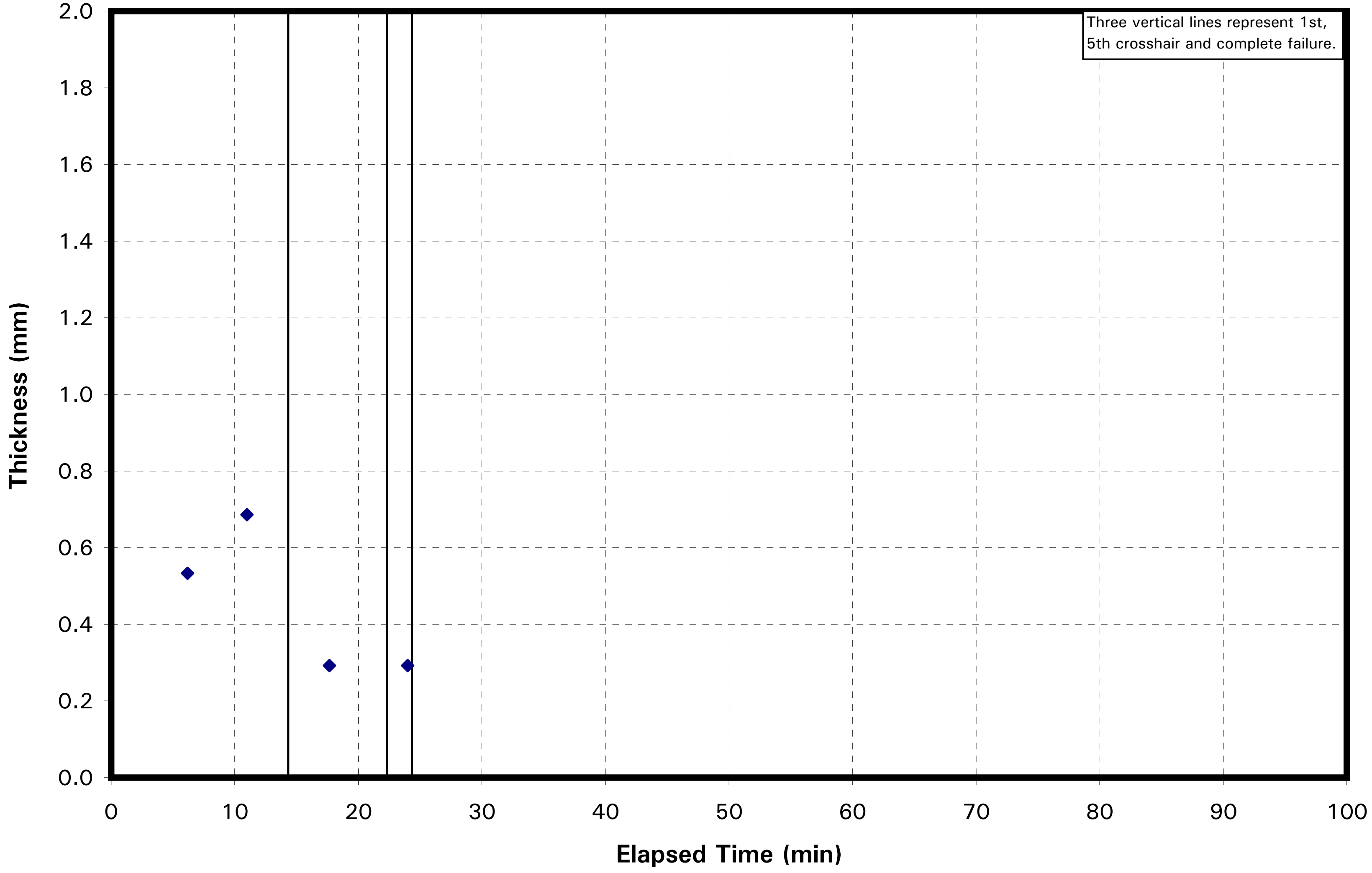


Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

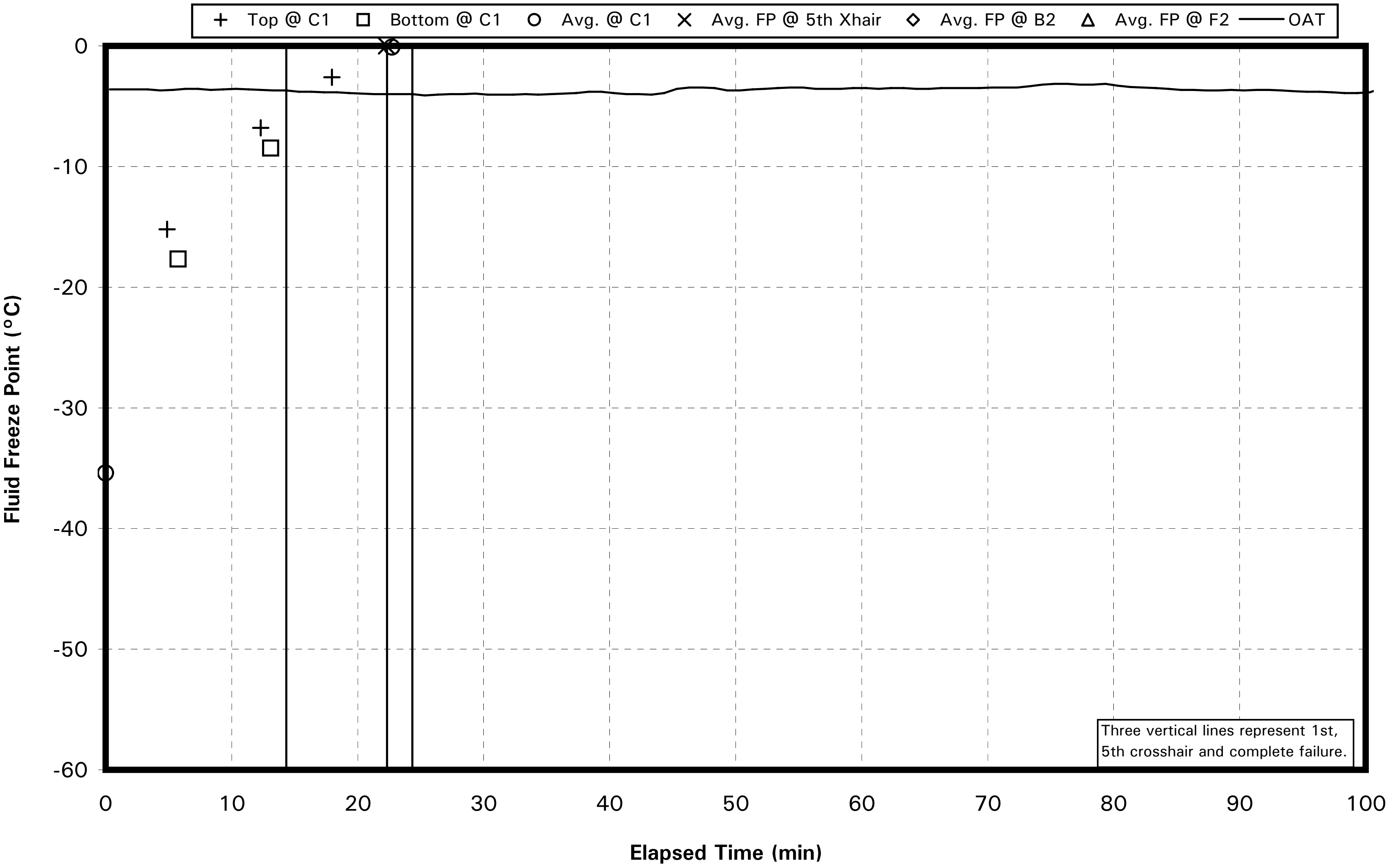
ID # 16



DOCUMENTATION OF FLUID FAILURE

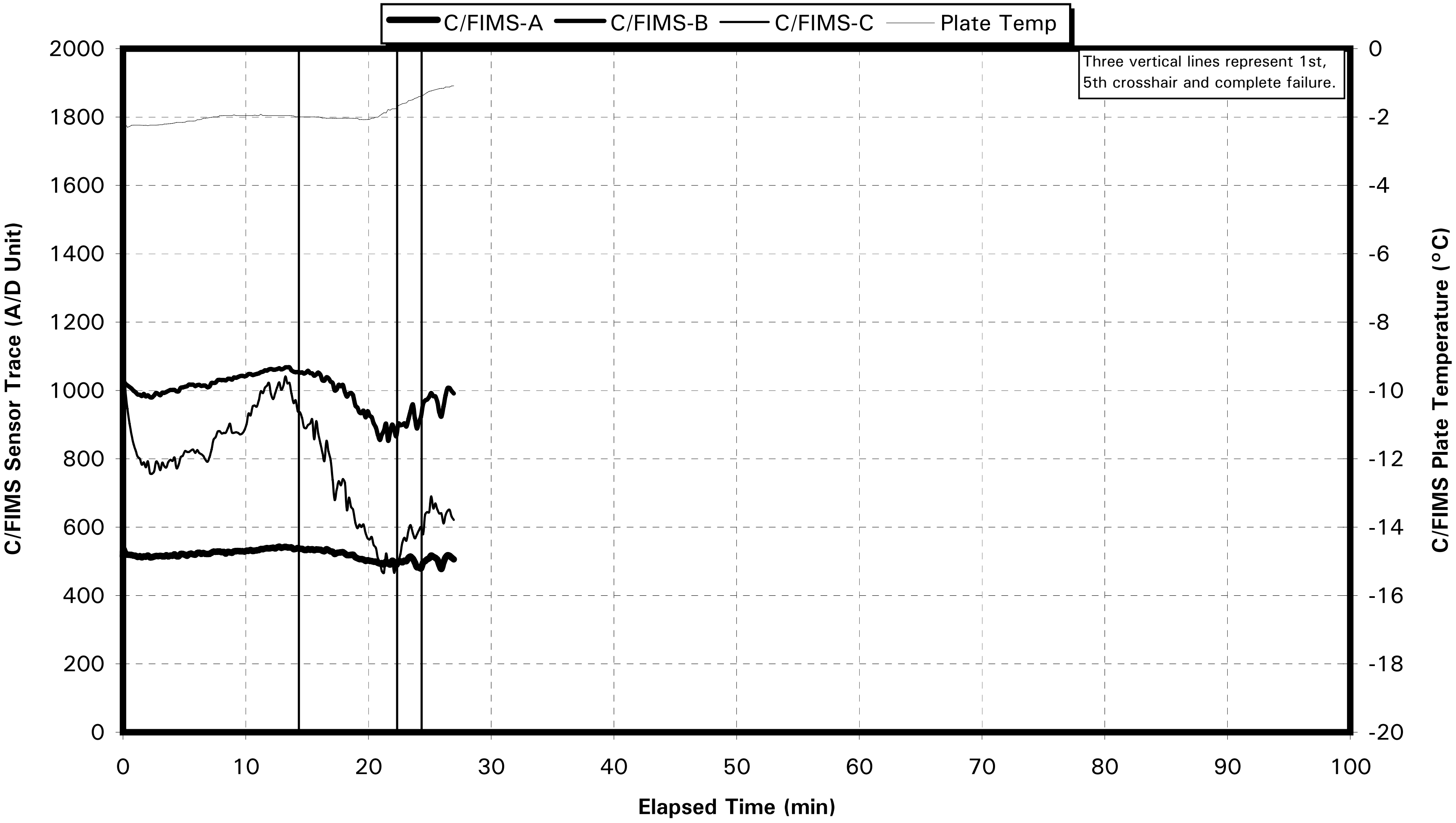
FLUID FREEZE POINT

ID # 16



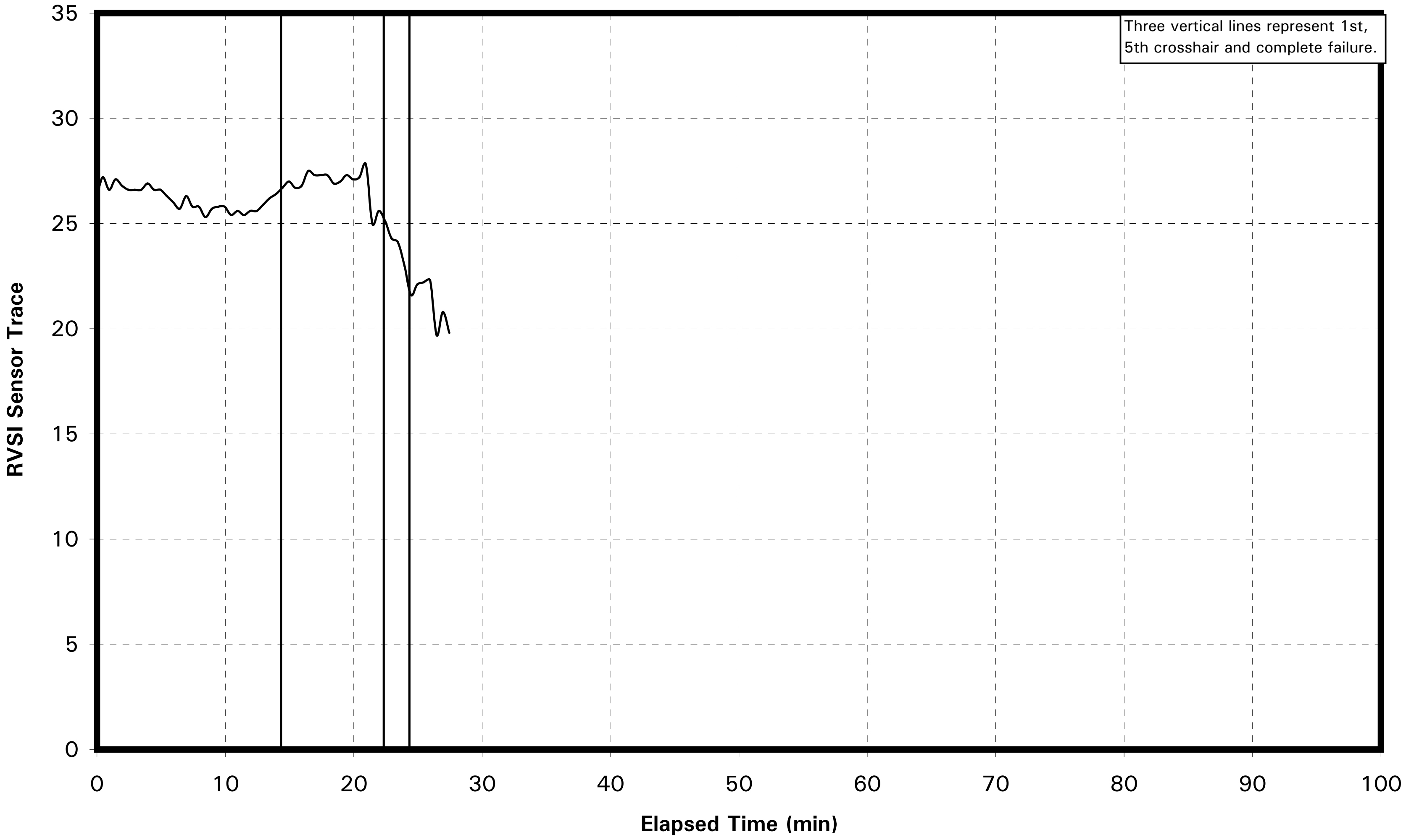
cm1380/analysis/doc_fail/brix/BRX_ID16
9/21/2006, 3:24 PM

DOCUMENTATION OF FLUID FAILURE
C/FIMS SENSOR TRACE
ID # 16



cm1380/analysis/doc_fail/cfims/CFM_ID16
9/21/2006, 3:25 PM

DOCUMENTATION OF FLUID FAILURE
RVSI SENSOR TRACE
ID # 16



cm1380/analysis/doc_fail/rvsi/RVS_ID16
9/21/2006, 3:25 PM

DOCUMENTATION OF FLUID FAILURE

COX/SPAR SENSOR TRACE

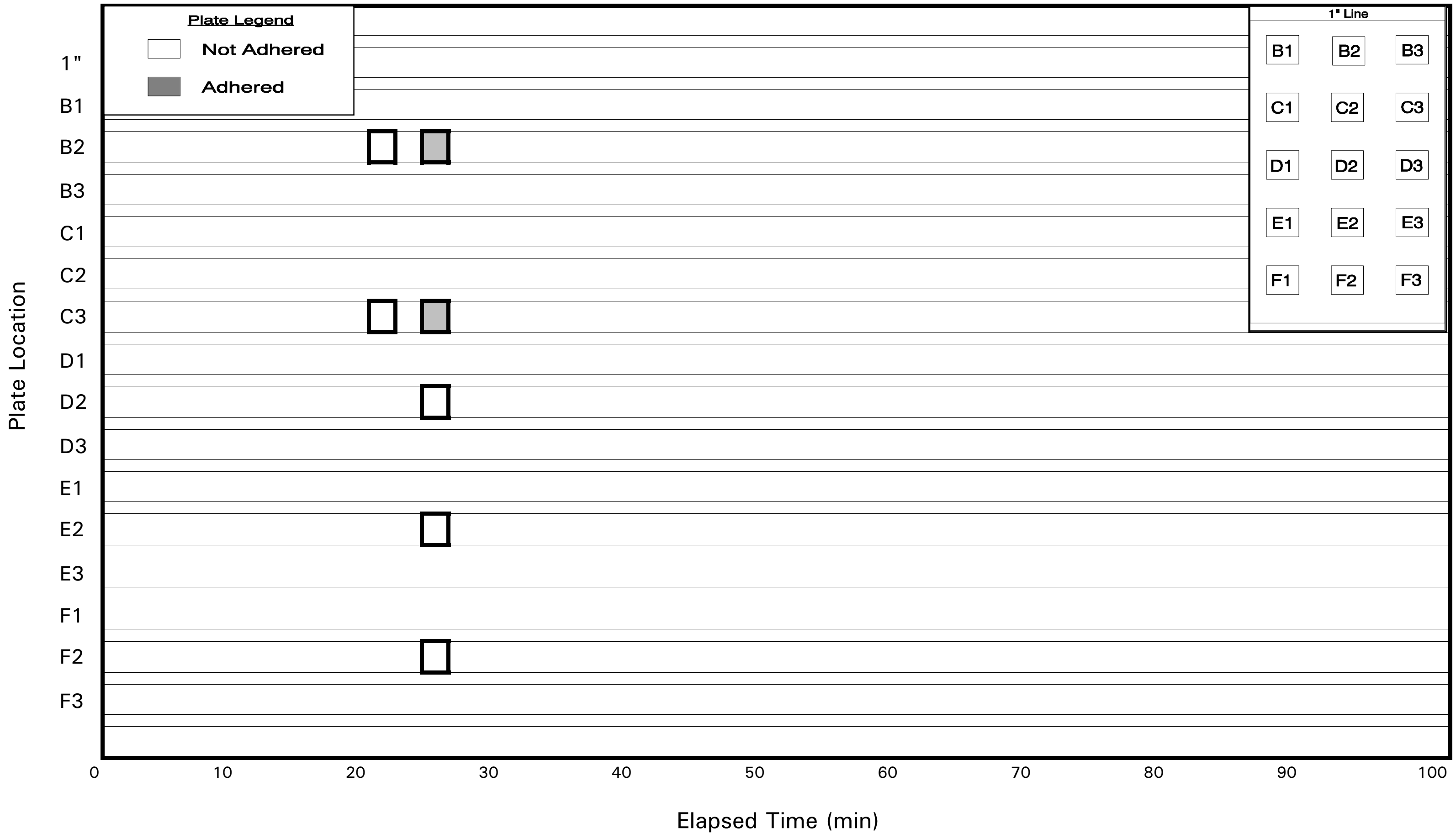
ID # 16

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 16



GENERAL TEST INFORMATION

ID # 17

July 9, 1998

Ambient Air Temperature:	-3.7°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.8 g/dm²/hr
Fluid:	SPCA AD-480
Dilution:	50%
Start of Test:	10:10:00
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	10:26:00
Failure Time (Complete Plate):	10:27:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 17

Photo C17.1 - After Pouring, t = 0 min

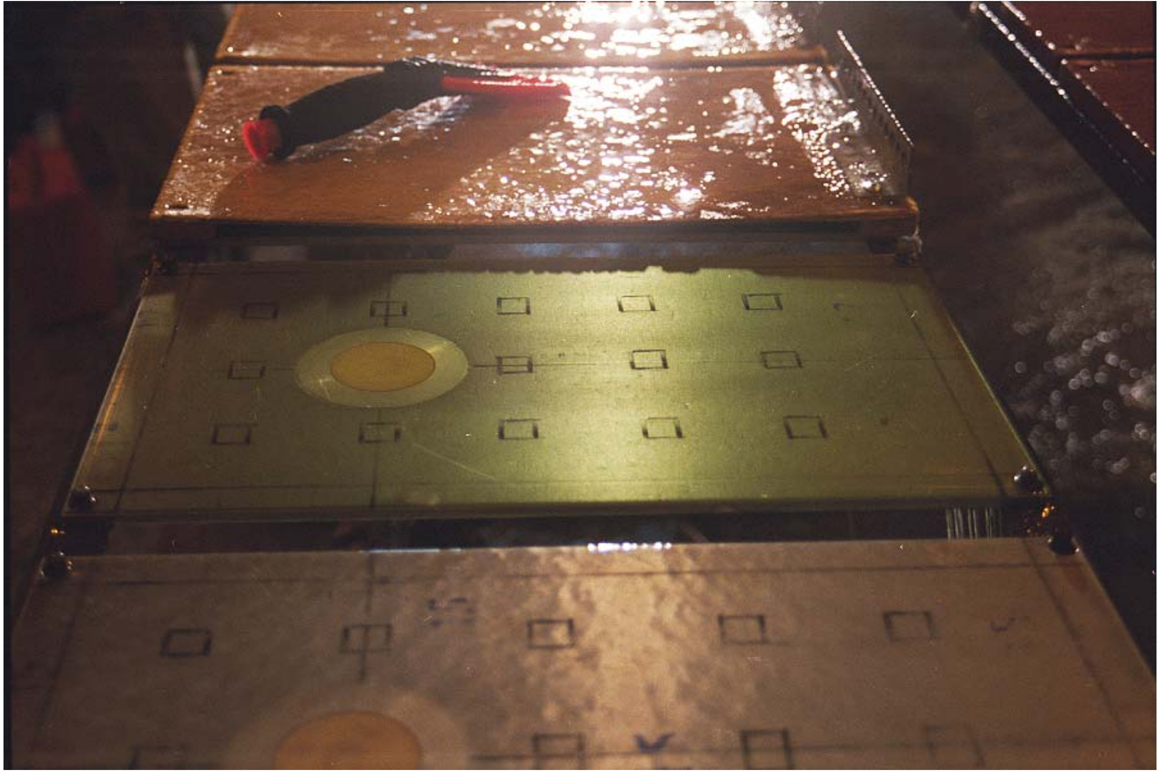
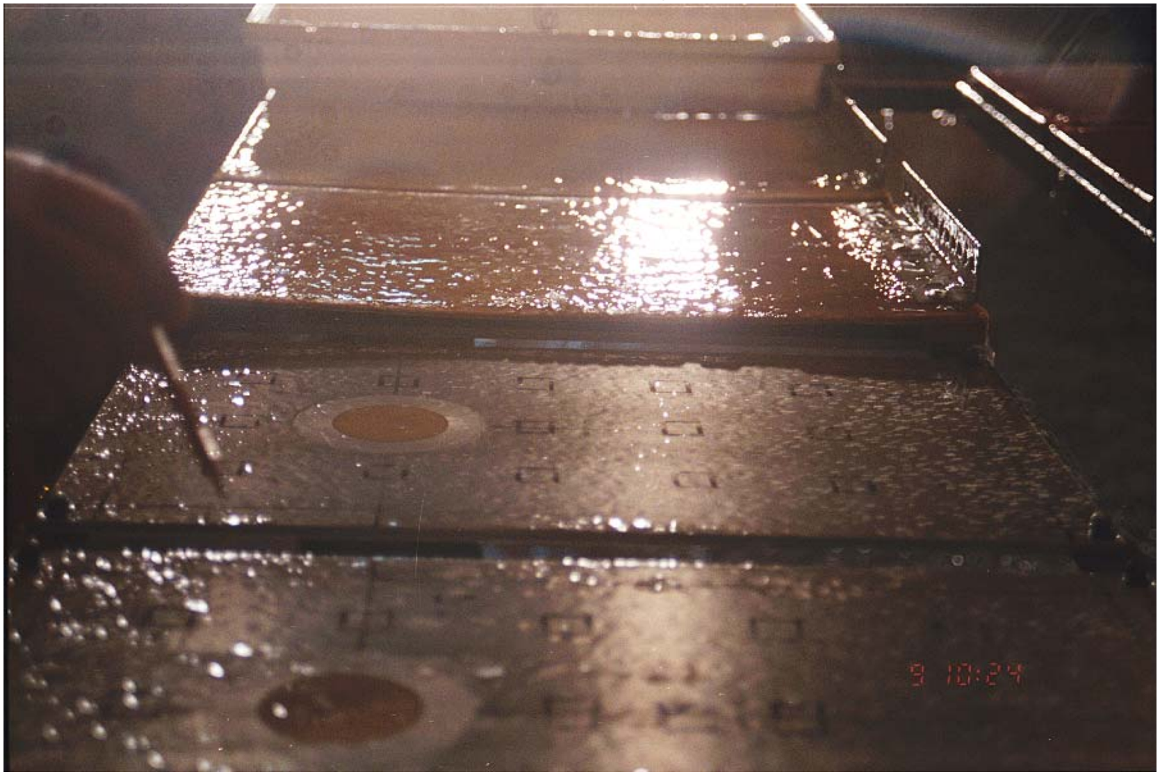


Photo C17.2 - 1st Failure, t = 14 min



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 17

Photo C17.3 - Standard Failure (1/3 or 5th Crosshair), t = 16 min (Est.)

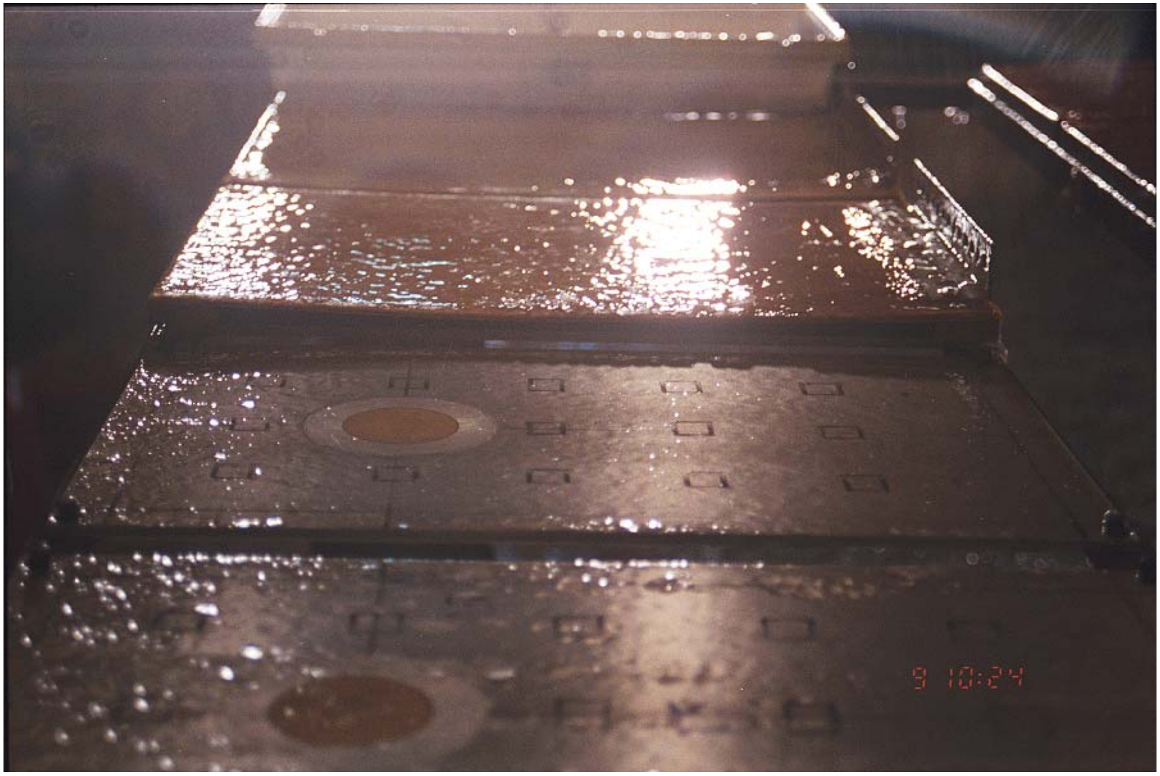
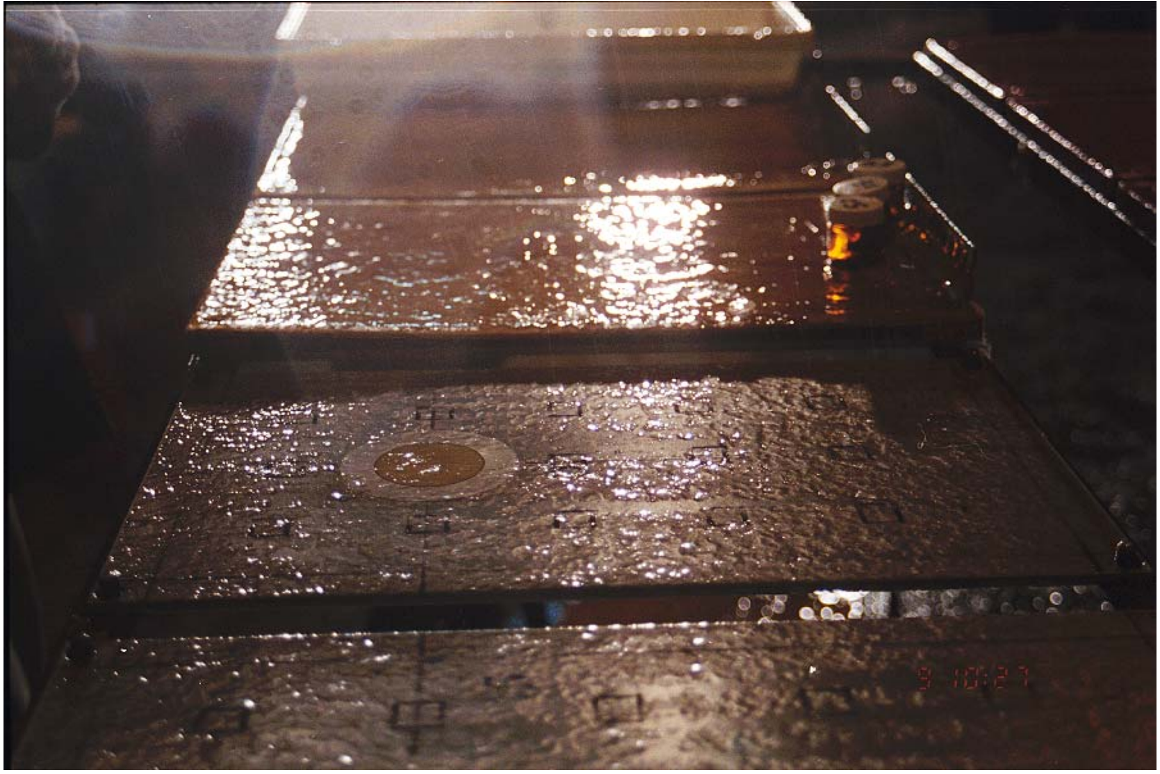


Photo C17.4 - Complete Fluid Failure, t = 17 min



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ID# 17

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 98

Time: 1010^{00}

Plate Location: 3

Run #: 1$_5$ (+5?)

Fluid Name: SH80

Fluid Dilution: 50/50

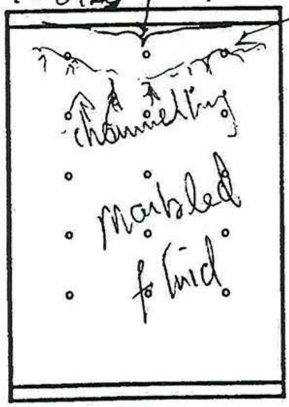
t =

0921 pre-failure condition thinned orange peel texture + rivulets formation.

Low: as per descrip. in Run 1$_3$.

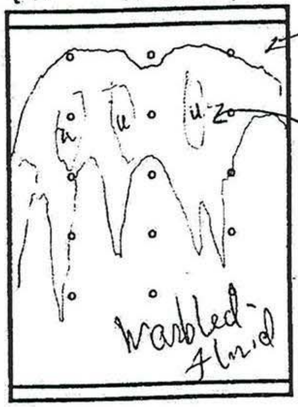
t = 0923^{30}

1st failure



Pre-failure region

t = 0926

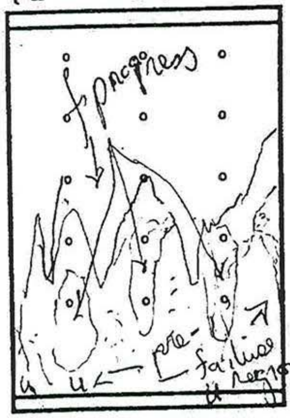


failure progress

pre failure region

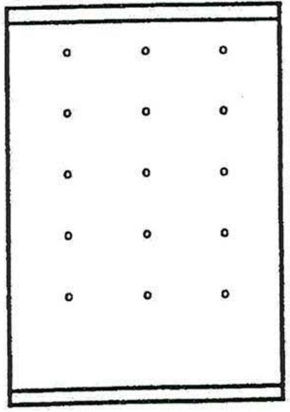
u = not-failed regions

t = 0927

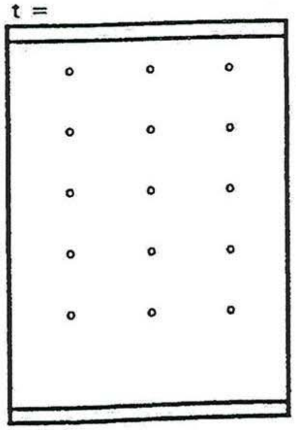


full plate failure, adhesion to 3" line

t =



t =

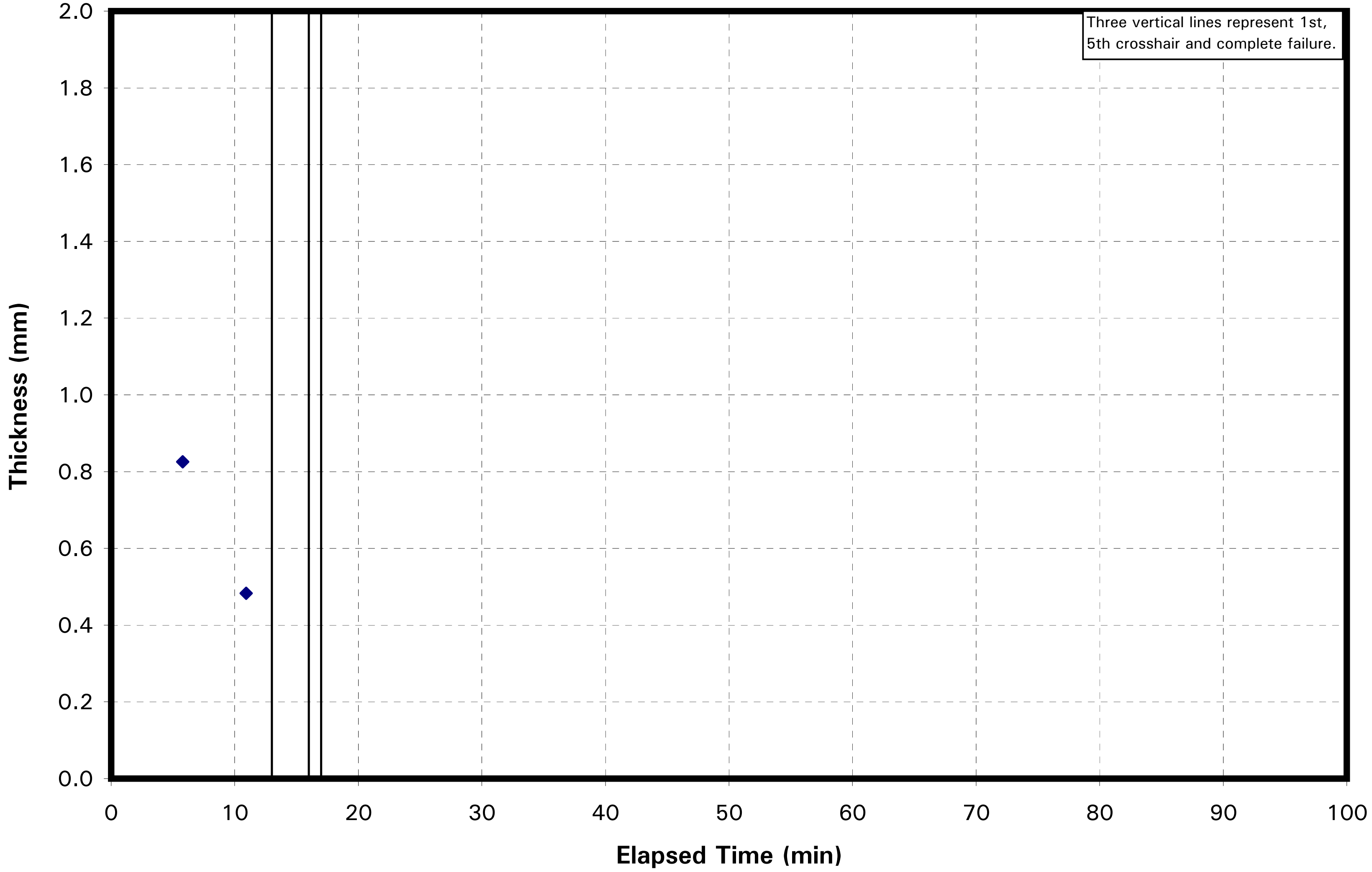


Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 17

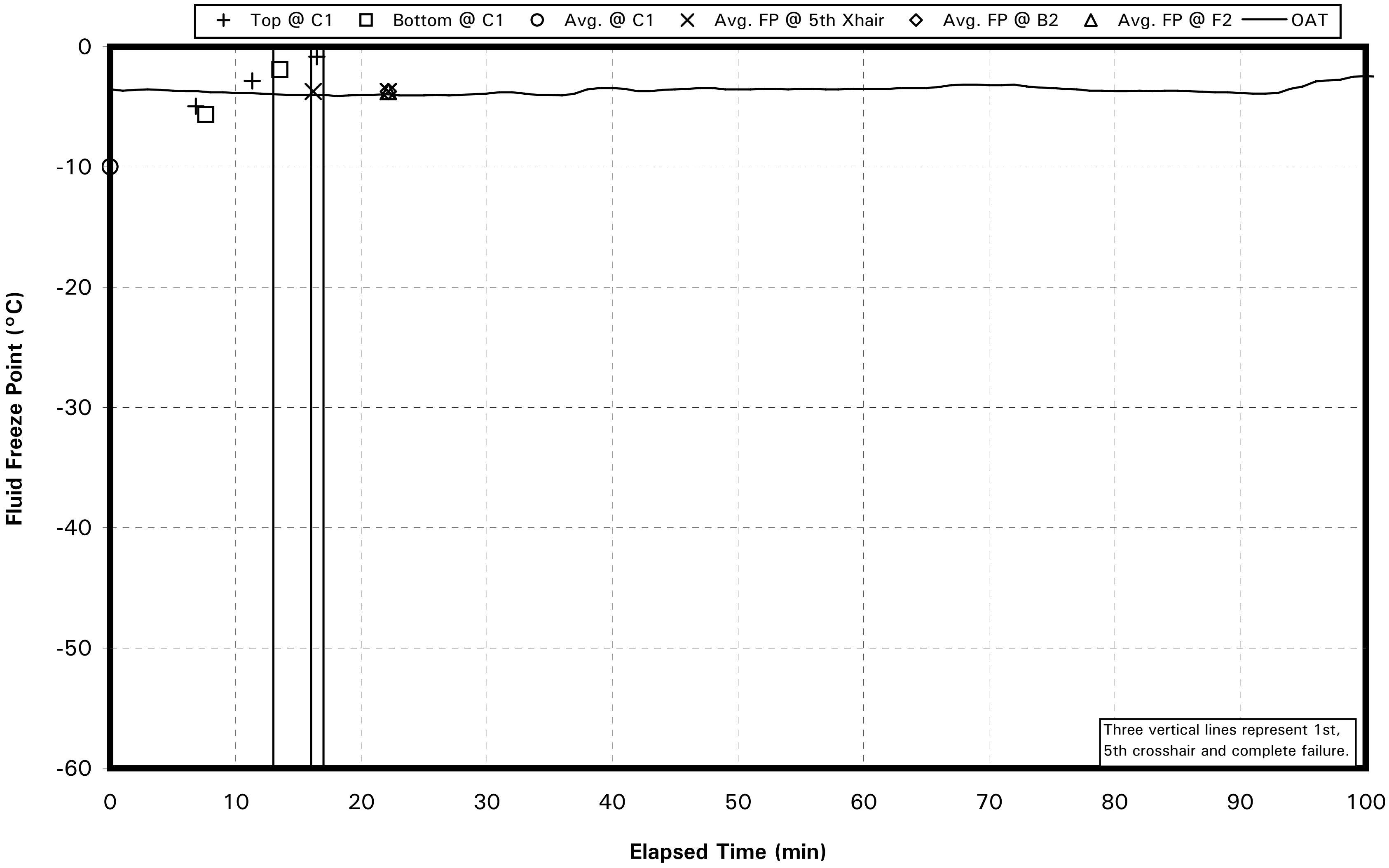


cm1380/analysis/doc_fail/thicknes/THK_ID17
9/21/2006, 3:39 PM

DOCUMENTATION OF FLUID FAILURE

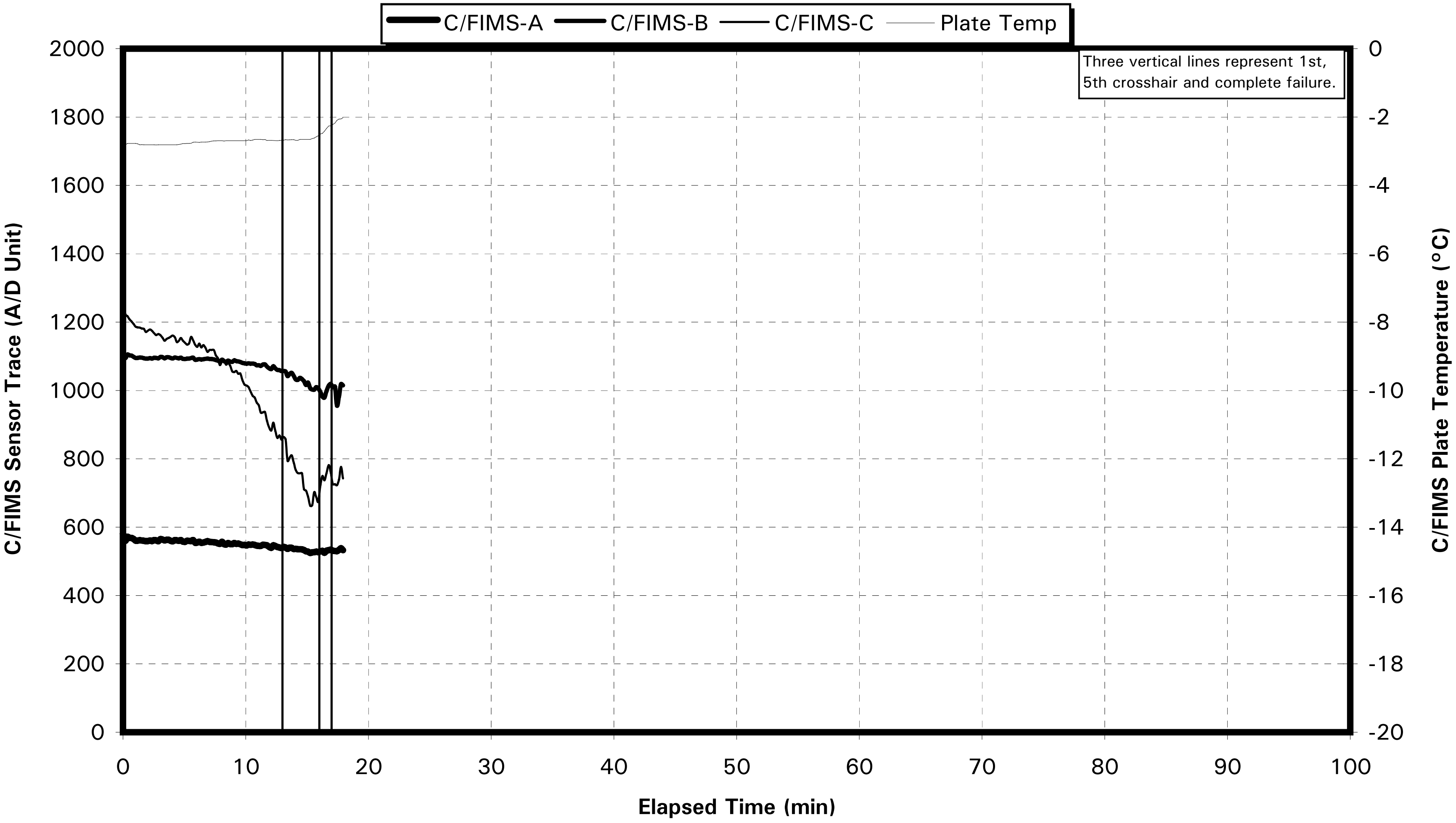
FLUID FREEZE POINT

ID # 17



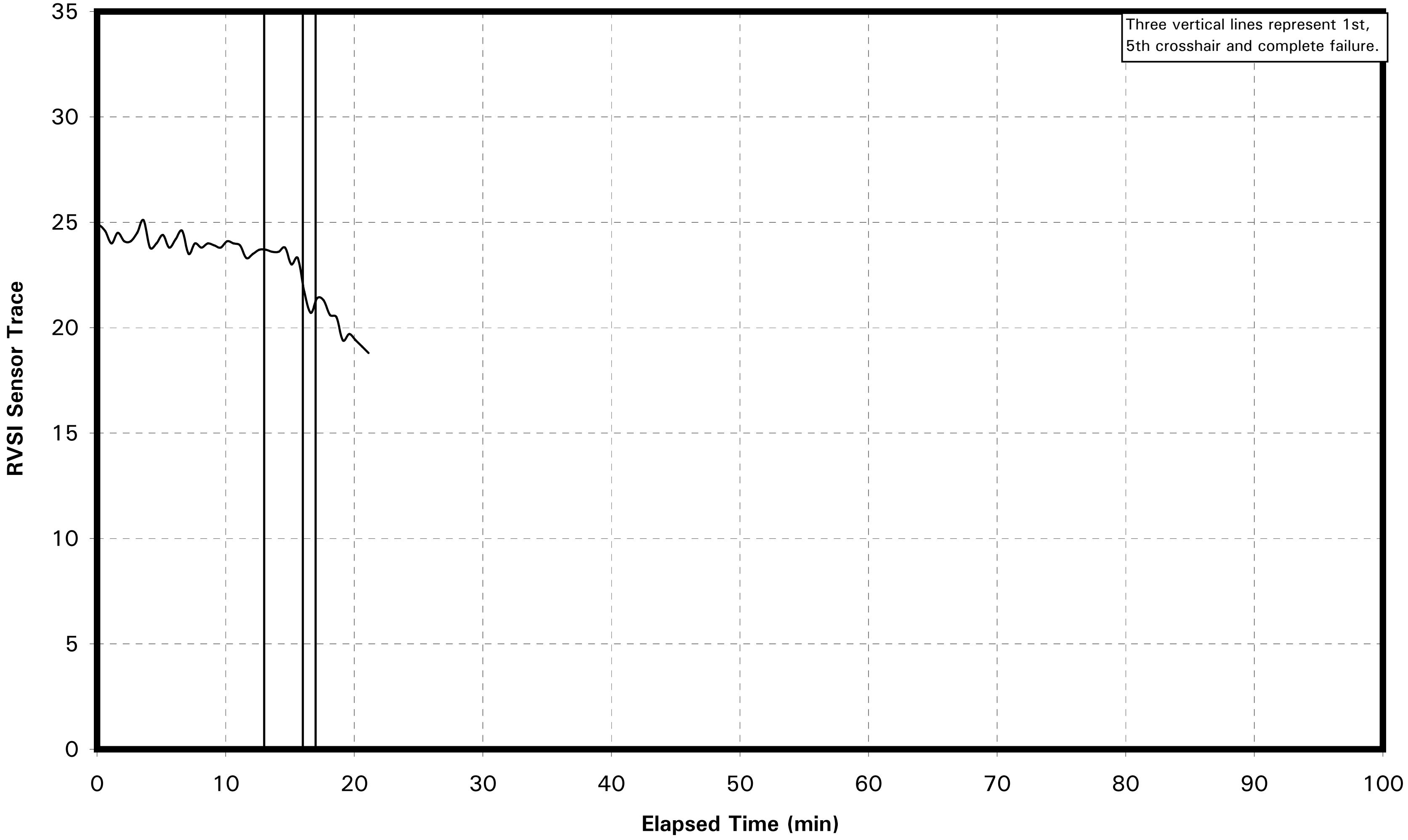
cm1380/analysis/doc_fail/brix/BRX_ID17
9/21/2006, 3:39 PM

DOCUMENTATION OF FLUID FAILURE
C/FIMS SENSOR TRACE
ID # 17



cm1380/analysis/doc_fail/cfims/CFM_ID17
9/21/2006, 3:41 PM

DOCUMENTATION OF FLUID FAILURE
RVSI SENSOR TRACE
ID # 17



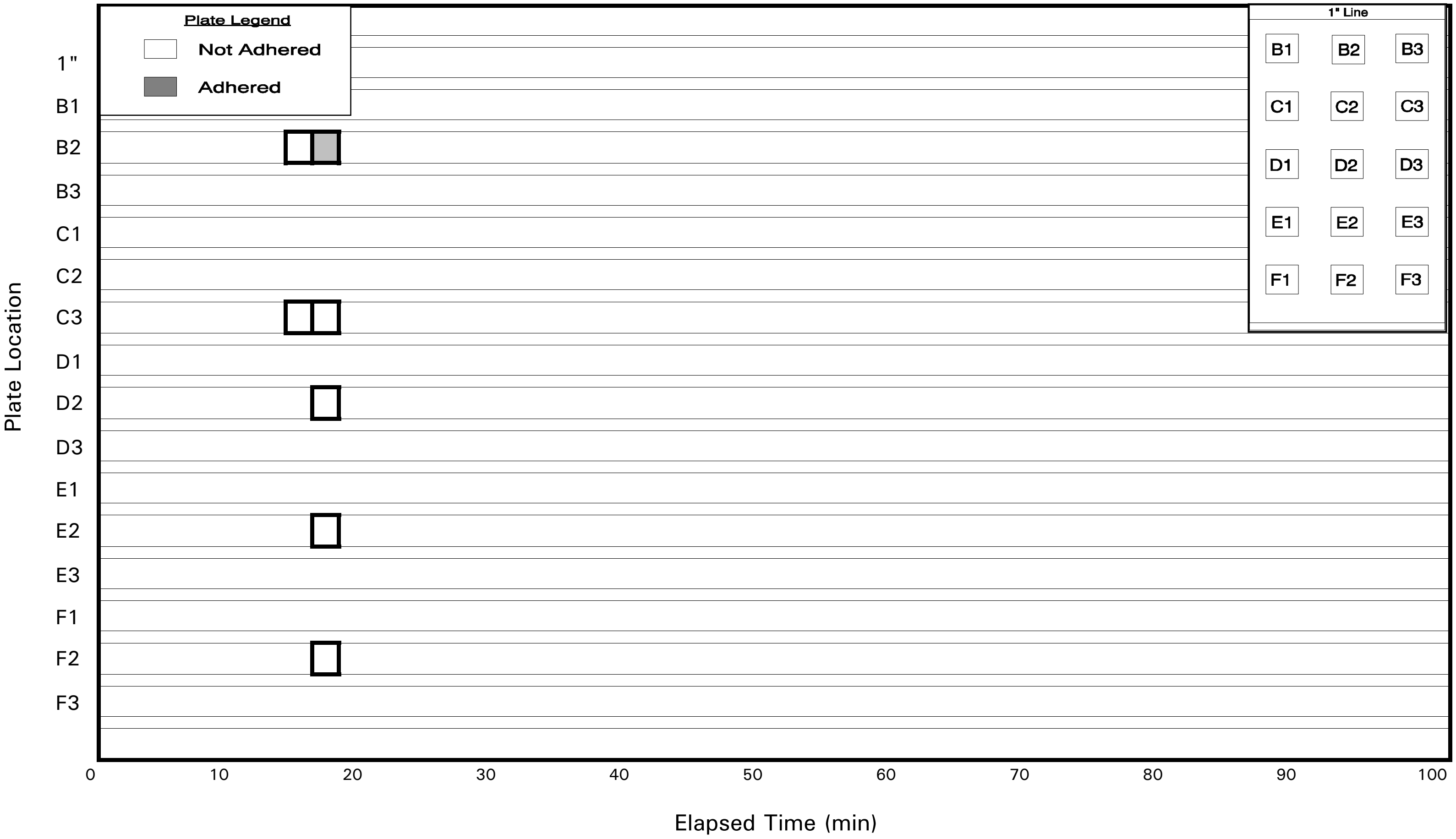
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 17

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 17



cm1380/analysis/doc_fail/ADH_ID17
9/21/2006, 3:43 PM

GENERAL TEST INFORMATION

ID # 18

July 9, 1998

Ambient Air Temperature:	-4°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.1 g/dm²/hr
Fluid:	UCAR XL54
Dilution:	Std
Start of Test:	10:33:45
Failure Mode:	5th X-hair
Failure Location:	C2
Failure Time (Standard):	10:42:00
Failure Time (Complete Plate):	10:47:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 18

Photo C18.1 - After Pouring, t = 0 min (Est.)

