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INTEGRATED LOW EMISSIONS CLEANUP SYSTEM FOR DIRECT COAL FUELED TURBINES
(Moving Bed, Fluid Bed Contactor/Ceramic Filter)

Twenty-Fifth Quarterly Report

Quarterly Status Report for the Period October - December 1993

By

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ABSTRACT

The United States Department of Energy, Morgantown Energy Research Center (DOE/METC), is sponsoring the development of direct coal-fired turbine power plants as part of their Heat Engines program. A major technical challenge remaining for the development of the direct coal-fired turbine is high-temperature combustion gas cleaning to meet environmental standards for sulfur oxides and particulate emissions, as well as to provide acceptable turbine life.

The Westinghouse Electric Corporation, Science & Technology Center, is evaluating two Integrated Low Emissions Cleanup (ILEC) concepts that have been configured to meet this technical challenge: a baseline ceramic barrier filter ILEC concept, and a fluidized bed ILEC concept. These ILEC concepts simultaneously control sulfur, particulate, and alkali contaminants in the high-pressure combustion gases at turbine inlet temperatures up to 2300°F. This document reports the status of a program in the twenty-fifth quarter to develop this ILEC technology for direct coal-fired turbine power plants.

EXECUTIVE SUMMARY

During the Twenty-Fifth Quarter of the program, the Phase III bench-scale, high-temperature, high-pressure (HTHP) testing was initiated. Ten tests were completed to characterize the filter cake permeability of 3 PFBC fly ashes as a function of temperature. The tests were highly controlled measurements of filter cake pressure drop for deposited cakes without pulse cleaning. The transient nature of the filter cake permeability and its sensitivity to temperature were evident. The behavior trends were consistent with field unit observations.

1. INTRODUCTION

Development of direct coal-fueled turbine power cycles, in the Department of Energy Heat Engines program, is focused on staged, slagging combustor designs that potentially provide high performance, compact and low cost power generation systems. The power generation systems demand high performance from hot-gas cleaning equipment to meet environmental requirements and to satisfy turbine protection requirements, using concepts that are, as yet, undeveloped.

To provide emissions control and turbine protection from gas- and solid-phase contaminants in direct coal-fired turbine systems, contractors are currently testing: beneficiation of coal to minimize ash and sulfur content; injection of sulfur sorbents into or following the combustor; staged combustion to limit NO_x formation; slag removal by impaction; inertial particle collection; and barrier filters within the combustor-cleanup train. While there is a basis for the development of some of these proposed approaches to hot-gas cleaning a number of concerns make the development of an innovative, integrated, low emission, gas cleanup (ILEC) concept desirable. Specific concerns include the high cost of highly beneficiated coals, the economic penalty of separate gas cleaning functions arranged in series, the potentially limited ability of in-situ sulfur control to achieve low sulfur emissions, the potentially limited ability of inertial collection to achieve sufficiently low particulate emissions, and the need for gas-phase alkali control to provide acceptable turbine life.

New approaches for sulfur and alkali control may be required at the proposed temperature levels of some direct coal-fired systems, and new approaches for particulate control may be required in the environment of potentially molten and/or sticky particles. An integrated, multi-function cleaning stage may be an economic requirement when using minimally-cleaned, high-sulfur, high-ash coals.

In addition, the ILEC system must be compatible with the application. In its programs on Heat Engines, the Department of Energy is attempting to develop coal-fueled turbines for large electric utility power plants, for industrial power plants, and for small, stationary and transportation power generation systems. This broad range of applications encompasses a large variety of turbine sizes and designs, a range of turbine operating conditions, different arrangements for coupling the coal combustor to the gas turbine, and greatly differing gas cleanup requirements. ILEC concepts that can be adapted to all of these applications are needed.

In this program, two advanced, high-temperature Integrated Low Emissions Cleanup concepts are addressed that combine particulate and gas phase contaminant removal in a single, compact filter device that is intended for operation in direct, coal-fueled turbine systems. The program will investigate the key process and design parameters of the concepts, evaluating both a "baseline" and a fluid bed ceramic filter with immersed barrier filters. In both concepts finely sized sulfur and alkali sorbents are injected into the combustion gas stream, react with the gas-phase sulfur and alkali species while modifying the sticky nature of the ash that is carried over from the combustor. Additives may also be injected to control the filter coal behavior. Sorbent and ash particles are collected on ceramic barrier filters placed in the contactor vessel.

The program has been divided into three phases. Phase I of the program deals with critical laboratory testing and conceptual commercial design evaluation. Phase I has been completed, although continuation of some key Phase I test work has been undertaken. In Phase II, upgrading of a HTHP bench-scale facility will take place along with the design and procurement of the baseline integrated cleanup test system. Phase II has been initiated. Phase III of the program involves the actual HTHP bench-scale testing and engineering assessment of the integrated cleanup devices and systems.

2. WESTINGHOUSE ILEC CONCEPTS

The Westinghouse ILEC concepts are extrapolations to higher temperatures of gas cleaning technologies being developed for similar technical purposes in other applications. These generally lower temperature technologies are:

- ceramic barrier filter particulate control (up to 1700°F)
- fluidized bed filtration (up to 1200°F)
- sulfur sorbent injection into high-temperature gas streams (up to 3000°F), and fluidized bed desulfurization (up to 2000°F)
- alkali sorbent injection into high-temperature gas streams (up to 1600°F)

These technologies are currently being developed for applications that require high-pressure gas cleaning at temperatures up to about 1700°F (Pressurized fluid bed combustion and pressurized coal gasification systems, for example). Additional technical basis for the development of these ILEC concepts is provided by the Department of Energy and GRI development programs for high temperature heat recovery systems using fluidized bed heat exchangers,[1] and for high temperature ceramic heat exchangers that operate at temperatures exceeding those required for direct coal-fired turbines.[2,3]

Ceramic barrier filters have the potential to provide extremely high particle removal efficiencies at high gas temperatures. Testing at temperatures up to 1700°F has shown that they can exceed the particulate removal needed for both environmental standards and for turbine erosion and deposition protection. The major concern for their use in direct coal-fired turbine applications is that adhesive particles (slag particles or sticky fly ash particles) will be emitted from the coal combustor that may form a filter cake that is difficult to remove from the filter elements by normal pulse cleaning. It is the premise of the ILEC concepts proposed in this program that the combustion gas containing adhesive particles will interact with added sorbent particles, or inert additive particles, to either remove the adhesive particles before they reach the ceramic barrier filter elements, or to modify the filter cake adhesive nature so that it is removable. This premise is applied in the two ILEC concepts pictured in Figures 2.1 and 2.2.

In the first concept shown in Figure 2.1, the "baseline" ILEC concept, is a ceramic barrier filter vessel having a design much like that of the ceramic barrier filters vessels being developed for lower temperature applications. An array of vertical filter elements, candle-type or cross-flow type, is supported from a tube sheet, and is housed in a refractory-lined pressure vessel. Filter cake is periodically released from the filter elements by back-pulsing with clean gas. The released filter cake drops into a conical bin at the base of the vessel for removal. The baseline ILEC concept is operated with the injection of sulfur sorbents, alkali sorbents, and possibly selected deposit-modifying additives (e.g., kaolin) that produce a filter cake on the filter elements that is easily removed by pulsed cleaning. The potential success of the baseline ILEC concept is suggested by deposit formation observed in other programs that inject sulfur sorbents into conventional coal-fired furnaces, and programs that have injected deposit additives into coal-fired turbine gases.[4,5,6] The injected sulfur sorbents are -325 mesh calcium-based sorbents, or advanced sulfur sorbents (strontium carbonate, for example), that effectively capture SO_2 at the turbine inlet temperatures in the relatively short contact times available. The injected alkali sorbent is -325 mesh emathlite, hectorite, or others, that removes alkali species (sodium and potassium components) from the gas to meet projected turbine alkali limits. The