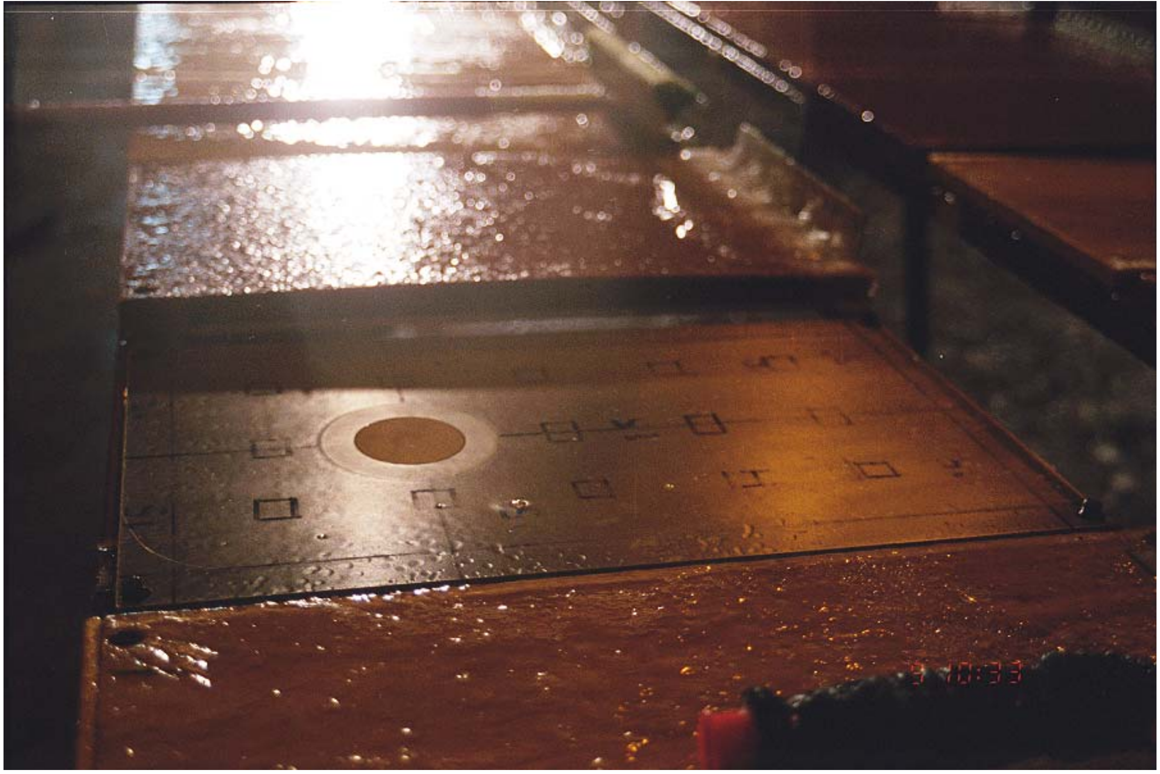


Photo C18.2 - 1st Failure, t = 6 min

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 18

Photo C18.3 - Standard Failure (1/3 or 5th Crosshair), t = 8 min

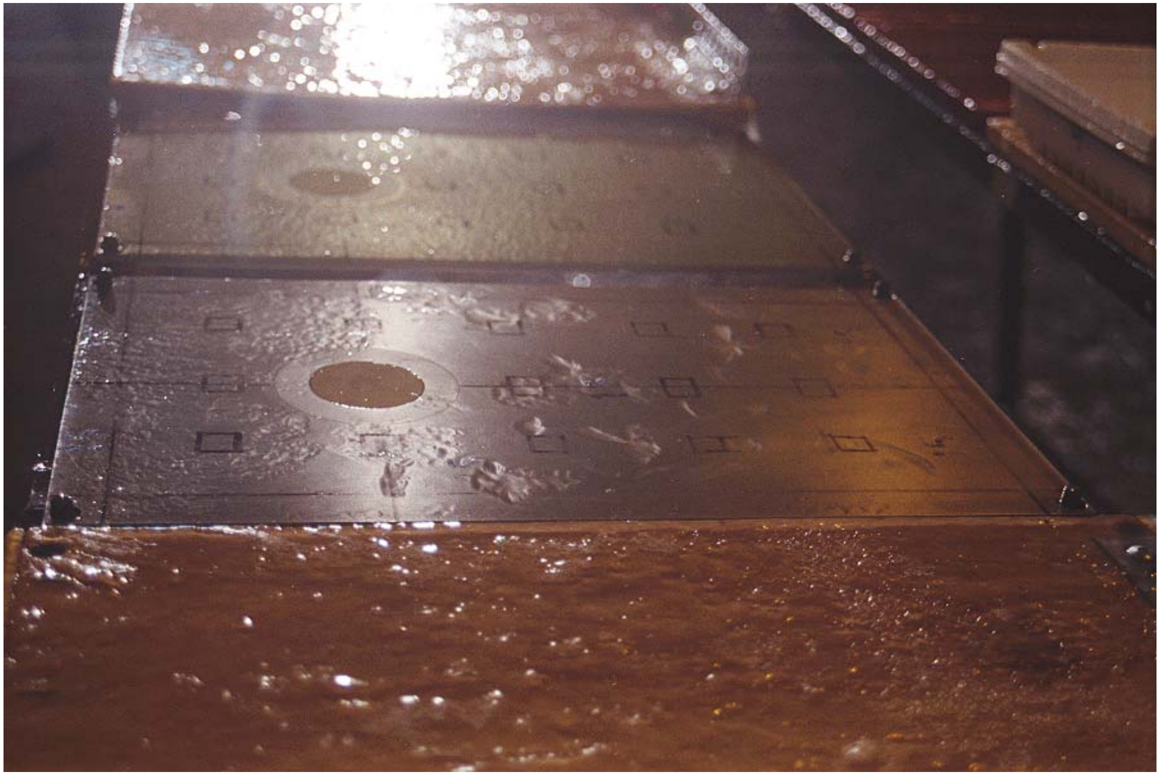
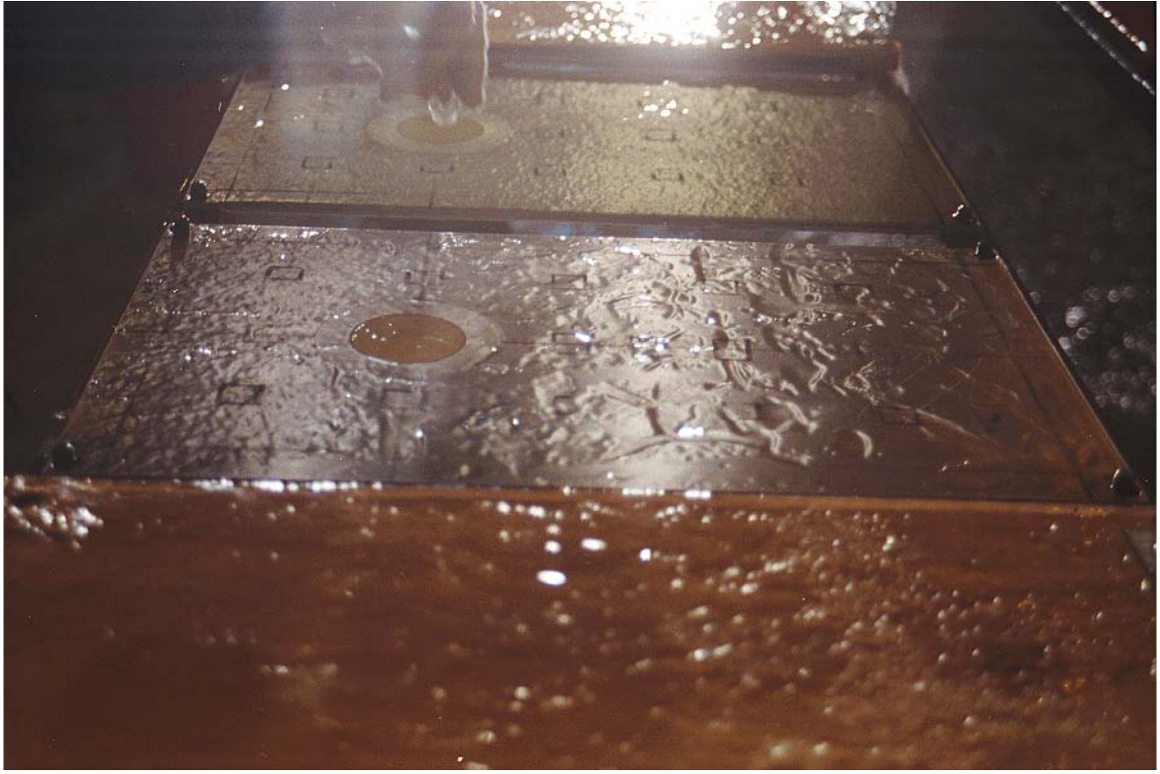


Photo C18.4 - Complete Fluid Failure, t = 13 min



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ID# 18

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 08

Time: 10^{33} ^{20}

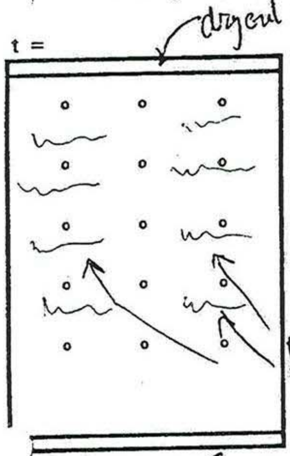
Plate Location: 2

Run #: l_6(+5)?

Fluid Name: XL54

Fluid Dilution: STD

t =

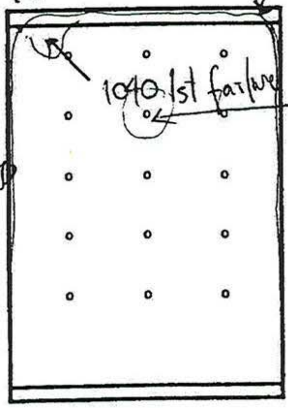


Porm: as per prev. description

1034 Extensive beading, bounce, and roll-off.

1036 lateral rivulet formation

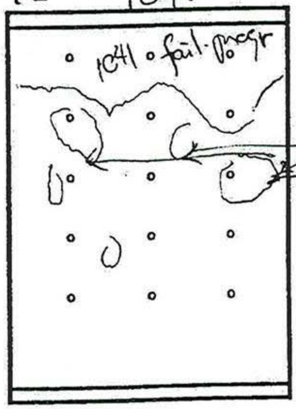
t =



1038 dry out contour.

1038, C/Fim also beginning to dry out.

t = 1041



1042 5th Xhair + islands

wet islands beginning to fuse: Failure is on substrate surface, ADH 6".

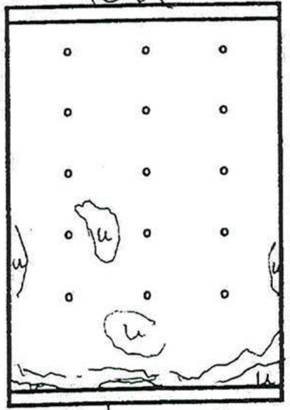
t = 1045

ISLANDS growing and beginning to fuse

Prefailure regions almost saturated with solid contam-

ADHESION ON ALL Failed Regions

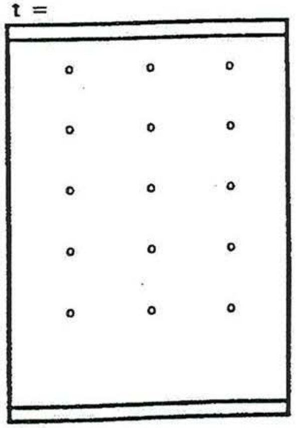
t = 1047



full plate failure ICE ADH.

u = not yet failed

t =

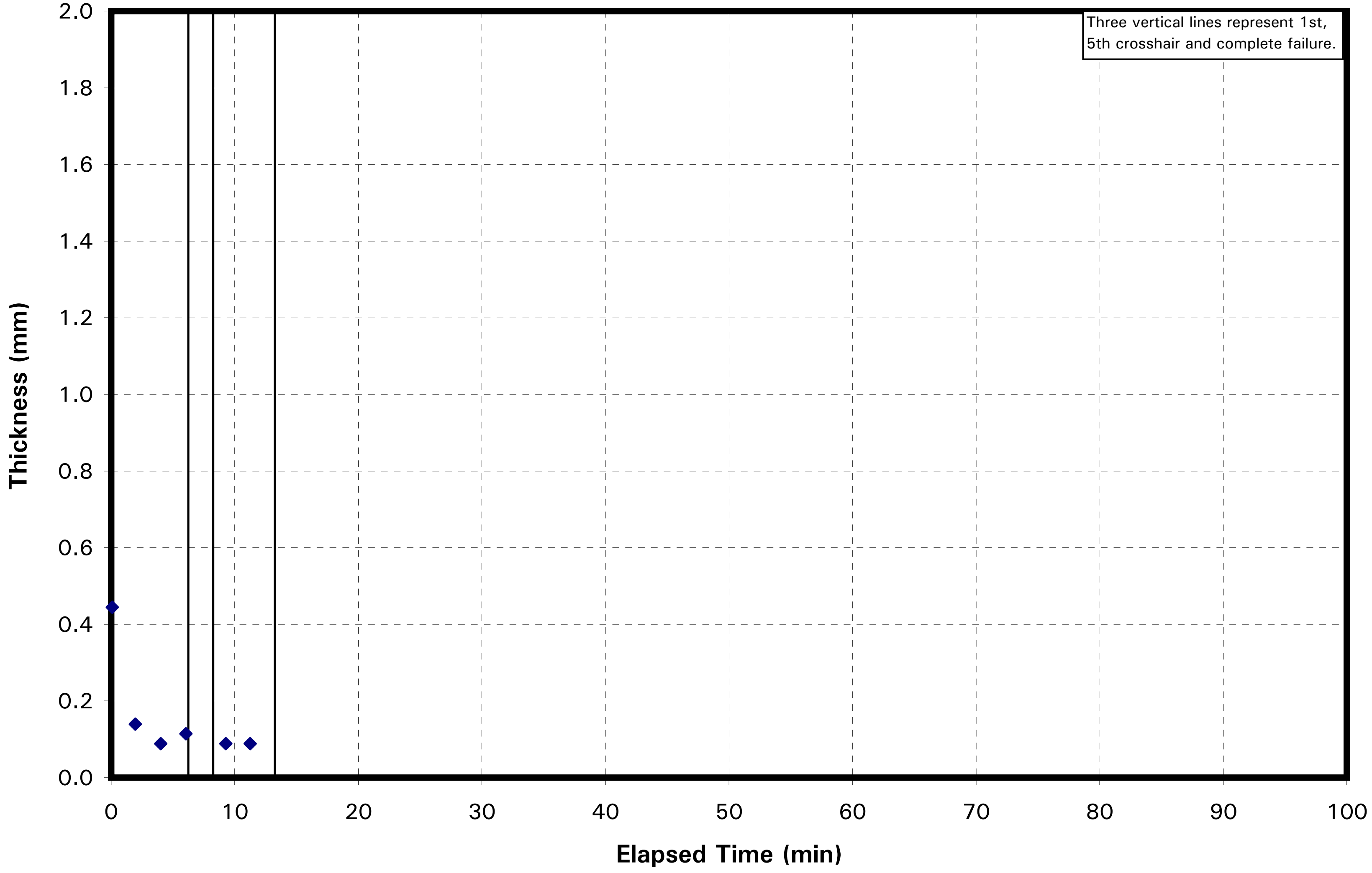


Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 18

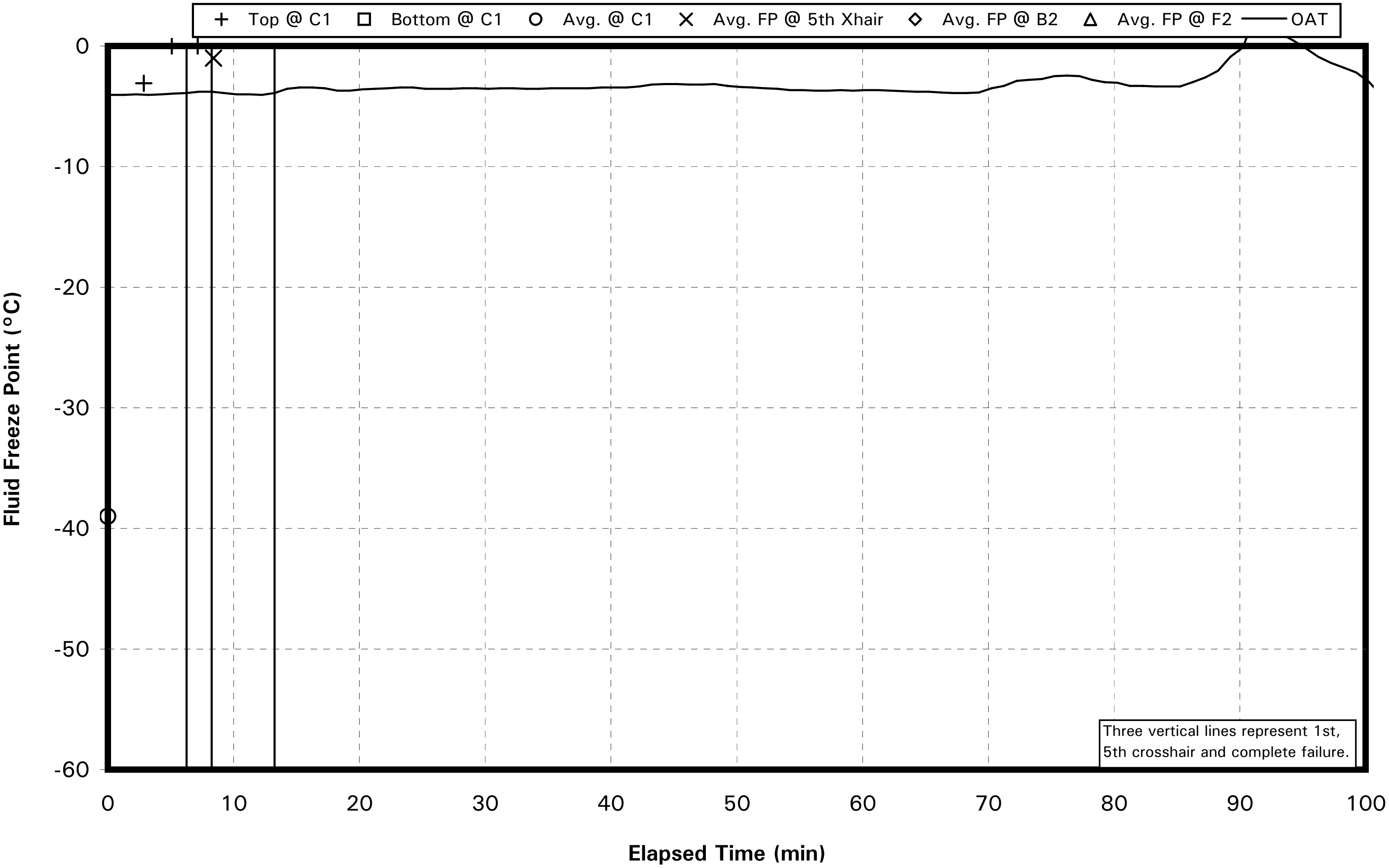


cm1380/analysis/doc_fail/thicknes/THK_ID18
9/21/2006, 3:45 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 18



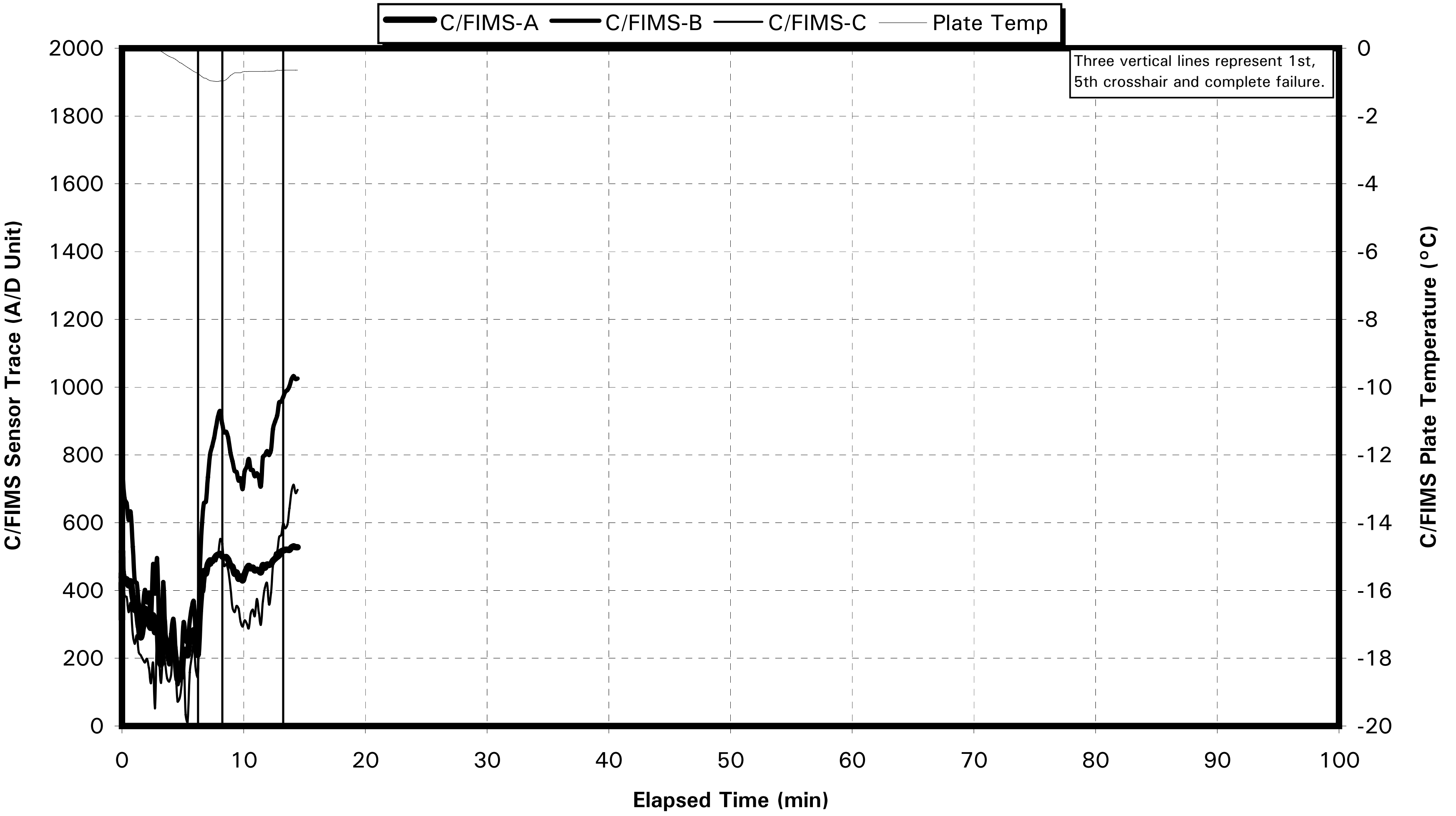
Three vertical lines represent 1st, 5th crosshair and complete failure.

cm1380/analysis/doc_fail/brix/BRX_ID18
9/21/2006, 3:46 PM

DOCUMENTATION OF FLUID FAILURE

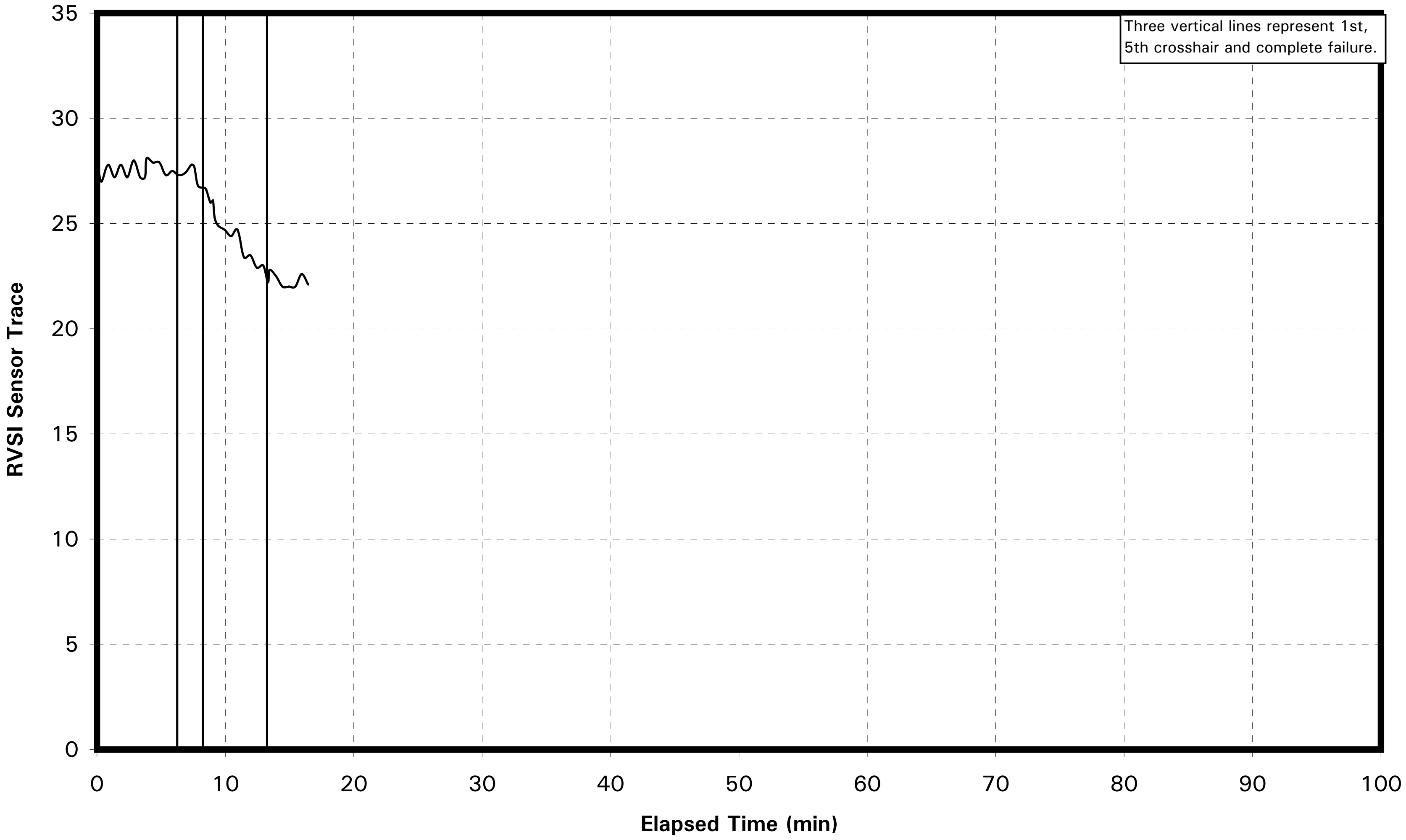
C/FIMS SENSOR TRACE

ID # 18



cm1380/analysis/doc_fail/cfims/CFM_ID18
9/21/2006, 3:47 PM

DOCUMENTATION OF FLUID FAILURE
RVSI SENSOR TRACE
ID # 18



cm1380/analysis/doc_fail/rvsi/RVS_ID18
9/21/2006, 3:48 PM

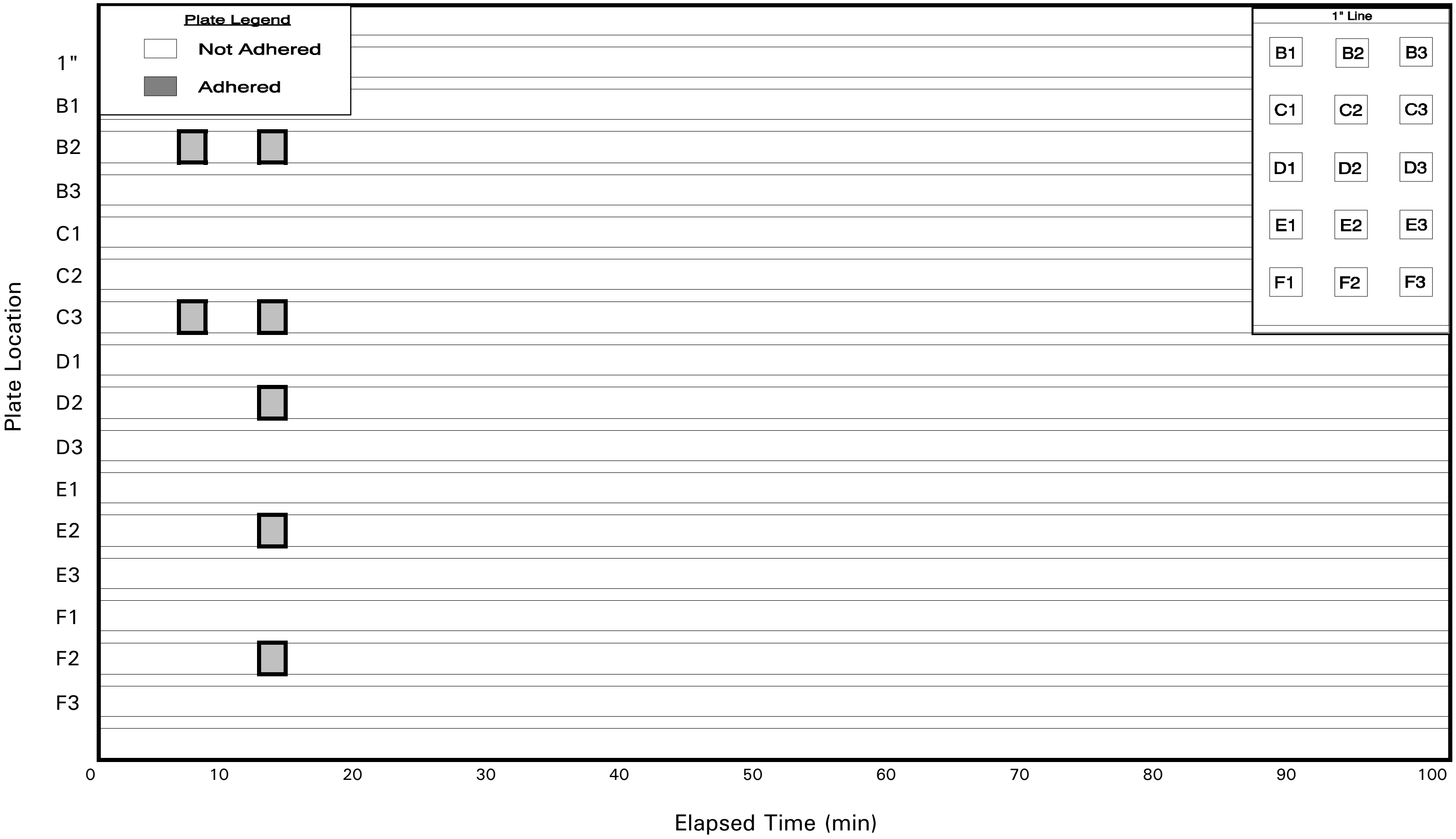
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 18

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 18



cm1380/analysis/doc_fail/ADH_ID18
9/21/2006, 3:50 PM

GENERAL TEST INFORMATION

ID # 19

July 9, 1998

Ambient Air Temperature:	-3.7°C
Precipitation Type:	Light Freezing Rain
Rate of Precipitation:	24.8 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	10:37:30
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	11:10:00
Failure Time (Complete Plate):	11:17:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 19

Photo C19.1 - After Pouring, t = 0 min

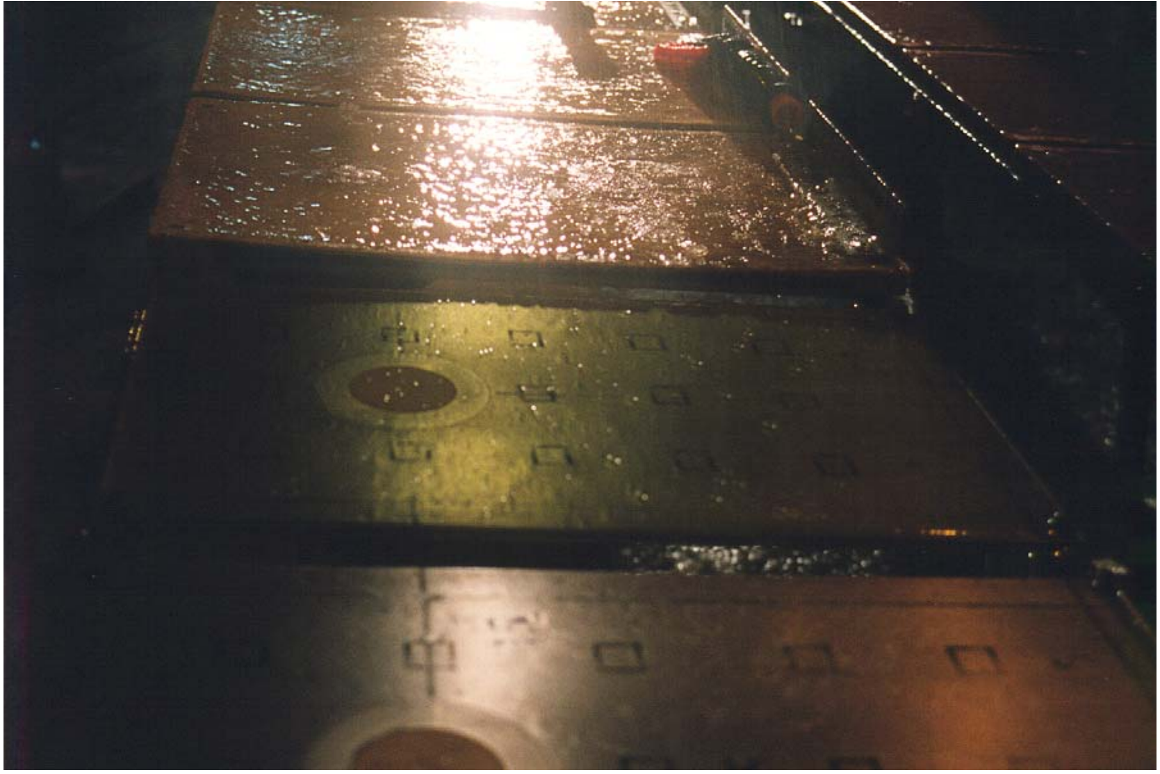


Photo C19.2 - 1st Failure, t = 24 min (Est.)

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 19

Photo C19.3 - Standard Failure (1/3 or 5th Crosshair), t = 35 min

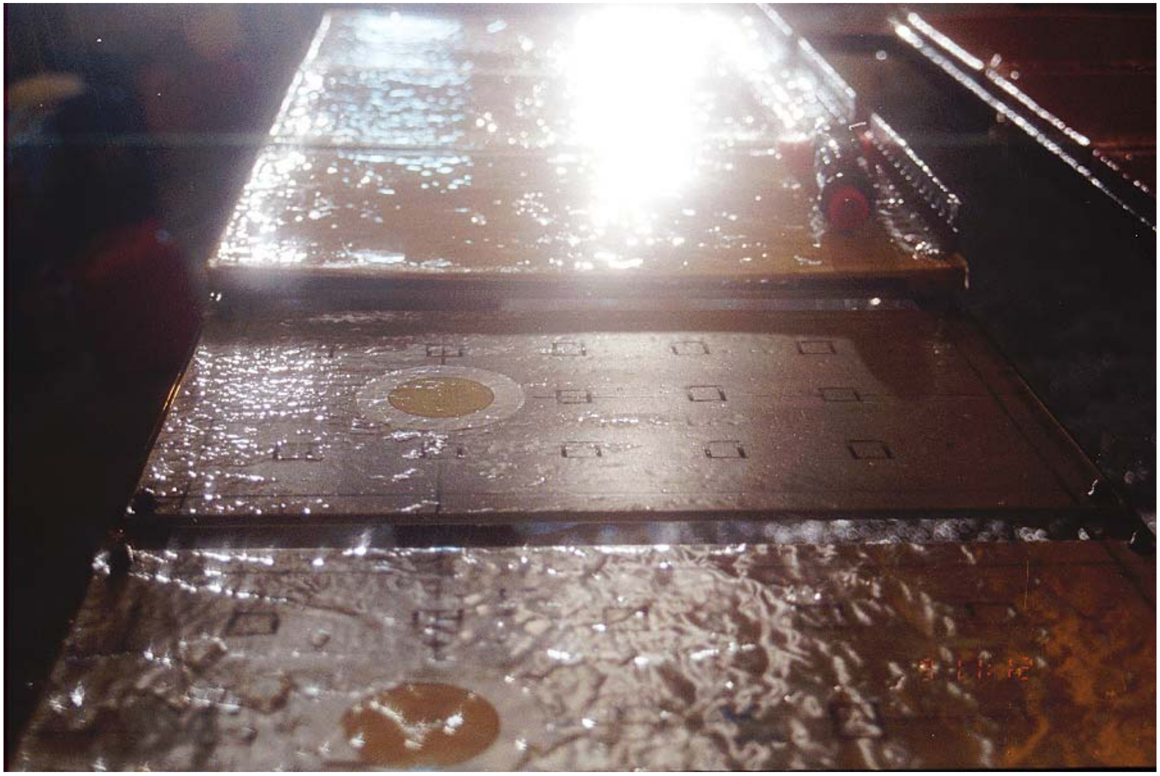
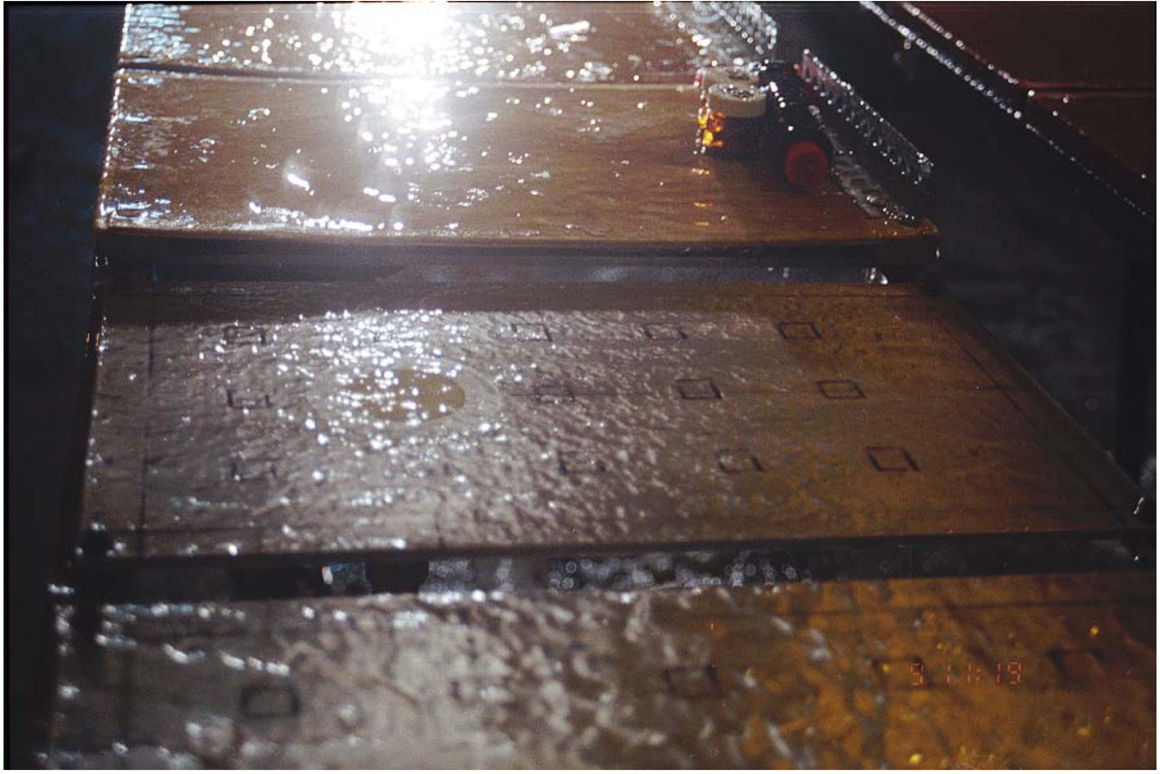


Photo C19.4 - Complete Fluid Failure, t = 42 min



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ID# 19

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09

Run #: 17 (+5?)

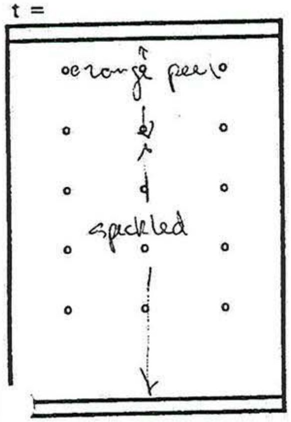
Time: 1037lo

Fluid Name: ULTRA+

Plate Location: 3

Fluid Dilution: 100%

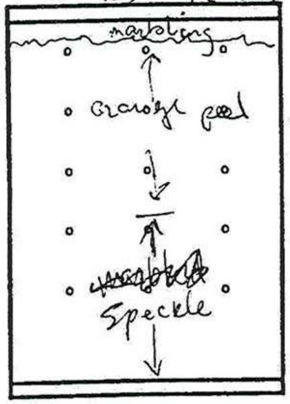
t =



Pour! Same as prev. descriptions

1040 speckle and orange peel.

t = 1056-57 - Prefailure above 1" line (platelets beginning to overlap

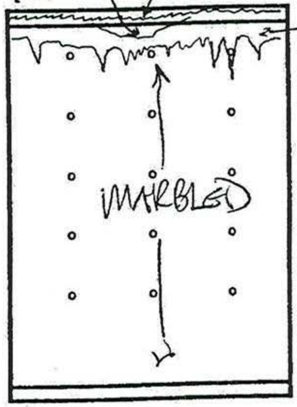


t =

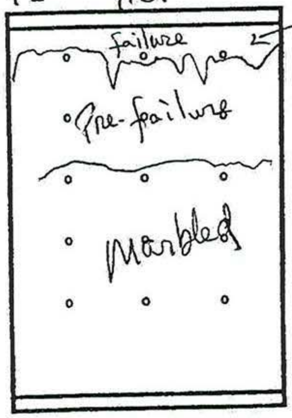
1101 1st failure

1059 failure above 1" line

1107 1st X-Hair

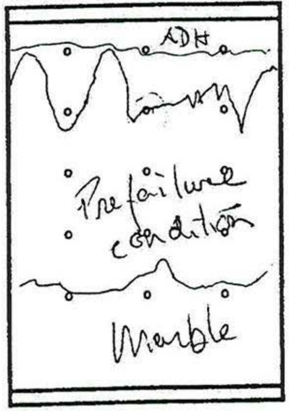


t = 1109



1109

t = 11:11



5th X-Hair

11:11 ADH. To 3" line

finger fusion at 1115

finger fusion at 1116

t =

1115 fp has moved down to prefailure area of last diagram

1116 prefailure area from 1115 is now almost all failed. (mechanism - finger fusion)

MARBLED ISLANDS

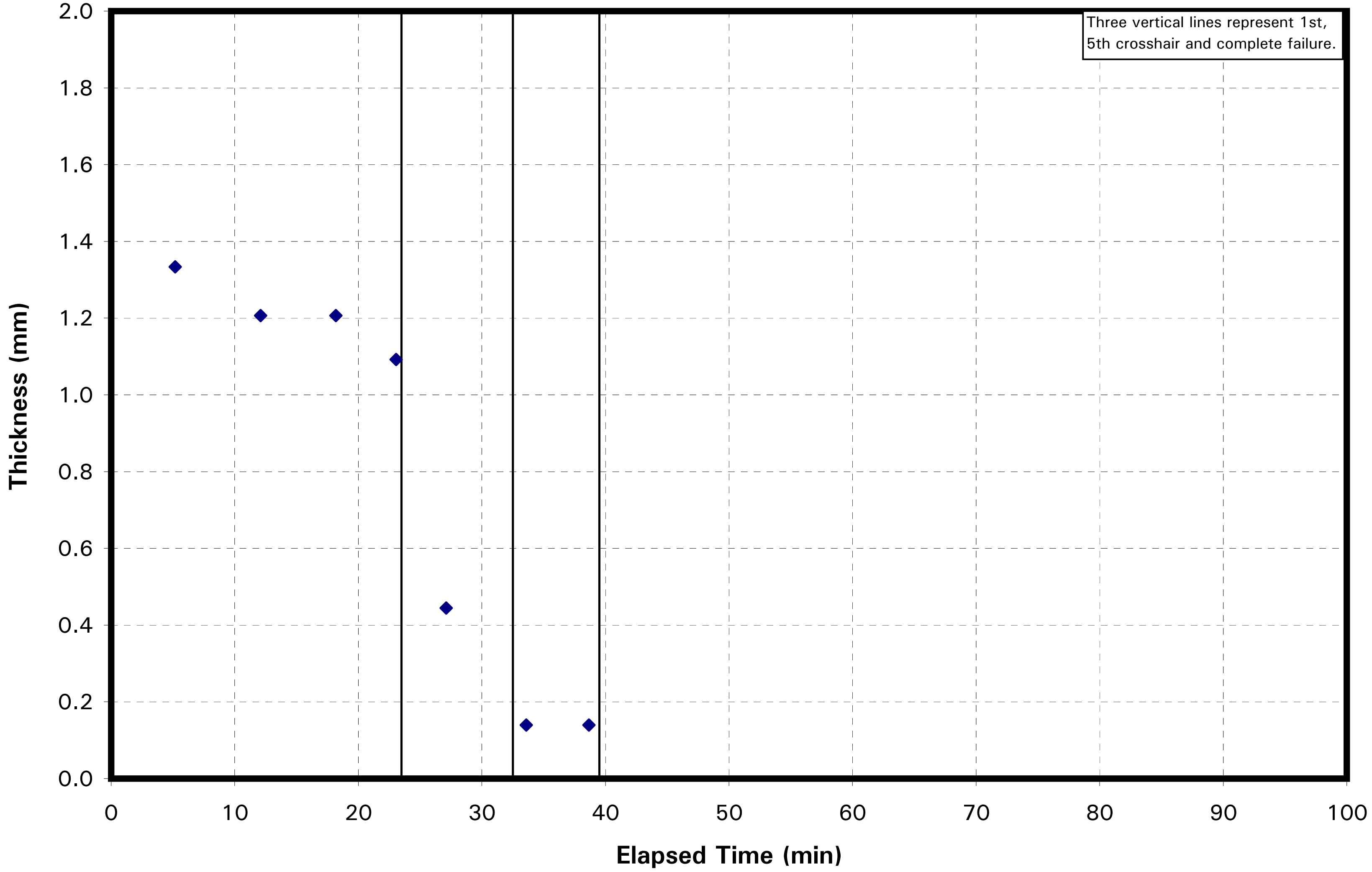
1117 full plate failure

Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 19

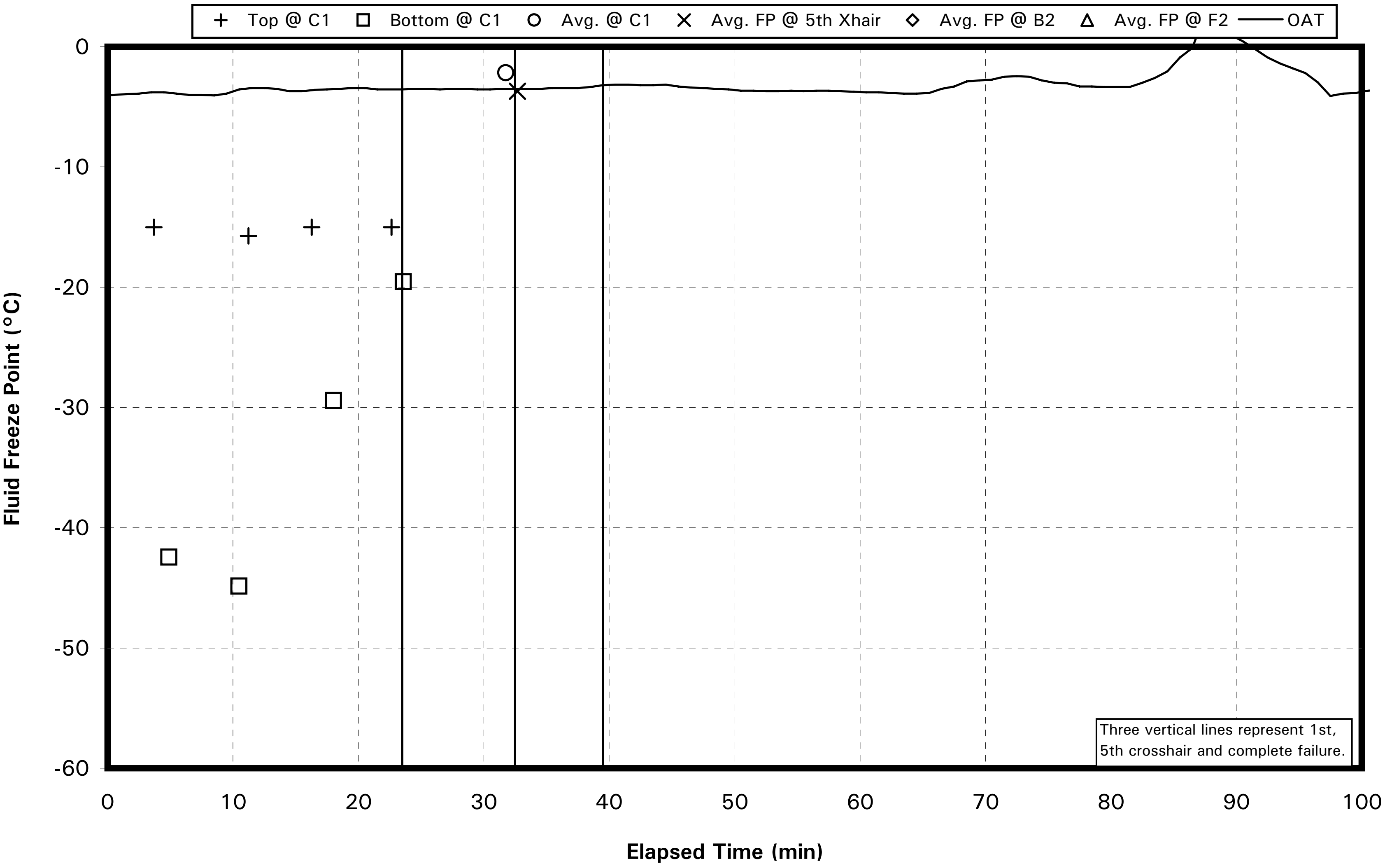


cm1380/analysis/doc_fail/thicknes/THK_ID19
9/21/2006, 3:53 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 19



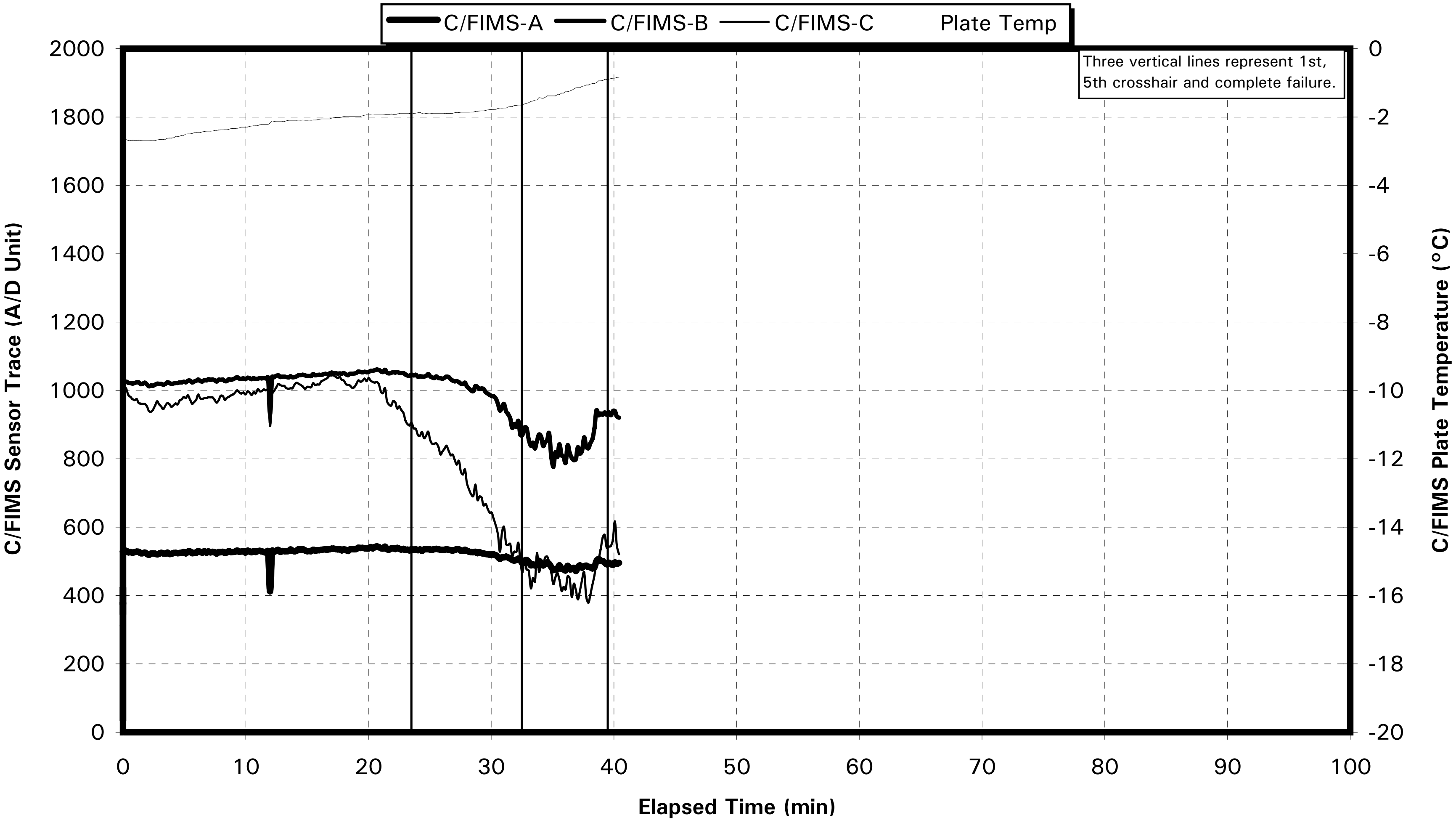
Three vertical lines represent 1st, 5th crosshair and complete failure.

cm1380/analysis/doc_fail/brix/BRX_ID19
9/21/2006, 3:54 PM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 19

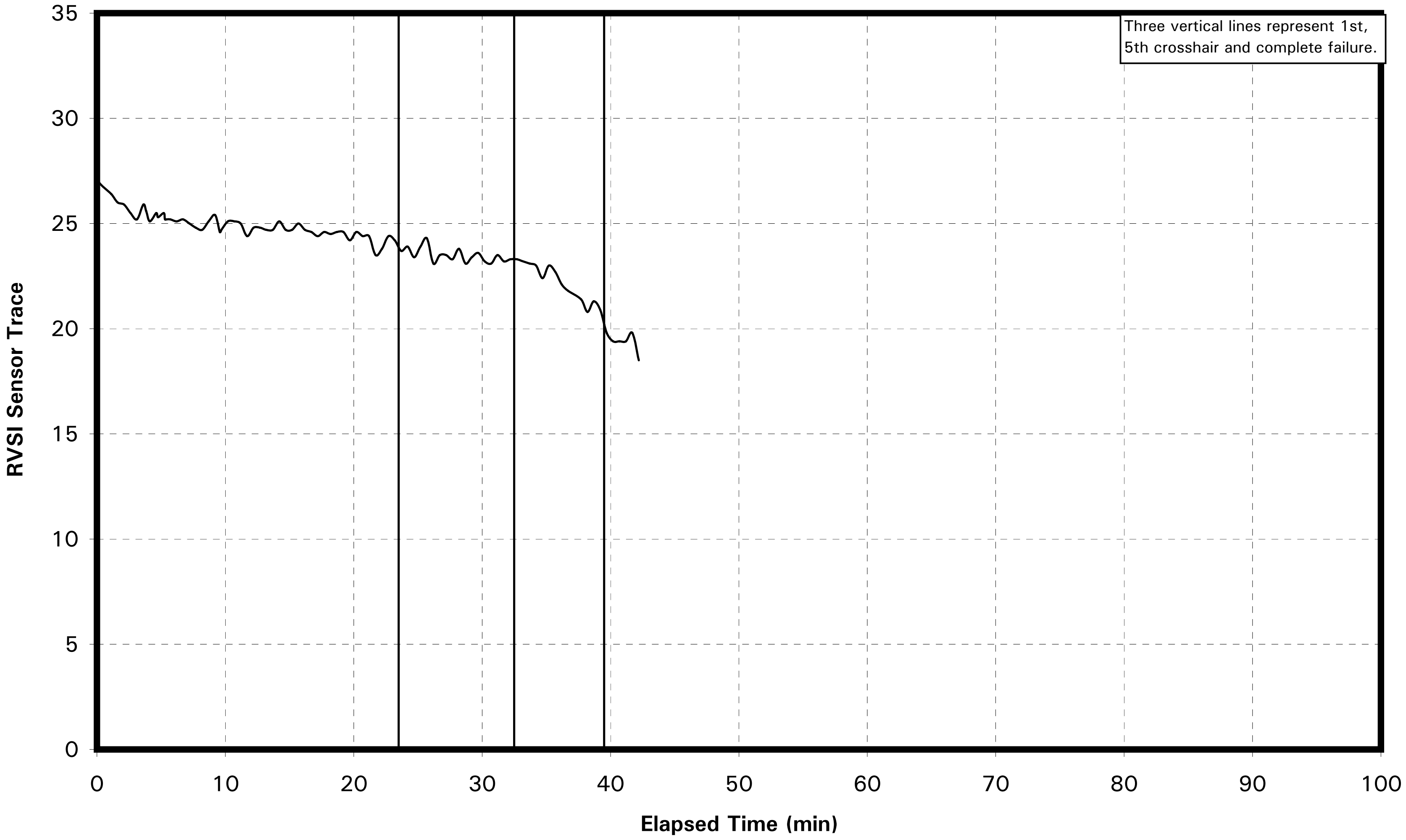


cm1380/analysis/doc_fail/cfims/CFM_ID19
9/21/2006, 3:55 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 19



cm1380/analysis/doc_fail/rvsi/RVS_ID19
9/21/2006, 4:01 PM

DOCUMENTATION OF FLUID FAILURE

COX/SPAR SENSOR TRACE

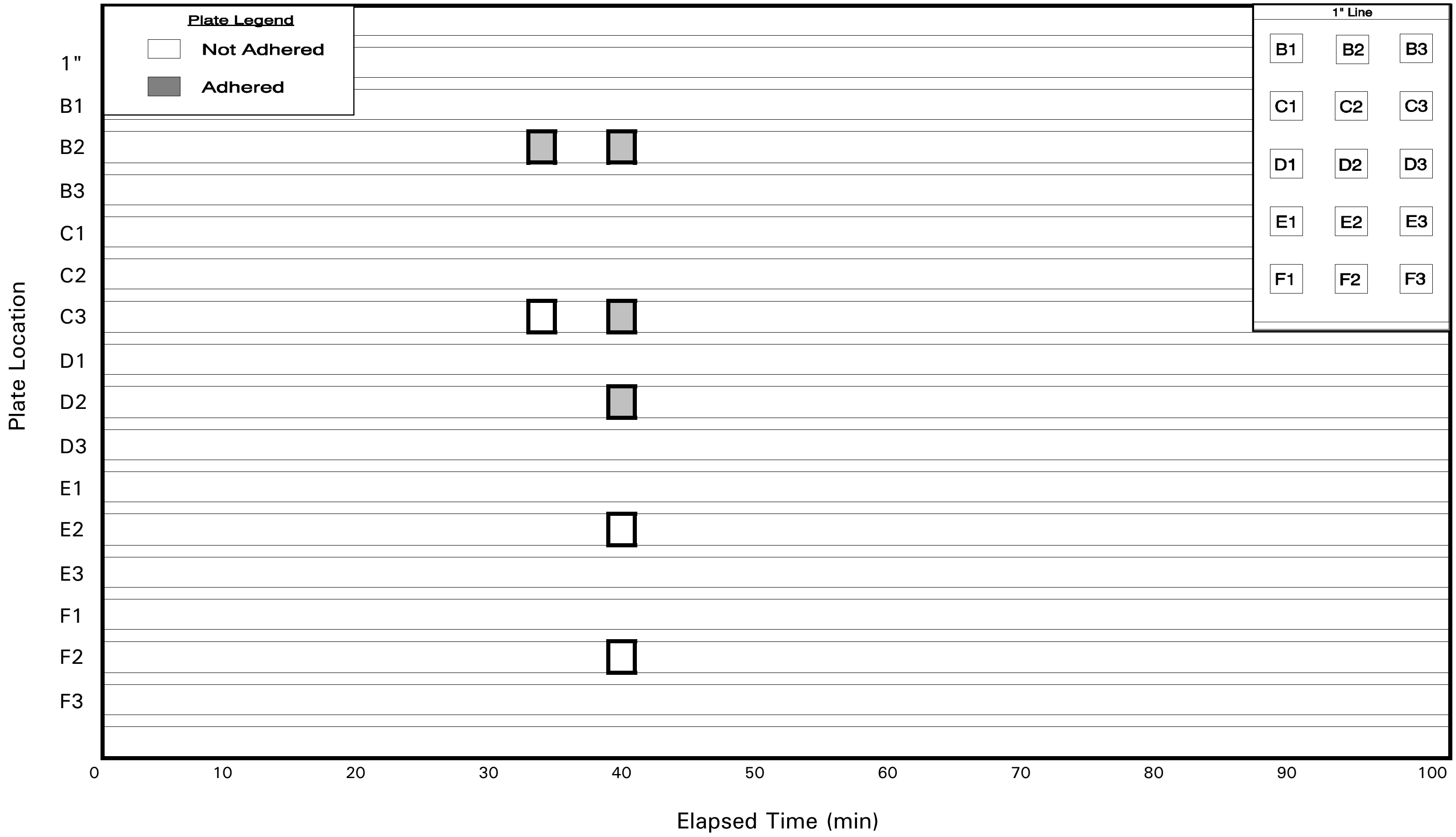
ID # 19

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 19



cm1380/analysis/doc_fail/ADH_ID19
9/21/2006, 4:02 PM

GENERAL TEST INFORMATION

ID # 20

July 9, 1998

Ambient Air Temperature:	-3.5°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	12.4 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	12:47:30
Failure Mode:	5th X-hair
Failure Location:	D1
Failure Time (Standard):	13:44:00
Failure Time (Complete Plate):	13:51:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 20

Photo C20.1 - After Pouring, t = 0 min

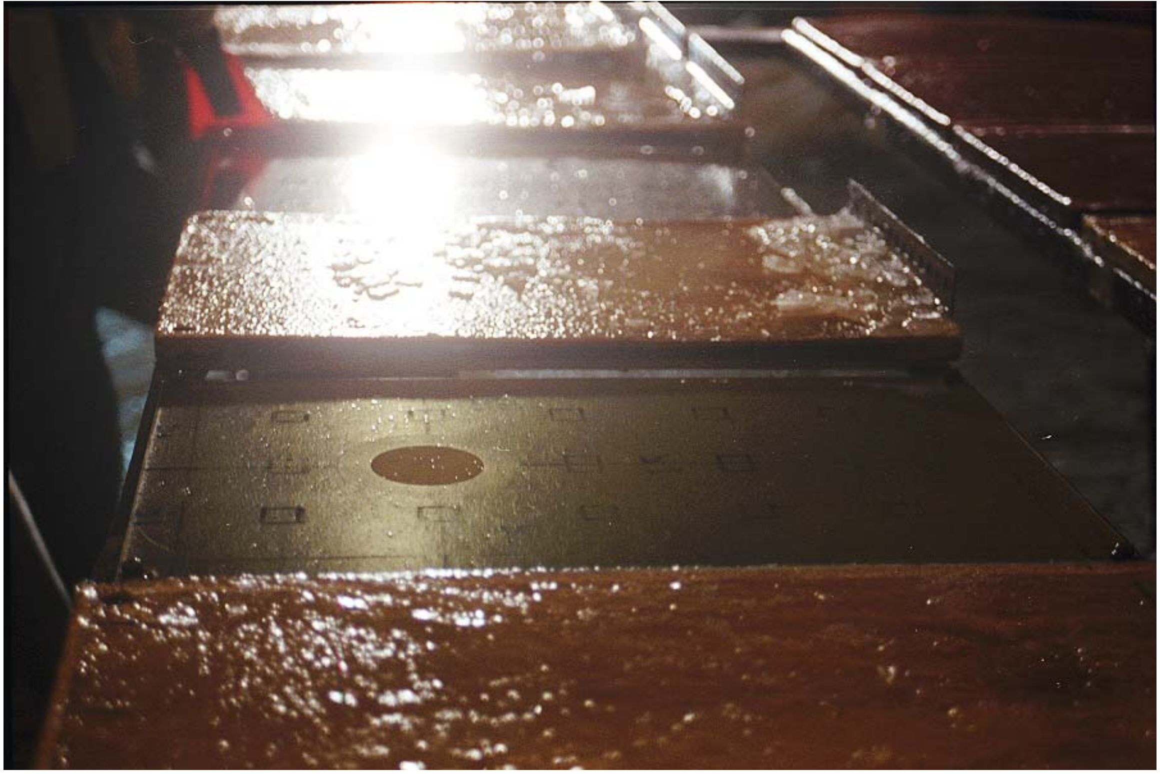


Photo C20.2 - 1st Failure, t = 47 min (Est.)

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 20

Photo C20.3 - Standard Failure (1/3 or 5th Crosshair), t = 59 min

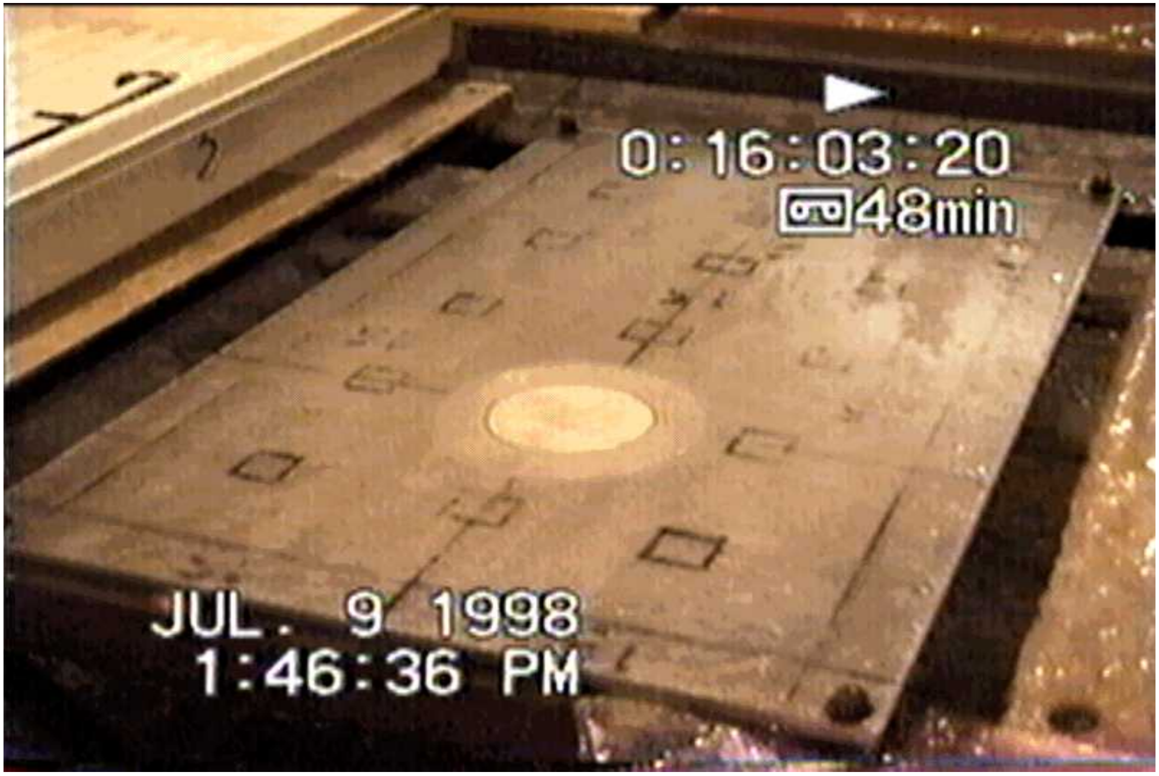


Photo C20.4 - Complete Fluid Failure, t = 64 min (Est.)

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ID# 20

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09

ZD
R=13
T=-3°C

Time: 1247 30

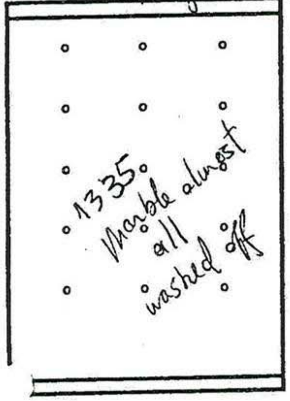
Plate Location: ______

Run #: 3b.

Fluid Name: ULTRA+

Fluid Dilution: ______

t = 1328 top edge initial contamination (solid)



Pours. as prev. descr.

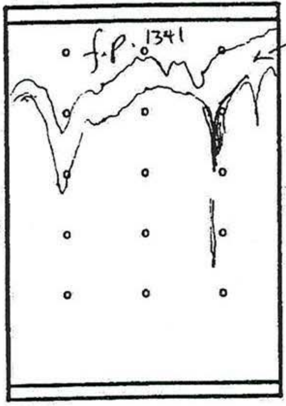
1248-1306 long speckle phase.

1305-1308 orange peel

1308 → 1318 orange peel→ marble phase

1318 all marbled

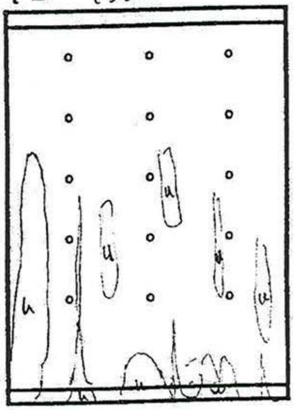
t = 1341 -> 1345



f.p. 1345
5th X-Hair

Failure progress is fast. All remaining non-failed area is Thin dilute fluid (pre failure cond.)

t = 1350



1351 total plate failure

Failure is very wet; ADH only to 3" line.

(u = not yet completely failed regions

t =

t =

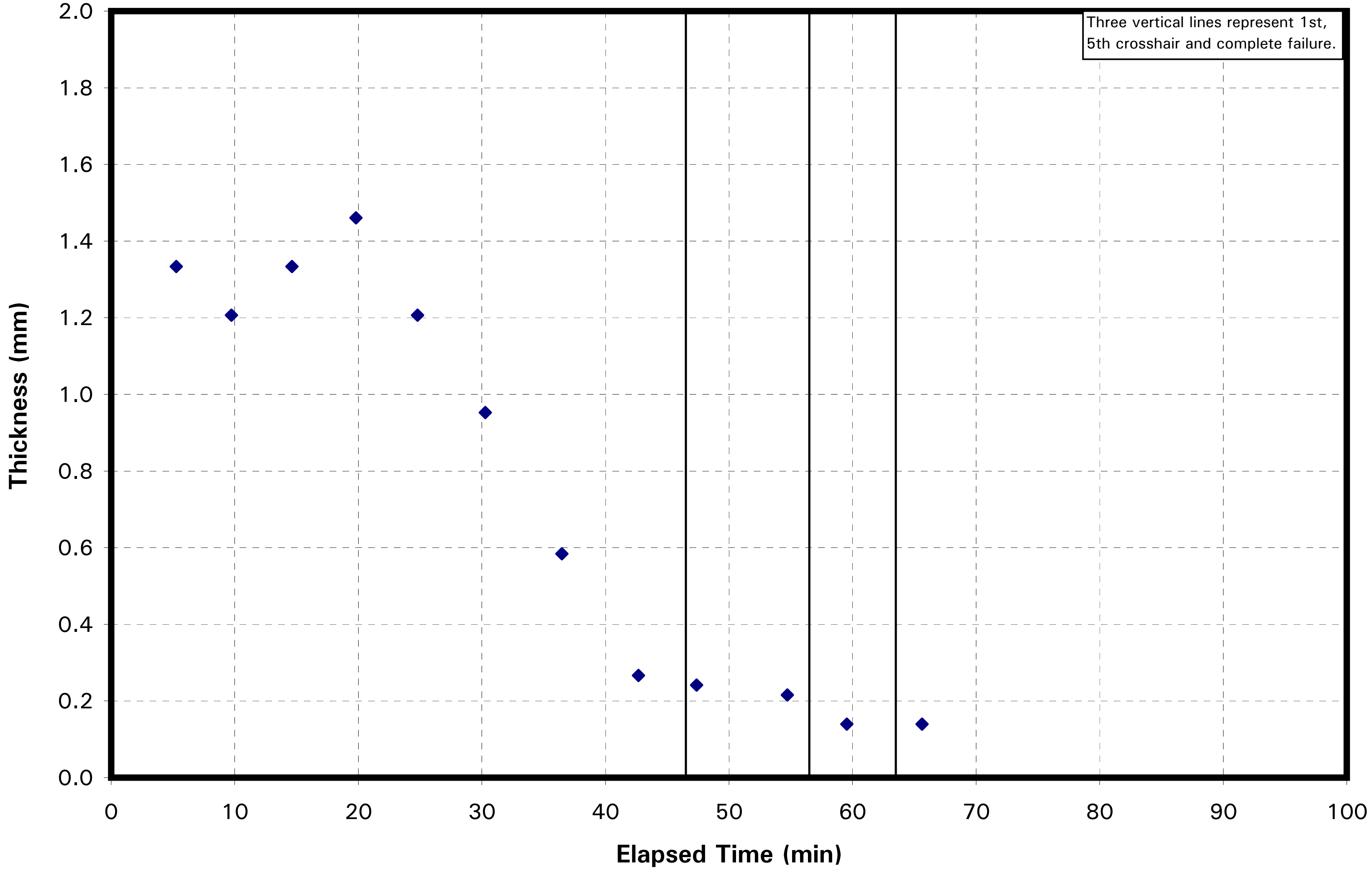
t =

Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 20

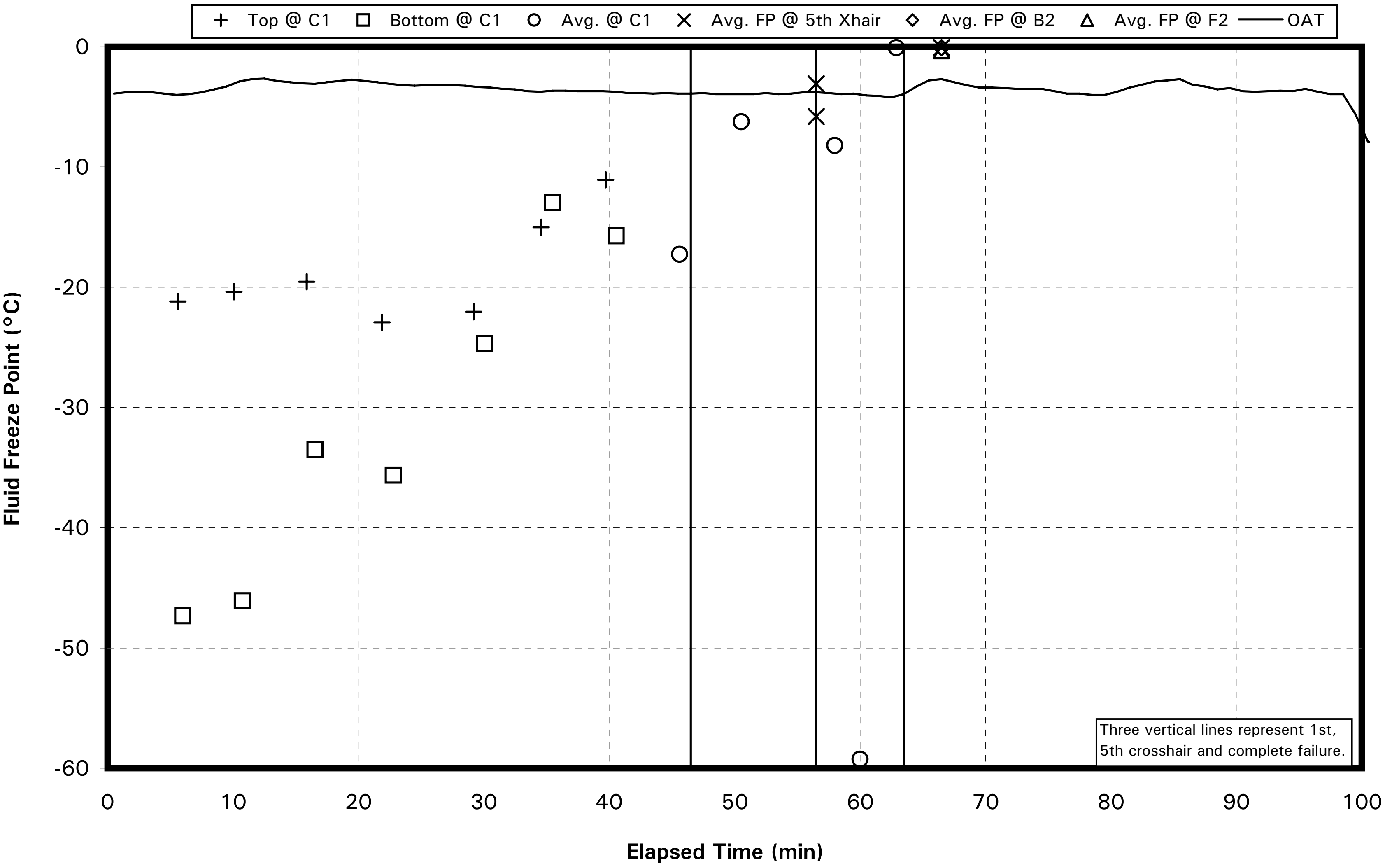


cm1380/analysis/doc_fail/thicknes/THK_ID20
9/21/2006, 4:05 PM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 20

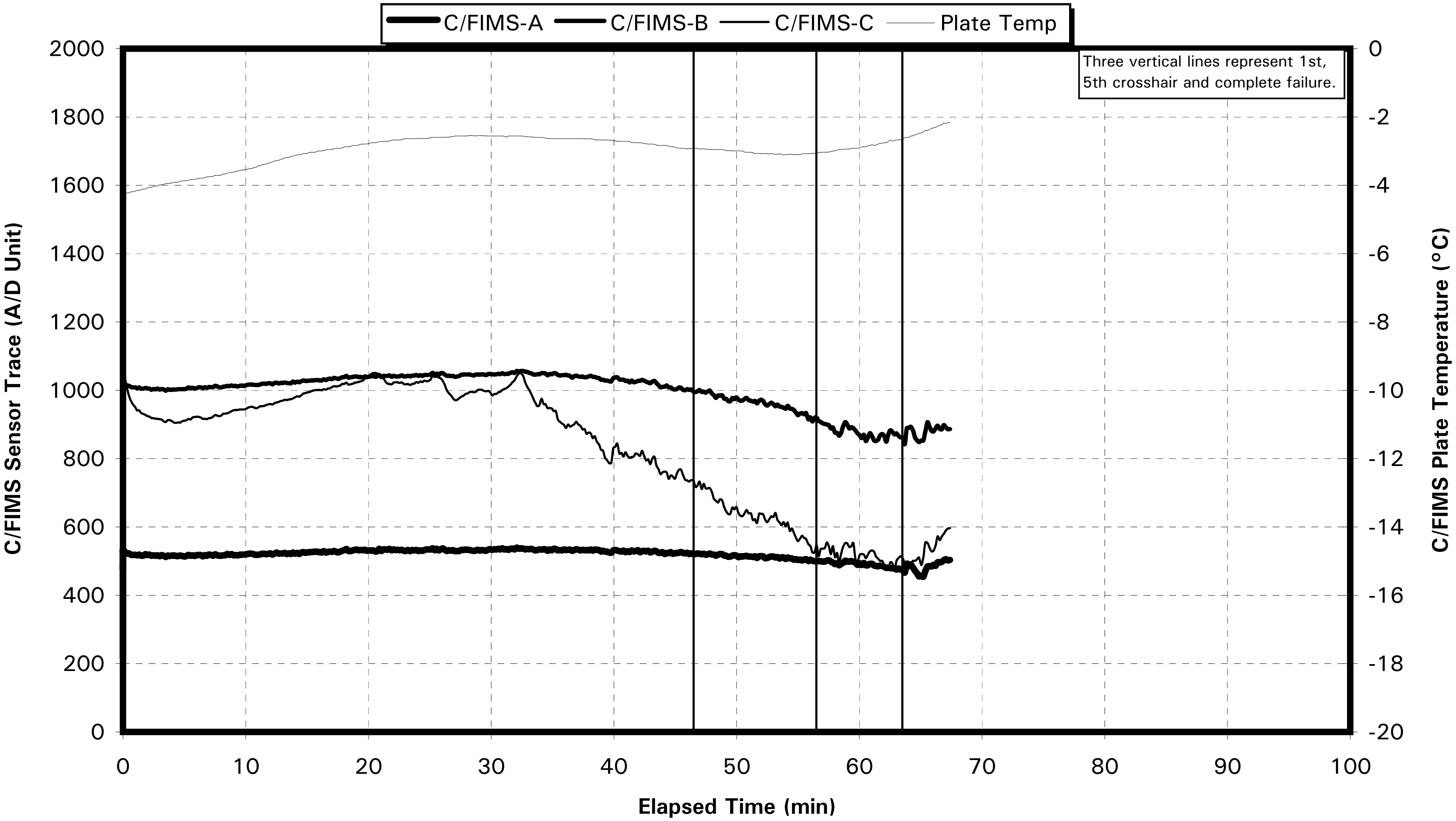


cm1380/analysis/doc_fail/brix/BRX_ID20
9/21/2006, 4:06 PM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 20

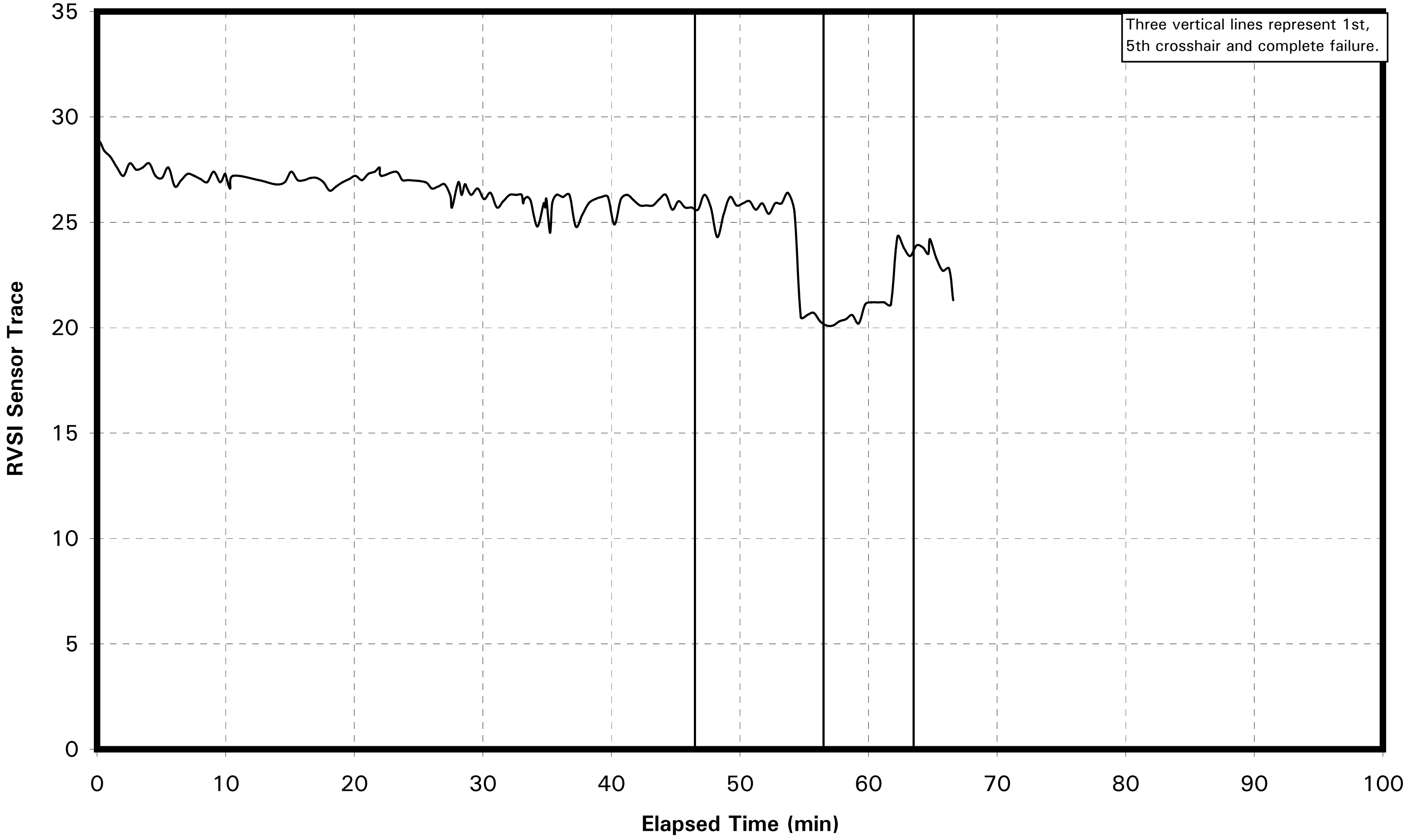


cm1380/analysis/doc_fail/cfims/CFM_ID20
9/21/2006, 4:07 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 20

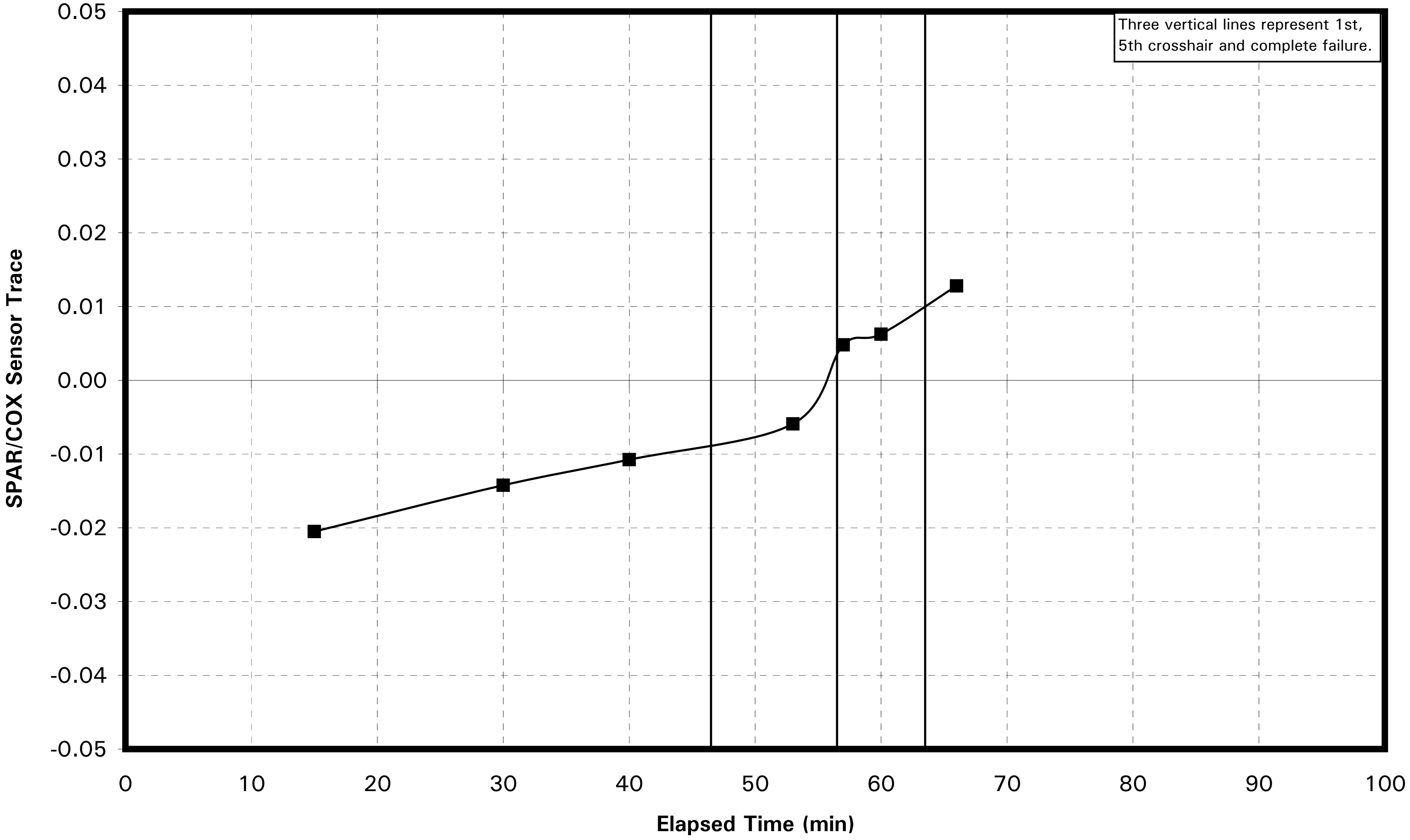


cm1380/analysis/doc_fail/rvsi/RVS_ID20
9/21/2006, 4:08 PM

DOCUMENTATION OF FLUID FAILURE

SPAR/COX SENSOR TRACE

ID # 20

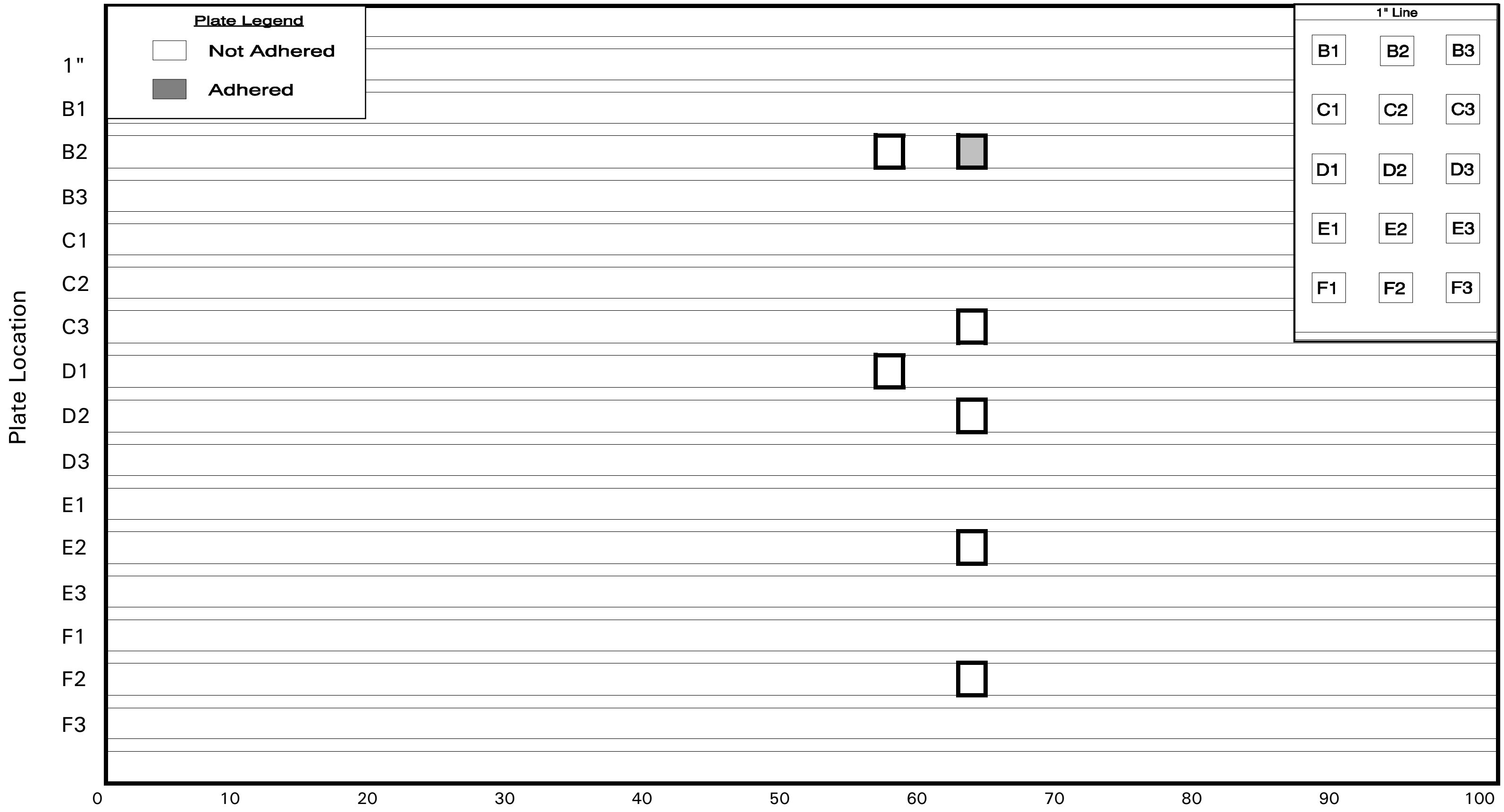


cm1380/analysis/doc_fail/cox/COX_ID20
9/21/2006, 4:09 PM

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 20



Elapsed Time (min)

GENERAL TEST INFORMATION

ID # 21

July 9, 1998

Ambient Air Temperature:	-3.4°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	12.4 g/dm²/hr
Fluid:	OCTAGON
Dilution:	Neat
Start of Test:	12:50:05
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	13:28:00
Failure Time (Complete Plate):	13:35:00

cm1380/analysis/doc_fail/GEN_INFO
At: 21
9/21/2006, 4:16 PM

PHOTOS OF POUR AND FIRST FAILURE - ID # 21

Photo C21.1 - After Pouring, t = 0 min (Est.)