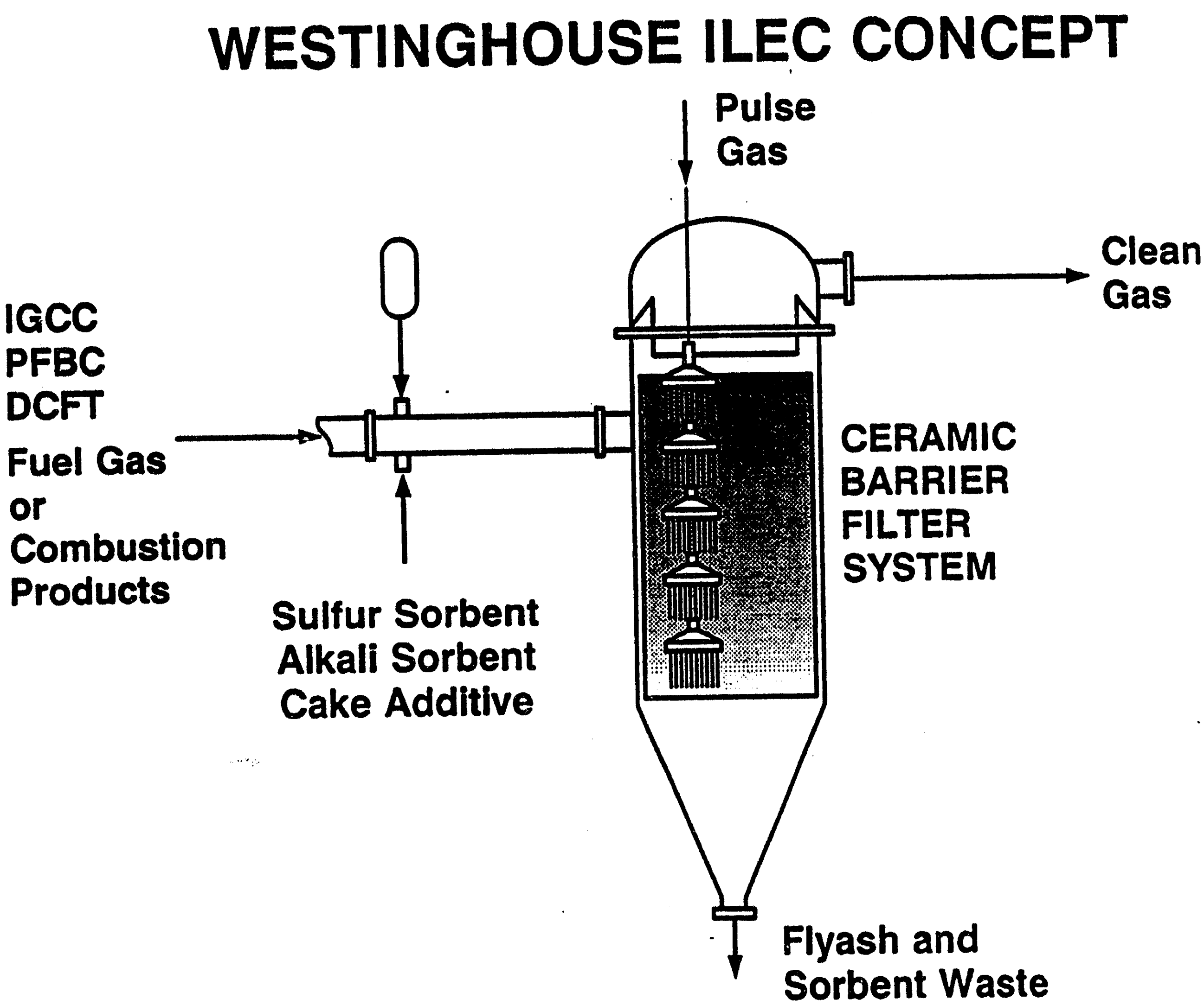

Figure 2.1 - ILEC Concept

effectiveness of emathlite has been demonstrated at a small-scale at temperatures up to about 1600°F in both reducing and oxidizing gases.[7] Other alkali sorbents such as hectorite and bauxite are also candidates.

The second ILEC concept, in Figure 2.2, is a fluid bed filter concept. In this concept the combustion products are passed through a fluidised bed of either inert particles or sulfur sorbent particles. The adhesive particles agglomerate with the fluid bed media, removing them from the gas. The effectiveness of fluidised bed filters for particle removal by agglomeration phenomena has been demonstrated in other development programs at lower temperatures. Ceramic candle filters are vertically immersed into the fluid bed to prevent the elutriation of coarse particles, or the entrainment of fine particles from the fluid bed. In addition, the mixing action of the fluid bed provides cleaning of the filter cake from the ceramic candle filter surfaces, resulting in the potential elimination, or minimization, of the pulsed gas filter cleaning system. A similar fluid bed filter concept, using immersed candle filter elements in the bed, has been previously proposed for use in catalytic reactor systems.[8]

The fluid bed media has a particle size similar to particles used in bubbling PFBC applications. The fluid bed media if inert could be either alumina, sintered dolomite, slag particles generated in the combustor, or fly ash particles generated from the plant solid waste. The most economical material is used. If the fluid bed media is to function as a sulfur sorbent, it would be a cheap, calcium-based material such as dolomite. Sulfur sorbent particles and alkali sorbent particles can also be injected into the gas stream prior to the fluid bed filter.

The gas distributor for the fluid bed requires a design that is free from plugging of the orifice holes. Prior technology development suggests that water cooling, or air cooling, of the distributor plate to some critical temperature, combined with the selection of large orifices having sufficiently high gas velocities will provide protection against

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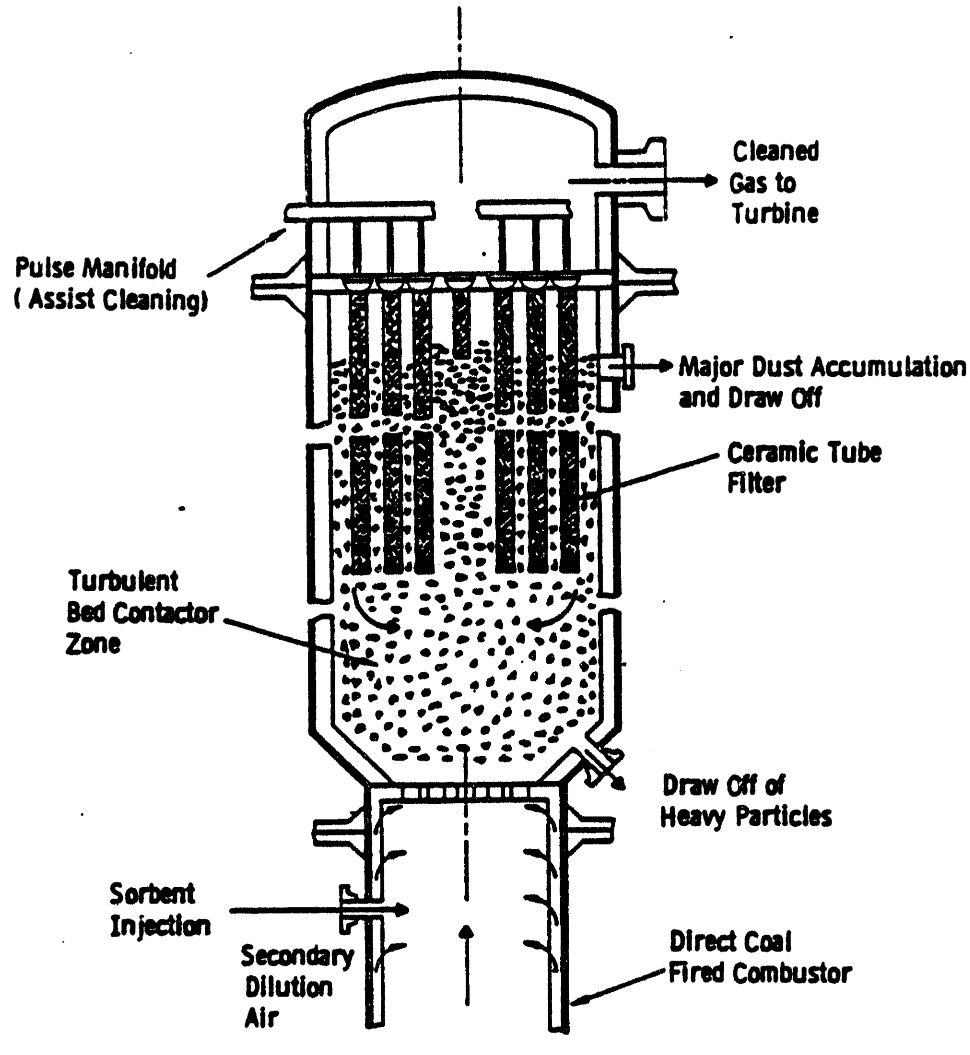

Figure 2.2 - Fluid Bed ILEC Concept

deposit formation and plugging. The resulting fluid bed is relatively compact because the immersed ceramic candle filters permit the size of the freeboard region above the fluid bed to be minimized. The captured adhesive particles are removed with a continuous underflow stream of bed media. Fine particles that are not adhesive in nature will tend to segregate to the top of the fluid bed where they can be separately removed from the vessel.

References

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3. PROGRAM STRUCTURE AND OBJECTIVES

The program is being conducted in three phases to demonstrate at the bench scale the ILEC concepts. Phase I of the program has been completed, but some Phase I extended testing is being conducted. Phase I of the program deals with laboratory sorbent screening tests, cold flow testing, and commercial system evaluation of the ILEC concepts to support the bench-scale facility design and testing in Phases II and III. In Phase II, upgrading of a HTHP facility will take place along with the design and procurement of the filter test systems. The bench-scale test program will utilize an existing, high temperature, high pressure (HTHP) facility located at the Westinghouse Science and Technology Center. The facility will be upgraded for coal feeding to attain a range of combustion gas conditions that would be typical of the conditions expected at the exhaust of direct coal-fired combustors being developed in the current DOE Heat Engines programs. This facility will be used in Phase III to test the components and advanced design features of the baseline ILEC systems and to verify the engineering design principles of the concepts.

4. SUMMARY OF TWENTY-FIFTH QUARTER PROGRAM STATUS

4.1 - PHASE I CONTINUATION: SUPPLEMENTAL LAB-SCALE TESTING

Objectives: Conduct laboratory testing that supports the bench-scale facility design and operation, as well as testing of critical fluid bed ILEC concept issues.

OBJECTIVE I-1 - TEST PLAN DEVELOPMENT

Identify areas requiring supplemental laboratory testing to support the bench-scale facility modification design and operation. Include critical issues for fluid bed ILEC concept. Define detailed test plan for each supplemental area. The test plan shall be reviewed and approved by the DOE COR.

Status

The test plan development has been completed. Some aspects of the test plan have been modified as the program focus and issues have been re-established. No effort has been expended on this task during this quarter.

OBJECTIVE I-5.1 - ENTRAINED SULFUR REMOVAL

Conduct tests of HTHP sulfur removal in the existing entrained reactor at specific test conditions to optimize sorbent properties and operating conditions for effective sulfur removal, as detailed in the Objective I-1 test plan.

Scope

Conduct tests to measure sulfur removal kinetics with the specific sulfur removal sorbents to be used in bench-scale testing. Preliminary range of test conditions:

- 1850 to 2100°F
- calcium-based sorbents (limestone, dolomite, hydrated lime)
- 0.1 to 1 second gas residence time
- oxidizing conditions
- sorbent particle size a parameter

Analyze the reaction products and the kinetic data. Confirm the existing entrained sulfur removal model by evaluation of known DCFT test data. Select the sulfur sorbent types, sizes and feed rates to be used in the bench-scale testing.

Status

This testing has been completed, with an option to return to complete some critical testing if needed at a later date. The data collected has been combined with past data, including DCFT tests reported by Solar Turbines, and an evaluation has been completed. Commercial ILEC sulfur removal performance has been projected. The sulfur removal evaluation was presented in the Twelfth Quarterly Report. No effort was expended on this task during this quarter.

OBJECTIVE I-5.2 - ALKALI REMOVAL

Modify the entrained reactor and conduct tests, as detailed in the Objective I-1 test plan, of HTHP alkali removal at specific conditions to optimize sorbent properties and operating conditions for effective alkali removal.

Scope

Design the entrained reactor modification required to test alkali removal kinetics. Modify the equipment. Conduct tests to measure alkali removal kinetics with the specific alkali removal sorbents to be used in bench-scale testing. Preliminary range of test conditions:

- 1850 to 2100°F
- emathlite and hectorite sorbents
- 0.1 to 1 second gas residence time
- oxidizing and reducing conditions
- sorbent particle size a parameter

Analyze the reaction products and the kinetic data, and re-assess the existing entrained alkali removal model. Select the alkali sorbent types, sizes and feed rates to be used in the bench-scale testing.

Status

A total of 22 tests have been conducted in the program, with temperatures of 1850 and 2100°F, and NaCl vapor contents ranging from 1.3 to 112 ppmw. Two operating modes of testing were used to assess the relative contributions of the entrained and the cake removal. In all of the tests the gas-particle contact time in the entrained zone was 2 seconds, and in the cake zone the particles resided for 15 minutes. The test results have been reported in the 15th and 16th Quarterly Reports. Conversions up to 9.24 weight percent of the emathlite reaction product were measured, almost 50% of the saturation conversion of emathlite. In general, the performance under entrained conditions was better than with a cake only. The results have been correlated and estimates of commercial alkali removal performance in the ILEC have been developed. The complete evaluation will be reported in the task topical report currently in preparation.

OBJECTIVE I-5.3 - ADDITIVE SELECTION AND PERFORMANCE

Select deposit additives for the specific operating conditions, coal ash types, alkali and sulfur sorbents to be used in the bench testing. Confirm additive effectiveness in furnace tests.

Scope

Use prior test results and thermodynamic phase diagrams to select economical additives for filter cake modification. Procure these additives. Conduct furnace tests with the mixtures to confirm their performance.

Status

This objective has been reduced in scope to a minimum effort of identifying appropriate additives for Phase 3 testing. Some preliminary filter cake additive tests completed in a test unit very similar in design to the bench-scale unit under construction were evaluated and reported in the 21st Quarterly Report.

OBJECTIVE I-5.4 - FLUID BED CONCEPT CRITICAL ISSUES TESTING

Design, construct, and operate cold flow hydrodynamic simulation of fluid bed filter based on Phase I commercial conceptual design.

Scope

Identify critical issues, including distributor design, ash-bed separation, entrained sorbent mixing in the bed, filter element movement, filter element self-cleaning, element arrangement, etc. Include continuous ash feeding and ash removal capabilities. Eliminate fluidized slugging bed behavior by sizing gas flow to near 1000 actual cubic foot per minute. Prepare detailed design and assemble the facility. Select and procure commercial candle elements. Conduct tests as detailed in the Objective I-1 test plan. Re-assess critical issues and re-evaluate commercial design concept. Develop test plan for HTHP fluid bed testing.

Status

In prior cold model testing effective design and operating conditions have been identified. The major feature remaining to be developed is the removal of the fly ash particles from the fluid bed filter. The fluid bed filter concept appears to be of significant interest to some high-temperature applications:

- applications of relatively small gas flow where the tube sheet required to support the single layer of ceramic candles does not become too large in diameter to be practical;
- applications having primarily "sticky" fly ash particles that will be substantially removed by injection into the fluid bed media.

The small-scale, industrial DCFT applications such as those of Solar Turbine and Allison Gas Turbine appear to fit this description. The ability to simulate sticky fly ash particle behavior in the cold model, while possible, would be very uncertain, and it seems likely that cold model testing will not be appropriate for the development needed for this process. Hot testing of the concepts is needed under simulated DCFT conditions.

OBJECTIVE I-6 - TOPICAL REPORTS

Prepare a Phase I Technical Report detailing the supplemental lab-scale efforts and two topical reports, i.e., High Temperature, High Pressure Deposit Additives; and Sorbents for High Temperature, High Pressure Vaporous Alkali Species Removal.

Status

Topical reports are scheduled near the completion of the appropriate Objectives. No topical reports have been completed during this quarter.

4.2 - PHASE II: BENCH-SCALE FACILITY DESIGN AND FABRICATION

OBJECTIVE II-1 - TEST PLAN DEVELOPMENT

Update from Phase I the test plan for the bench-scale facility test program based on the Westinghouse baseline ILEC concept. Include integrated particle, sulfur, and alkali removal performance, deposit additive characteristics of the filter cake, pressure drop, cleaning, and materials.