Photo C21.2 - 1st Failure, t = 22 min (Est.)

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 21

Photo C21.3 - Standard Failure (1/3 or 5th Crosshair), t = 38 min (Est.)

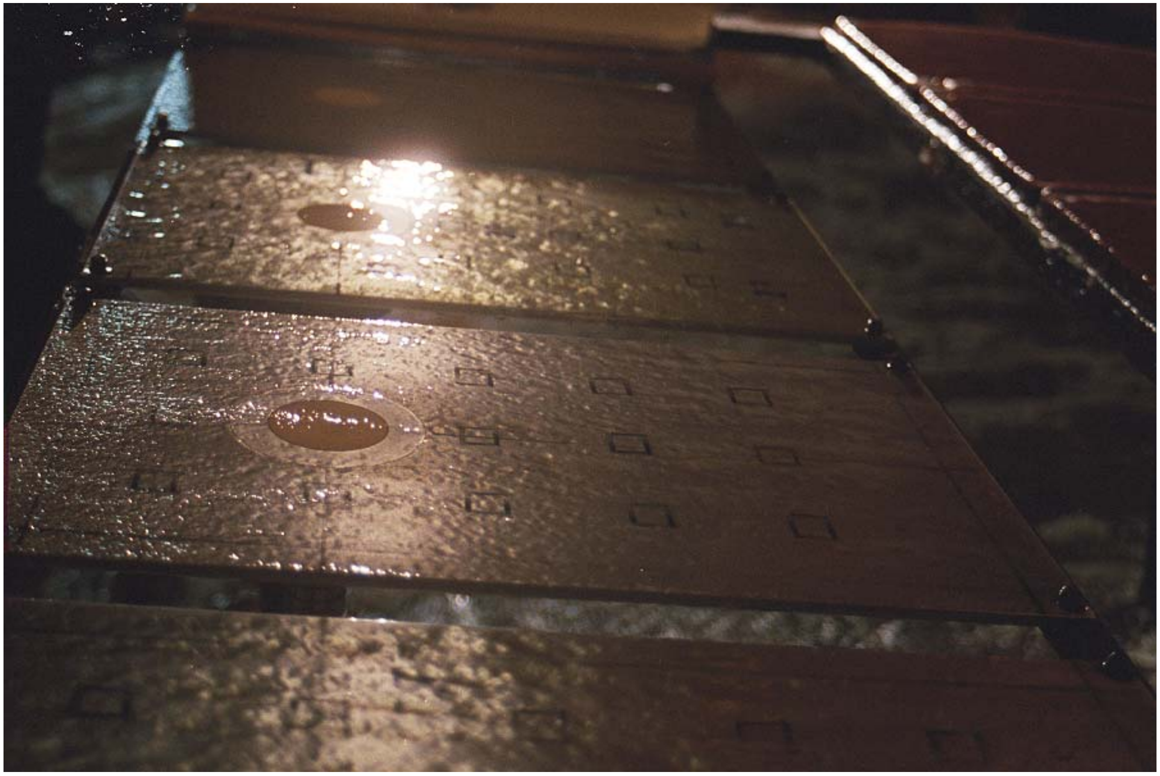
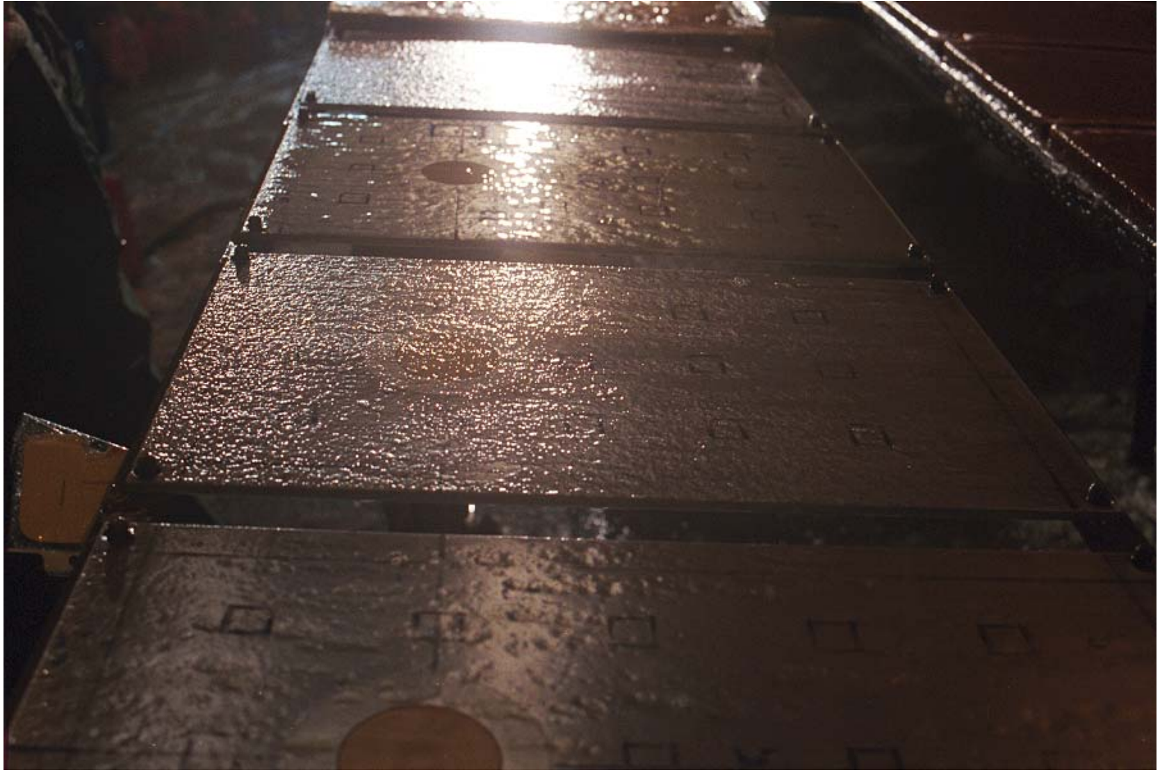


Photo C21.4 - Complete Fluid Failure, t = 45 min (Est.)



ID # 21

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09

Time: 1258^{00}

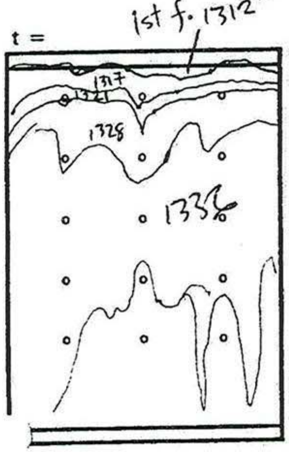
Plate Location: 3

Run #: 3b$_2$

Fluid Name: Oct Max

Fluid Dilution: 100%

t =



Pour: same as prev.

~~thick~~ description:

turbid green transparent fluid c̄ bubbles run off rapidly to leave super smooth srf. before fluid flow slows to steady state.

smooth -> orange peel stage from 0 -> 3" line

1258-1304 smooth beyond 3" line.

t =

1310 Rivulet formation is breaking up thicker fluid at top of plate (above 6" line)

1312^{30} 1st failure within work area.

small platelet fusion mech.

↓

streaks develop into fingers (v. wet, pre-failure areas saturated in solid precip.

↓

fingers fuse laterally to continuous failure areas as they progress down the plate.

t =

1328 5th X-Hair

1336 complete plate failure

ADW to 6" line

t =

t =

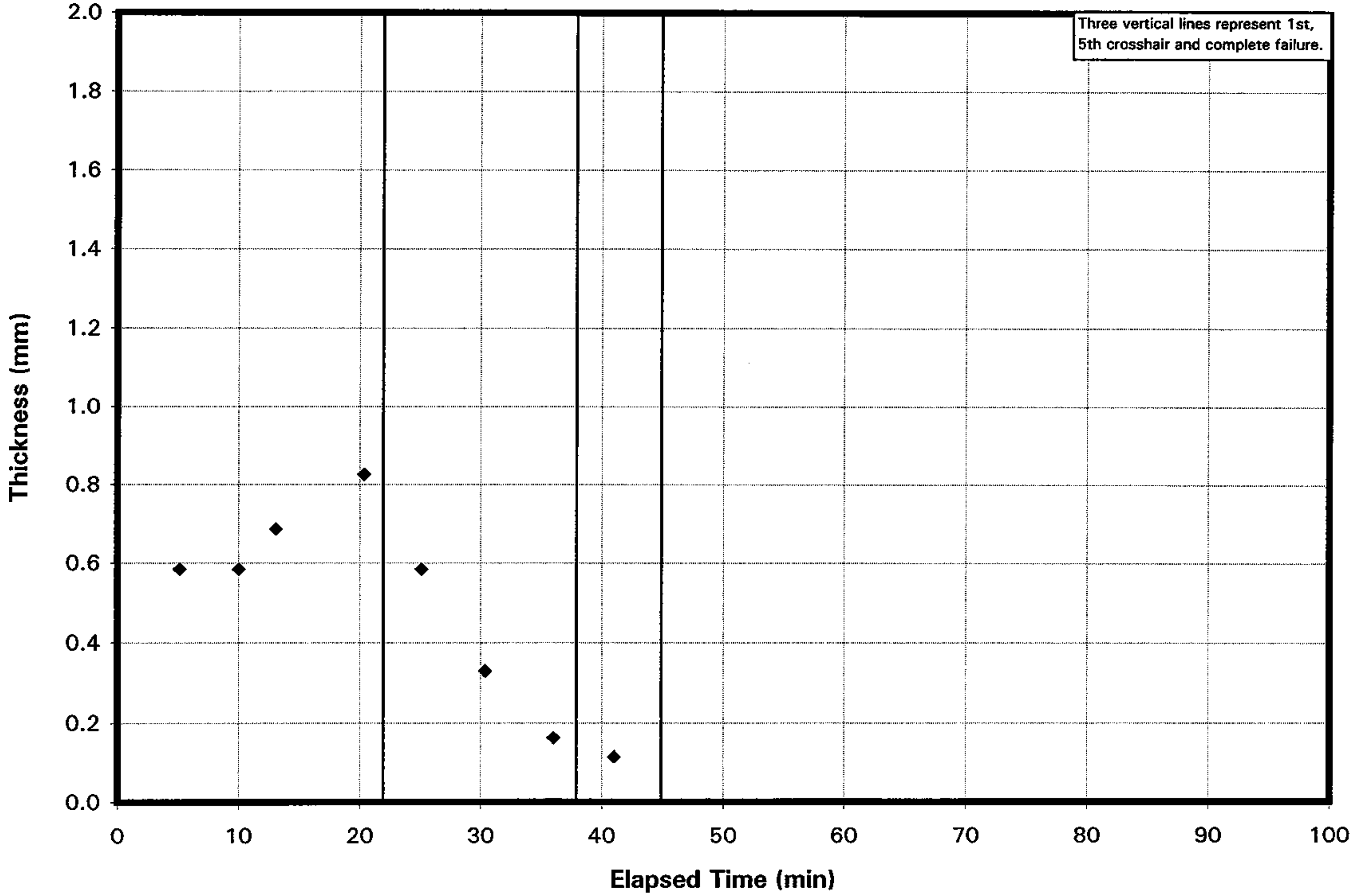
t =

Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 21

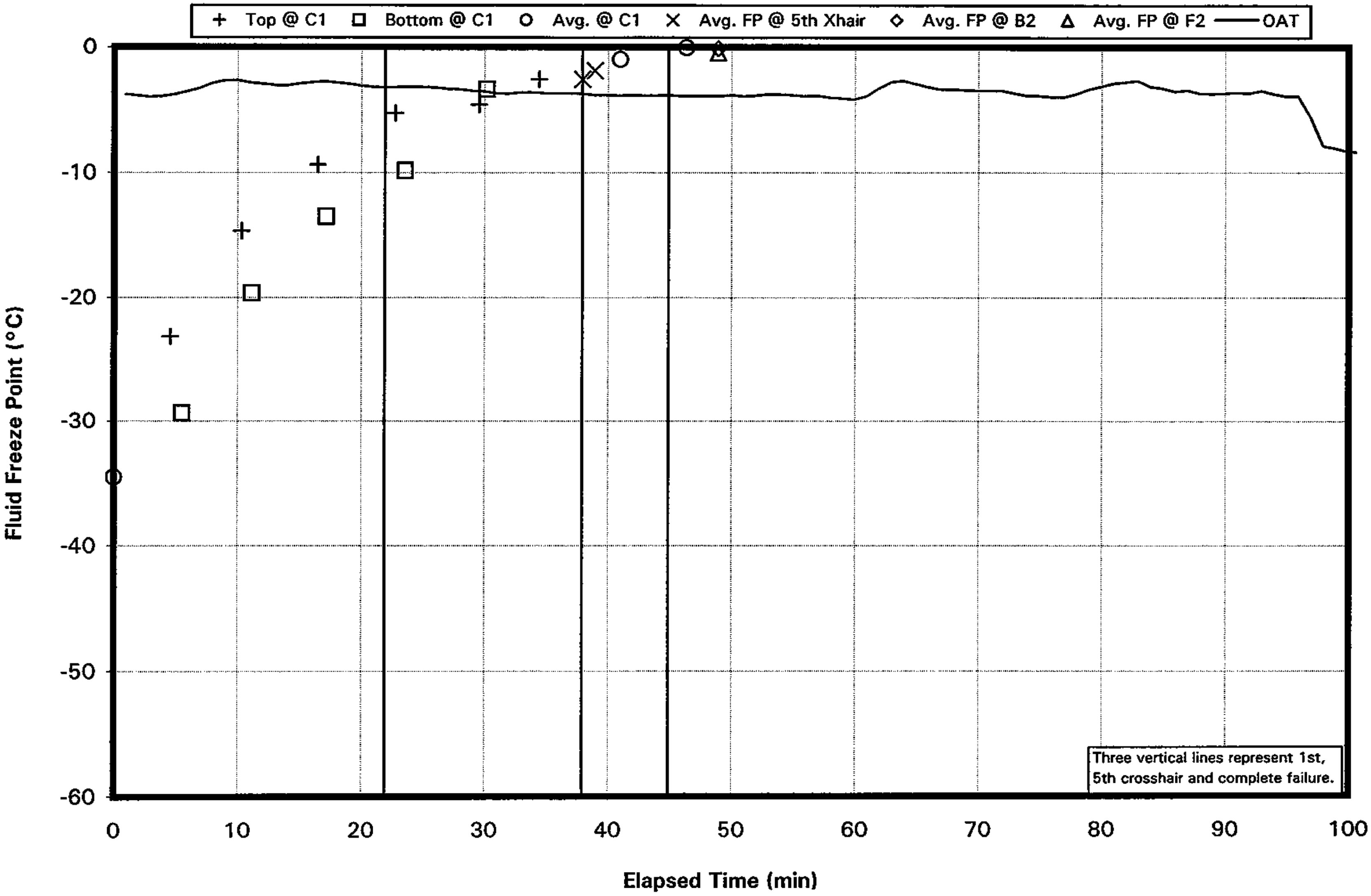


cm1380/analysis/doc_fail/thicknes/Thk_id21
10/14/98, 10:40 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 21

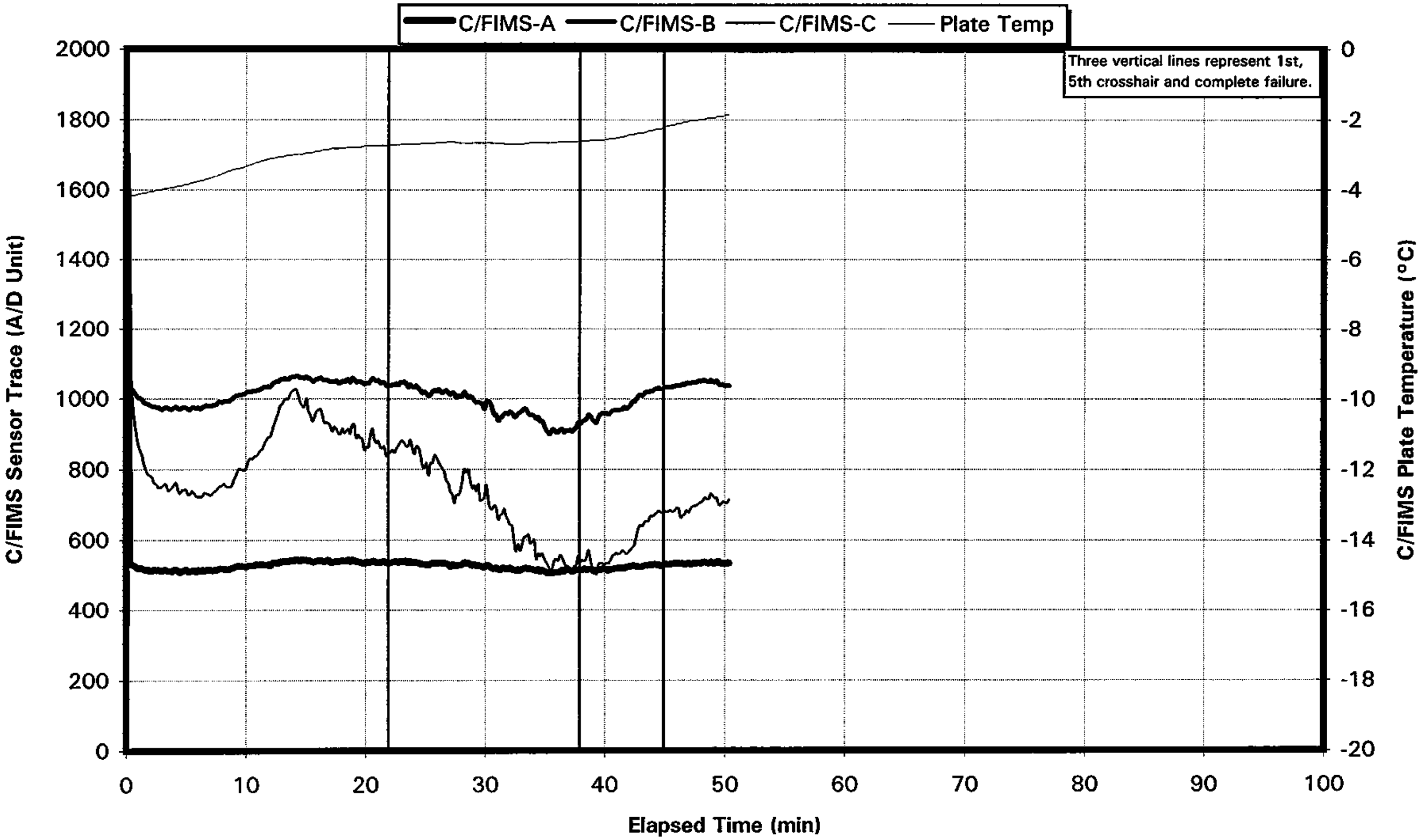


cm1380/analysis/doc_fail/brix/Brx_id21
10/15/98, 9:32 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 21

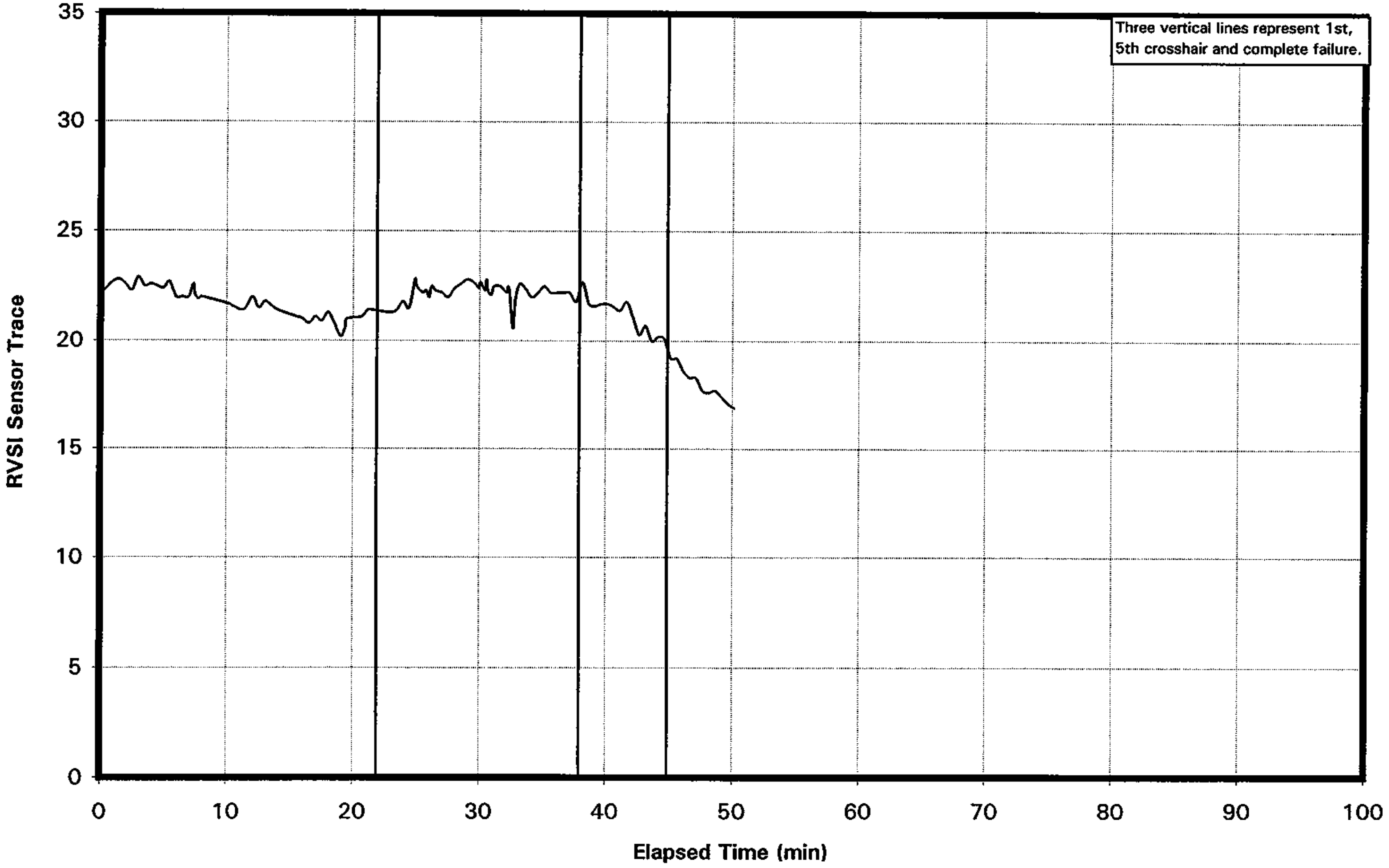


cm1380/analysis/doc_fail/cfims/Cfm_id21.xls
10/15/98, 11:24 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 21



cm1380/analysis/doc_fail/rvsi/Rvs_id21.xls
10/15/98, 12:26 PM

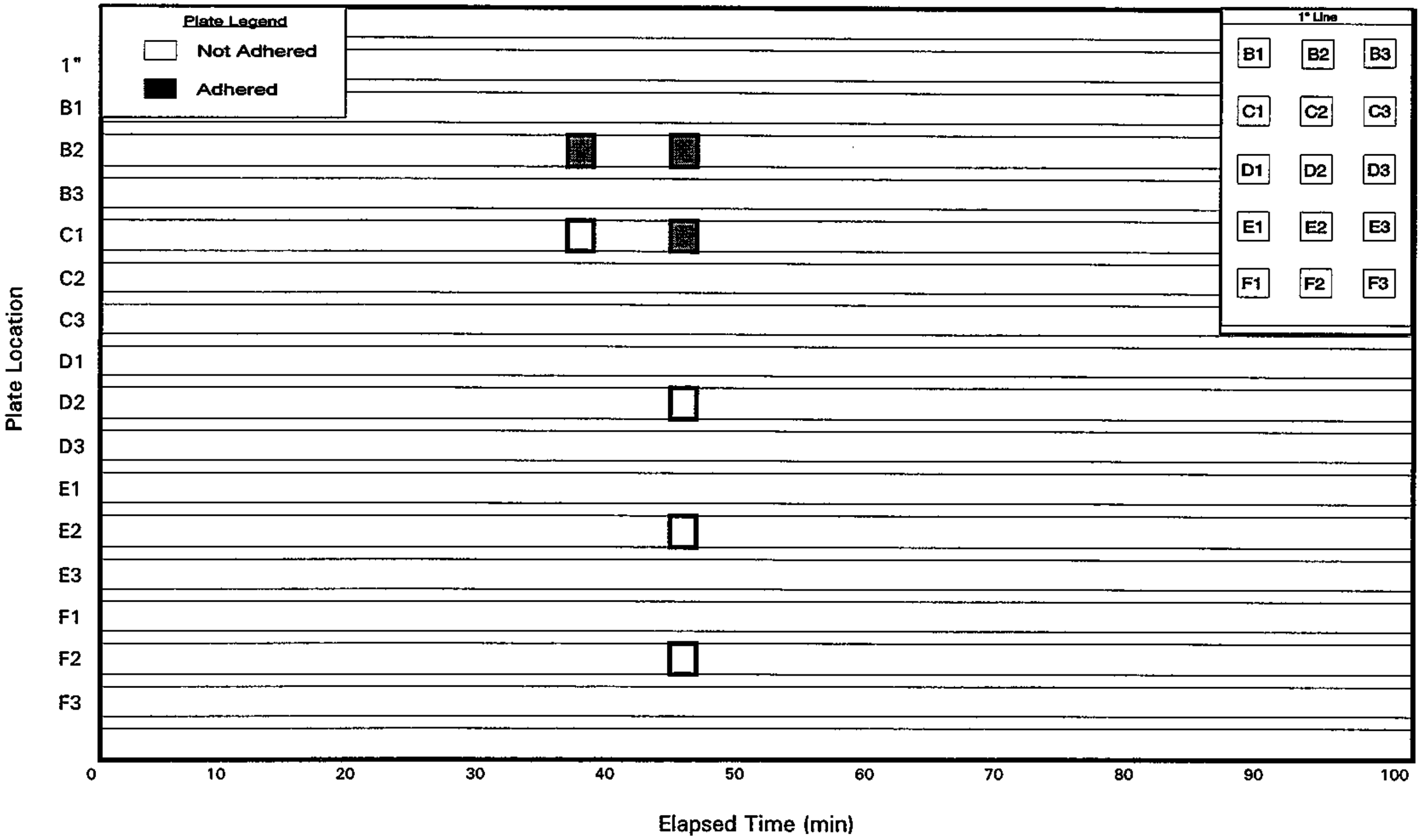
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 21

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 21



cm1380/analysis/doc_fail/Adh_id21
7/28/98, 10:35 AM

GENERAL TEST INFORMATION

ID # 22

July 9, 1998

Ambient Air Temperature:	-3.5°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	13 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	12:54:45
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	13:52:00
Failure Time (Complete Plate):	13:57:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 22

Photo C22.1 - After Pouring, t = 0 min

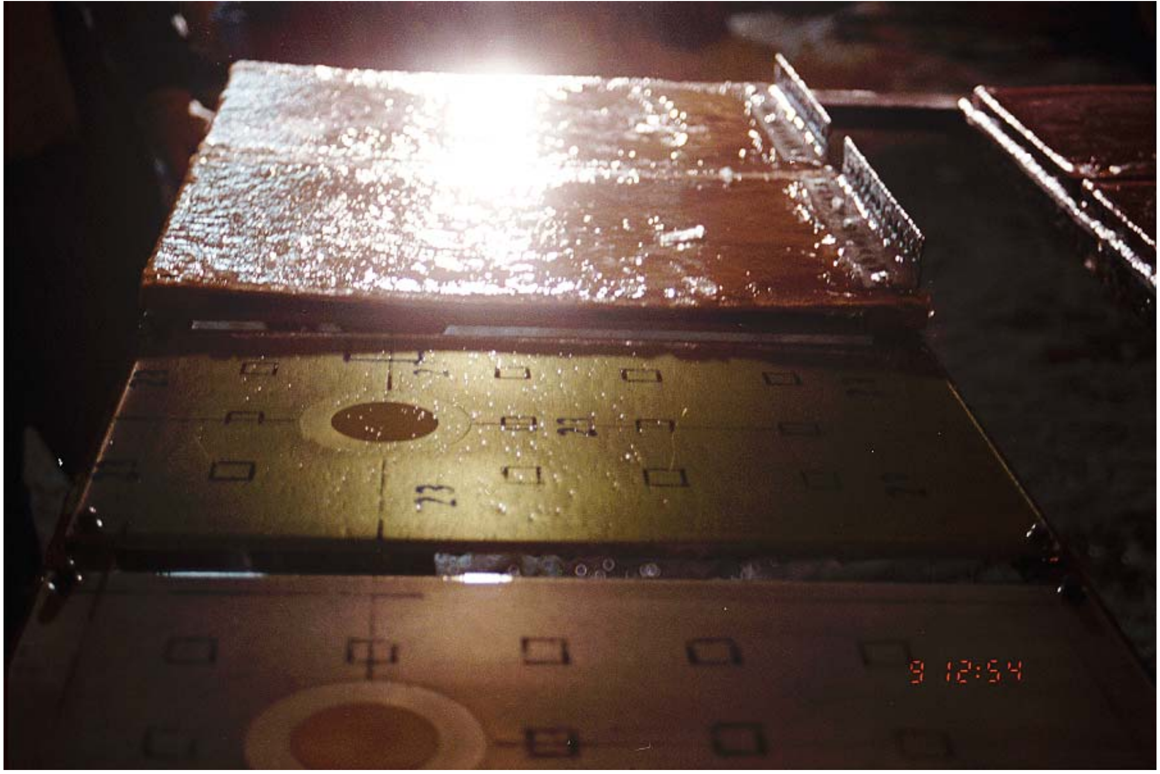
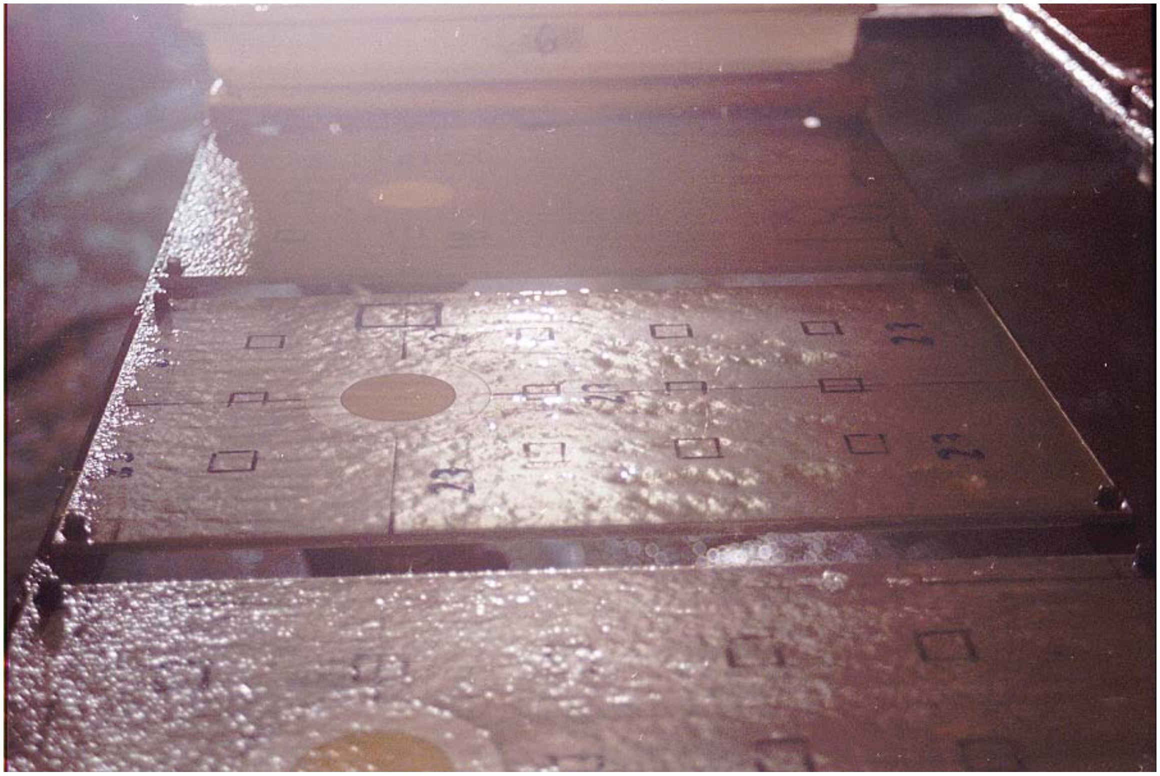


Photo C22.2 - 1st Failure, t = 39 min



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 22

Photo C22.3 - Standard Failure (1/3 or 5th Crosshair), t = 57 min

Photo C22.4 - Complete Fluid Failure, t = 64 min

H:\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID22.doc
Last printed 10/14/98 9:13 AM

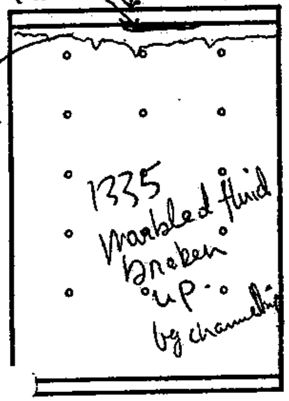
ID# 22

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09
Time: 1254 30
Plate Location: 4

Run #: 3b3
Fluid Name: Ultra +
Fluid Dilution: 100%

t = 1st f. 1335 inside 1" top edge failure 1327

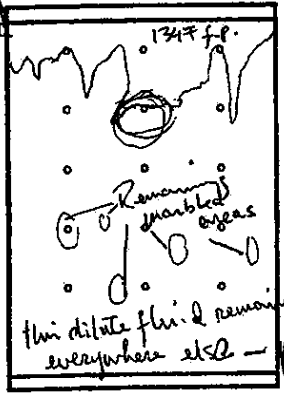


Pour: as prev. described

speckle phase
↓
orangepeel phase
↓
marble phase 1315

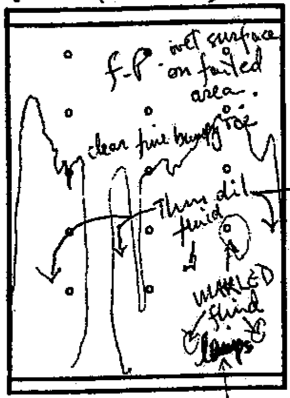
1315 plate completely marbled.

t = 1347



thin dilute fluid remaining everywhere else – pre failure condition

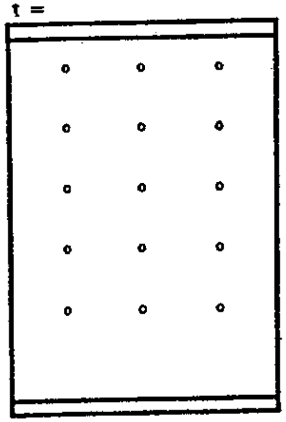
t = 1352 5th X-Hair



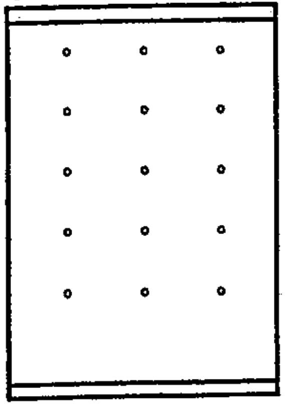
pre failure condition.

wet failed surface
↓
fused platelets
↓
~~fin~~ streaks
↓
fingers
↓
lateral finger fusion
↓
total plate failure
1358
ADH to 3" line