Scope

Estimate test conditions to evaluate the performance of simulated coal-fired turbine operation with the Westinghouse baseline ILEC concept. Include integrated

- particle removal performance
- sulfur removal performance
- alkali removal performance
- filter cake modification performance
- filter pressure drop and cleaning performance
- filter material behavior

Status

A revised test plan has been developed to focus on a key aspect of ceramic barrier filter technology - the effective pulse cleaning of candles in PFBC applications. This plan was presented in the Twenty-Third Quarterly Report.

OBJECTIVE II-2 - BENCH-SCALE FACILITY MODIFICATION DESIGN

Develop detailed design of the facility for the baseline ILEC concept bench-scale testing that meets the test plan requirements. Designs shall be submitted to the DOE COR for review and approval.

Scope

Utilise an existing HTHP filter test facility modified for

- temperatures up to 2100°F
- oxidising environment
- partial coal injection/methane-fired
- sulfur removal with calcium-based sorbents
- alkali sorbent injection
- deposit additives
- cross-flow and candle filters elements

Select:

- appropriate candle material for this duty
- appropriate instrumentation for SO_x, and alkali measurement
- sorbent and additive feeding equipment and feed nozzles

Prepare:

- material and energy balances
- process flow diagrams
- equipment sizes, designs, and specifications
- vessel fabrication drawings

Status

The original bench-scale facility design modifications had been completed during the twenty-third quarter of the program. These designs were modified to incorporate the needs of the revised test plan.

OBJECTIVE II-3 - BENCH-SCALE FACILITY FABRICATION AND ASSEMBLY

Prepare the facility for testing the baseline ILEC by modifying the existing HTHP test facility as required.

Scope

Fabricate the facility modifications and required new test vessels. Purchase equipment, candle and cross-flow filters, and instruments. Assemble the facility. Procure and characterize sulfur sorbents, alkali sorbents, deposit additives, coals, and coal ashes.

Status

During the twenty-third quarter, assembly of the test facility equipment was completed, placing the filter unit into a prototypic, state-of-the-art, candle filter configuration applicable to PFBC. The standard Westinghouse candle figure configuration incorporates fail-safe devices.

OBJECTIVE II-4 - BENCH-SCALE SHAKEDOWN TESTING

Conduct shakedown testing of the bench-scale facility and instruments to demonstrate the operating capabilities and acceptance to design requirements.

Scope

In support of the Objective II-2 facility modification design, operate the existing facility, prior to modification, to determine its current capabilities for high temperature operation and conduct brief tests to examine the consequences of high temperature operation. Operate the modified facility at maximum and minimum flow test conditions. Operate coal, ash, sorbent and additive feed equipment. Confirm accuracy of instrumentation.

Status

Shakedown testing of the major components and of the integrated facility were completed the twenty-third quarter.

OBJECTIVE II-6 - TOPICAL REPORTS

Prepare the required Phase II Technical Report

Status

A Phase II Topical Report was completed the previous quarter and was submitted to DOE for review, and was approved during the twenty-fourth quarter.

OBJECTIVE II-7 - PROGRAM MANAGEMENT AND ADVISORY BOARD

Provide overall project management for meeting research objectives and for cost and schedule control. Continue Phase I Advisory Board activities in obtaining Heat Engine contractors' consultation and integration of ILEC cleanup research efforts through exchange of technical requirements and information.

Status

Program restructuring has occurred to a significant extent in the program, ensuring that the testing reflects the major technical issues facing ceramic barrier filter development as it relates to the Westinghouse ILEC. Approval to proceed with the Phase III test program was received during the twenty-fourth quarter.

4.3 - PHASE III: BENCH-SCALE TESTING

OBJECTIVE III-1 - PROCUREMENT

Procure the materials required for the Phase III test program.

Scope

Procurement of the following materials is required:

- Ceramic candles
- Fly ashes
- Additives
- Sulfur and alkali sorbents

Status

All procurement activities have been completed.

Candles	Fly Ashes	Additives	Sorbents
Schumacher	Tidd	Dolomite	Dolomite
Coors	Tidd Cyclone Catch	Kaolin	Lime
Refractron	Grimethorpe	Neutralite	Emathlite
	Karhula		
	Foster Wheeler		

OBJECTIVE III-2 - BENCH-SCALE TESTING

Conduct testing of the HTHP candle filter facility to develop improved pulse cleaning phenomena understanding and performance, and to demonstrate the feasibility of in-filter sulfur removal and alkali removal, under PFBC conditions.

Scope

The scope of the testing, as defined in the Phase III test plan (presented in the Twenty-Third Quarterly Report), includes the following parameters for the candle cleaning tests:

- Fly ash type
- Candle type
- Temperature
- Pulse cleaning intensity
- Additive type and amount

For the sulfur and alkali removal tests, the scope includes the sulfur and alkali sorbent type and amount. These parameters are to be tested in 6 Test Sets:

1. Cake Permeability tests,
2. Cake Pulse Removal tests,
3. Additive Tests,
4. Pulse Intensity tests,
5. Continuous Operation tests,
6. Sulfur/Alkali Removal tests.

Status

Testing was initiated during October, 1993, on the Test Set 1, Cake Permeability tests and has continued into November. Ten successful tests were completed in November. No testing was conducted during December while the facility was used for other key test activities. Testing will continue in January 1994.

OBJECTIVE III-3 - DATA EVALUATION

Analyze and evaluate the experimental results produced in the bench-scale testing.

Scope

Raw test data will be converted into basic engineering quantities and correlations that can be used for design applications. The significance of the test results will be determined and interpreted in terms of full-scale filter system design, operation and performance.

Status

This objective was initiated in November and continued into December.

Report Period Activity

Data from the 10 tests completed were evaluated, extracting "mass" permeabilities for the filter cake, and gross permeabilities for the candle filter element and residue layer. A minimum permeability occurred as a function of temperature in each test at about 1550-1650°F. The minimum appears to correspond to the point where equilibrium conditions change from $CaCO_3$ being stable to CaO being stable. Further evaluation is being performed using subsequent gas CO_2 measurements collected during some of the tests. The test data and evaluation results are shown in Appendix A.

OBJECTIVE III-4 - PROGRAM MANAGEMENT AND REPORTING

Provide overall project management for meeting research objectives and for cost and schedule control. Produce monthly, quarterly, and final reports for the program.

Status

A presentation of the test data and a tour of the test facility was made to DOE/METC personnel on December 13, 1993. Other test points of interest were discussed at that meeting. A six month time extension is being requested for this program.

APPENDIX A

Westinghouse - DOE/METC Filter Cake Cleaning Test Program

OBJECTIVES

- Resolve Issues Relating to Pulse Cleaning of Candles in PFBC

  How Does Candle Filter Cleaning Performance Relate to

  - Fly Ash Source
  - Temperature
  - Pulse Intensity
  - Additives
  - Sulfur/Alkali Sorbents

- Determine Sulfur/Alkali Removal Capabilities of Filter

Westinghouse - DOE/METC Filter Cake Cleaning Test Program
Test Sequence

1) Cake Permeability Tests

2) Cake Pulse Removal Tests

3) Additive Tests

4) Pulse Intensity Tests

5) Continuous Operation Tests

6) Sulfur Removal Tests

7) Alkali Removal Tests

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Westinghouse - DOE/METC Filter Cake Cleaning Test Program

CONFIGURATION

- 4 Candles in Current PFBC Holder/Gasket Design
- Fail-Safe/Regenerator in Place
- Oxidizing Atmosphere with Injected PFBC Fly Ashes

PARAMETERS

- Candle Type (Schumacher, Coors, Refractron)
- Ash Source (Tidd, Karhula, Grimethorpe, FWDC)
- Additives/Aids (Dolomite; Kaolin; Neutralite)
- Temperature (1300° - 1650° F)
- Pulse Tank Pressure
- Pulse Valve Parameters

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Westinghouse - DOE/METC Filter Cake Cleaning Test Program
Cake Permeability Tests

Objective: Observe Influence of Fly Ash Source, Temperature and Time on Filter Cake Permeability.