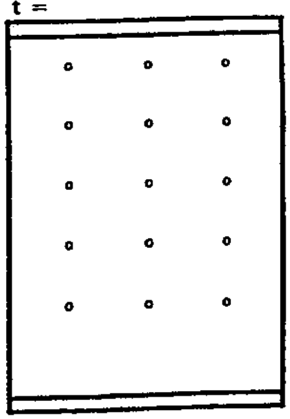
t =



t =



t =

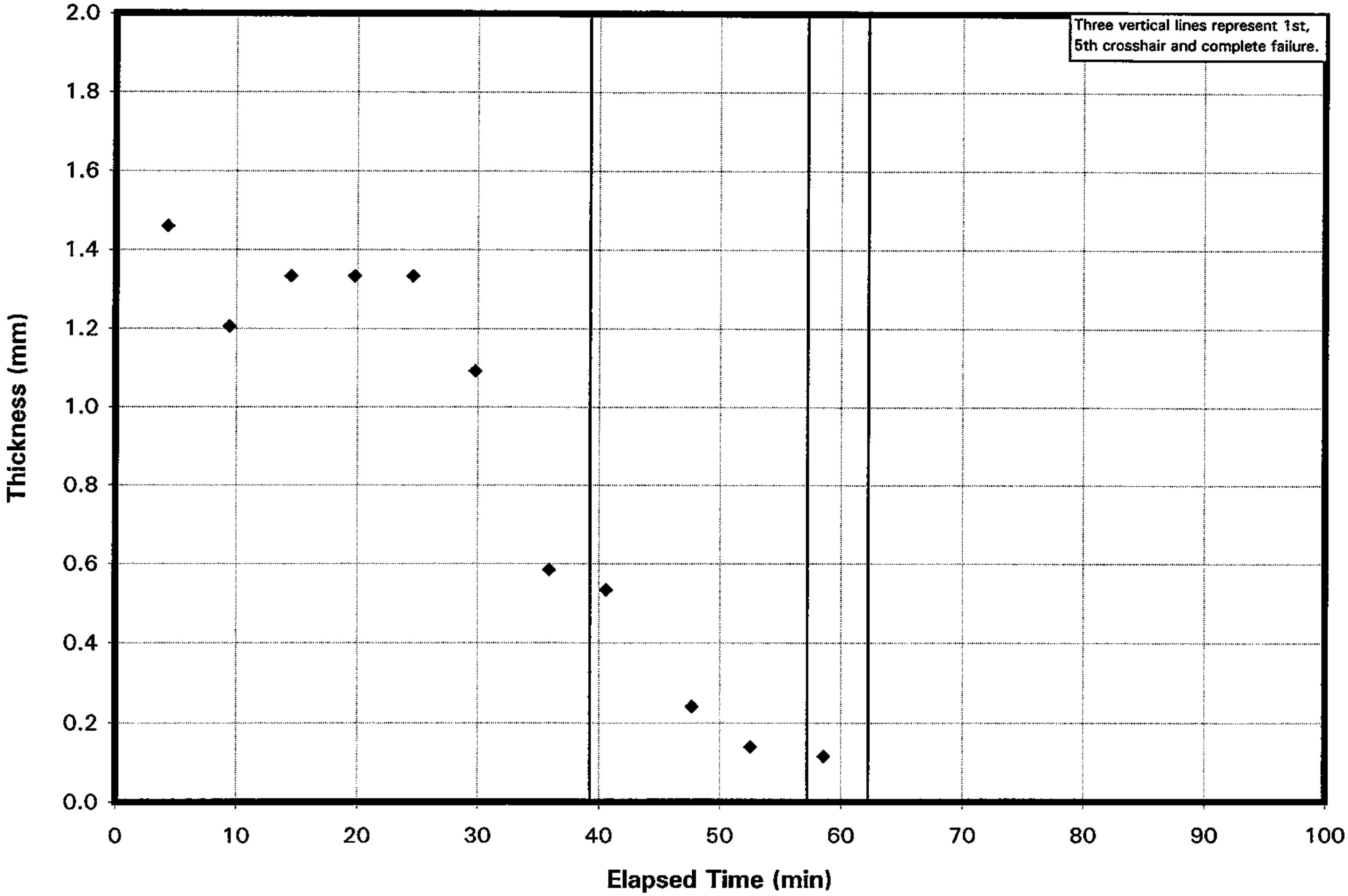


Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 22

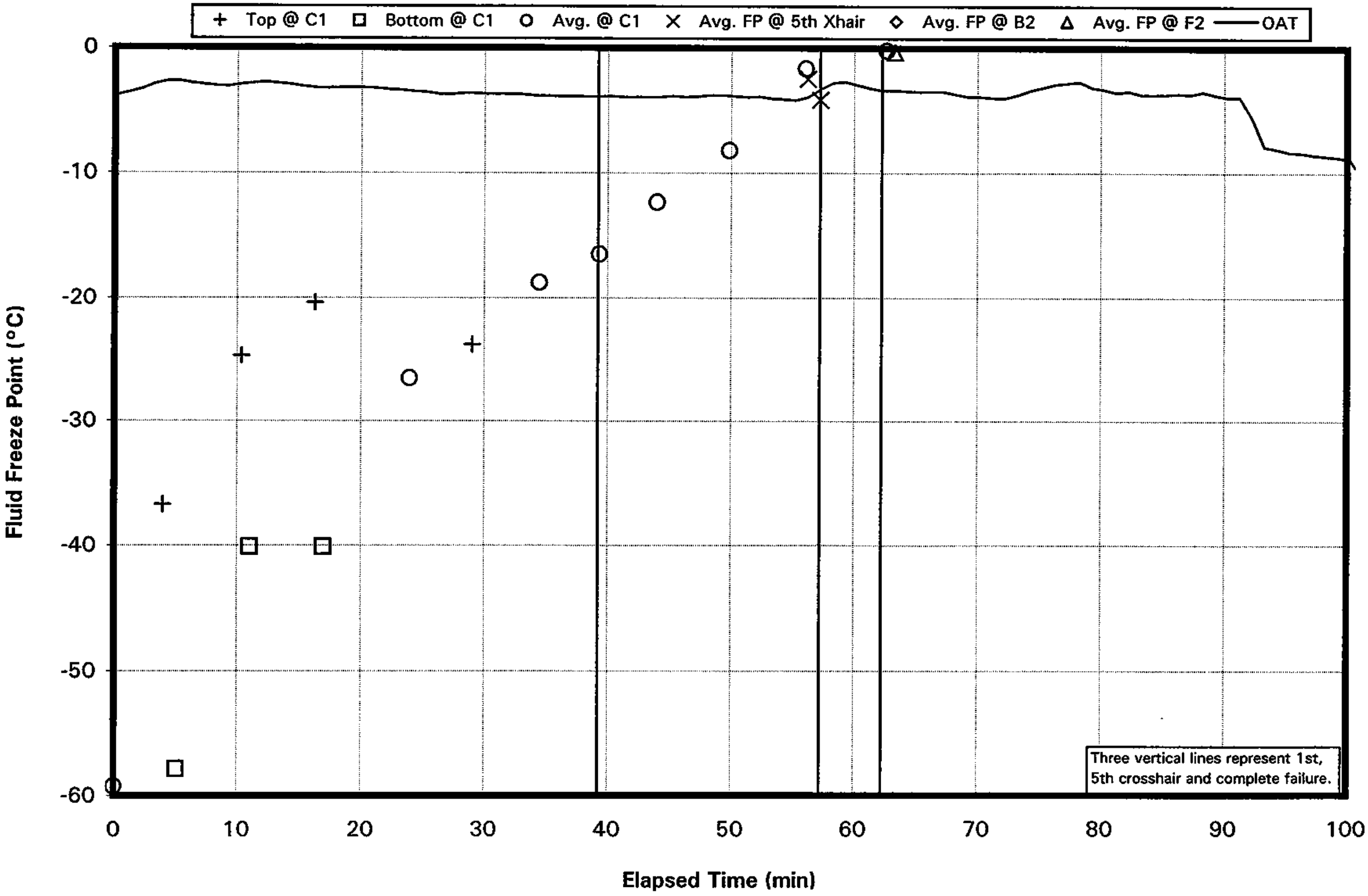


cm1380/analysis/doc_fail/thicknes/Thk_id22
10/14/98, 10:39 AM

DOCUMENTATION OF FLUID FAILURE

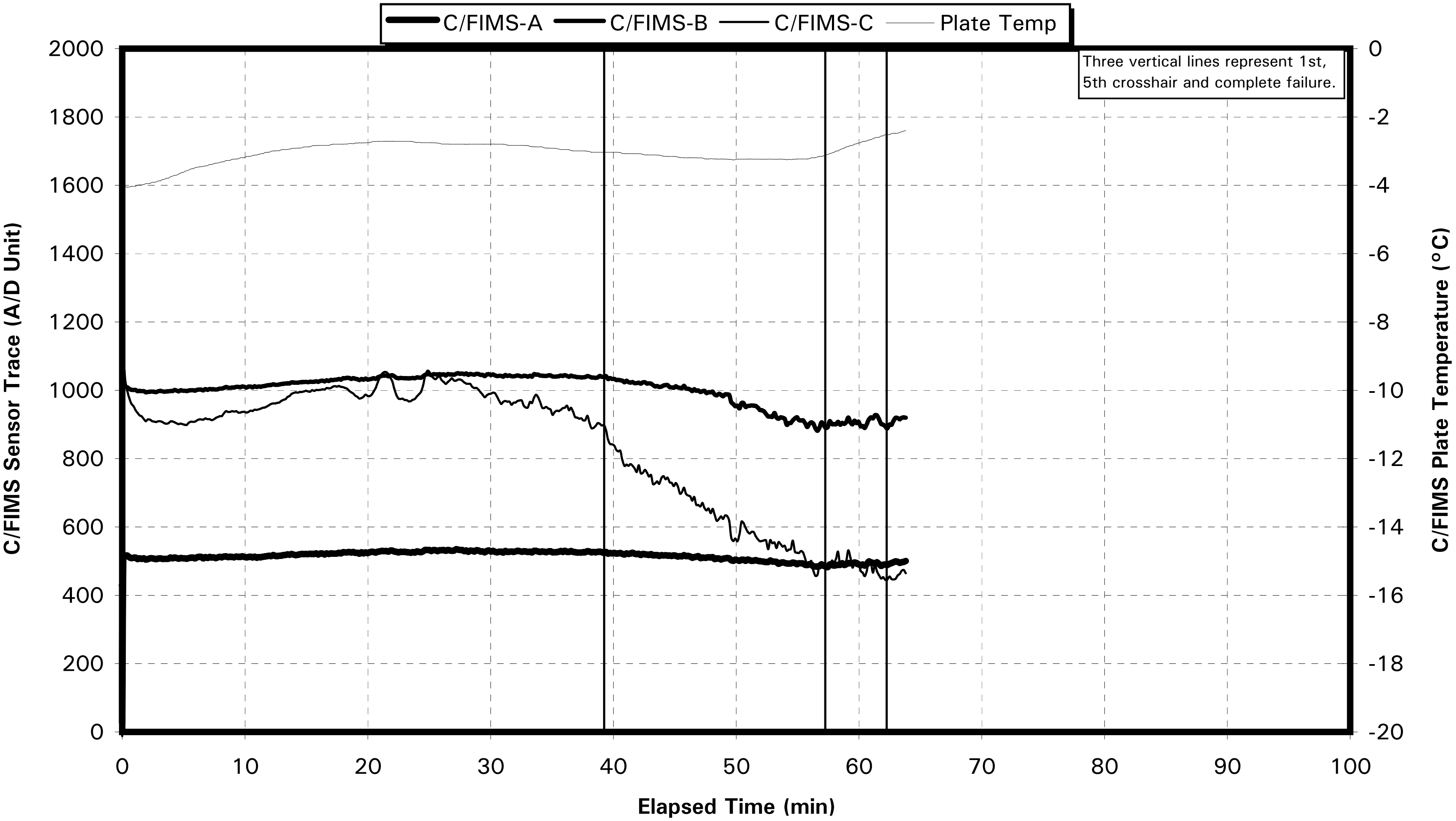
FLUID FREEZE POINT

ID # 22



cm1380/analysis/doc_fail/brix/Brx_id22
10/15/98, 9:44 AM

DOCUMENTATION OF FLUID FAILURE
C/FIMS SENSOR TRACE
ID # 22

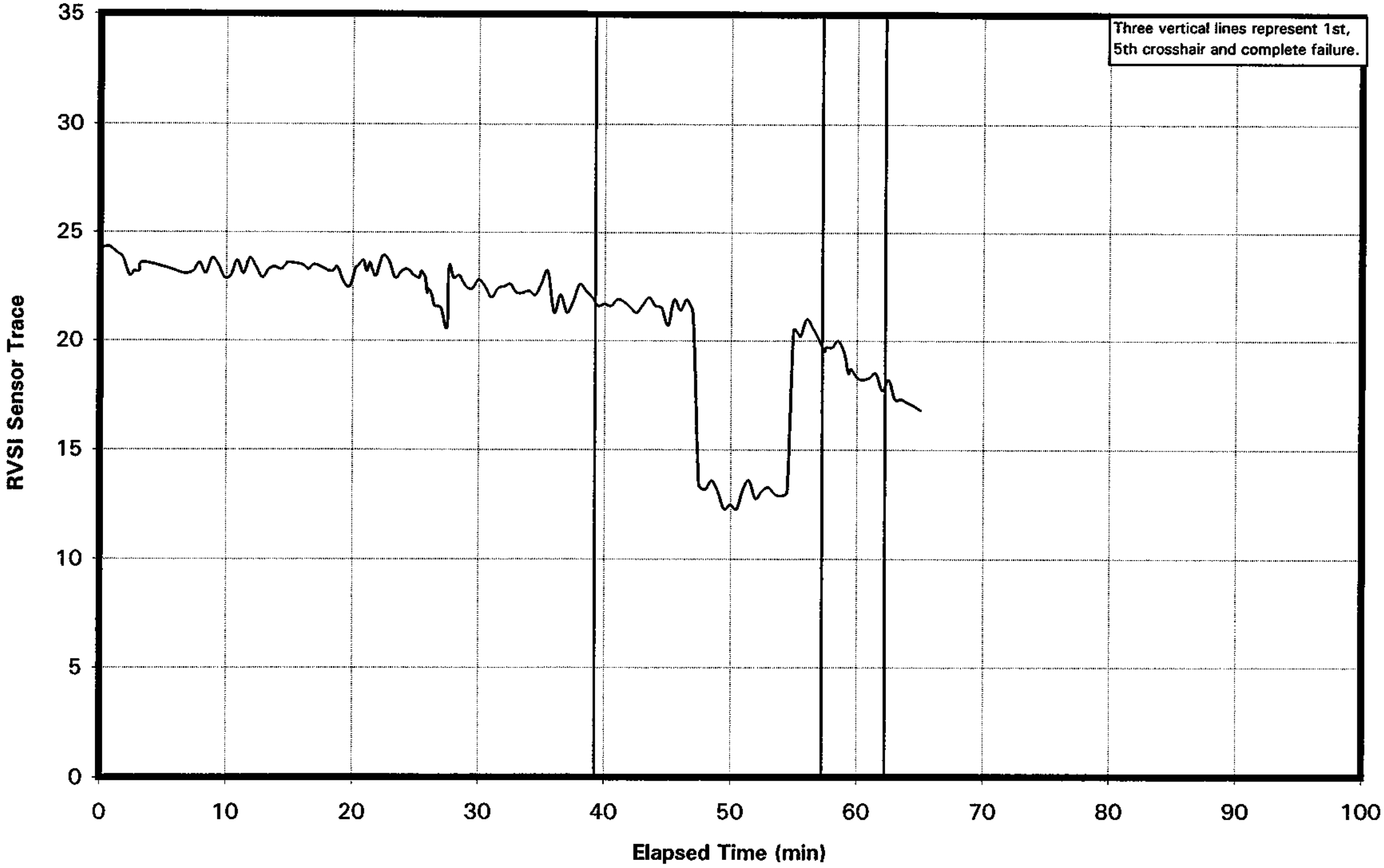


cm1380/analysis/doc_fail/cfims/CFM_ID22
9/21/2006, 4:26 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 22



cm1380/analysis/doc_fail/rvsi/Rvs_id22.xls
10/15/98, 12:26 PM

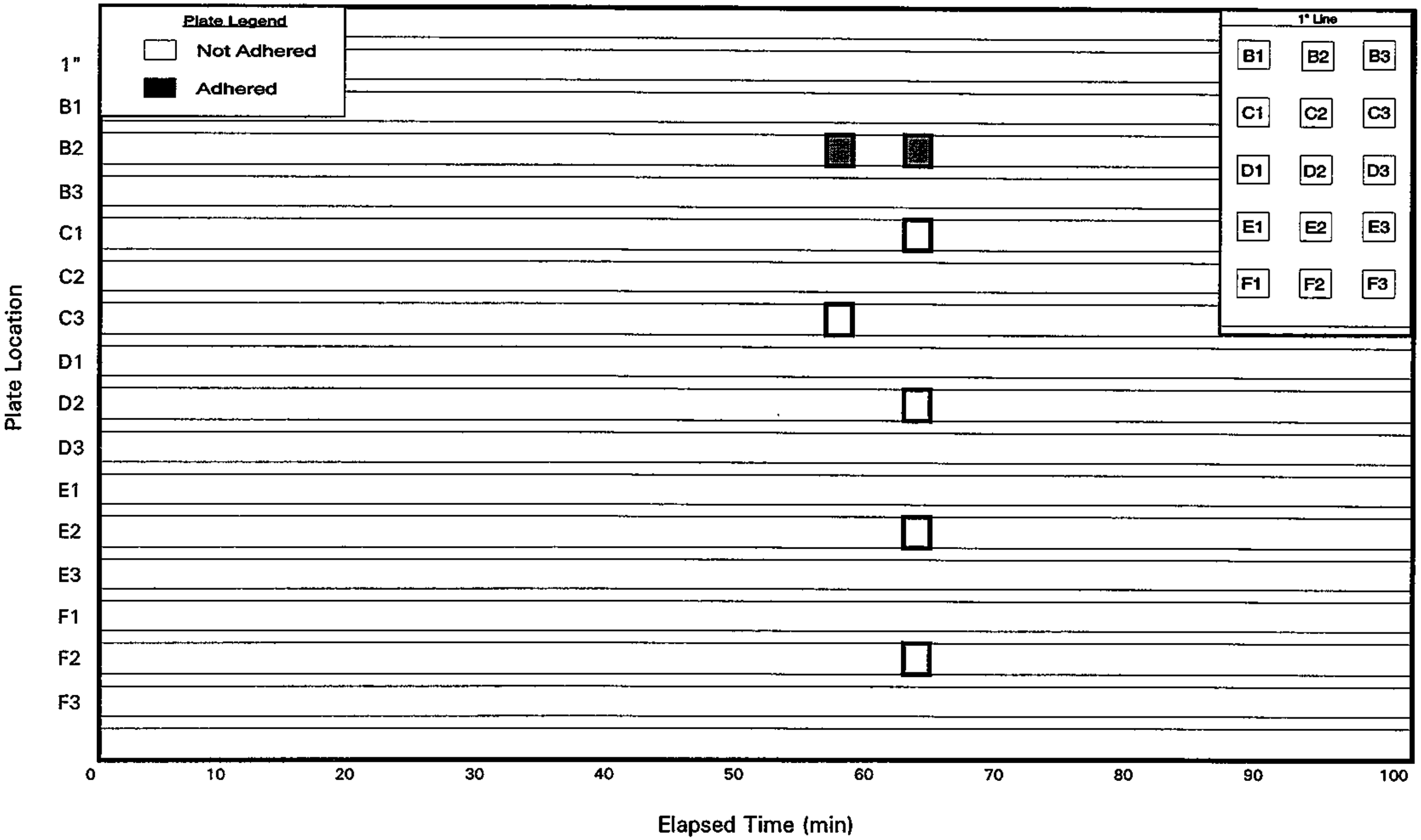
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 22

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 22



cm1380/analysis/doc_fail/Adh_id22
7/28/98, 10:36 AM

GENERAL TEST INFORMATION

ID # 23

July 9, 1998

Ambient Air Temperature:	-3.1°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	13.5 g/dm²/hr
Fluid:	OCTAGON
Dilution:	Neat
Start of Test:	12:56:15
Failure Mode:	5th X-hair
Failure Location:	D2
Failure Time (Standard):	13:20:00
Failure Time (Complete Plate):	13:37:00

cm1380/analysis/doc_fail/GEN_INFO
At: 23
9/21/2006, 4:27 PM

PHOTOS OF POUR AND FIRST FAILURE - ID # 23

Photo C23.1 - After Pouring, t = 0 min

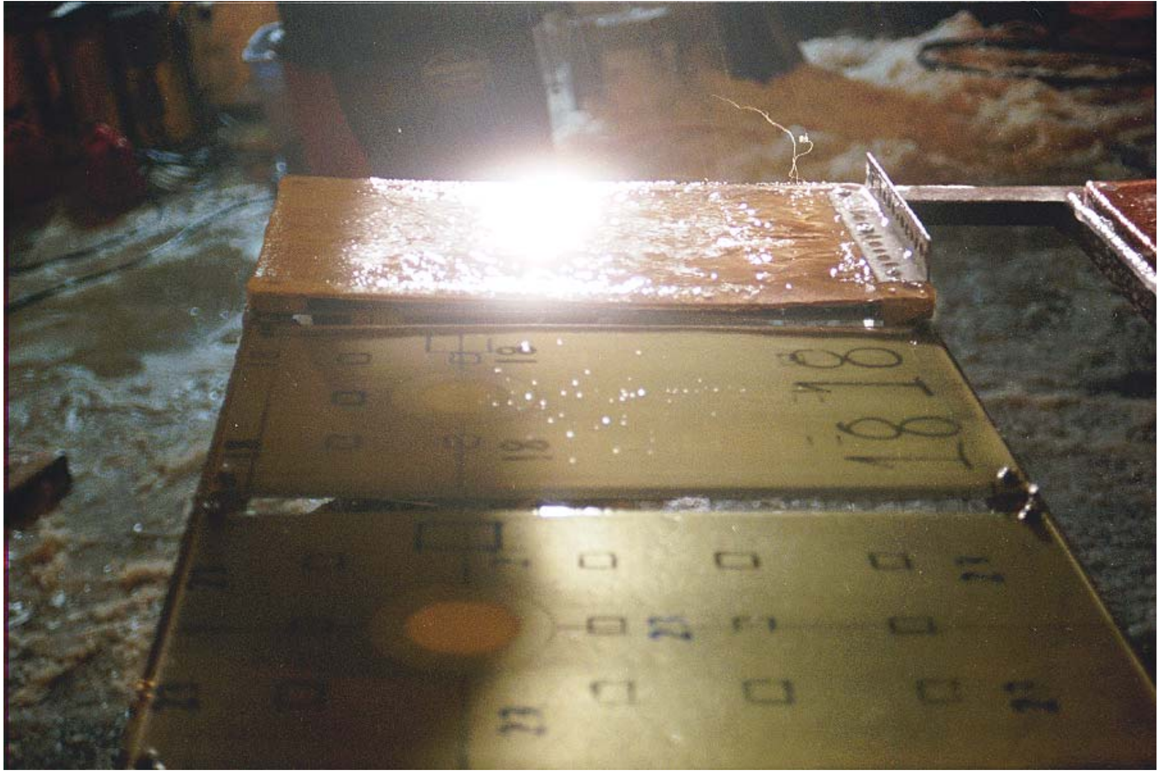


Photo C23.2- 1st Failure, t = 17 min (Est.)

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 23

Photo C23.3 - Standard Failure (1/3 or 5th Crosshair), t = 24 min

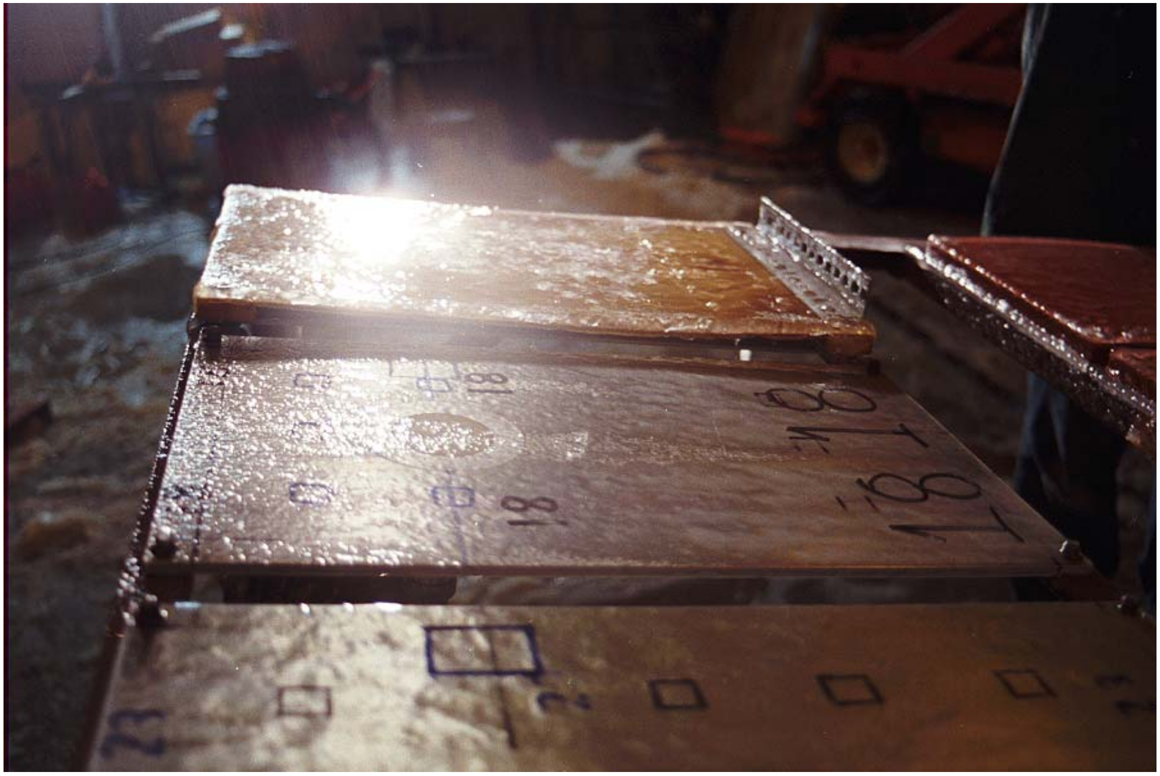
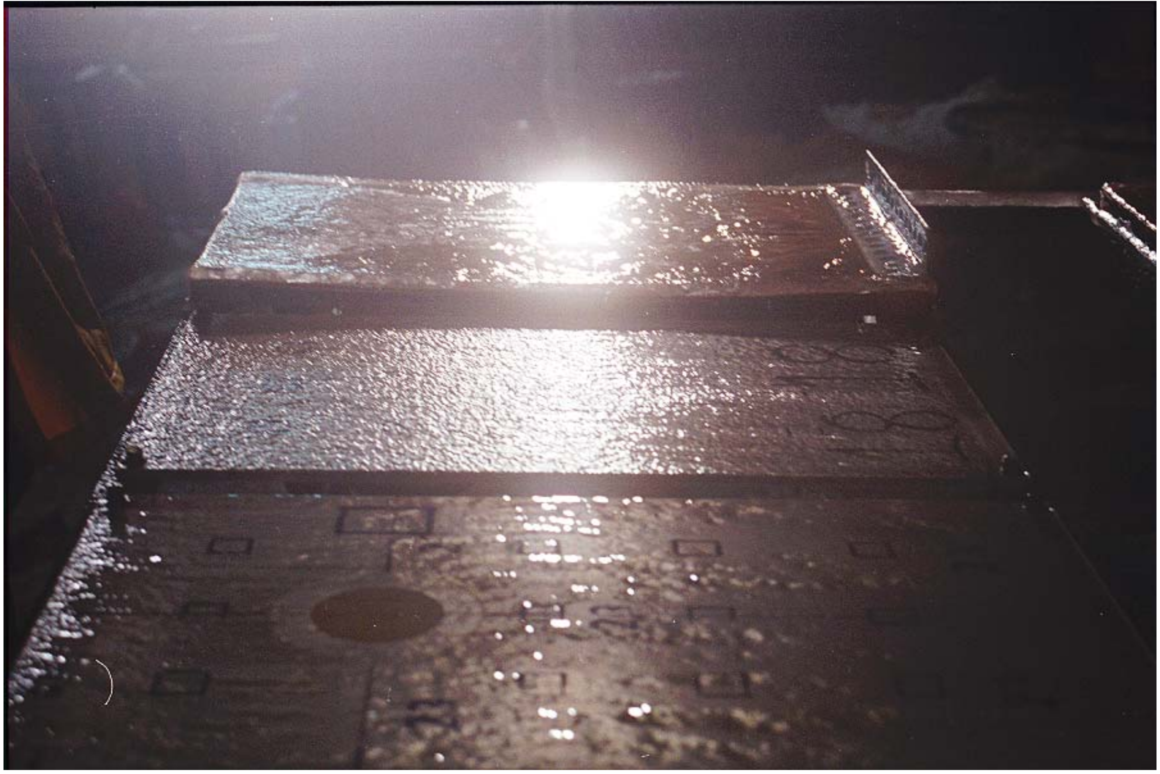


Photo C23.4 - Complete Fluid Failure, t = 41 min (Est.)



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Last printed 10/14/98 9:15 AM

ID# 23

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09

Time: 1256 20

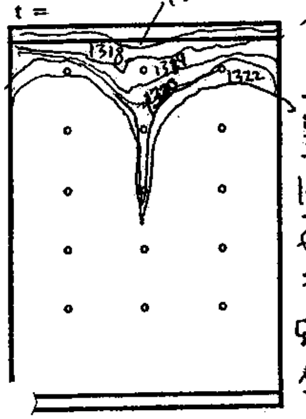
Plate Location: 5

Run #: 3b4

Fluid Name: Cet Wax

Fluid Dilution: 100%

t = 1313 1st f.



Pour; same as prev. descriptions

1313 1st failure

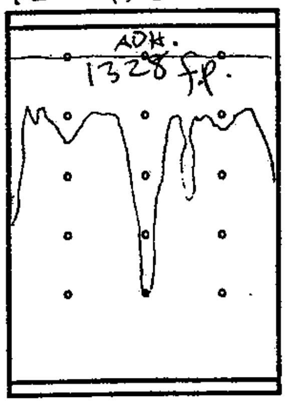
1st X Hair 1319

fine platelets -> streaks -> fingers.

~~5th X Hair~~ 1322

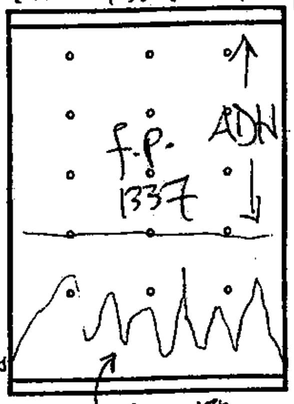
ADH above 3" line

t = 1328



f.p. = failure progress

t = 1337 Full plate failure: INECH



Small platelets ↓ streaks ↓ fingers ↓ ~~l~~ateral fusion of fingers.

~~thickened~~ thinned marbled liq with solids.

t =

t =

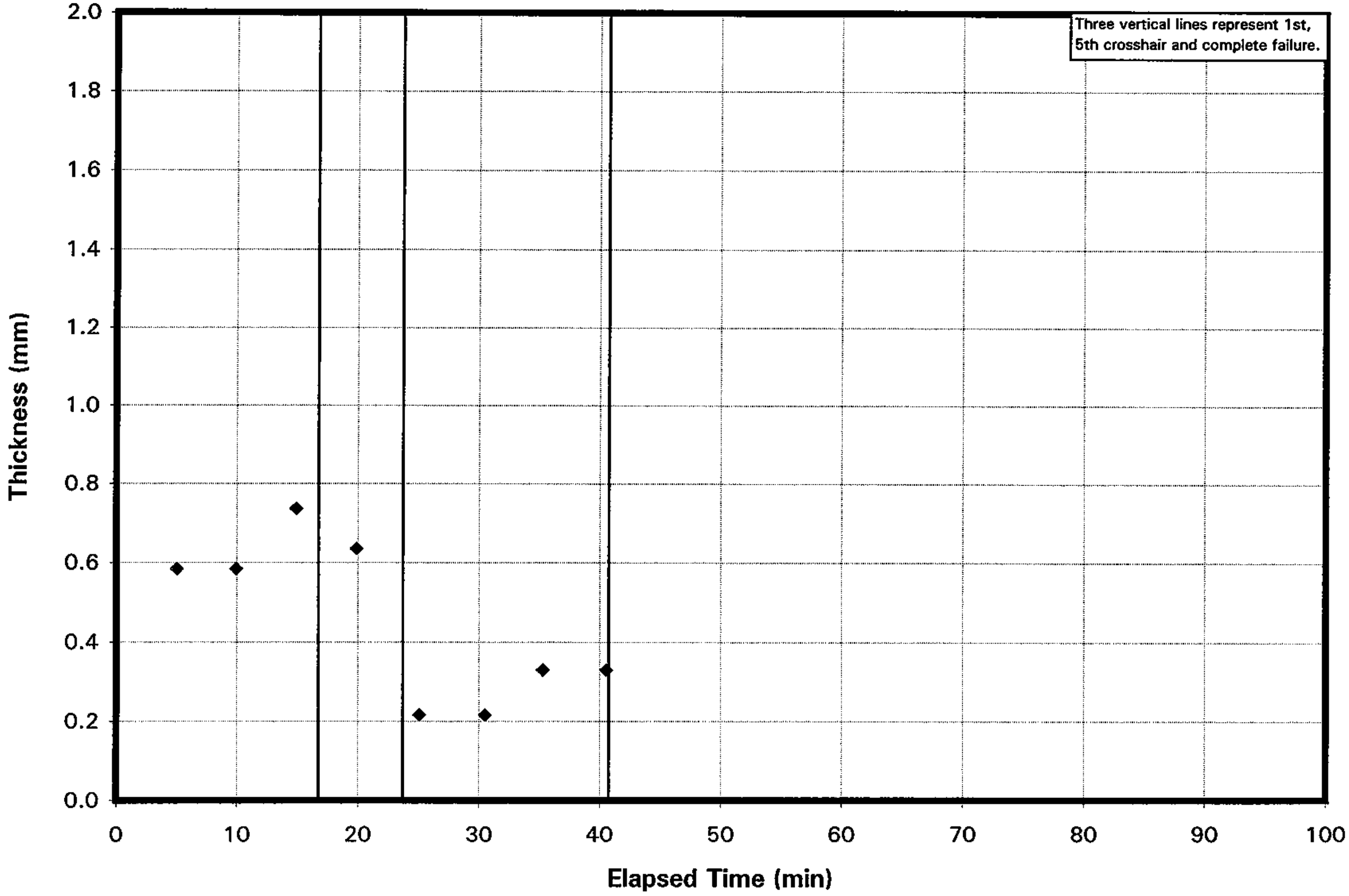
t =

Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 23

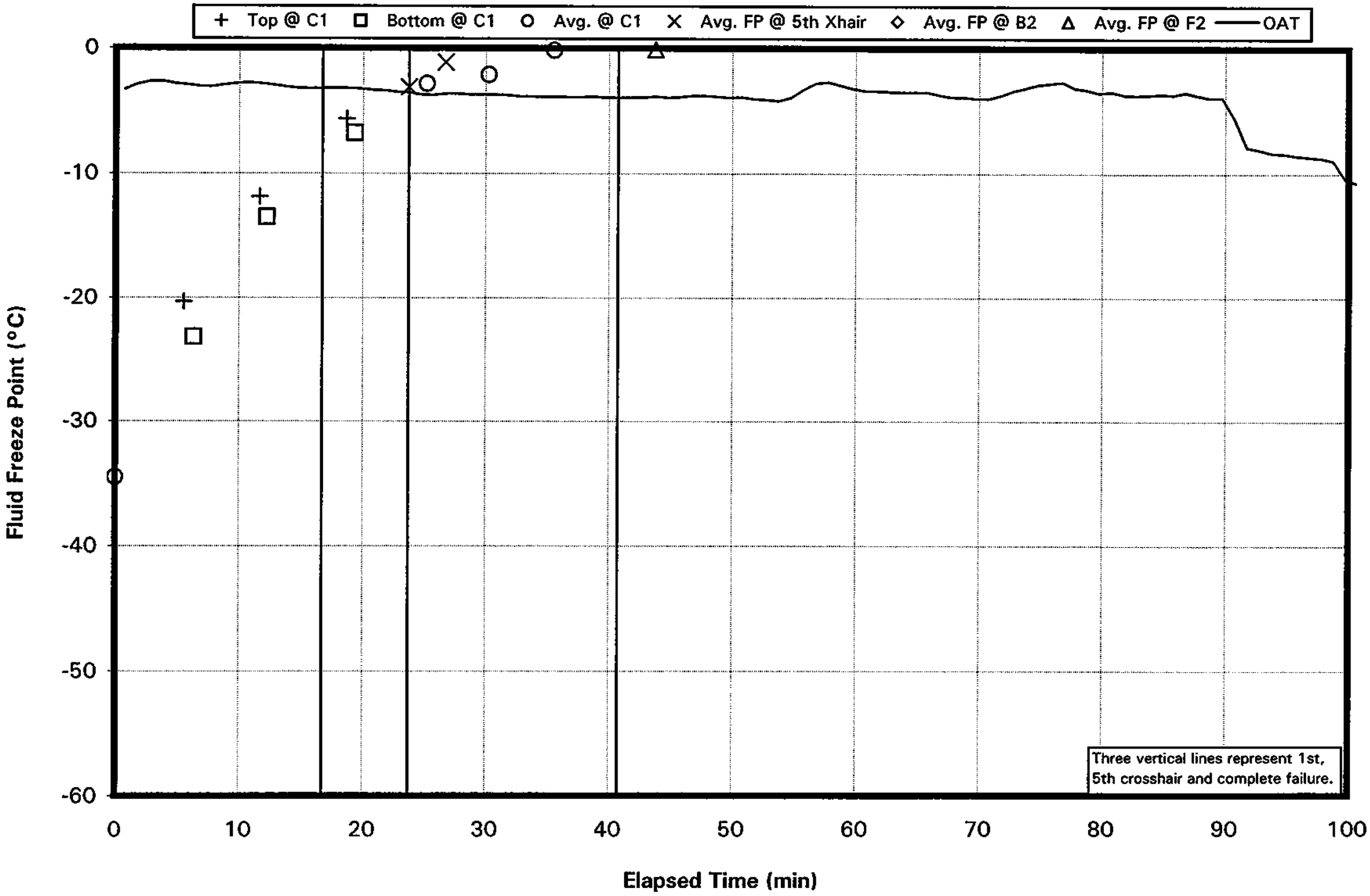


cm1380/analysis/doc_fail/thicknes/Thk_id23
10/14/98, 10:39 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 23

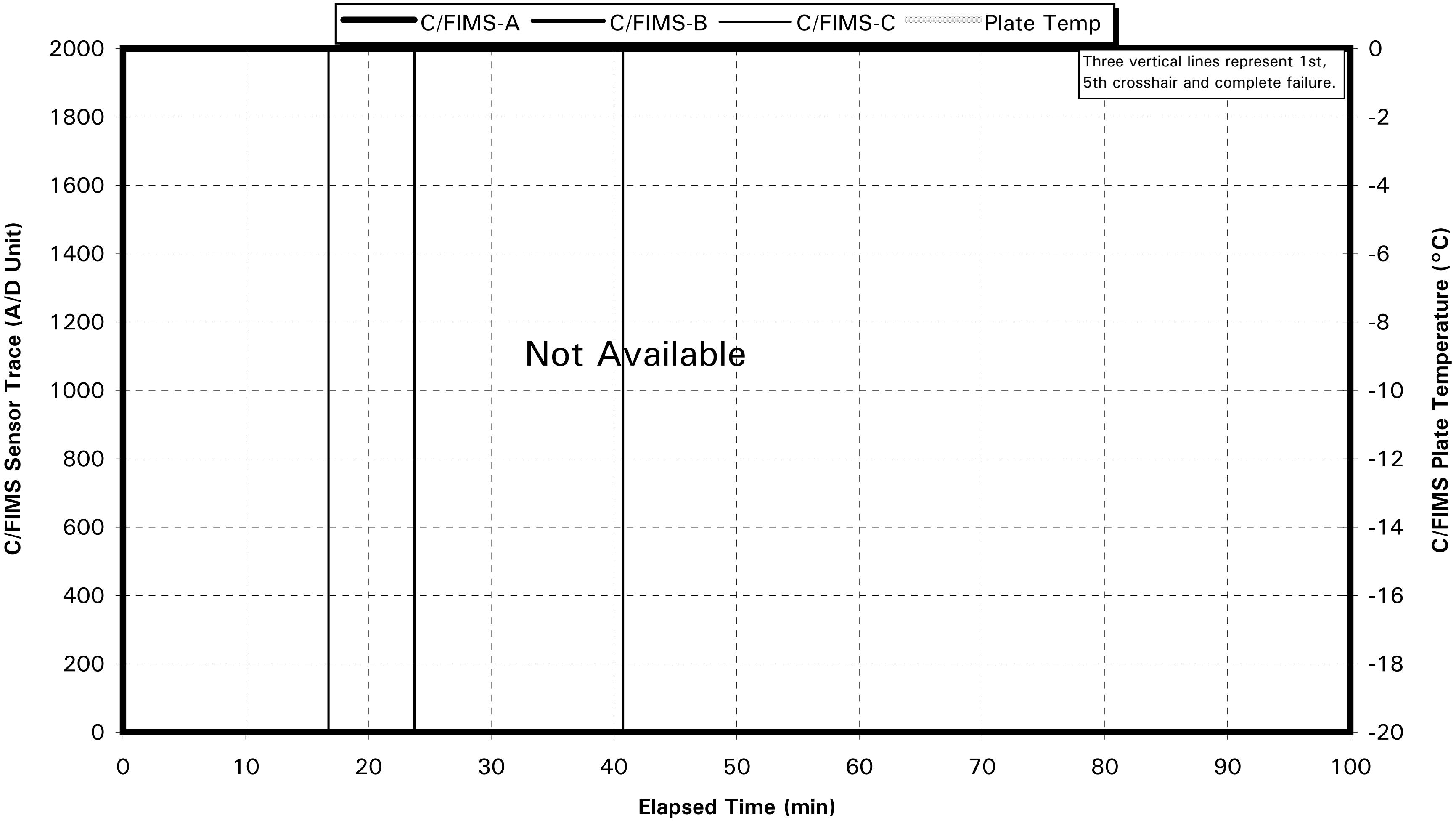


cm1380/analysis/doc_fail/brix/Brx_id23
10/15/98, 9:44 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 23

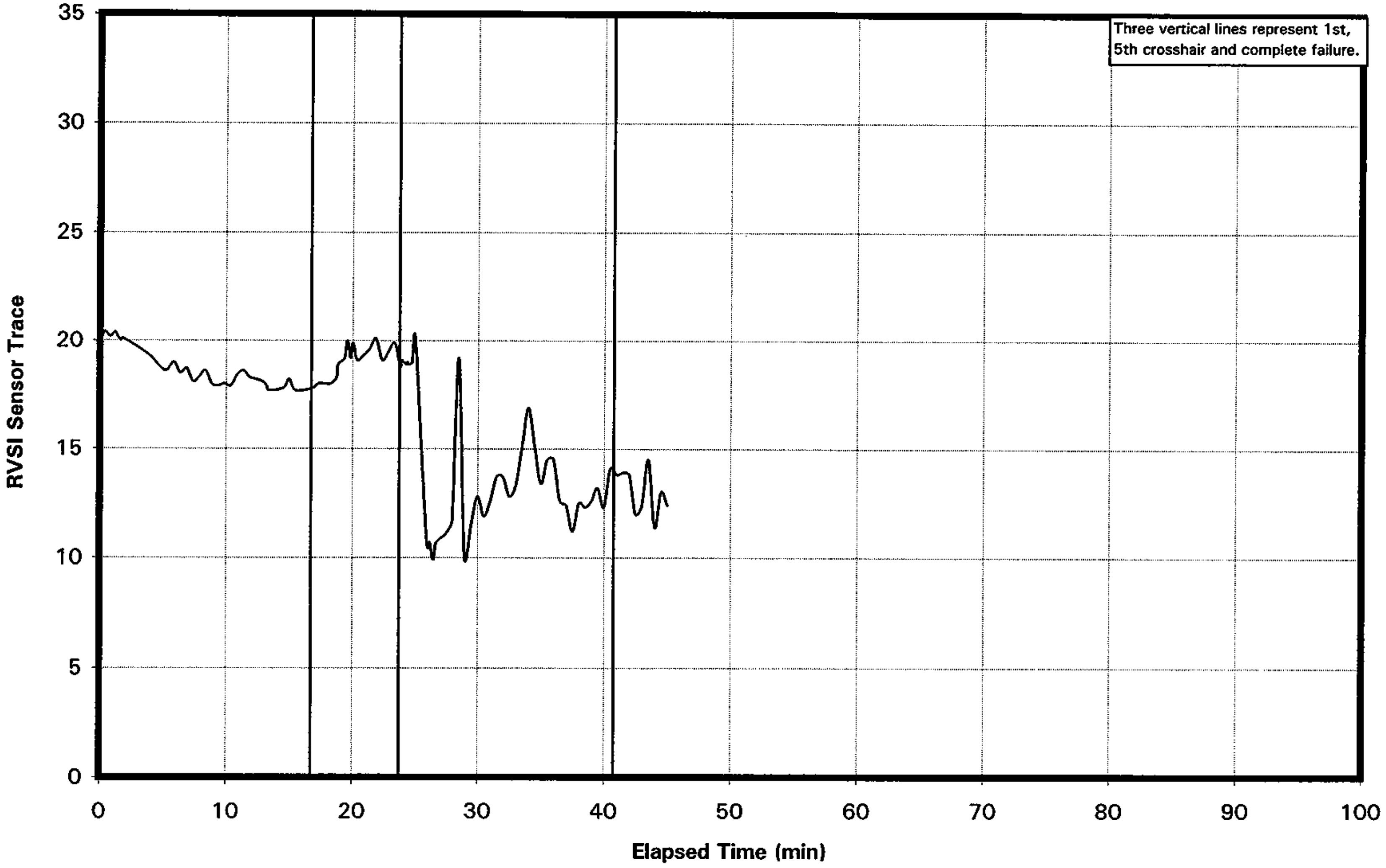


cm1380/analysis/doc_fail/cfims/CFM_ID23
9/21/2006, 4:30 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 23



cm1380/analysis/doc_fail/rvsi/Rvs_id23.xls
10/15/98, 12:25 PM

DOCUMENTATION OF FLUID FAILURE

COX/SPAR SENSOR TRACE

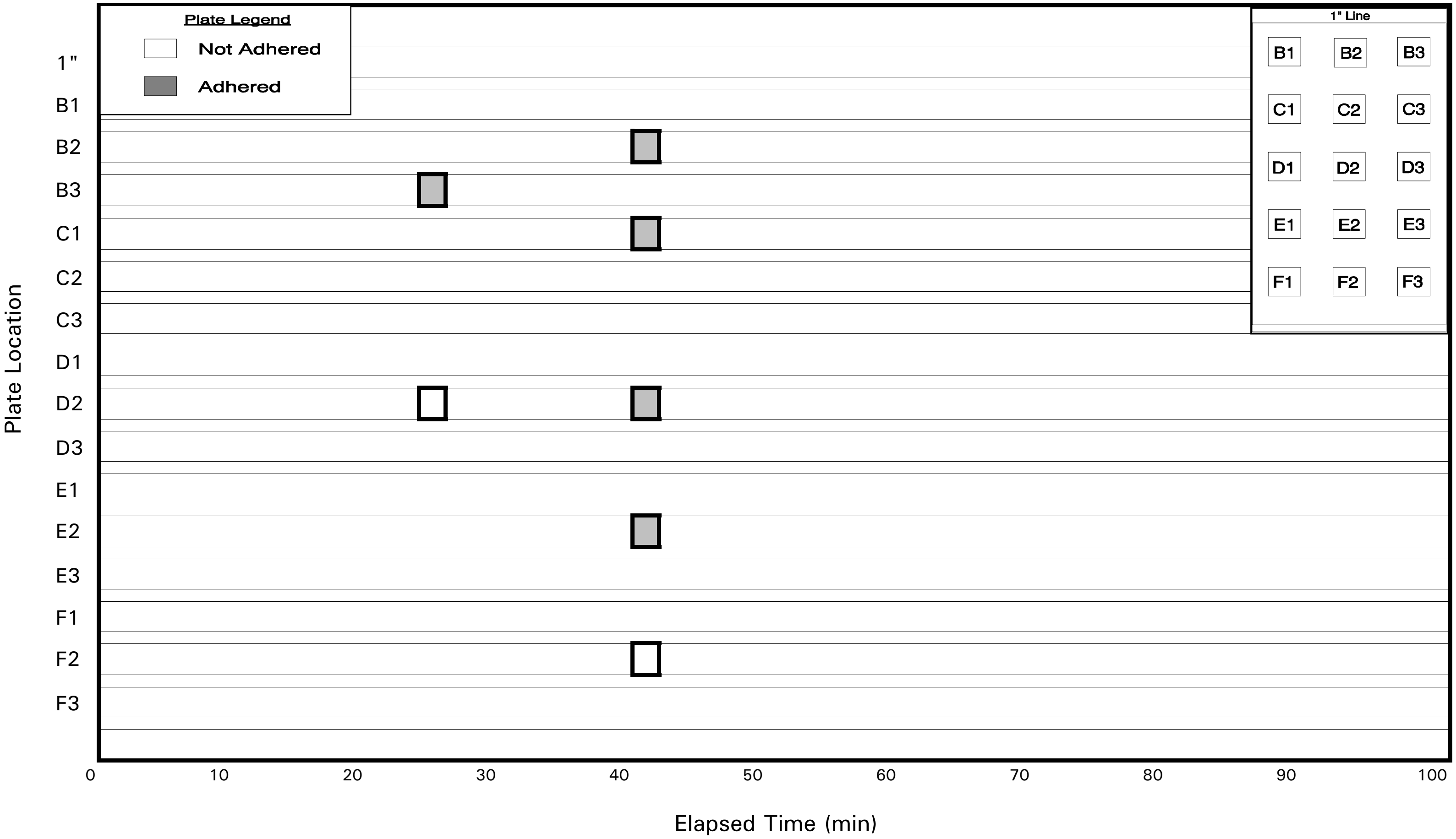
ID # 23

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 23



cm1380/analysis/doc_fail/ADH_ID23
9/21/2006, 4:32 PM

GENERAL TEST INFORMATION

ID # 24

July 9, 1998

Ambient Air Temperature:	-10.6°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	4.7 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	15:29:30
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	16:51:00
Failure Time (Complete Plate):	16:54:00

cm1380/analysis/doc_fail/GEN_INFO
At: 24
9/21/2006, 4:32 PM

PHOTOS OF POUR AND FIRST FAILURE - ID # 24

Photo C24.1 - After Pouring, t = 0 min

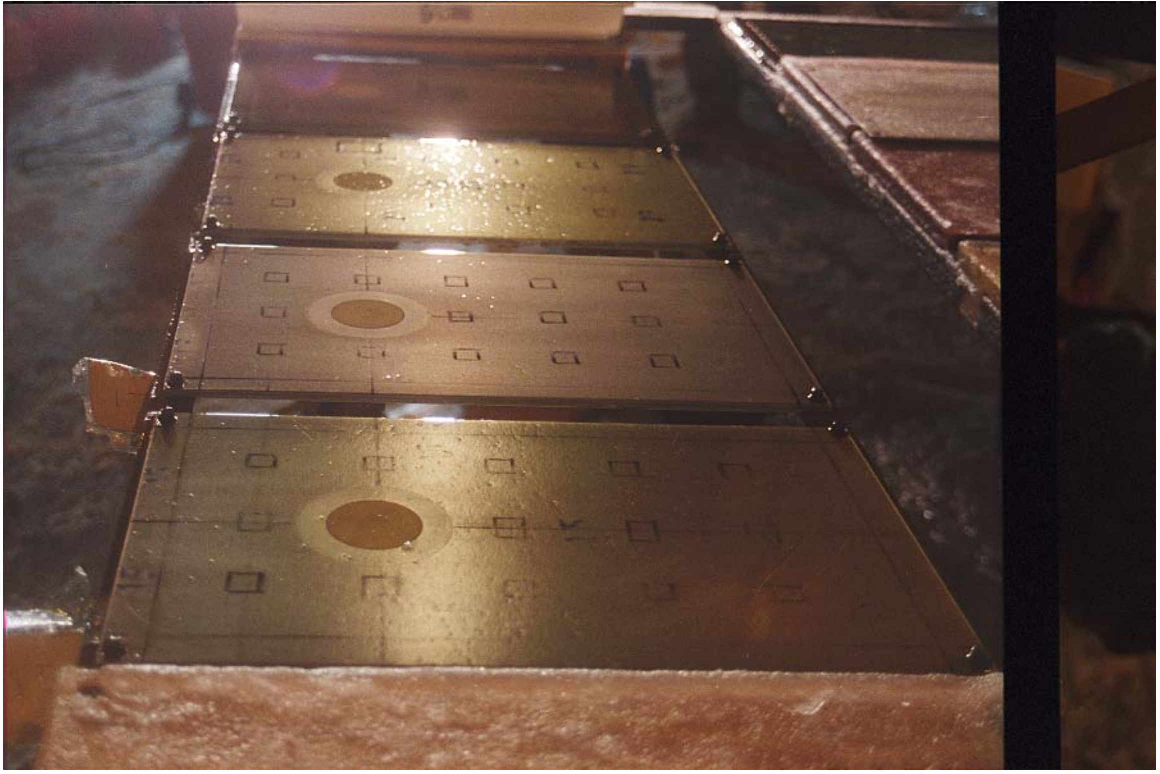
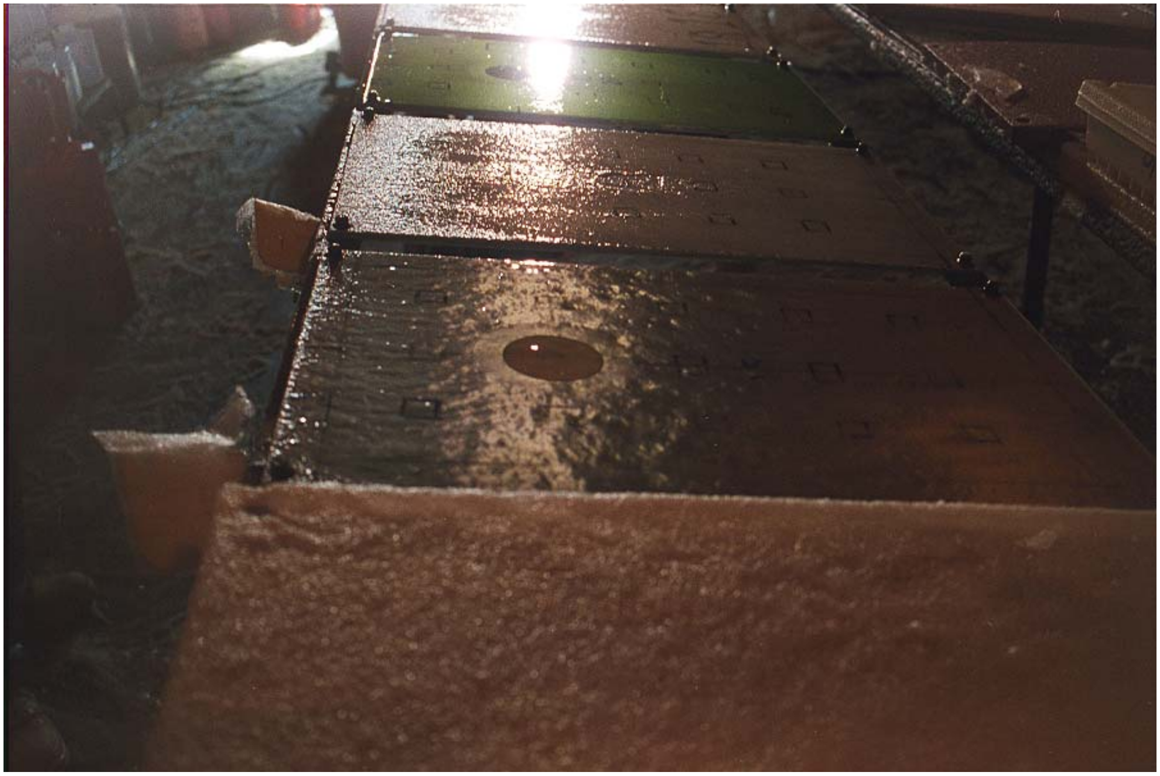


Photo C24.2 - 1st Failure, t = 67 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 24

Photo C24.3 - Standard Failure (1/3 or 5th Crosshair), t = 82 min (Est.)