Conditions: Schumacher Candles

Test Parameters:

- Temperature
- Fly Ash Type
  - Tidd Filter Drain
  - Tidd Primary Cyclone Drain Mixed with Tidd Filter Drain
  - Grimethorpe
  - Karhula
  - FWDC (Air Products Feedstocks)
- Fly Ash and Additives
- Status
  - Ten Tests Completed
  - Results Show Trends Consistent with Field Observations

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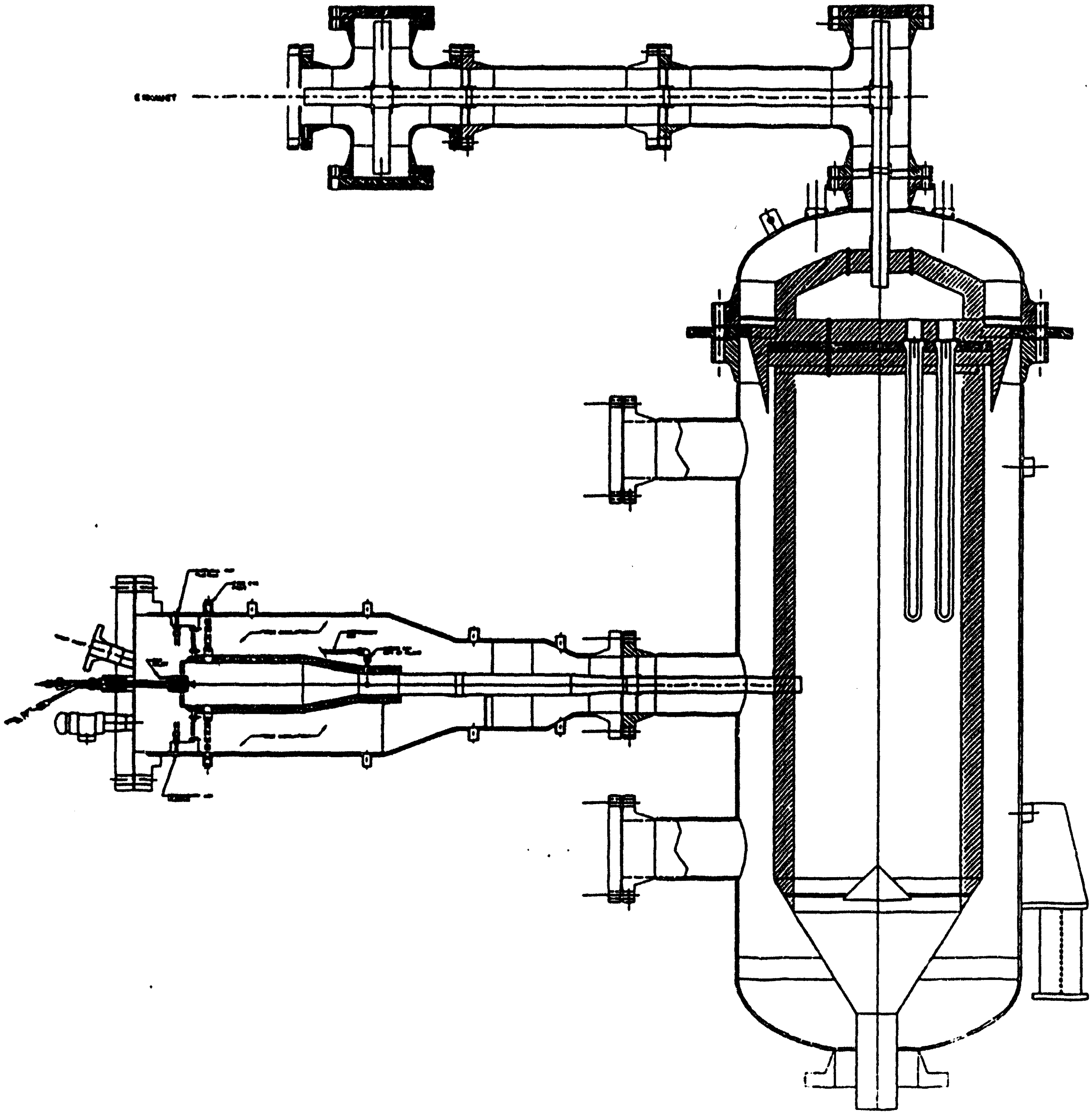


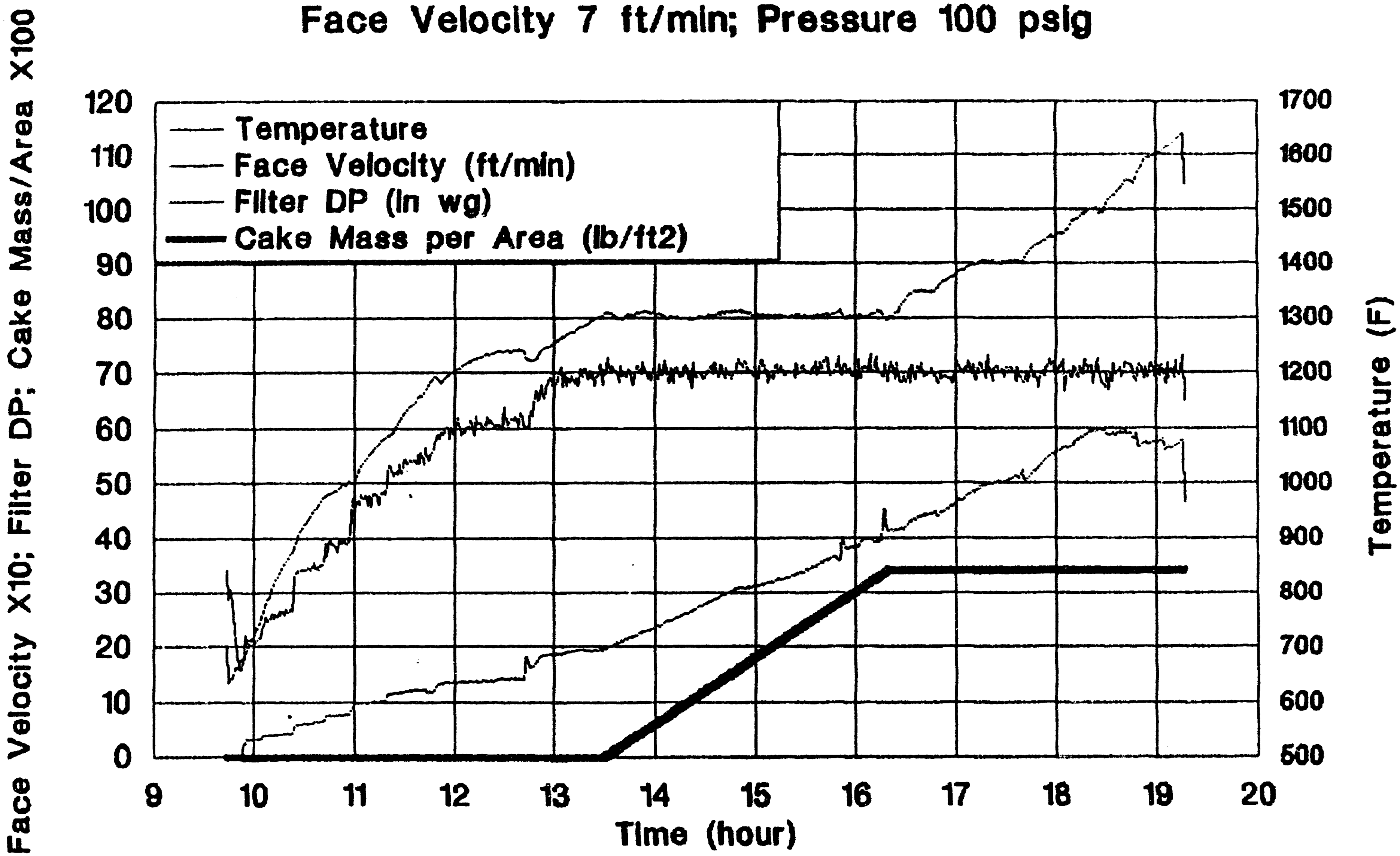
Westinghouse - DOE/METC Filter Cake Cleaning Test Program
Cake Permeability Test Results
(Through November 1993)

Perm. = Filter cake permeability
Temp. = Filter cake/gas temperature
Min. = Minimum