NOT AVAILABLE

Photo C24.4 - Complete Fluid Failure, t = 85 min (Est.)

NOT AVAILABLE

\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID24.doc
Last printed 10/14/98 9:16 AM

ID# 24

SUBJECTIVE APPEARANCE OF FLUID FAILURE

ZR
Rate = 5
T = -10°C

Date: July 09

Time: 1529³⁰

Plate Location: 2

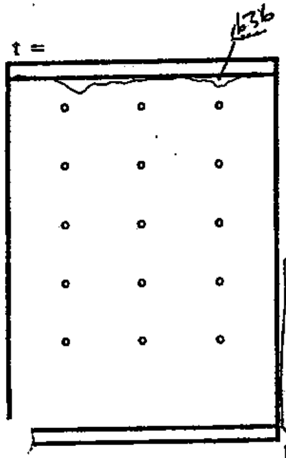
Run #: 26.

Fluid Name: ULTRA+

Fluid Dilution: 100%

1636 1st f.

t =



Perm: same as usu.

1543 NO ENG.

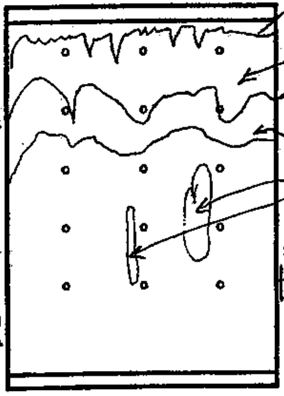
speckle phase development is very slow.

1602 1st failure at upper edge of plate mix of speckle + o.p. proceeding to marbled phase

1615 Completely marbled surface of fluid

1636 1st failure within 1" line: v. fine platelet overlapping. v. wet. Remaining marbled fluid beginning to break up by channelling

t =



1642 wet failure

1648 " "

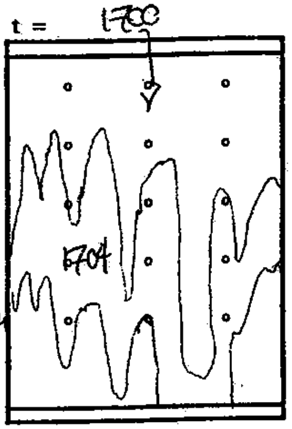
1651 5X-Hairs

1656 almost all

is a non-failed region thin ~~[illegible]~~ dilute fluid layer (pre-failure)

almost no marble left.

t = 1700



1705 full plate failure; ADD to 1" line only -

t =

t =

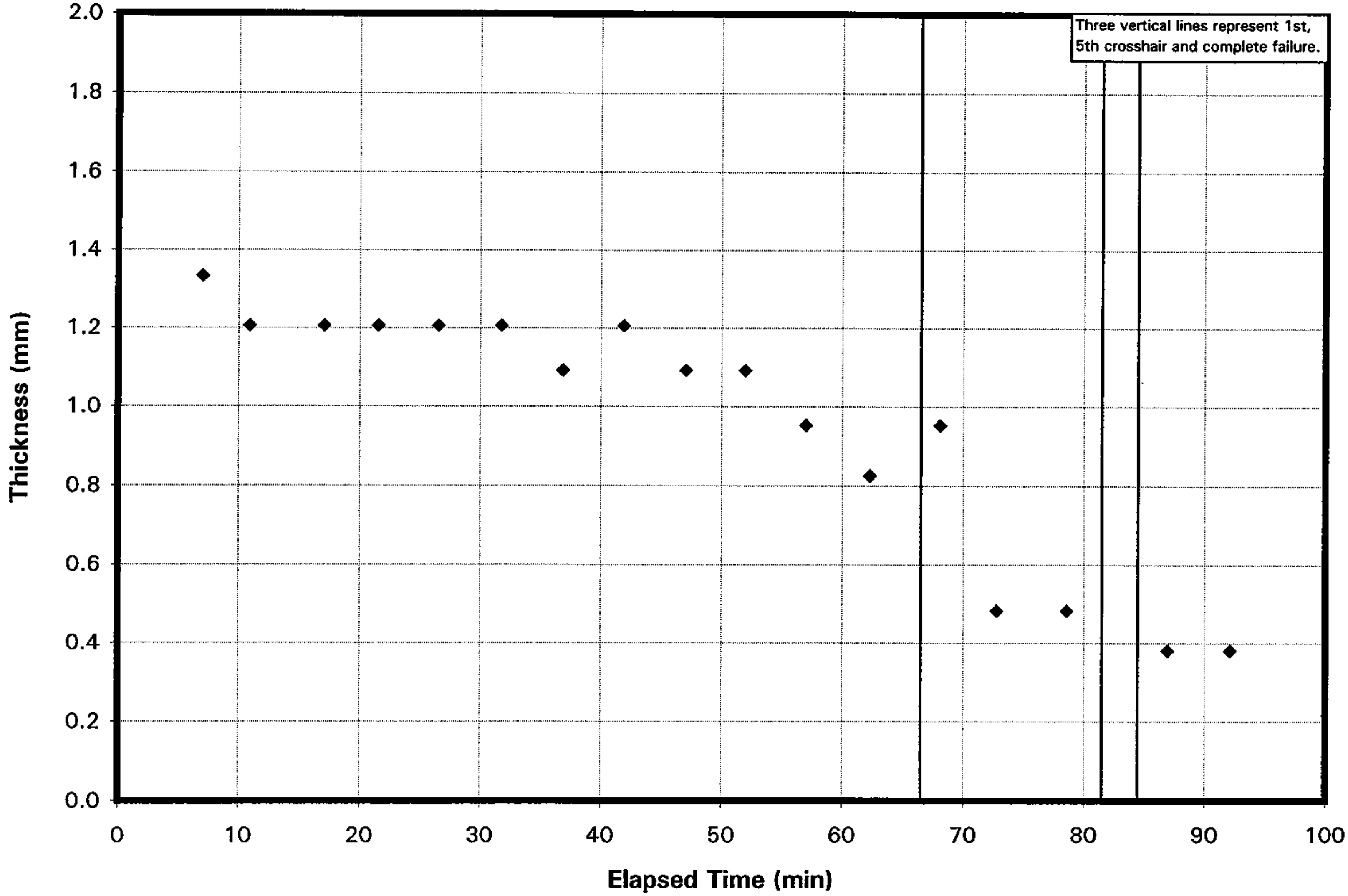
t =

Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 24

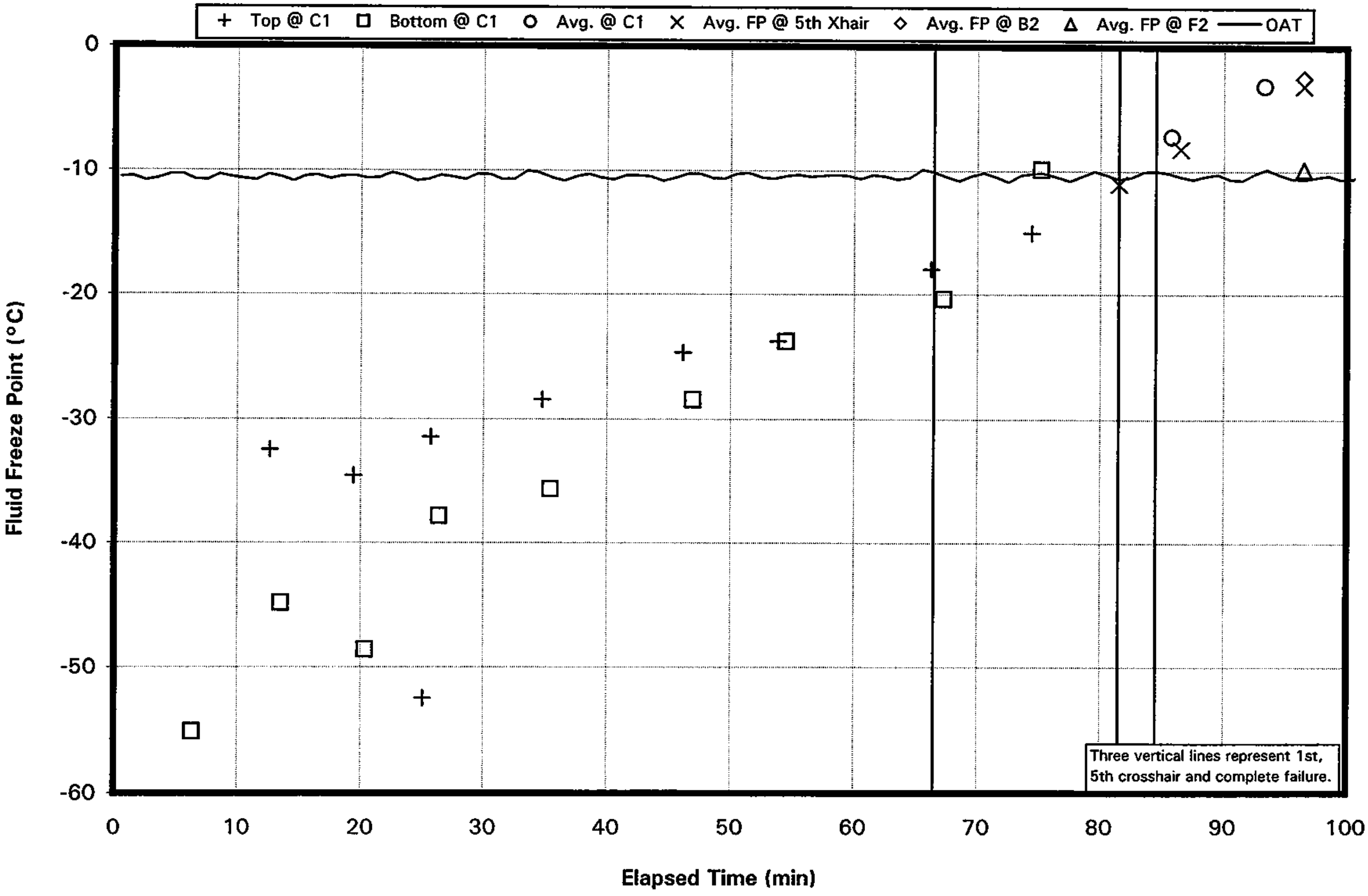


cm1380/analysis/doc_fail/thicknes/Thk_id24
10/14/98, 10:38 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 24

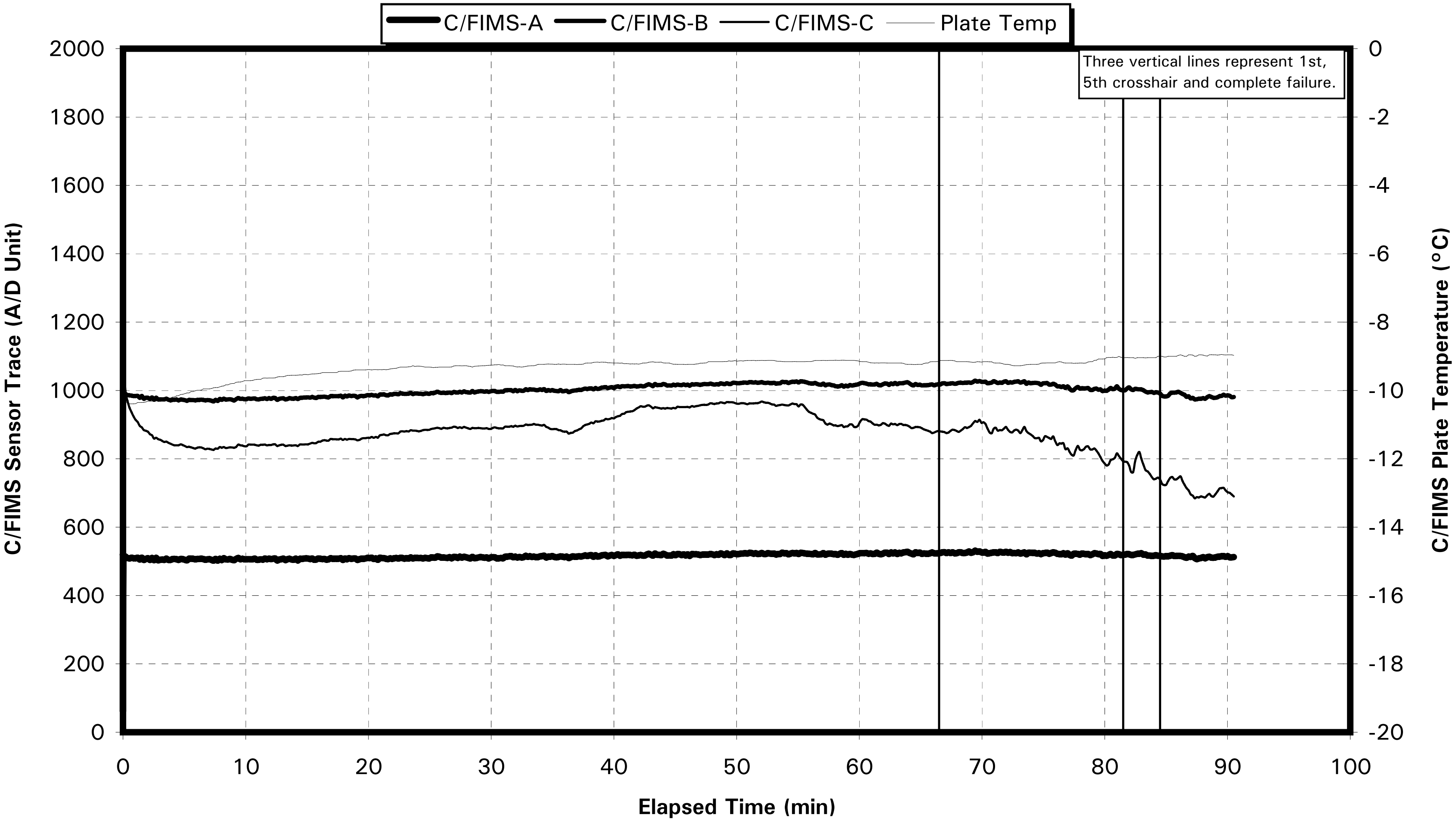


cm1380/analysis/doc_fail/brix/Brx_id24
10/15/98, 9:43 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 24

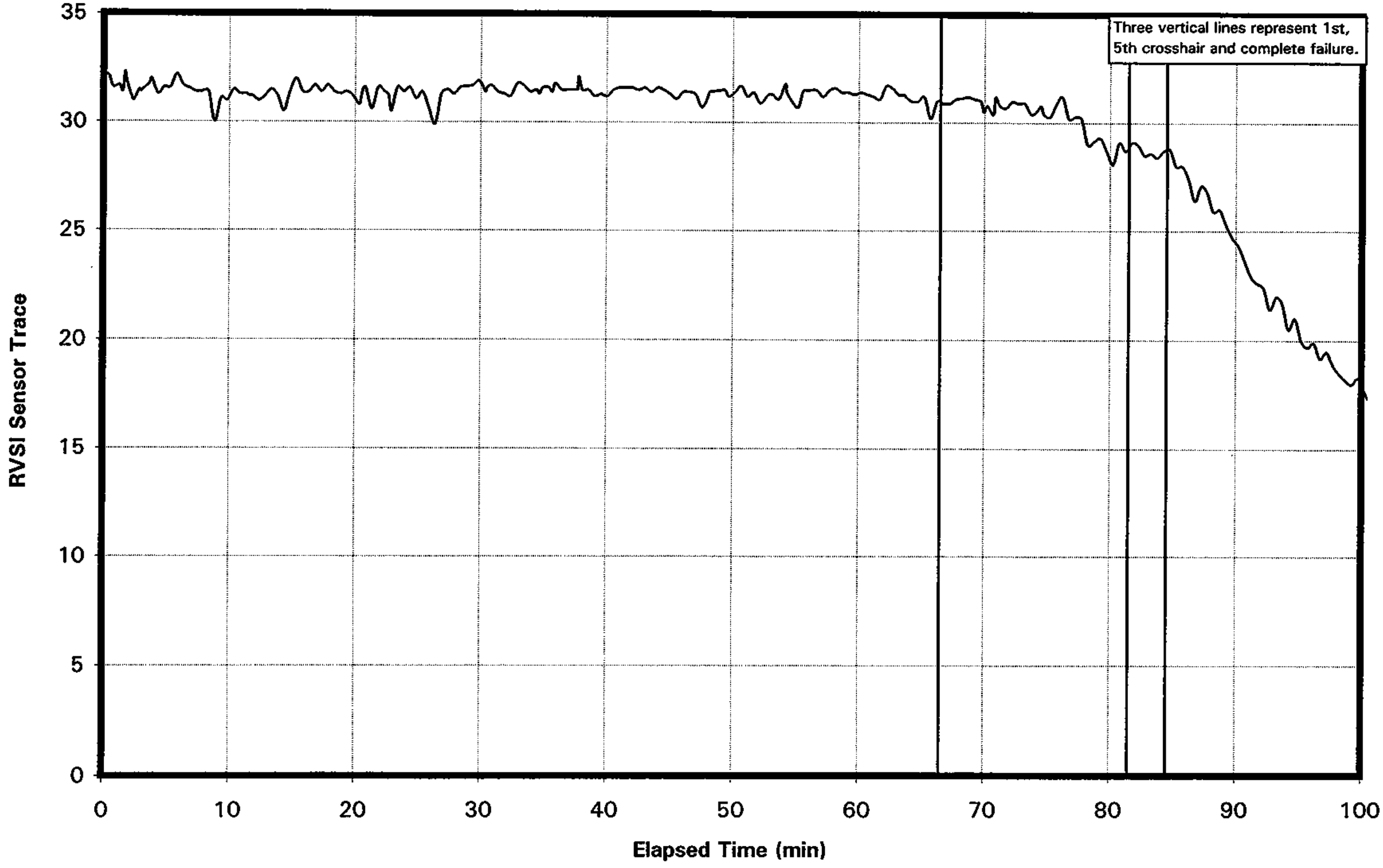


cm1380/analysis/doc_fail/cfims/CFM_ID24
9/21/2006, 4:45 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 24



cm1380/analysis/doc_fail/rvsi/Rvs_id24.xls
10/15/98, 12:24 PM

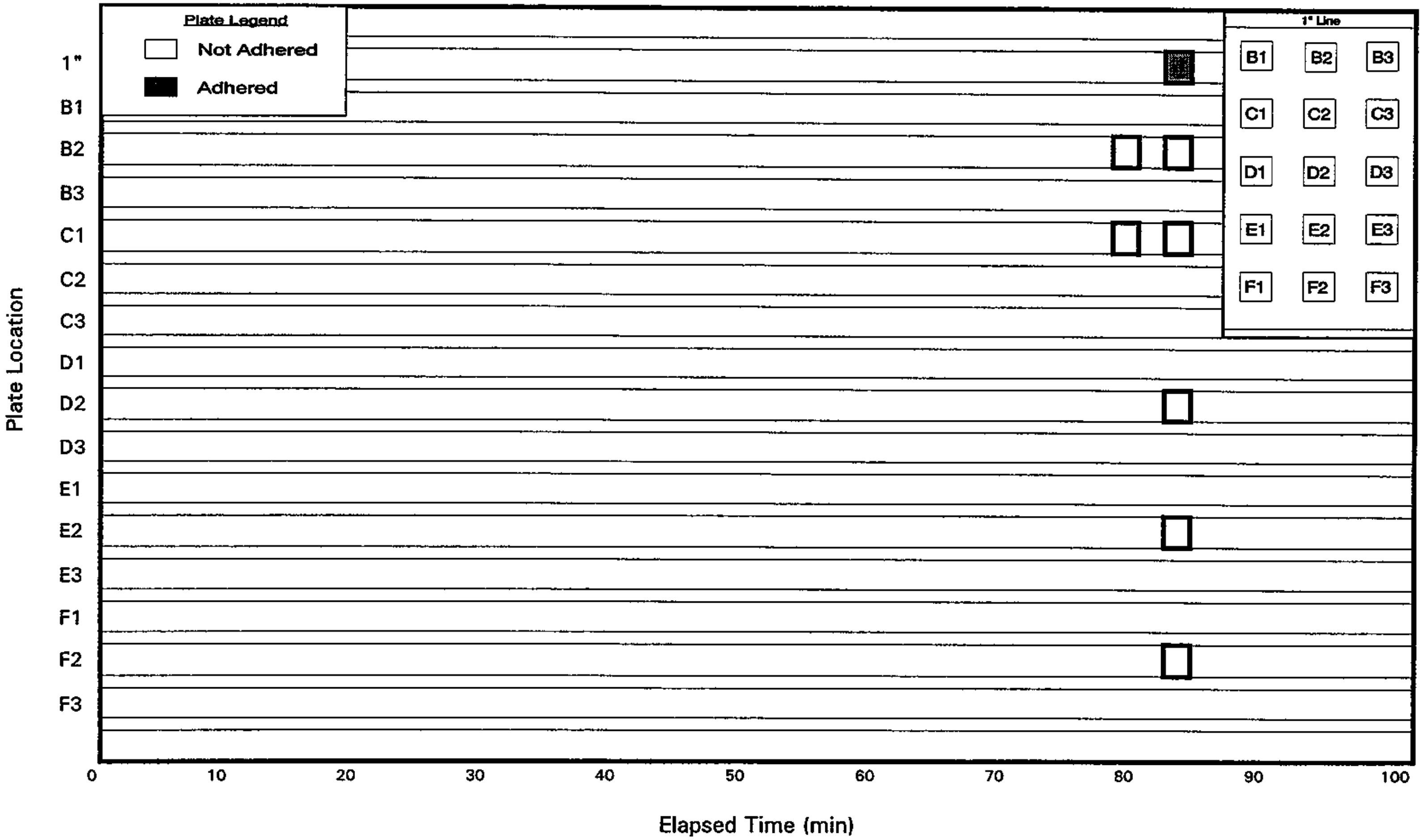
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 24

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 24



cm1380/analysis/doc_fail/Adh_id24
7/28/98, 10:40 AM

GENERAL TEST INFORMATION

ID # 25

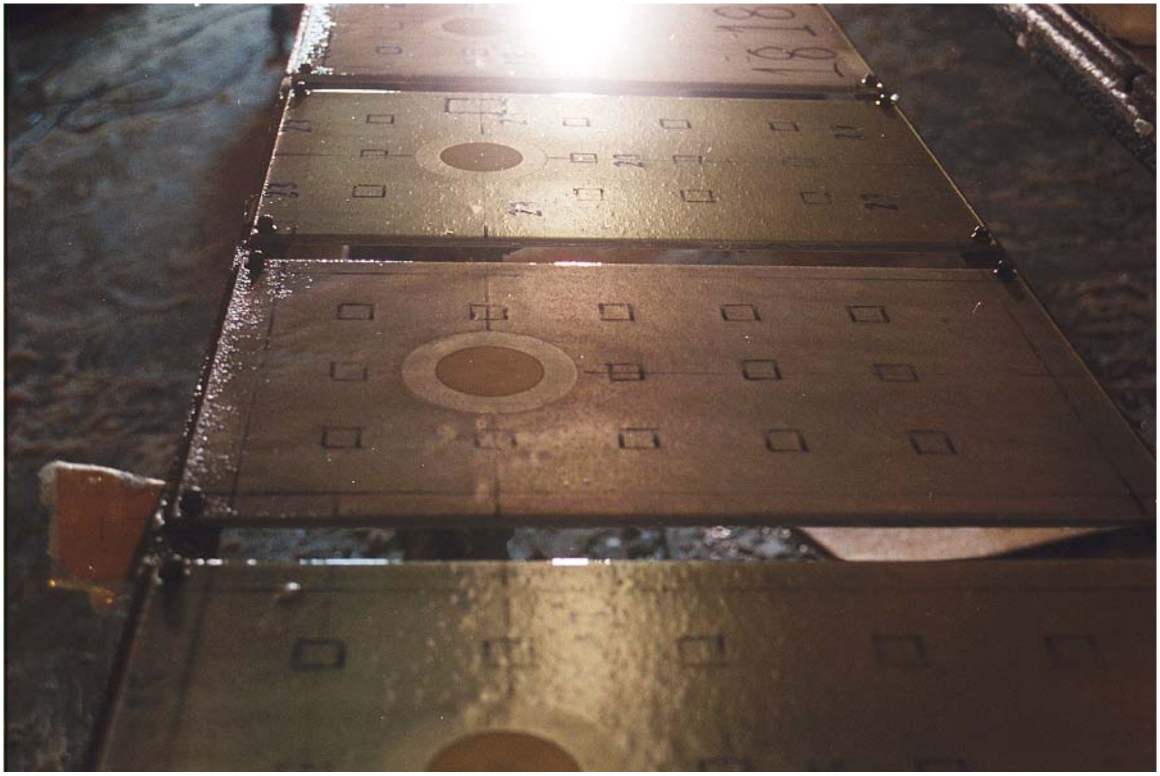
July 9, 1998

Ambient Air Temperature:	-10.6°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	5 g/dm²/hr
Fluid:	OCTAGON
Dilution:	Neat
Start of Test:	15:31:15
Failure Mode:	5th X-hair
Failure Location:	D2
Failure Time (Standard):	16:36:00
Failure Time (Complete Plate):	16:49:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 25

Photo C25.1 - After Pouring, t = 0 min

Photo C25.2 - 1st Failure, t = 23 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 25

Photo C25.3 - Standard Failure (1/3 or 5th Crosshair), t = 65 min (Est.)

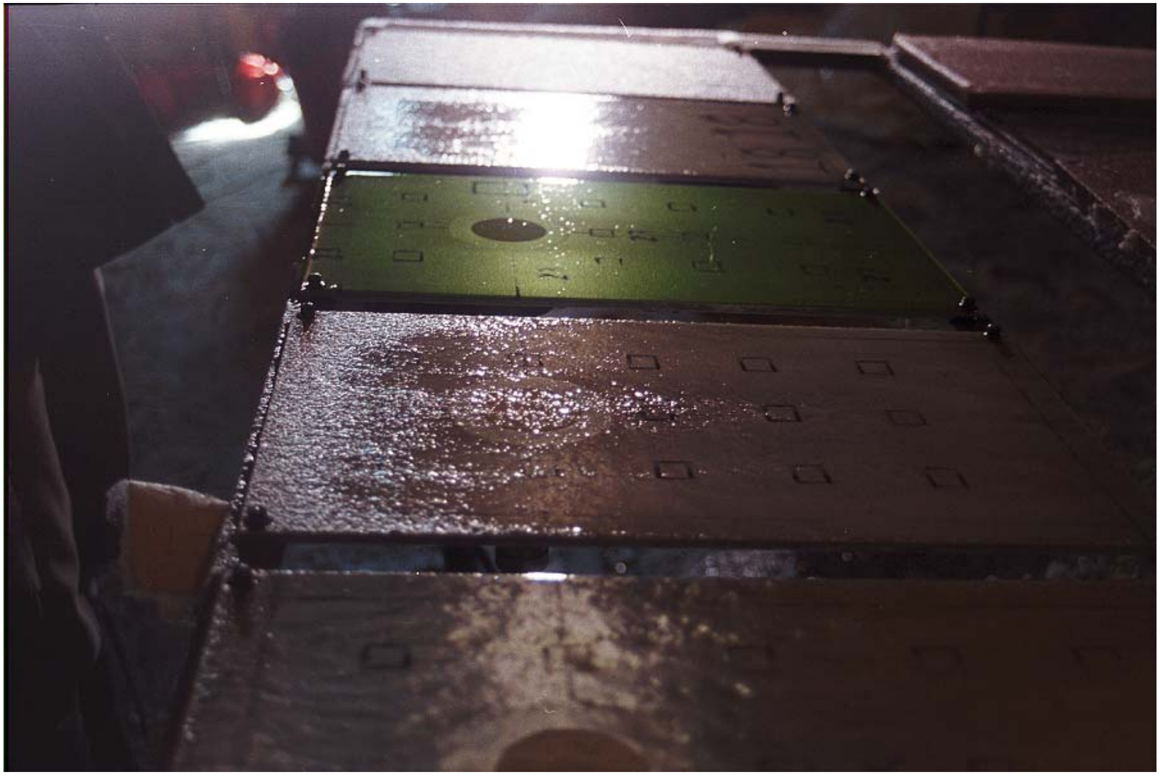


Photo C25.4 - Complete Fluid Failure, t = 78 min (Est.)

H:\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID25.doc
Last printed 10/14/98 9:18 AM

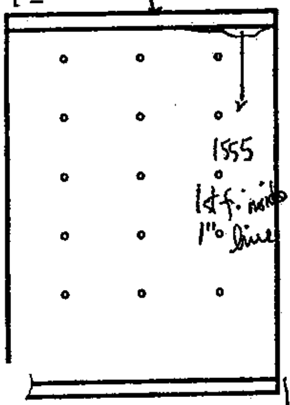
ID# 25

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09
Time: 1531 15
Plate Location: 3

Run #: 26z
Fluid Name: Oct Max
Fluid Dilution: 100%

t = 1544 Solid contam. (upper edge)



Pour. Same as usa.

1547 Of. to 6" line

fine islands of initial

gelid contamination noted

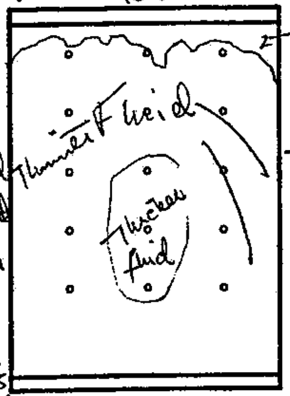
~~on fluid surface~~ which

flow with fluid down

plate.

1555. 1st f: v. fine platelets overlapping + fusing after accumulation just inside 1" line (v. wet).

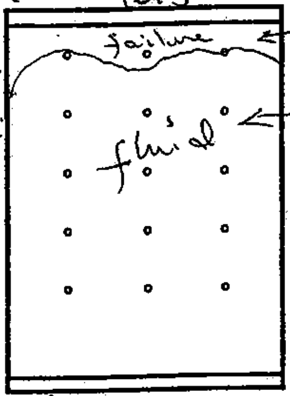
t = 1608



wet bumpy ices fused but no adhes.

~~[illegible]~~

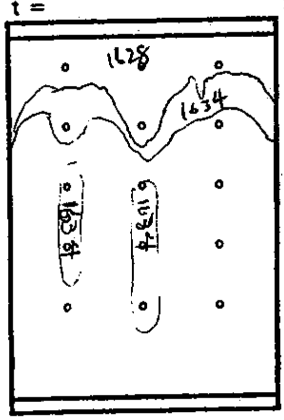
t = 1615.



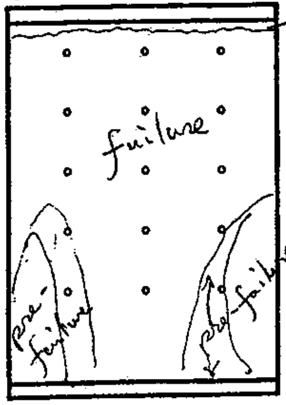
wet failure

more uniform variation in fluid thickness

t = 1634 5th X-Hair



t = 1650

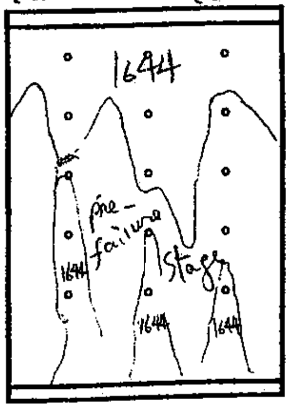


ADH to 1" line inside wk area.

Full plate

failure

t = 1644

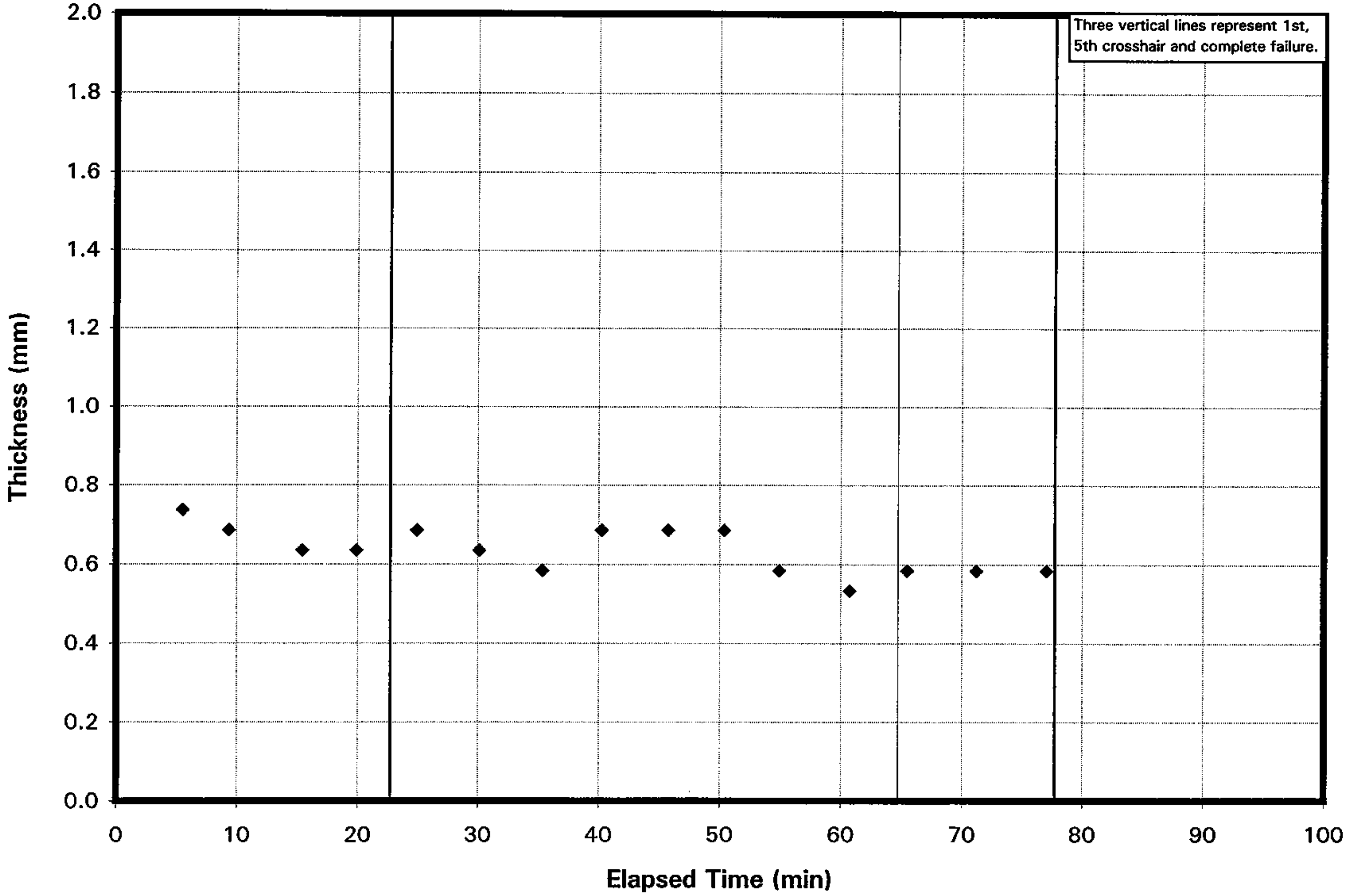


Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 25

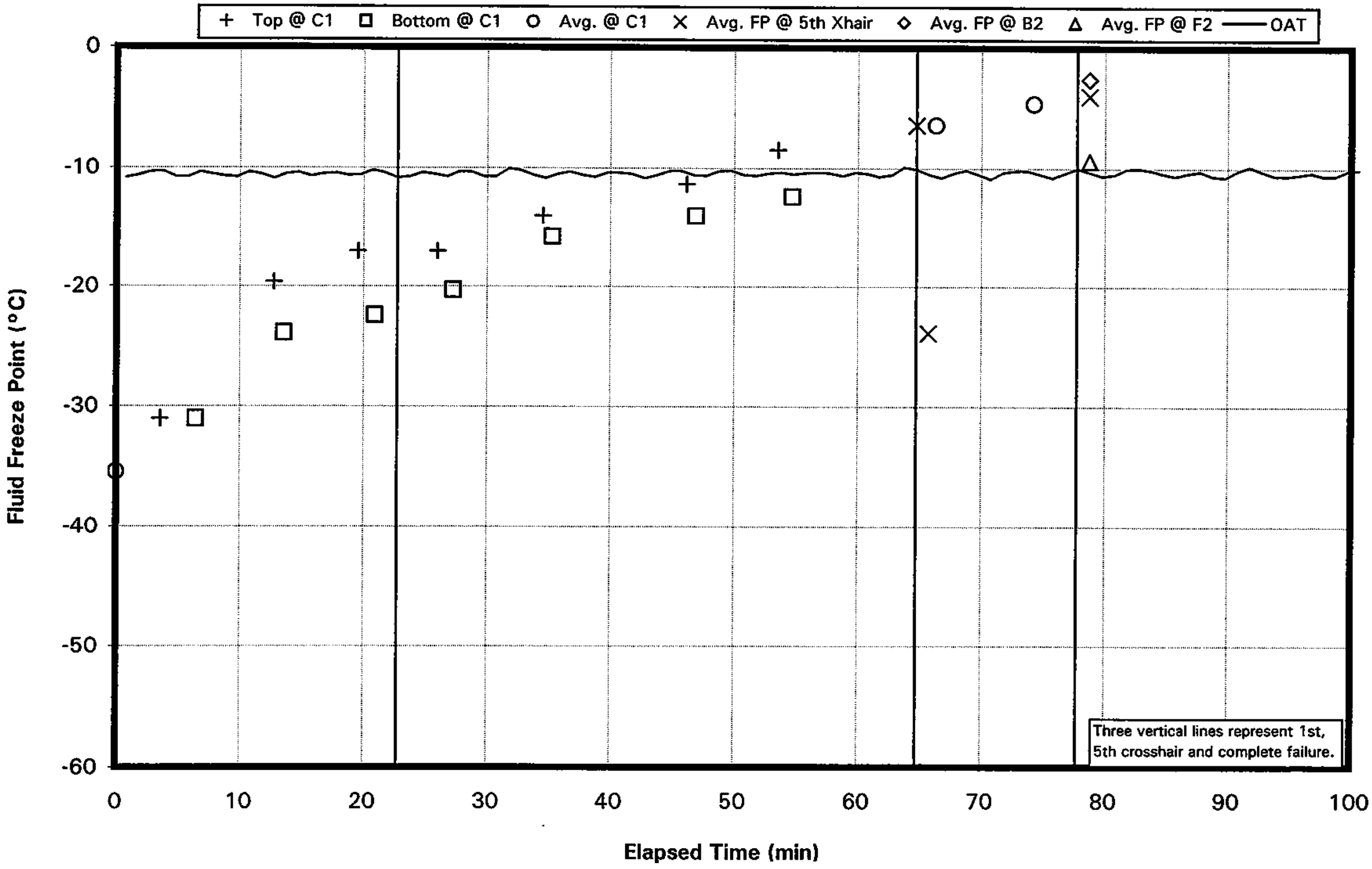


cm1380/analysis/doc_fail/thicknes/Thk_id25
10/14/98, 10:38 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 25

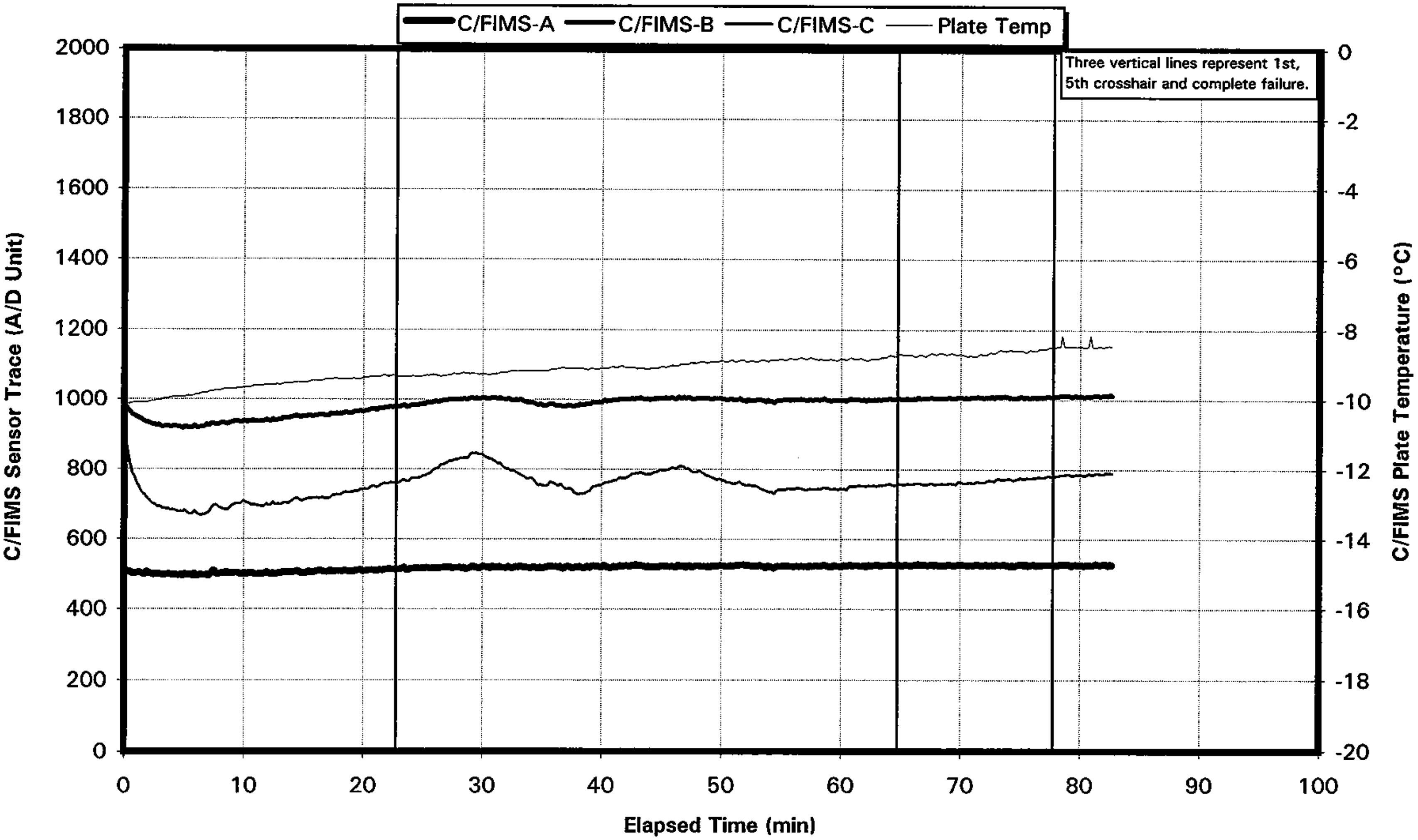


cm1380/analysis/doc_fail/brix/Brx_id25
10/22/98, 11:24 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 25