TEST	DATE	FLY ASH TYPE	FACE VELOCITY (ft/min)	PRESSURE (PSIG)	RESULTS
1	11/8	Tidd	7	100	Min. Perm. at >1500°F
2	11/9	Tidd	7	100	Min. Perm. at 1600°F; Fair test repeatability; Perm. does not recover as Temp. is reduced
3	11/10	Tidd	7	100	Min. Perm. at > 1600°F; Good test repeatability; Little impact of initial cake thickness
4	11/11	Tidd	7	100	Perm. drops with time
5	11/12	Tidd	12	100	Min. perm. at 1550°F; Higher velocity may result in lower Perm.
6	11/15	Grimethorpe	7	100	Min. Perm. > 1630°F; Lower Perm. than Tidd; Less Perm. sensitive to Temp.
7	11/16	Karhula	7	100	Min. Perm. at 1650°F; Higher Perm. than Tidd ash; Perm. Less sensitive to Temp.
8	11/17	None	7 and 12	100	Residue Perm. increase >1600°F; Residue Perm. drops at higher velocity
9	11/23	Tidd	7	150	Min. Perm. at 1550°F; Higher pressure may result in lower Perm.
10	11/24	Tidd plus 10 wt% dolomite	7	100	Min. Perm. at 1550°F; Higher Perm. with additive

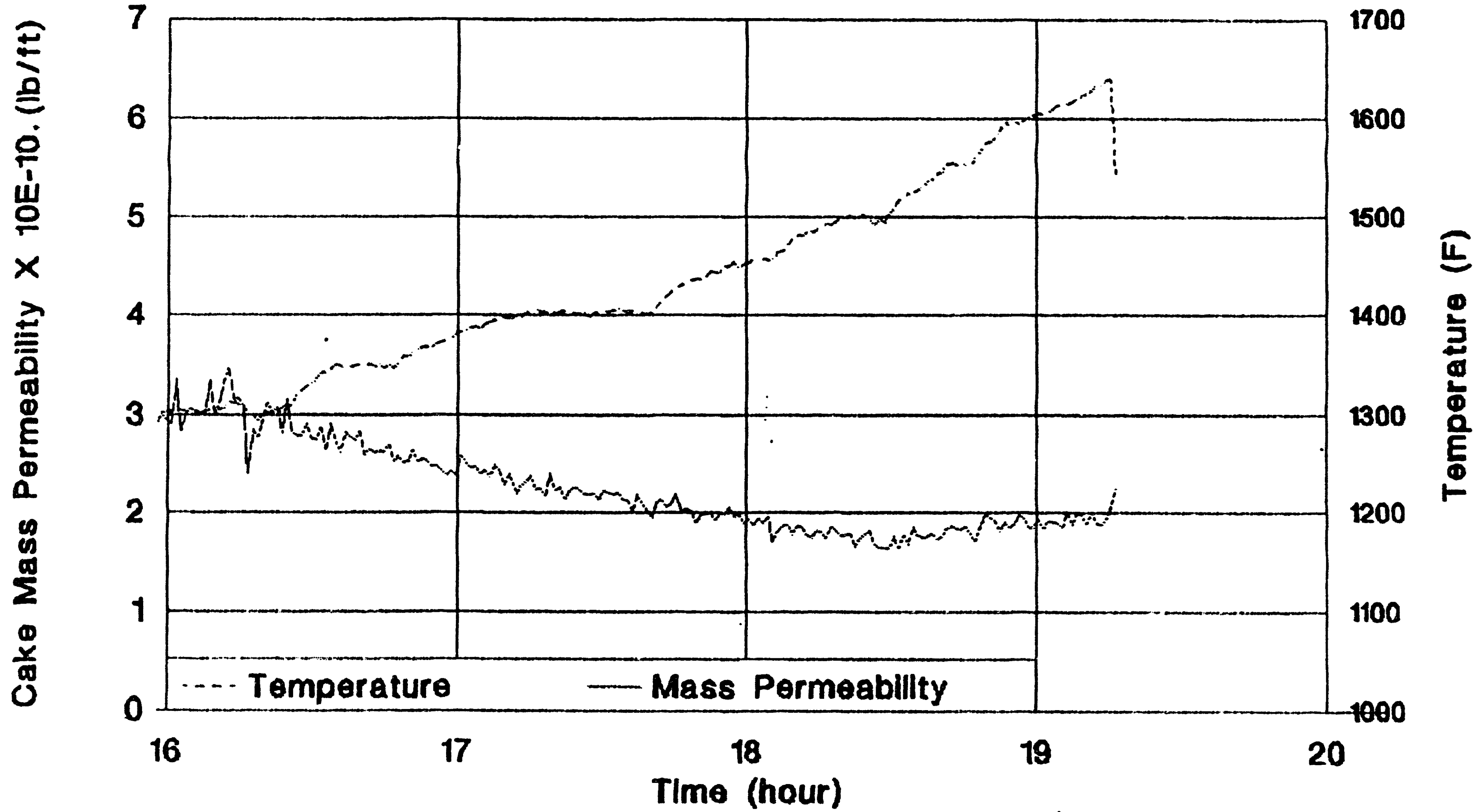
Test 1.01 - 11/08/93
Schumacher Candles / Tidd Flyash

Face Velocity 7 ft/min; Pressure 100 psig



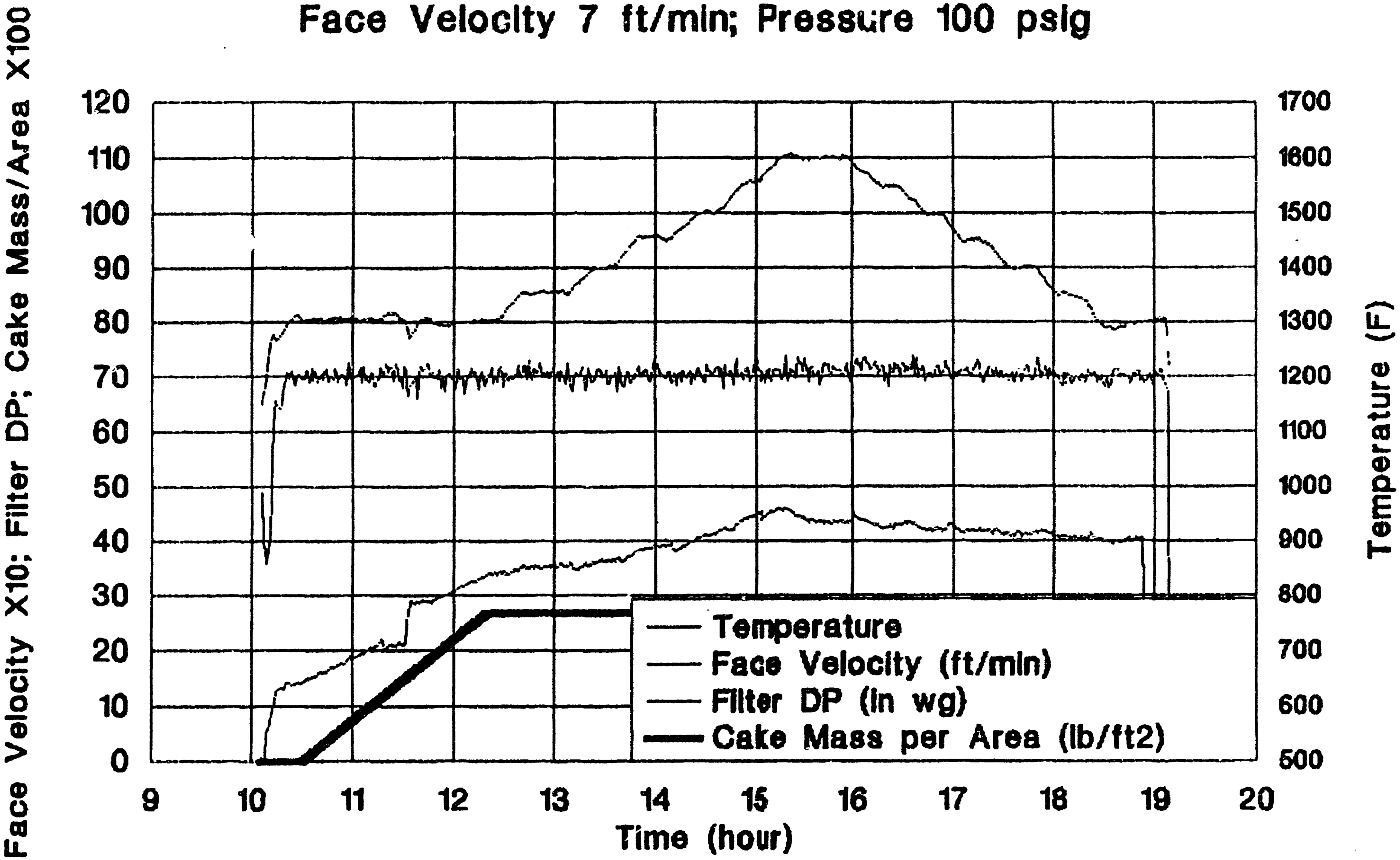
Test 1.01 - 11/08/93
Schumacher Candles / Tidd Flyash