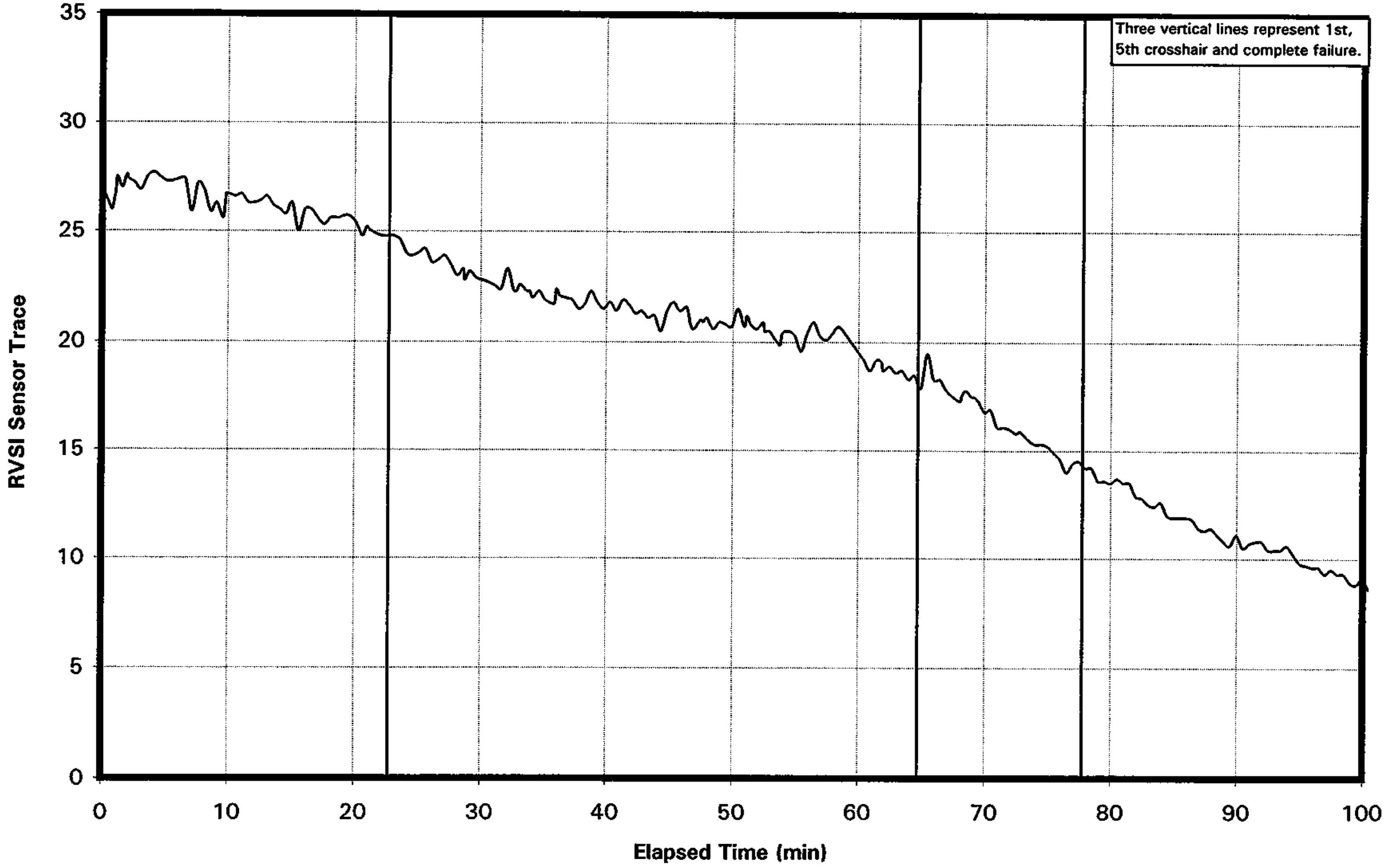


cm1380/analysis/doc_fail/cfims/Cfm_id25.xls
10/15/98, 11:21 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 25



cm1380/analysis/doc_fail/rvsi/Rvs_id25.xls
10/15/98, 12:22 PM

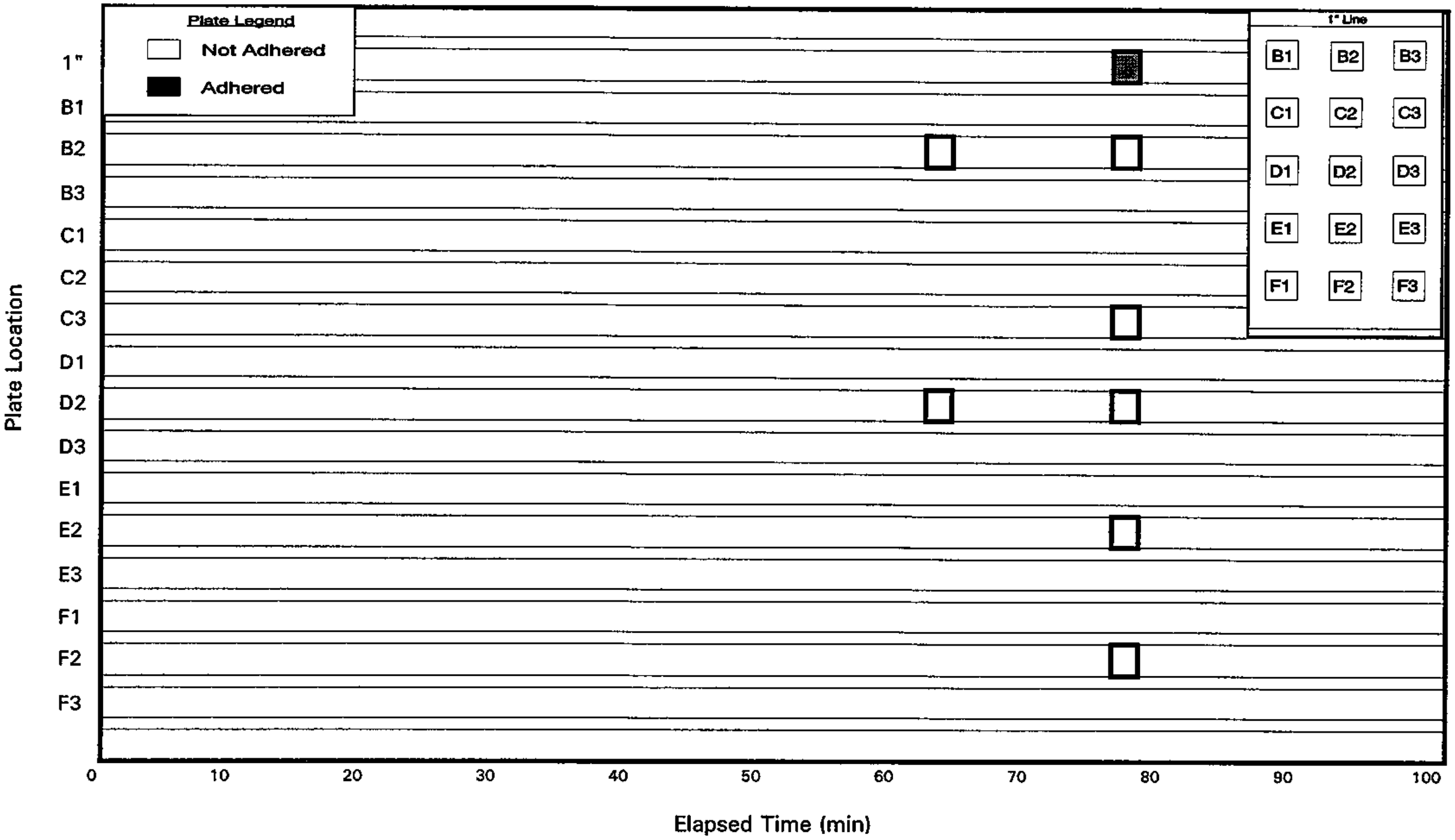
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 25

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 25



cm1380/analysis/doc_fail/Adh_id25
10/22/98, 11:34 AM

GENERAL TEST INFORMATION

ID # 26

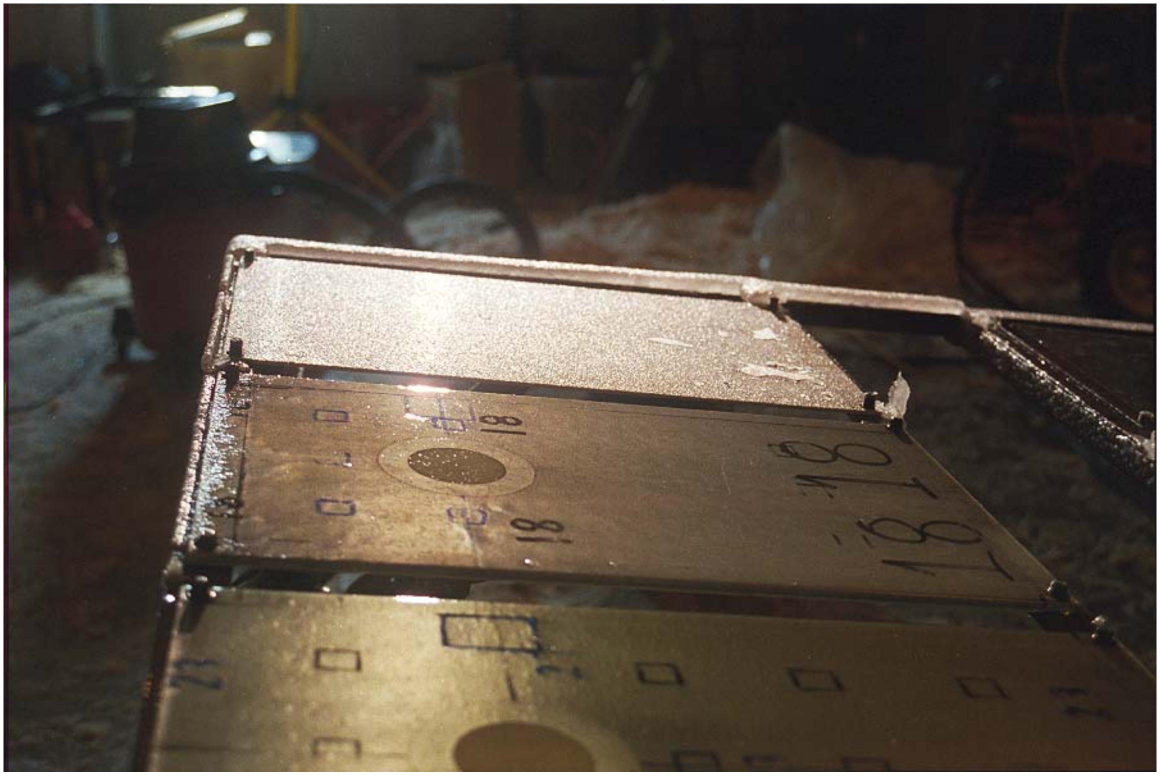
July 9, 1998

Ambient Air Temperature:	-10.6°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	4.9 $g/dm^2/hr$
Fluid:	OCTAGON
Dilution:	Neat
Start of Test:	15:33:20
Failure Mode:	5th X-hair
Failure Location:	C1
Failure Time (Standard):	16:34:00
Failure Time (Complete Plate):	16:50:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 26

Photo C26.1 - After Pouring, t = 0 min

Photo C26.2 - 1st Failure, t = 22 min



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 26

Photo C26.3 - Standard Failure (1/3 or 5th Crosshair), t = 61 min

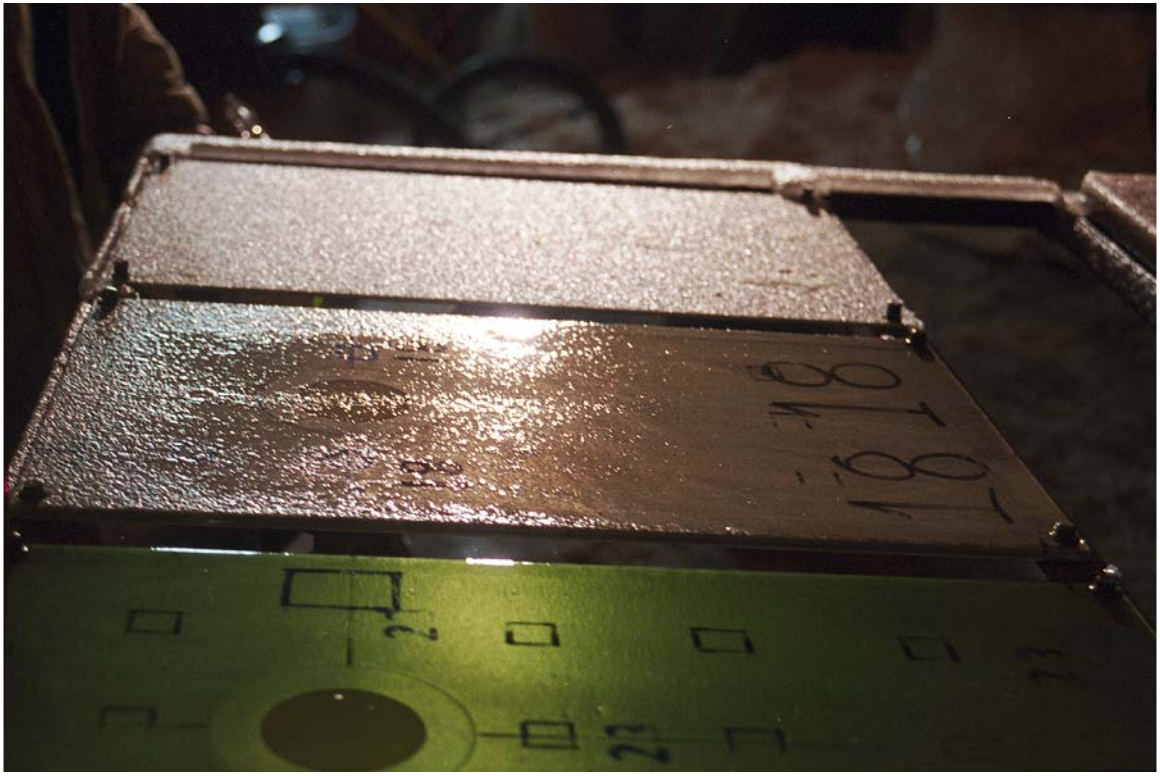


Photo C26.4 - Complete Fluid Failure, t = 77 min

\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID26.doc
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ID # 26

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09

Time: 1533³⁰

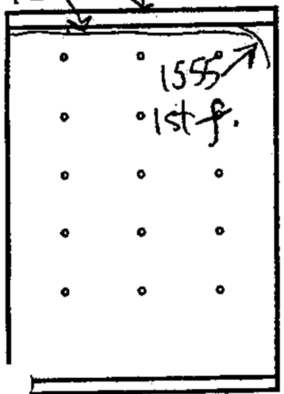
Plate Location: 5

Run #: 26s

Fluid Name: Oct

Fluid Dilution: 100%

t = 1545 — upper edge solid contam.



1545 speckled fluid.

1550 e.p. 0->6" line

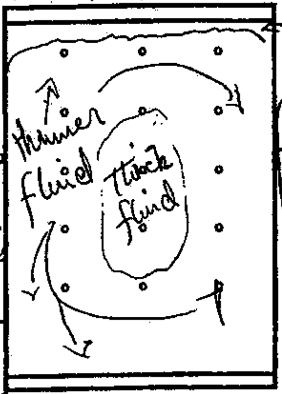
1548 initial suspended fine dot-type failures on fluid surface; flow with fluid

1555 1st failure

V. fine platelet fusion just below 1" line

1602 fine failure all across top plate edge up to 1" line

t = 1609

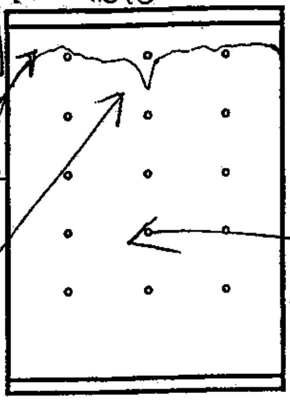


V. fine bumpy wet ice. no ADH.

1618 V. fine, wet failure on surface

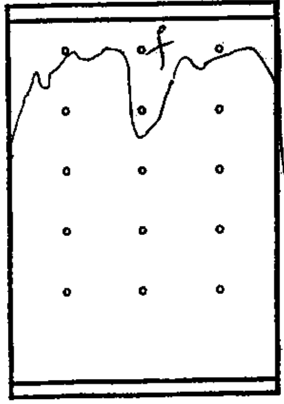
thicker fluid below tending to break up

t = 1618

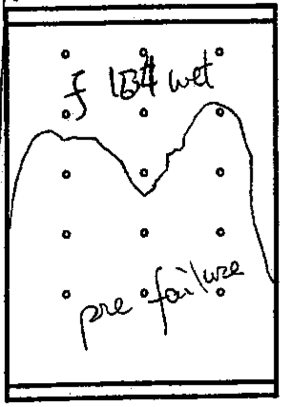


fluid thickness variation is more uniform than at 1609.

t = 1627



t = 1634



5 X-Hairs

wet failure

no ADH

t = 1648

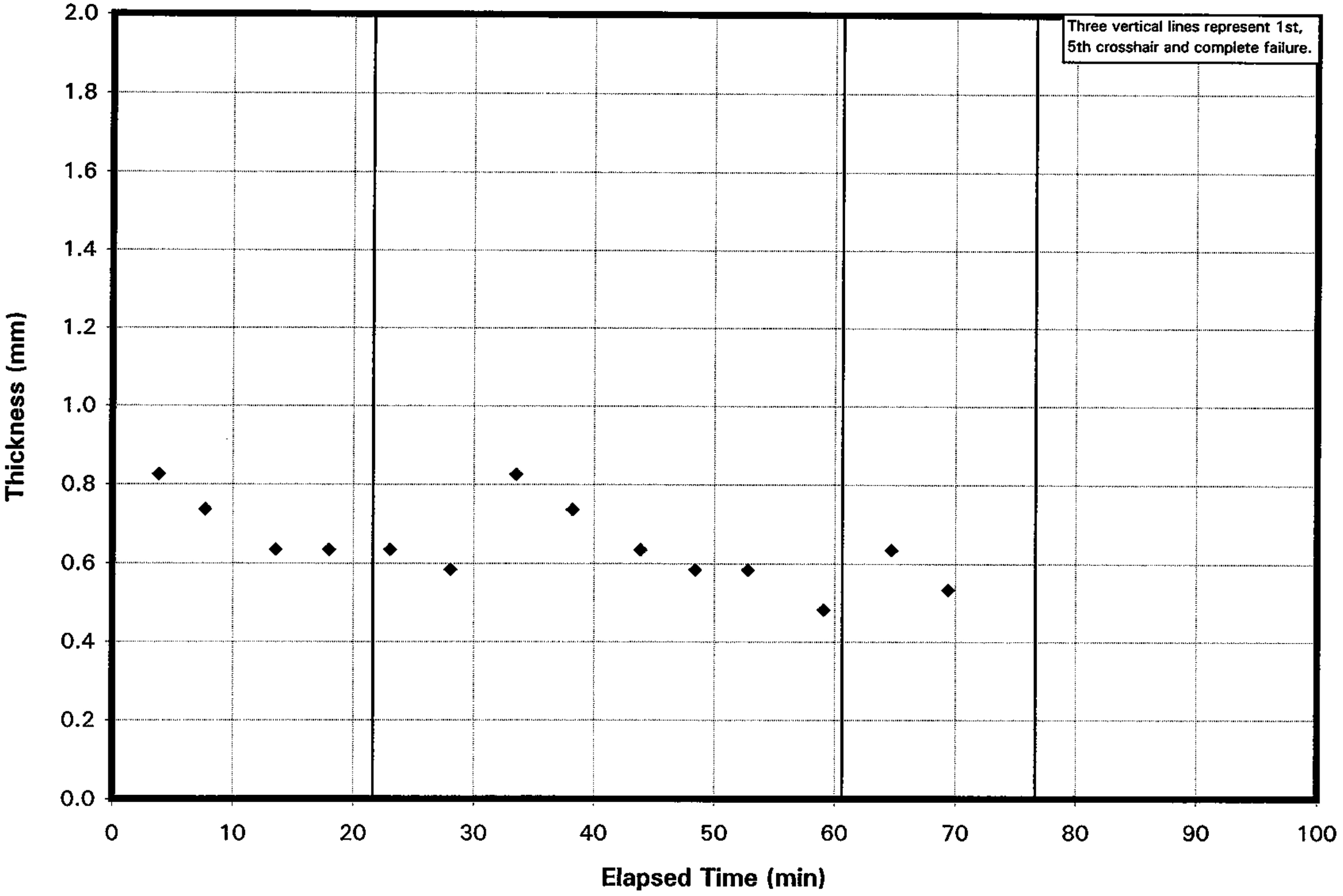
ADH. 2" line.

Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 26

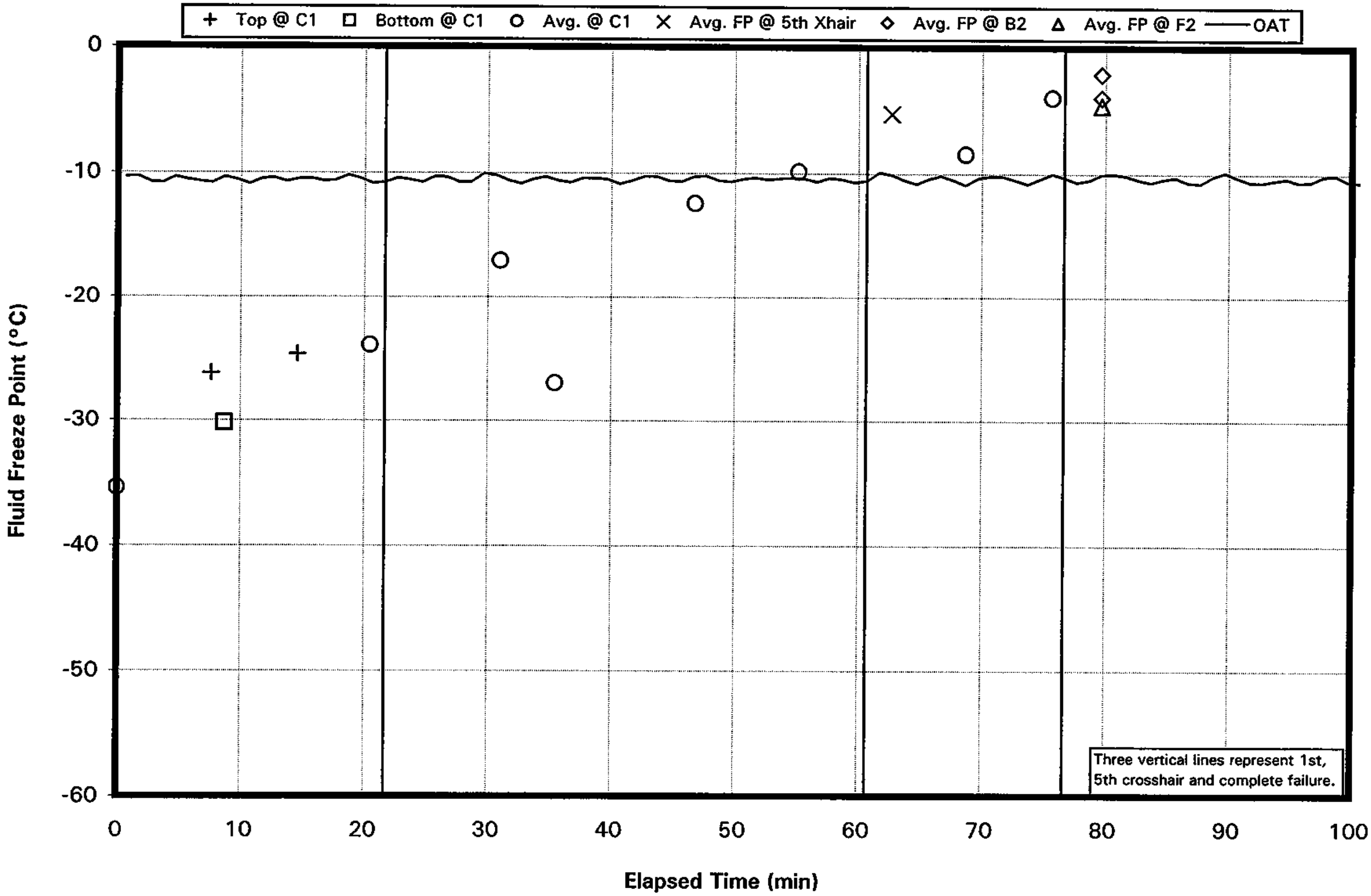


cm1380/analysis/doc_fail/thicknes/Thk_id26
10/14/98, 10:38 AM

DOCUMENTATION OF FLUID FAILURE

FLUID FREEZE POINT

ID # 26

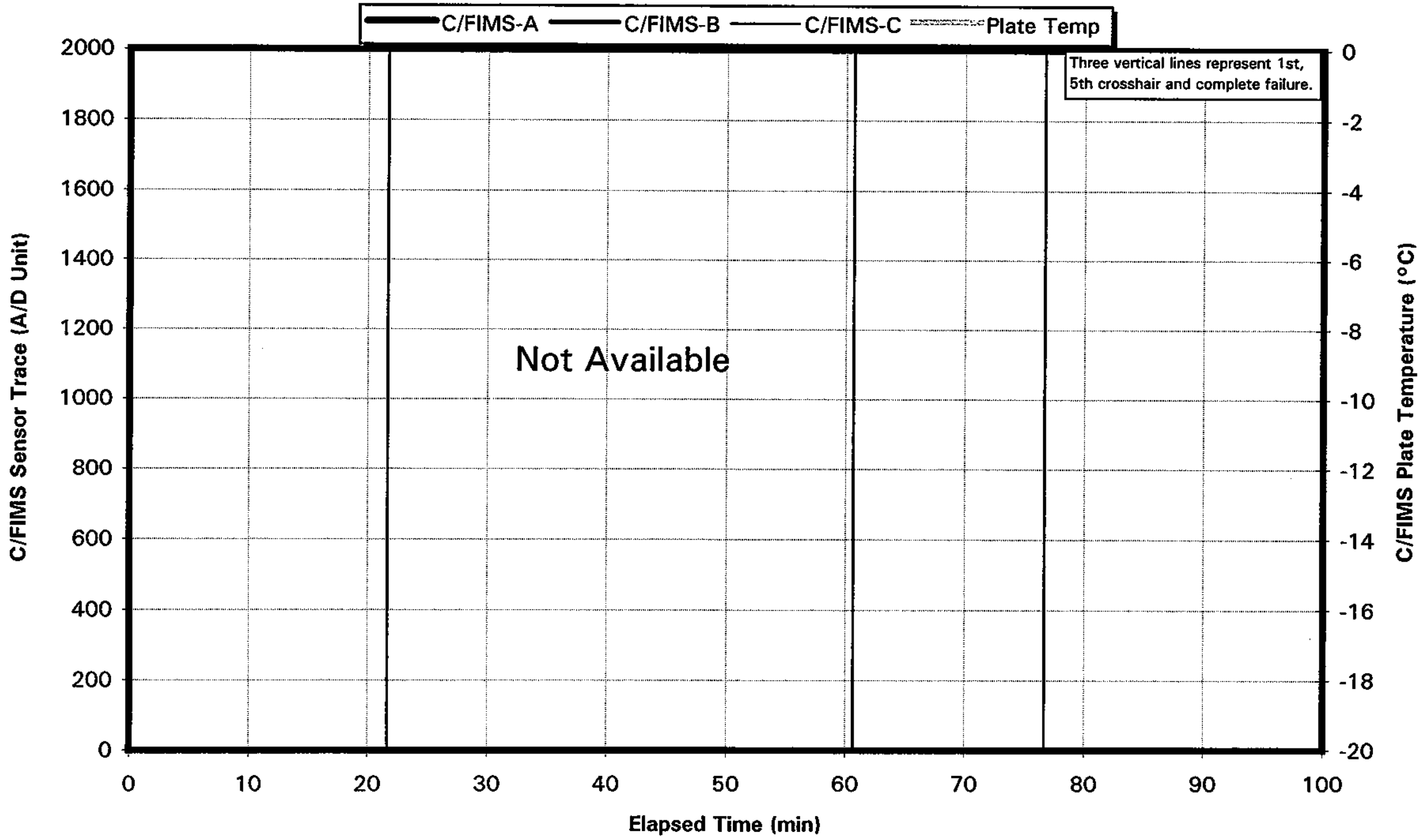


cm1380/analysis/doc_fail/brix/Brx_id26
10/15/98, 9:42 AM

DOCUMENTATION OF FLUID FAILURE

C/FIMS SENSOR TRACE

ID # 26

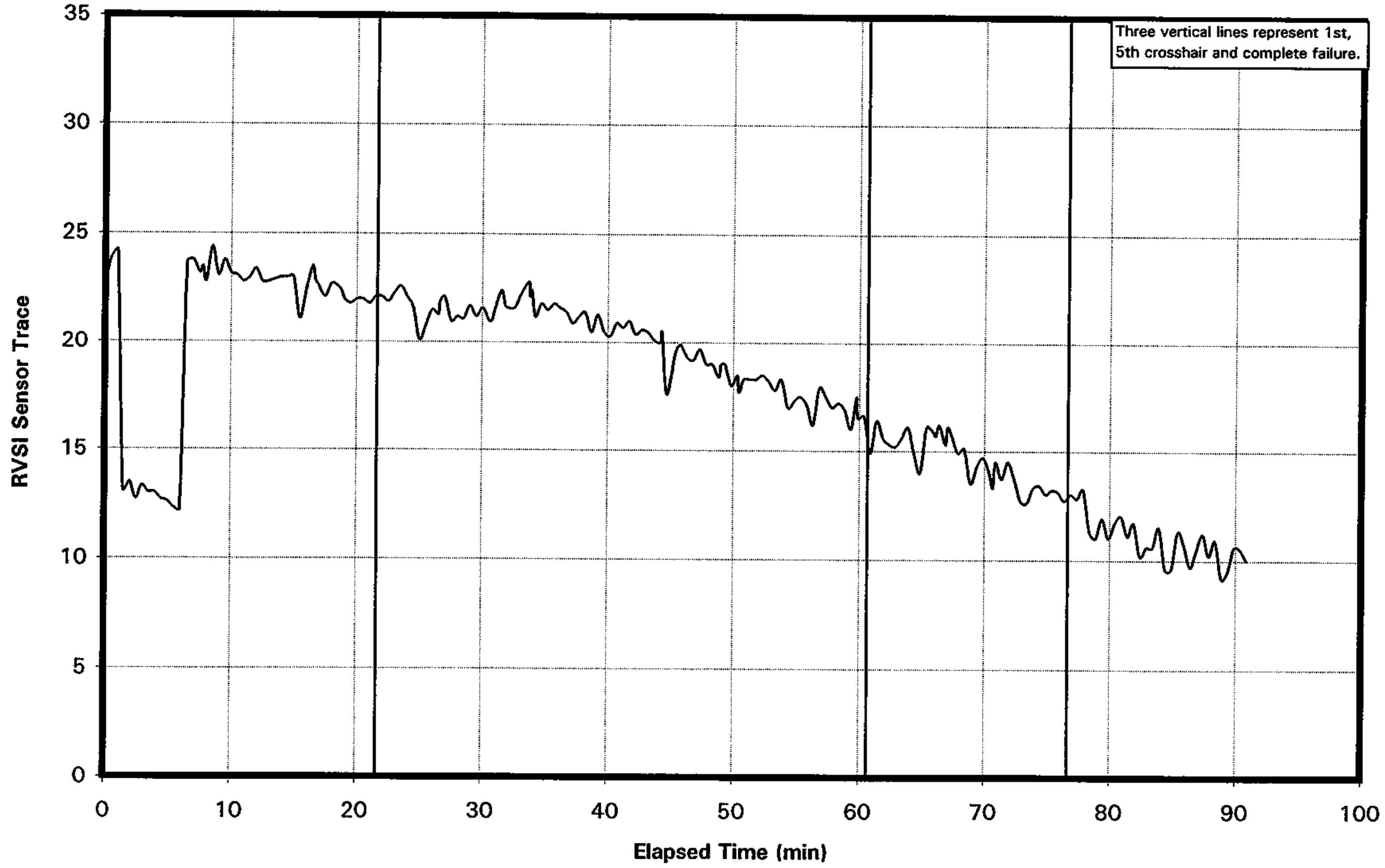


cm1380/analysis/doc_fail/cfims/Cfm_id26.xls
10/15/98, 11:20 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 26



cm1380/analysis/doc_fail/rvsi/Rvs_id26.xls
10/15/98, 12:21 PM

DOCUMENTATION OF FLUID FAILURE

COX/SPAR SENSOR TRACE

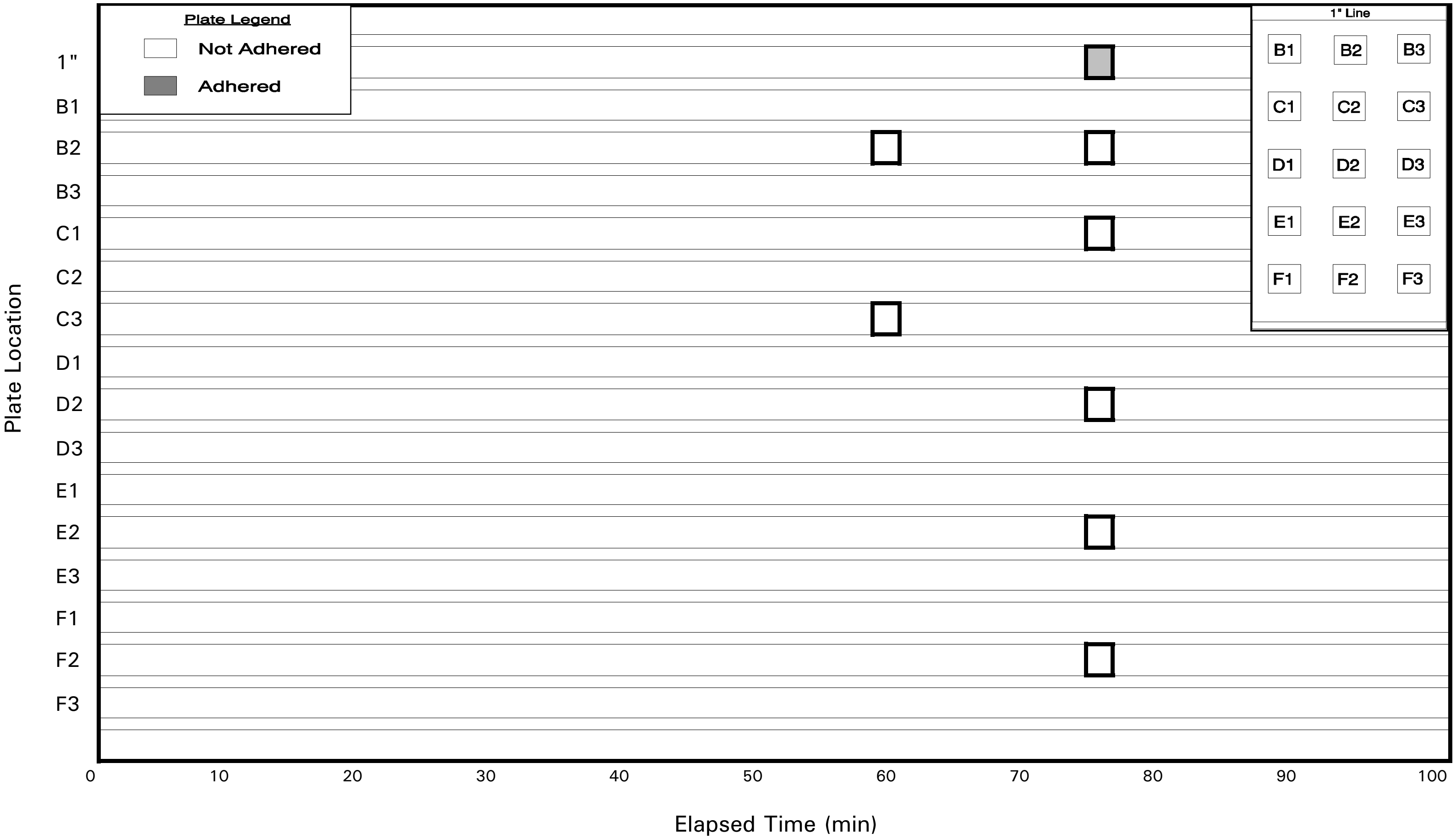
ID # 26

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 26



cm1380/analysis/doc_fail/ADH_ID26
9/22/2006, 8:45 AM

GENERAL TEST INFORMATION

ID # 27

July 09, 1998

Ambient Air Temperature:	-10.6°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	4.8 g/dm²/hr
Fluid:	UCAR ULTRA+
Dilution:	Neat
Start of Test:	15:32:20
Failure Mode:	N/A
Failure Location:	N/A
Failure Time (Standard):	N/F
Failure Time (Complete Plate):	N/F

Note: Test stopped after 53 minutes

PHOTOS OF POUR AND FIRST FAILURE - ID # 27

Photo C27.1 - After Pouring, t=1min

NOT AVAILABLE

Photo C27.2 - 1st Failure, t = xx min

NOT AVAILABLE

PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 27

Photo C27.3 - Standard Failure (1/3 or 5th Crosshair), t=xxmin

NOT AVAILABLE

Photo C27.4 - Complete Fluid Failure, t = xx min

NOT AVAILABLE

\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAIL\SUBJECTV\SUB_ID27.doc
Last printed 10/14/98 9:22 AM

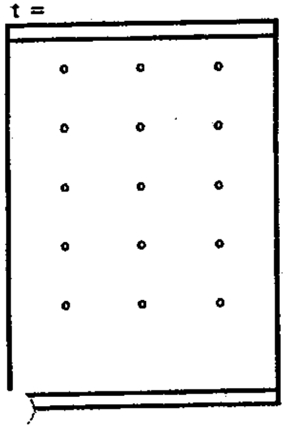
ID# 27

SUBJECTIVE APPEARANCE OF FLUID FAILURE

Date: July 09
Time: 1532^{20}
Plate Location: 4

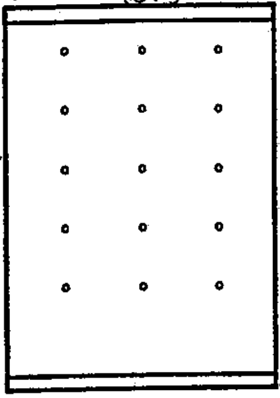
Run #: 264
Fluid Name: ULTRA⊕
Fluid Dilution: 100%

t =



Pour: same.
1544 NO CHG.
speckle phase taking
long time to kick in.
1603
fine failure begins
to kick in on upper
edge of plate.
speckle + op going
to marbled fluid
phase.

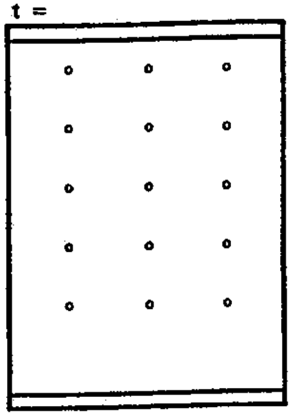
t = 1615



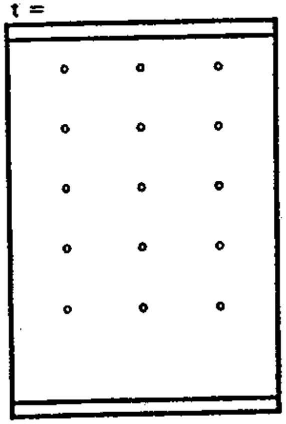
completely
marbled
fluid
phase.

1625 test stopped
[illegible] for next
fluid application

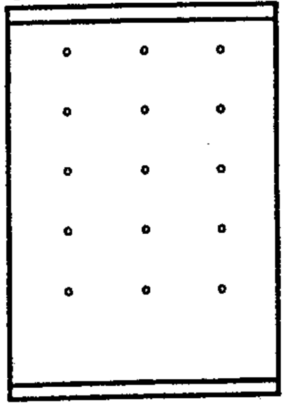
t =



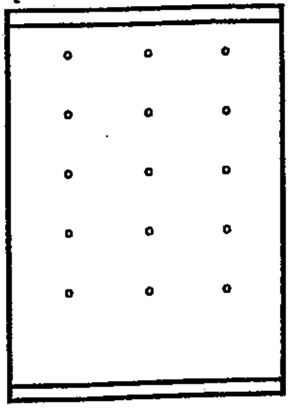
t =



t =



t =

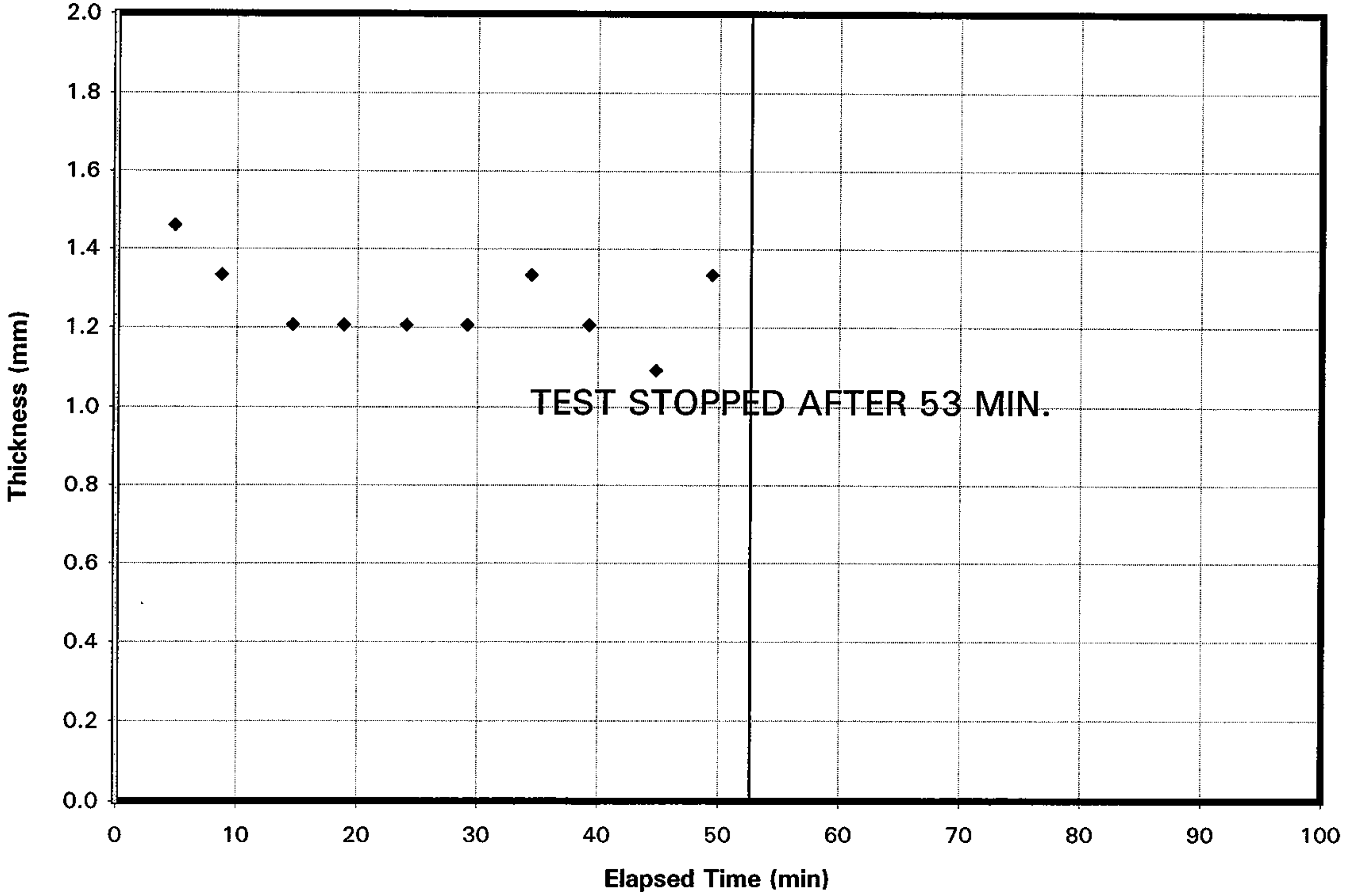


Note: Ensure observations made at t = 0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 27