Face Velocity 7 ft/min; Pressure 100 psig
Starting Cake 21.5 in. wg



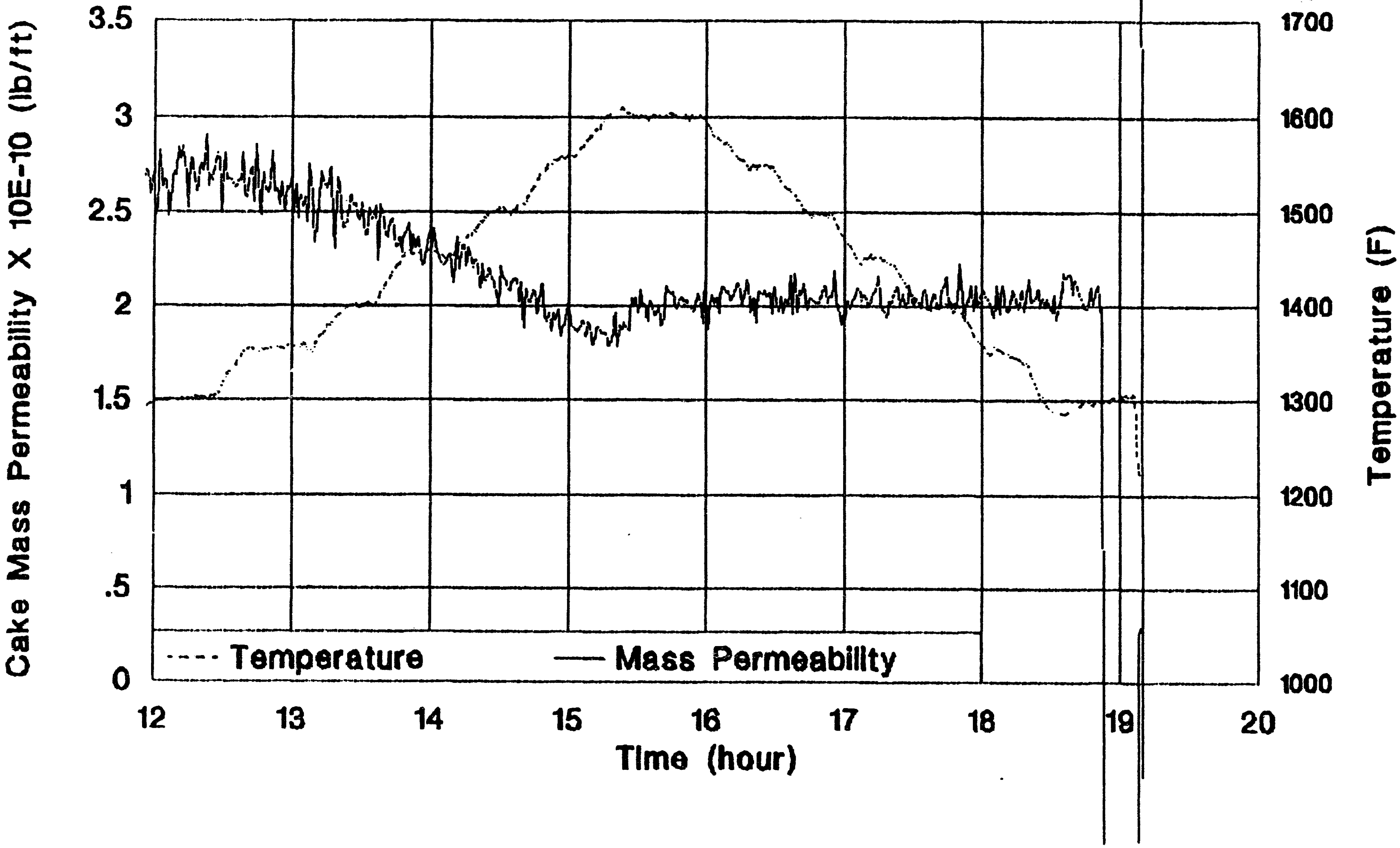
Test 1.02 - 11/09/93
Schumacher Candles / Tidd Flyash