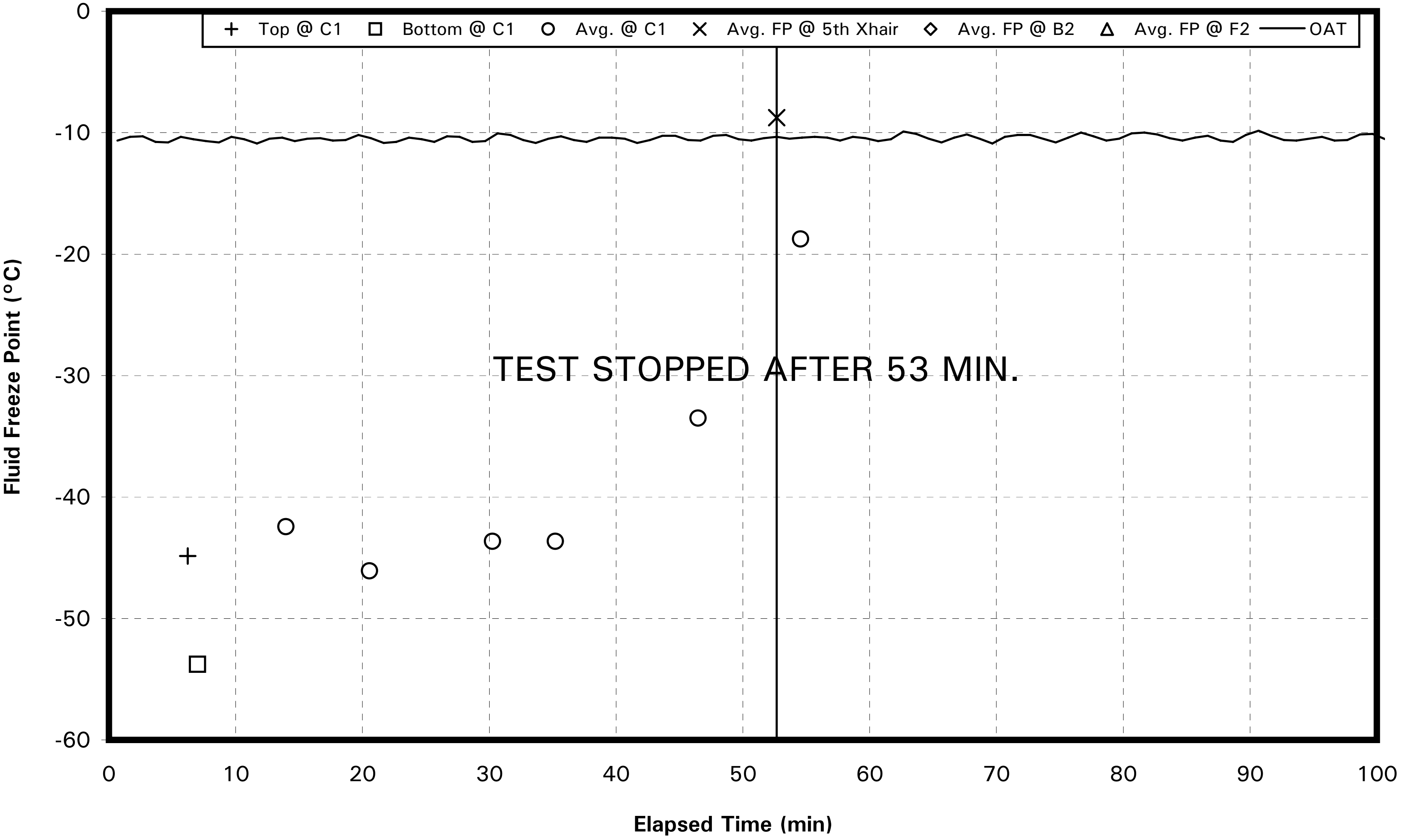


cm1380/analysis/doc_fail/thicknes/Thk_id27.xls
10/15/98, 1:18 PM

DOCUMENTATION OF FLUID FAILURE

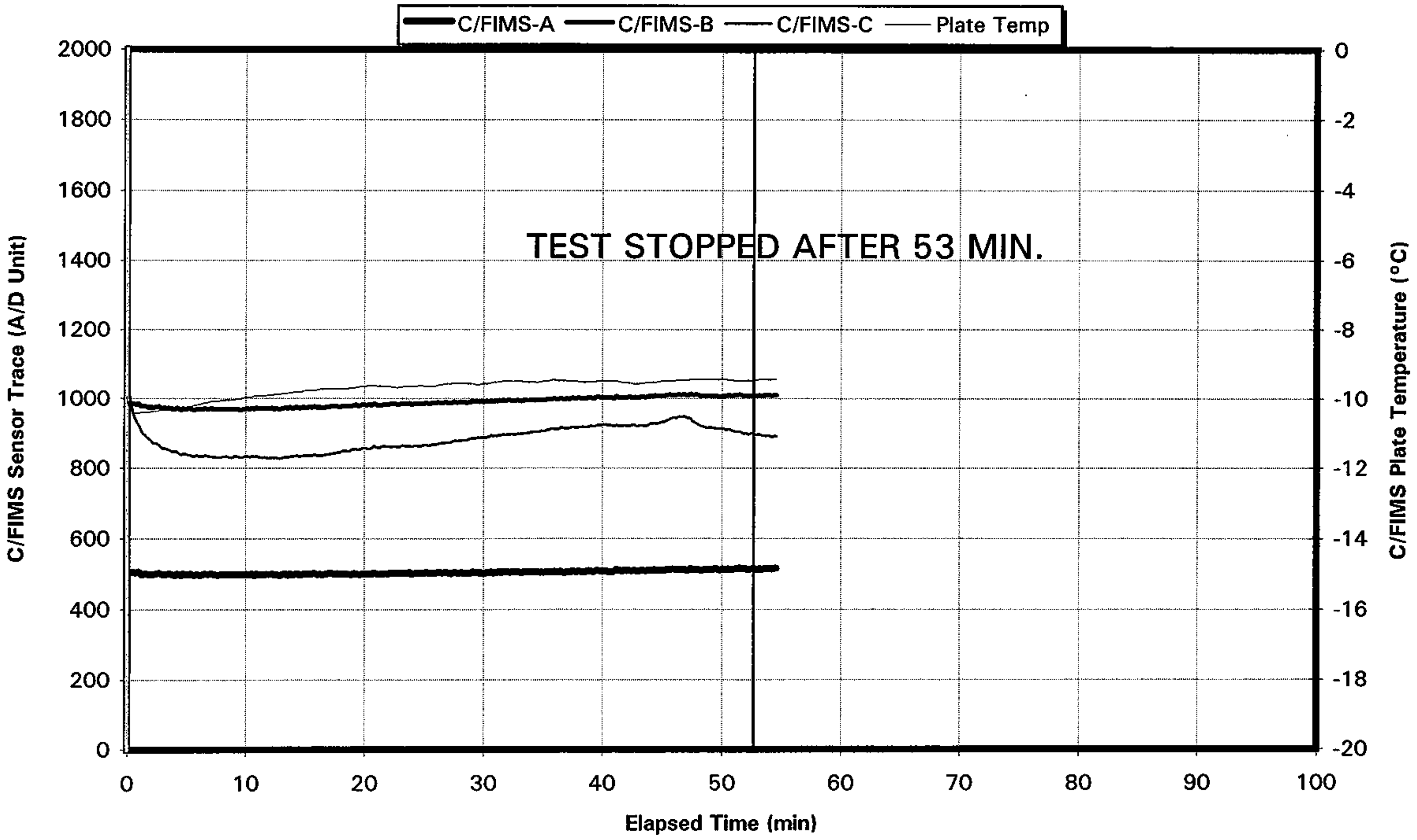
FLUID FREEZE POINT

ID # 27



cm1380/analysis/doc_fail/brix/BRX_ID27
9/22/2006, 9:03 AM

DOCUMENTATION OF FLUID FAILURE
C/FIMS SENSOR TRACE
ID # 27

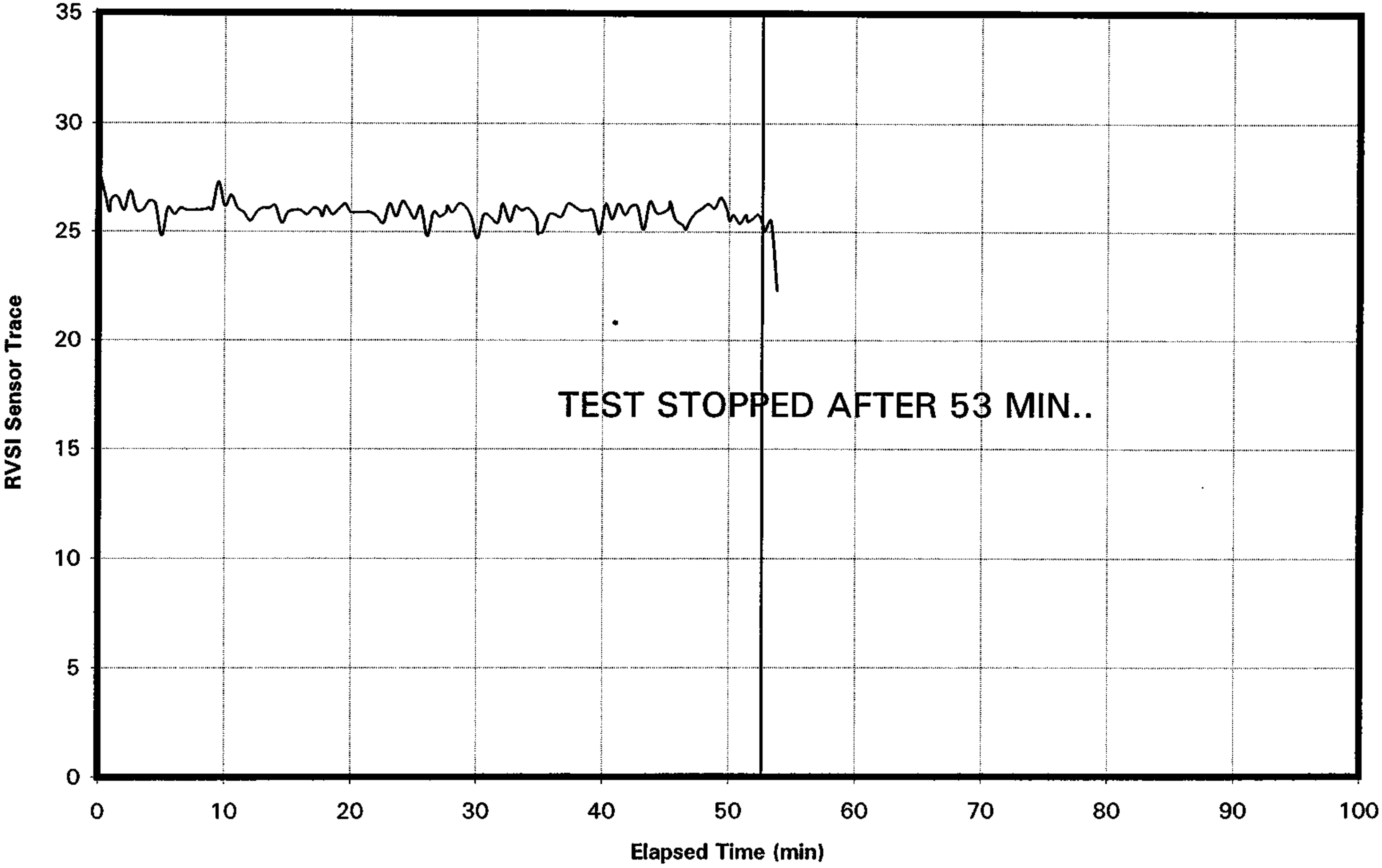


cm1380/analysis/doc_fail/cfims/Cfm_id27.xls
10/15/98, 1:10 PM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 27



cm1380/analysis/doc_fail/rvsi/Rvs_id27.xls
10/15/98, 1:11 PM

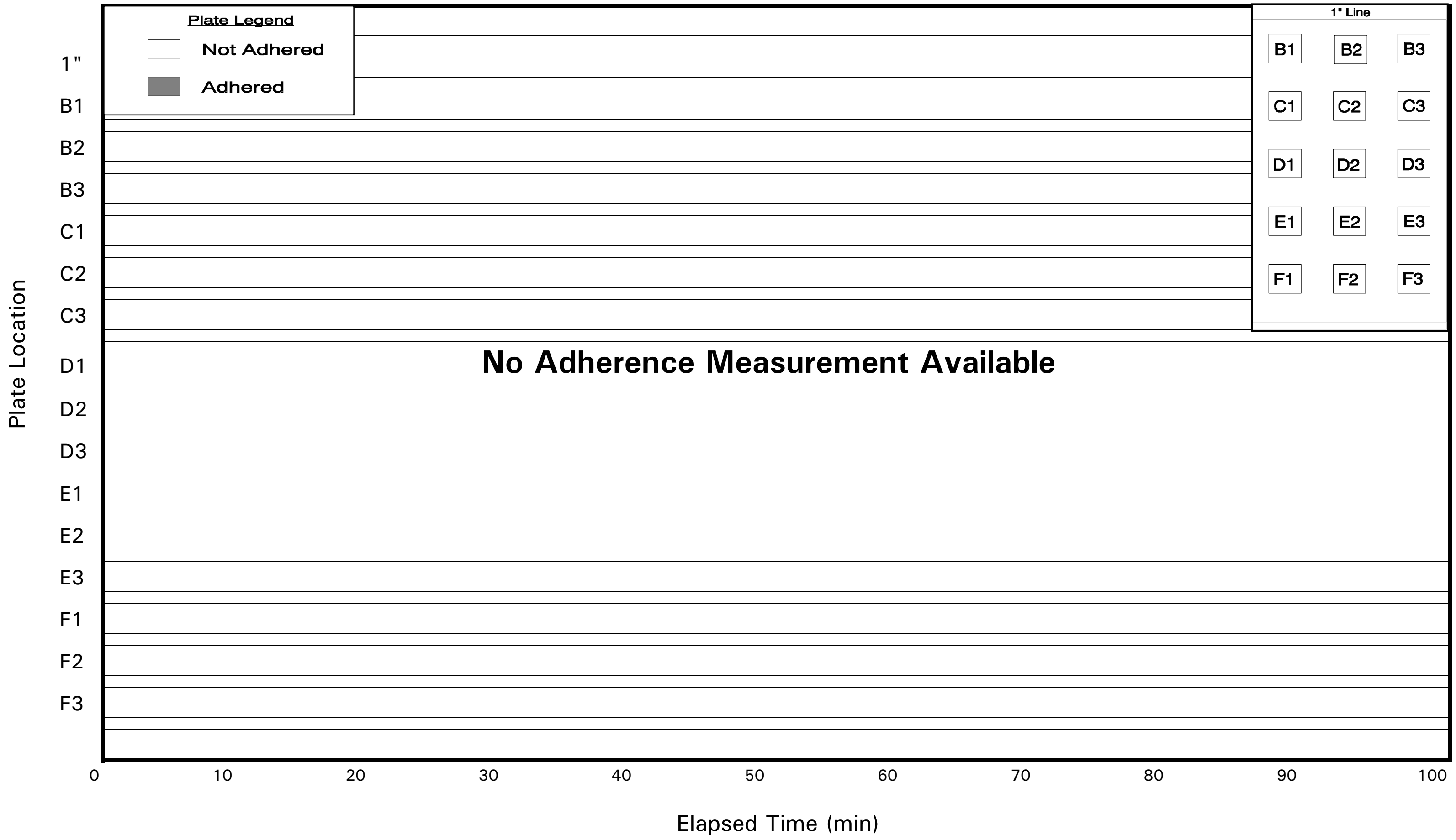
DOCUMENTATION OF FLUID FAILURE
COX/SPAR SENSOR TRACE
ID # 27

DATA NOT YET AVAILABLE FROM COX & CO.

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 27



cm1380/analysis/doc_fail/ADH_ID27
9/22/2006, 9:09 AM

GENERAL TEST INFORMATION

ID # 28

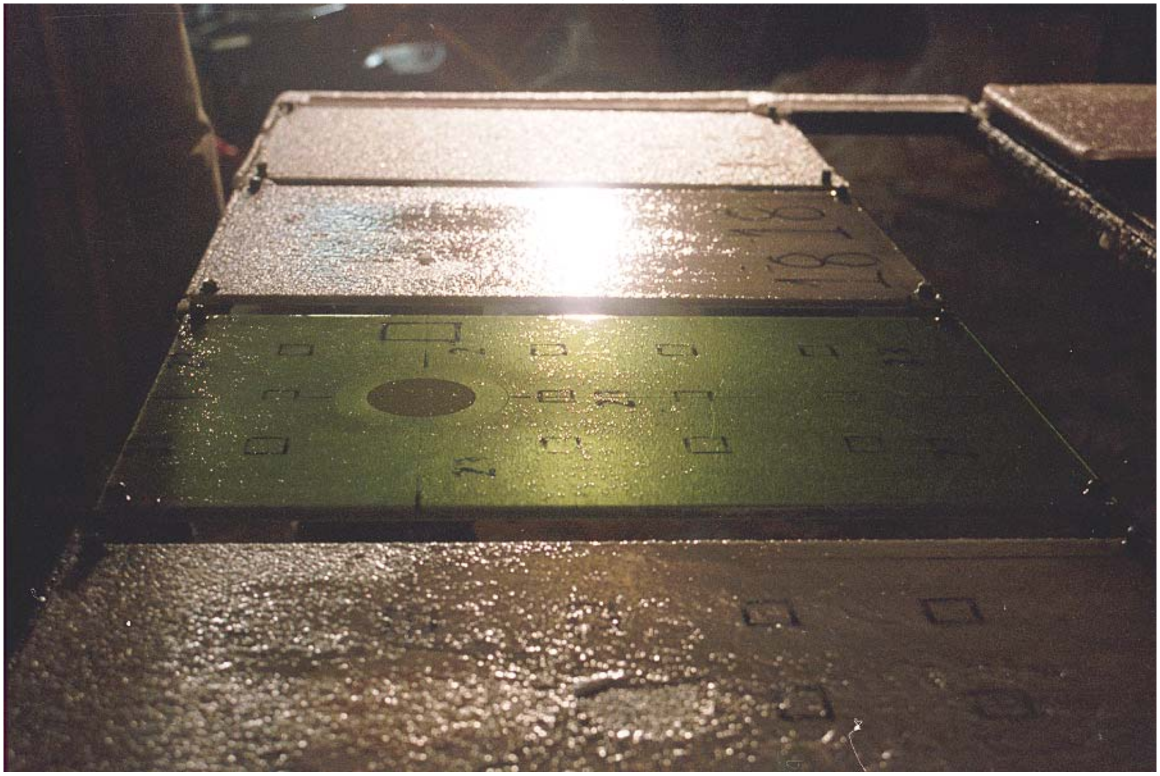
July 09, 1998

Ambient Air Temperature:	-10.9°C
Precipitation Type:	Freezing Drizzle
Rate of Precipitation:	4.8 g/dm²/hr
Fluid:	SPCA AD-480
Dilution:	Neat
Start of Test:	16:27:30
Failure Mode:	1/3 Plate
Failure Location:	C1
Failure Time (Standard):	17:26:00
Failure Time (Complete Plate):	17:46:00

PHOTOS OF POUR AND FIRST FAILURE - ID # 28

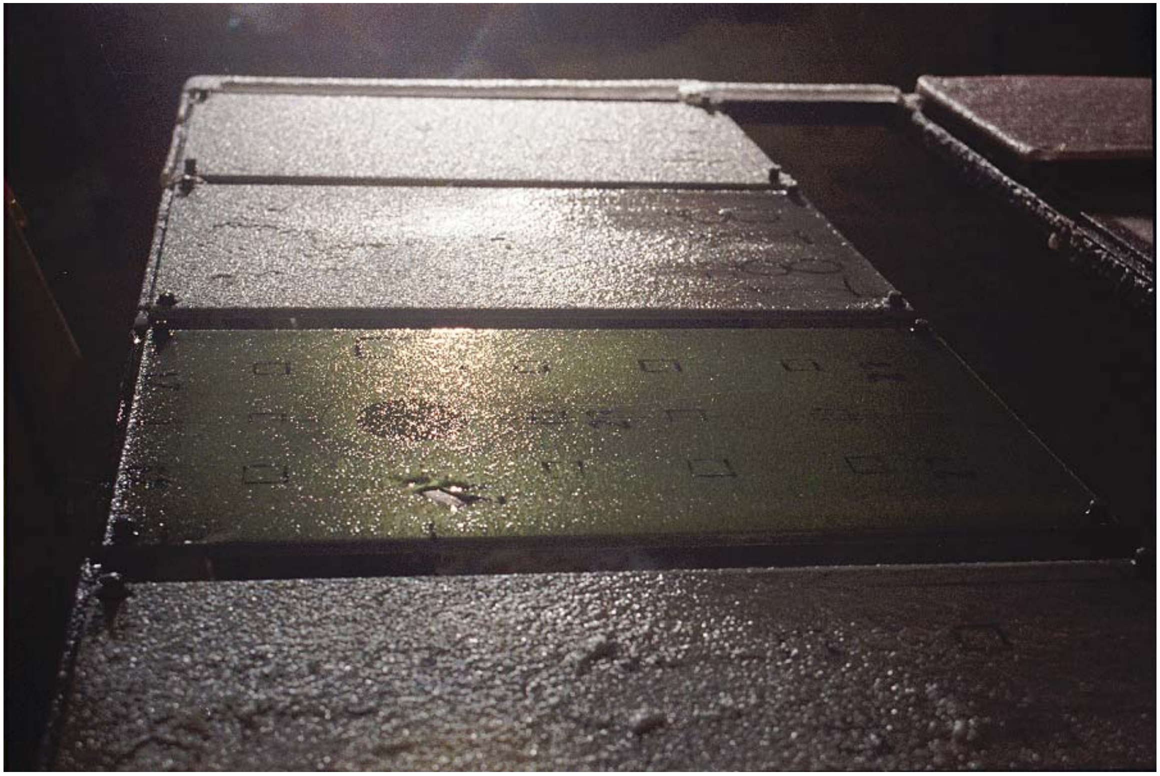
Photo C28.1 - After Pouring, t = 0 min

Photo C28.2 - 1^{st} Failure, t = 20 min (Est.)



PHOTOS OF STANDARD AND COMPLETE FAILURE - ID # 28

Standard Failure (1/3 or 5th Crosshair), t = 59 min (Est.)



Complete Fluid Failure, t = 79 min (Est.)

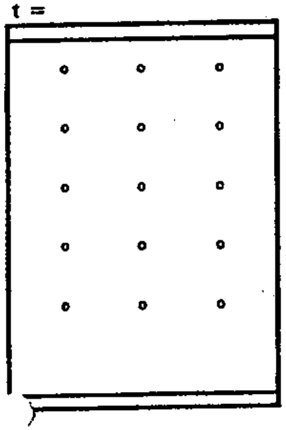
\\ADGA_APS\VOL1\CM1380\ANALYSIS\DOC_FAILS\SUBJECTV\SUB_ID28.doc
Last printed 10/14/98 9:24 AM

ID# 28

SUBJECTIVE APPEARANCE OF FLUID FAILURE

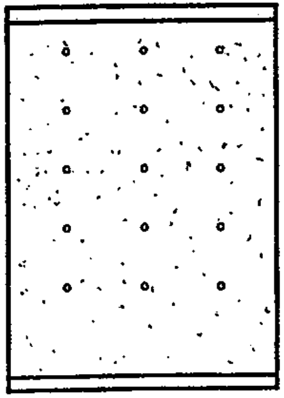
Date: July 09
Time: 1627 30
Plate Location: 4
Run #: 26
Fluid Name: S480
Fluid Dilution: 100%

t =



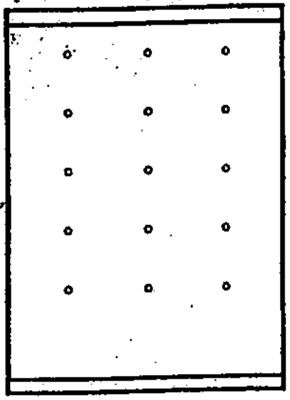
Pour: similar
to ULTRA+ but
more intense green
color
1635 slight speckling
of fluid srf.
no solids

t = 1704



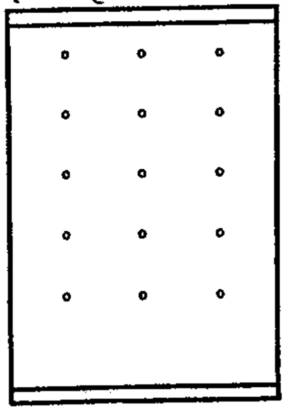
surface uniformly
covered with fine,
solidified droplets
thick fluid below
~~surface~~

t = 1717



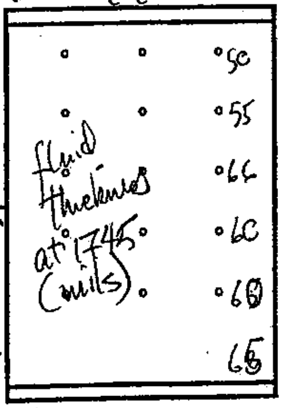
total fluid surface
covered by a
thin layer of
fine slush - Still
no actual failure
and no other
significant
features
Fluid thickness
is uniform +
no solids beneath
the surface of the
fluid.

t = 1726



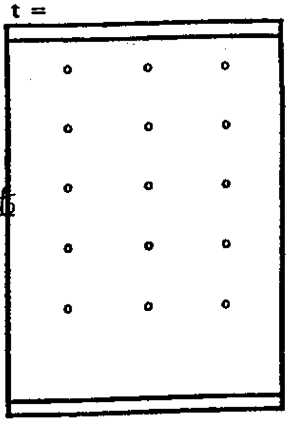
Surface of fluid
~~considered to~~
contain ½ area
covered by fine
solid contamination
~~No fusion + plenty~~
~~of good fluid~~
remains below the
top layer.
Absolutely no adhesion.

t = 1745



Solid specks begin
to fuse (2-3 at a
time), but incomplete
fusion over entire
surface.

t =

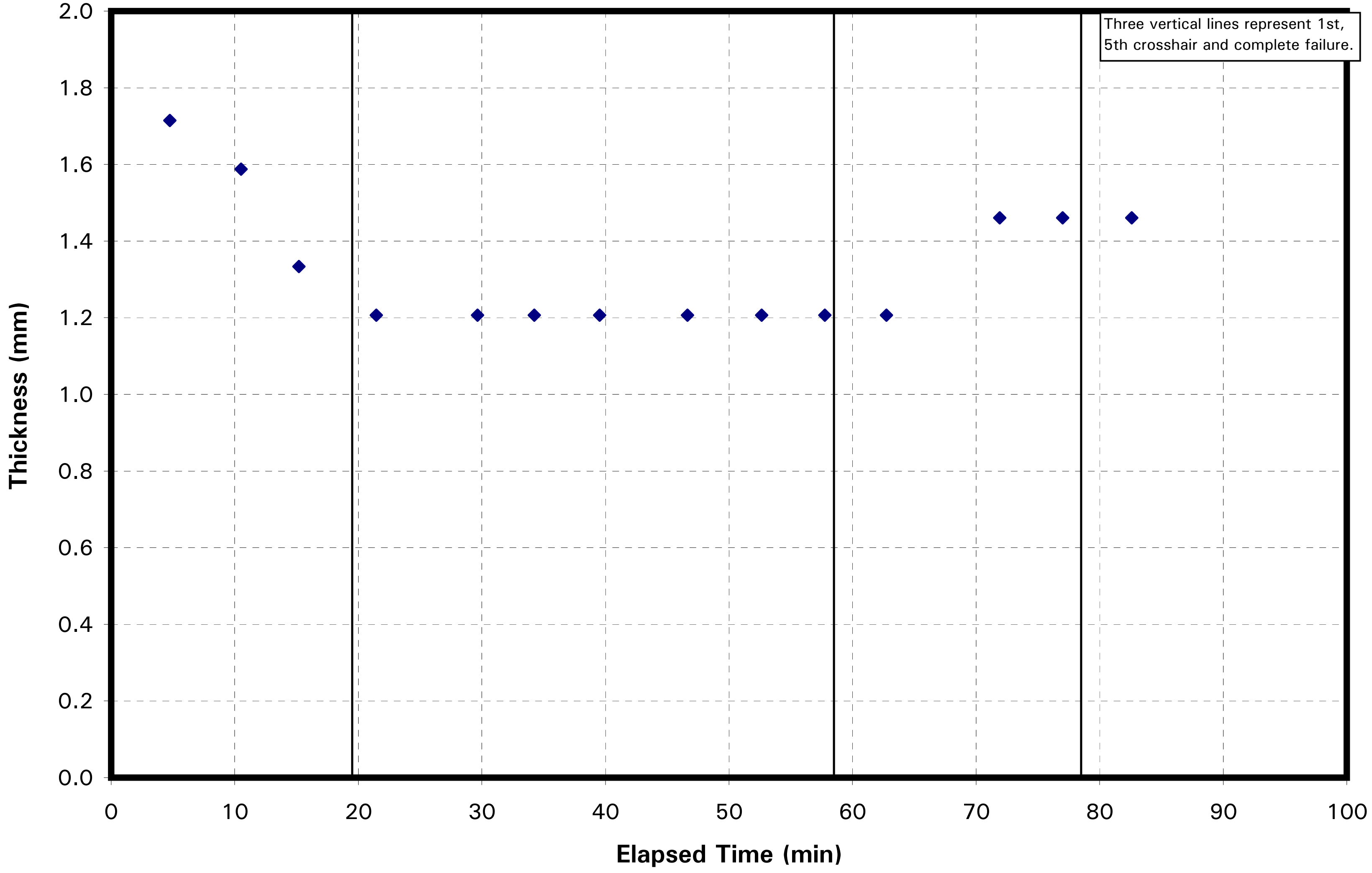


Note: Ensure observations made at t=0, 1st failure, 5th crosshair, whole plate

DOCUMENTATION OF FLUID FAILURE

FLUID THICKNESS TESTS

ID # 28

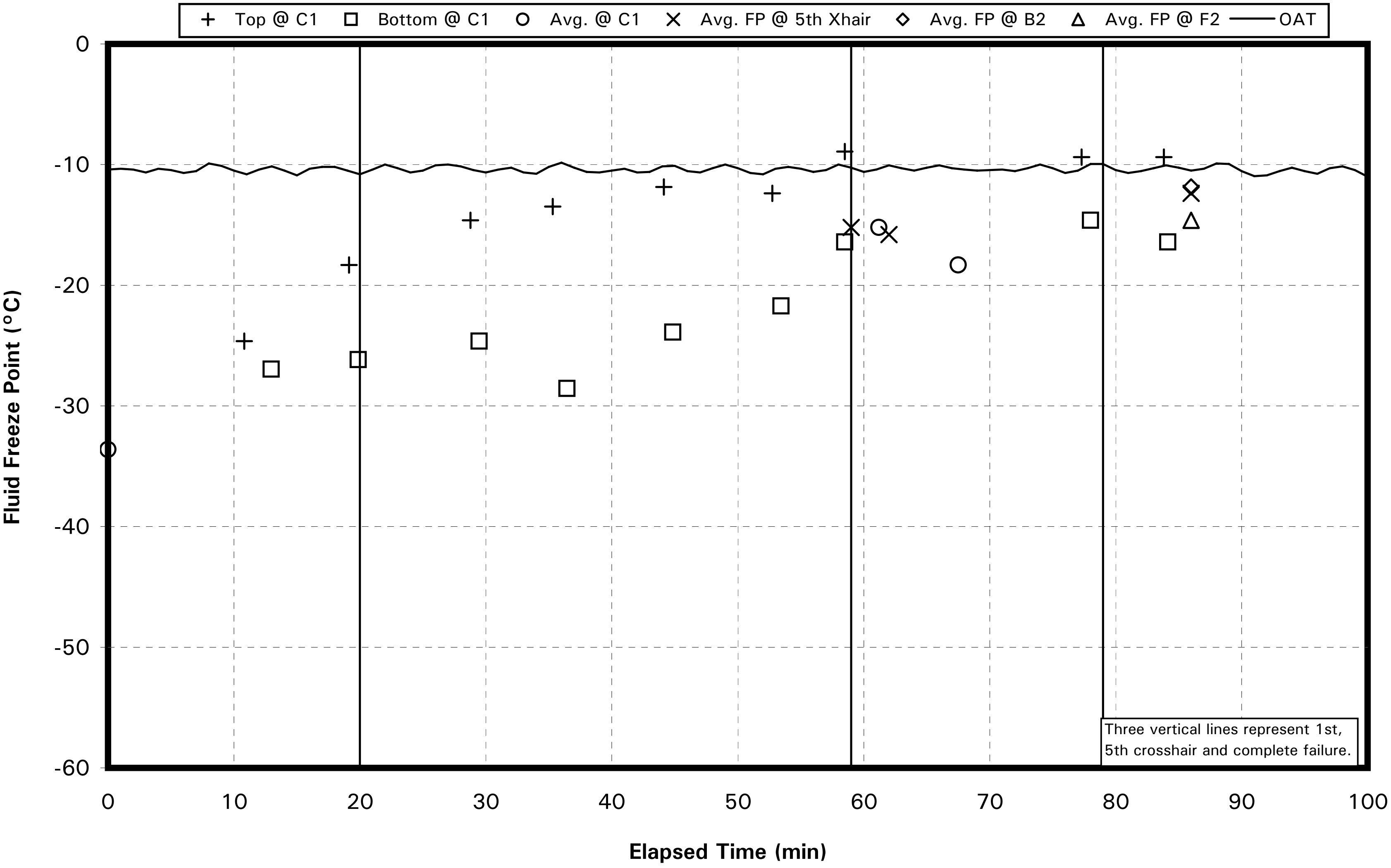


cm1380/analysis/doc_fail/thicknes/THK_ID28
9/22/2006, 9:46 AM

DOCUMENTATION OF FLUID FAILURE

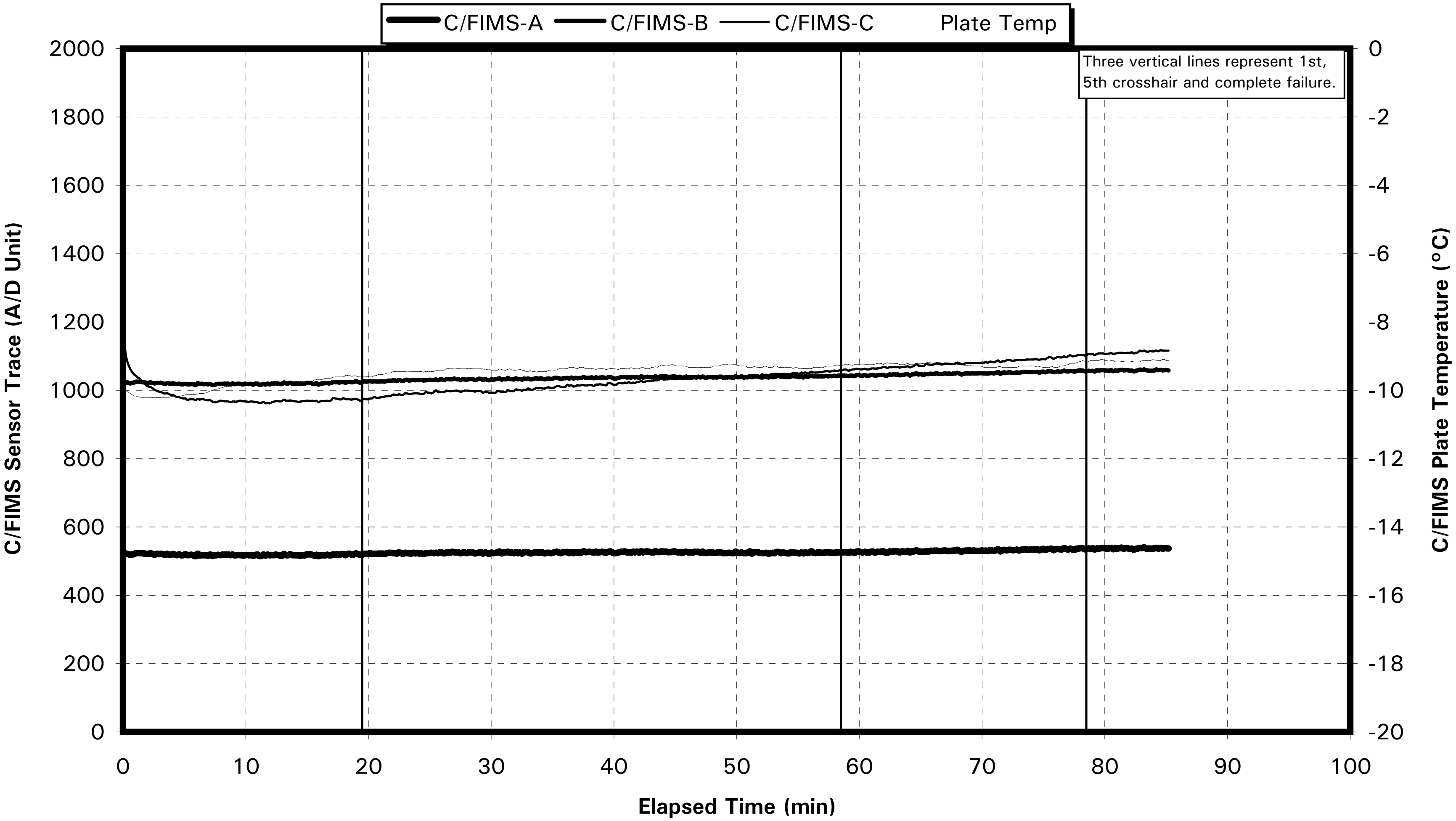
FLUID FREEZE POINT

ID # 28



cm1380/analysis/doc_fail/brix/BRX_ID28
9/22/2006, 9:47 AM

DOCUMENTATION OF FLUID FAILURE
C/FIMS SENSOR TRACE
ID # 28



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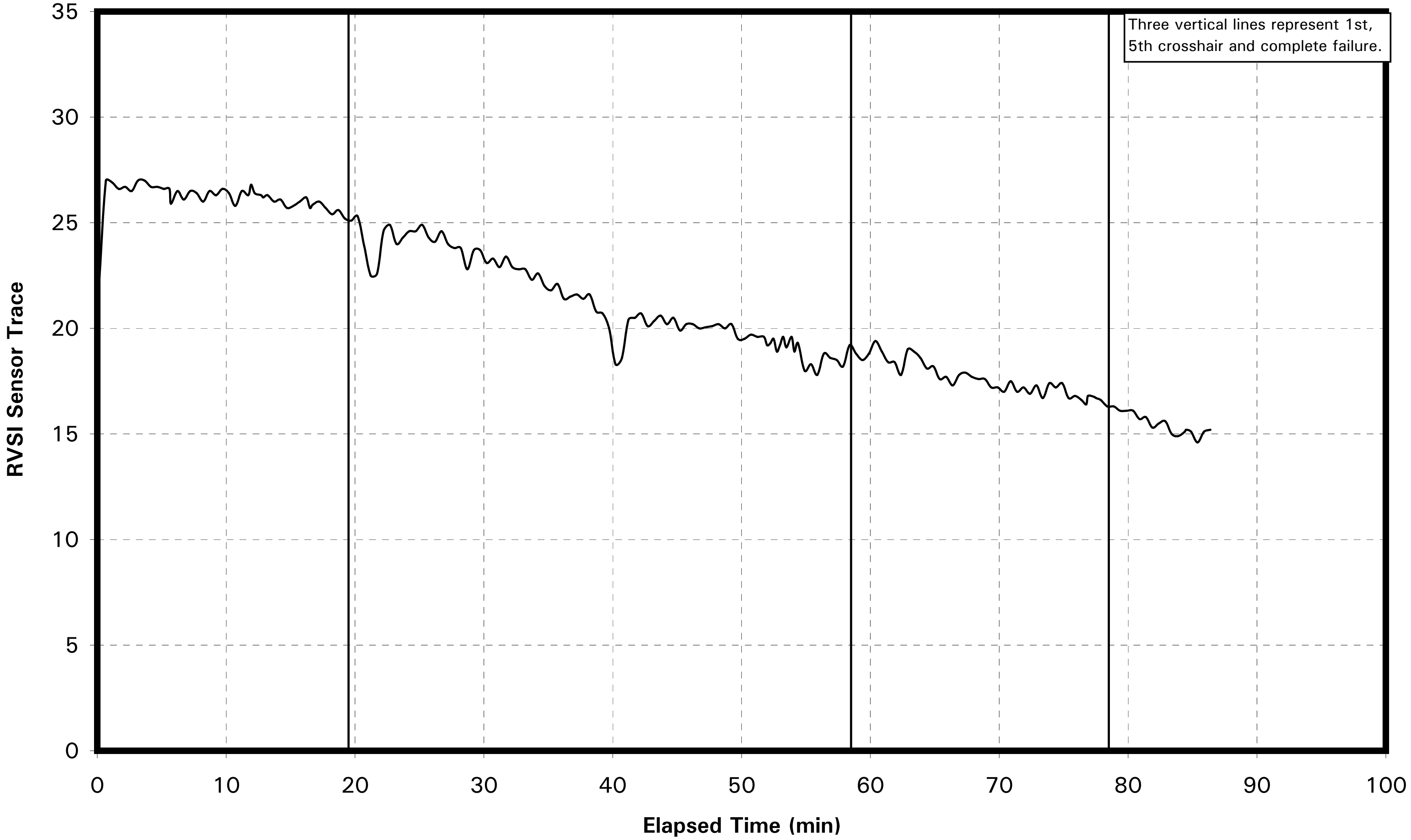
9/22/2006, 9:48 AM

DOCUMENTATION OF FLUID FAILURE

RVSI SENSOR TRACE

ID # 28



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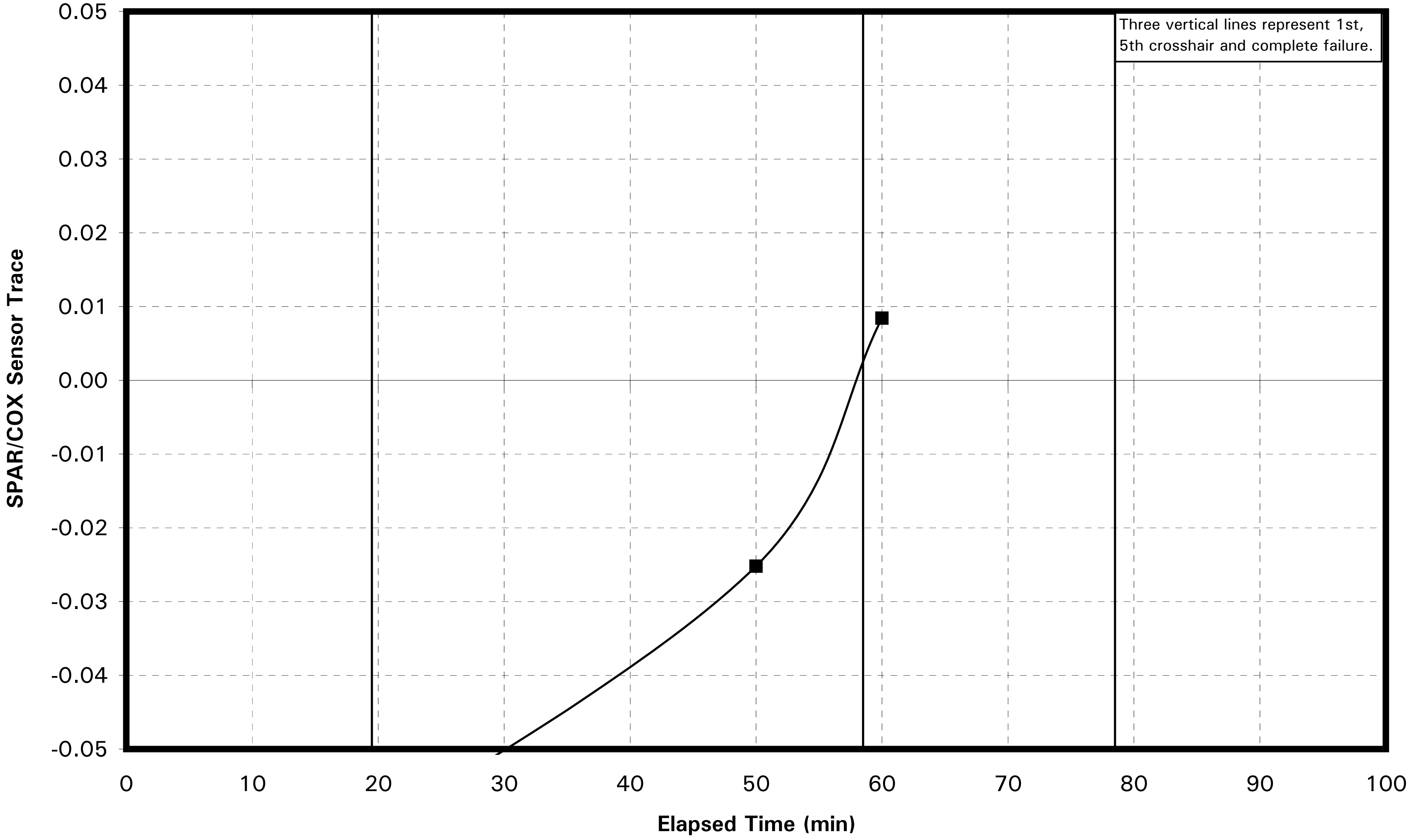
9/22/2006, 9:49 AM

DOCUMENTATION OF FLUID FAILURE

SPAR/COX SENSOR TRACE

ID # 28



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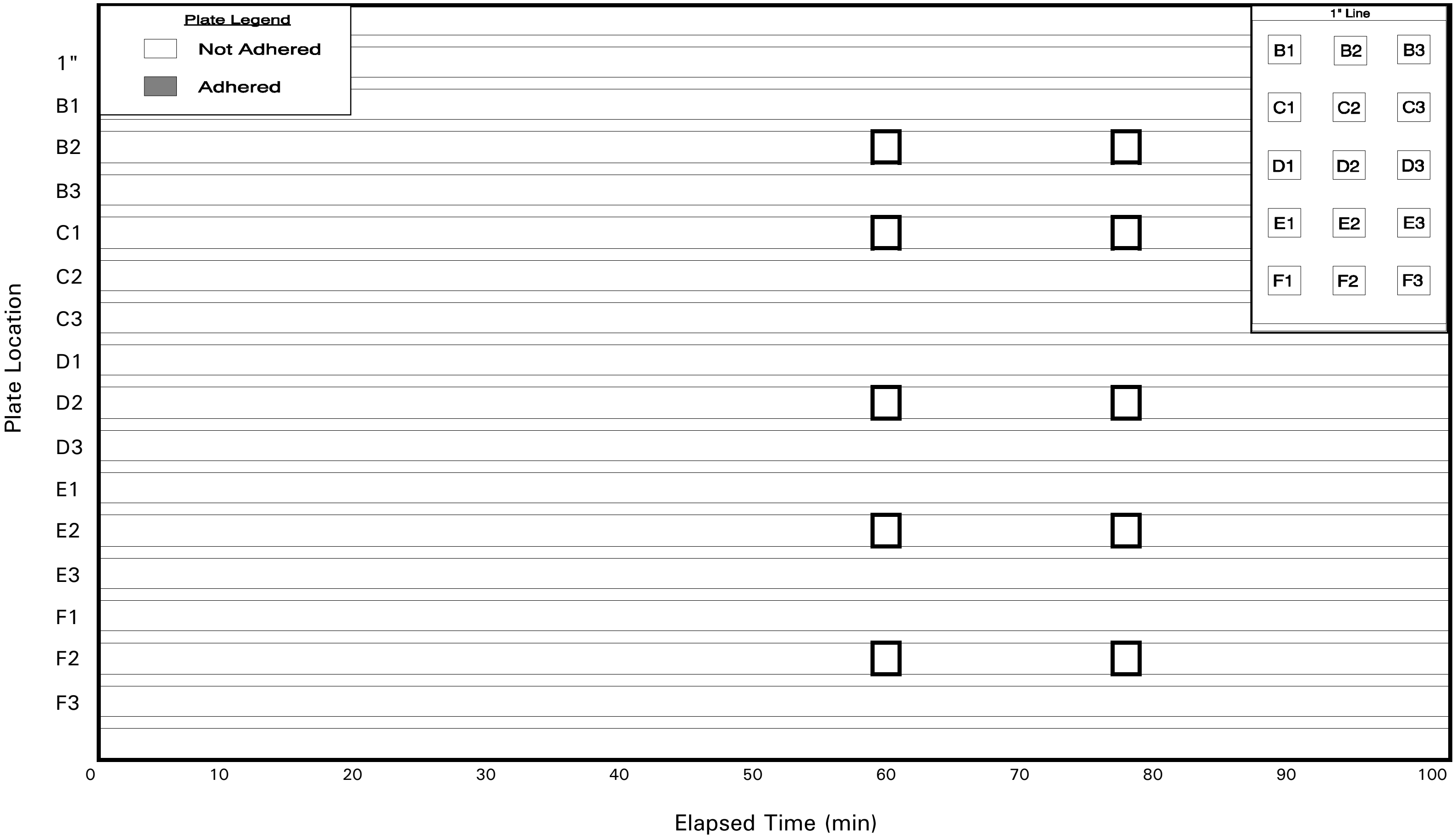
9/22/2006, 9:50 AM

DOCUMENTATION OF FLUID FAILURE

ADHERENCE TESTS

ID # 28



cm1380/analysis/doc_fail/ADH_ID28
9/22/2006, 9:53 AM