Face Velocity 7 ft/min; Pressure 100 psig

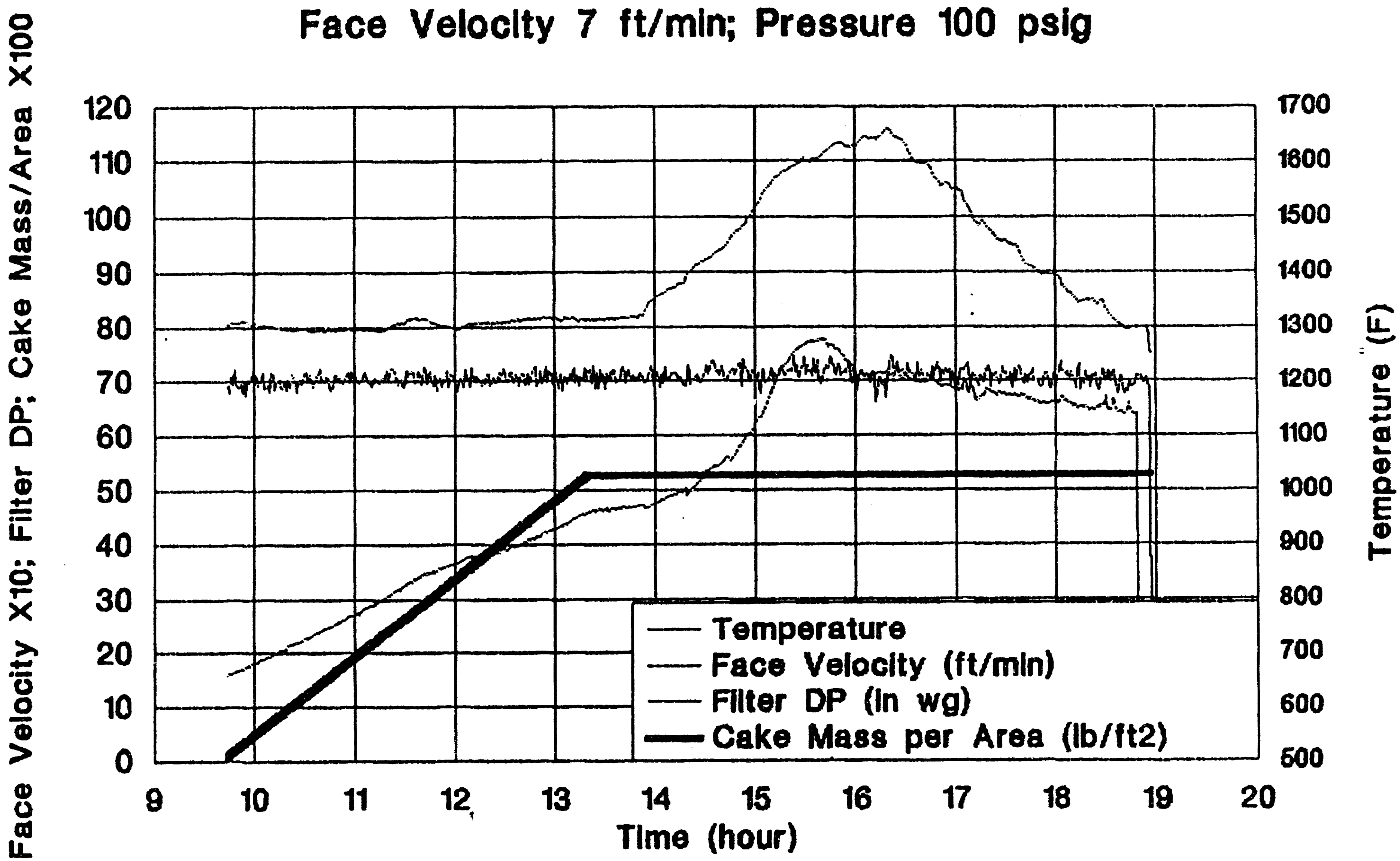


Test 1.02 - 11/09/93
Schumacher Candles / Tidd Flyash

Face Velocity 7 ft/min; Pressure 100 psig
Starting Cake 19 in. wg



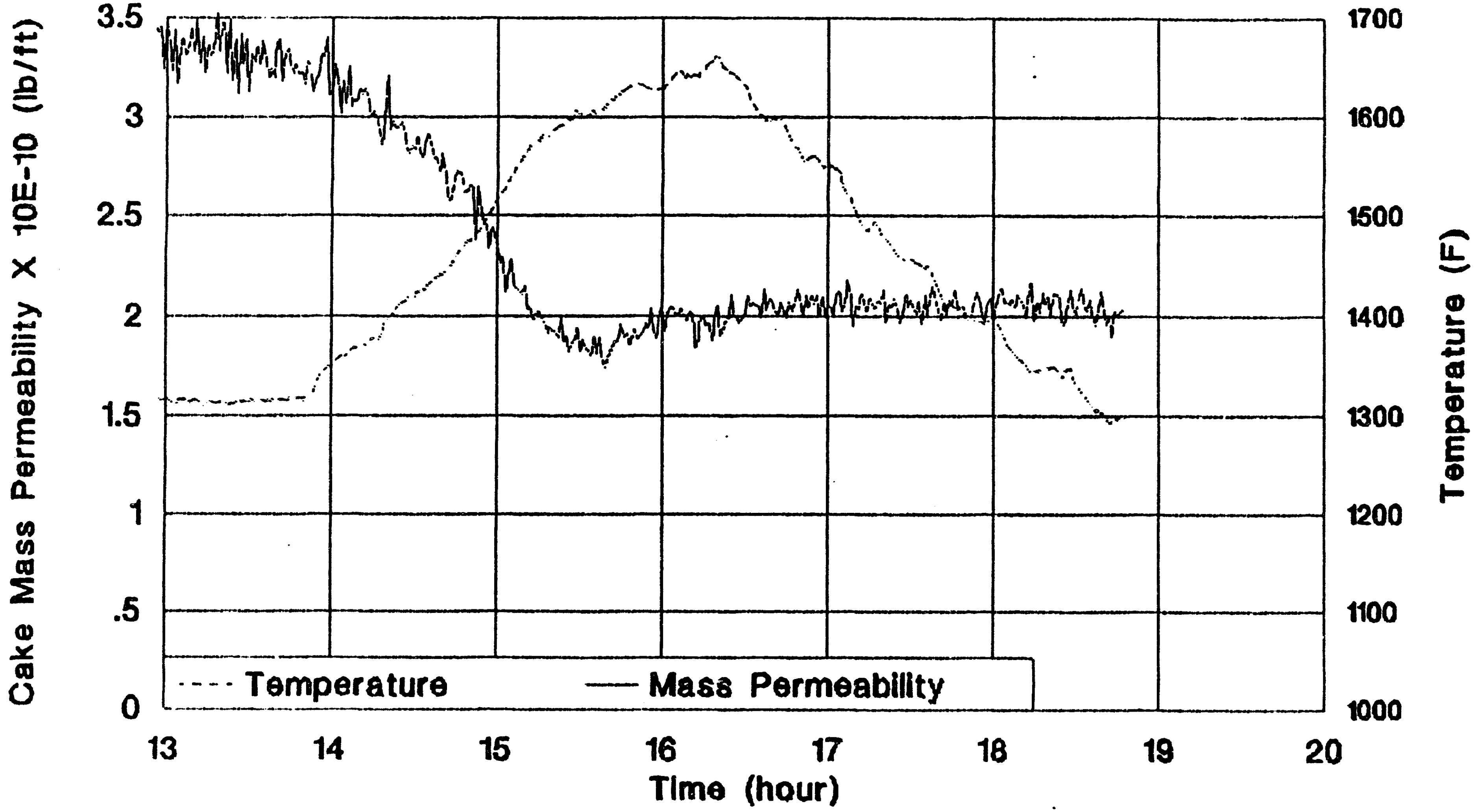
Test 1.03 - 11/10/93
Schumacher Candles / Tidd Flyash



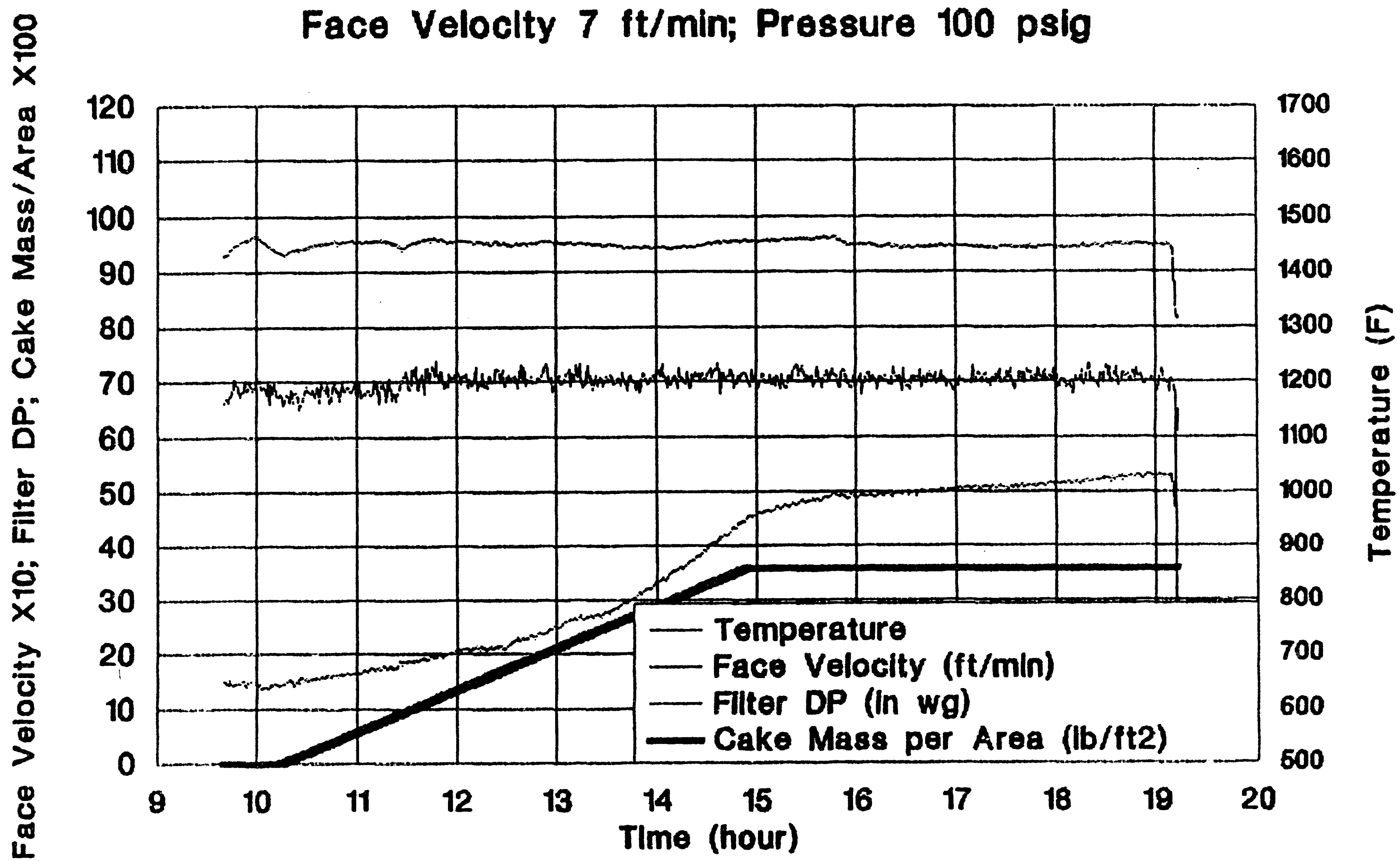
A-13

Test 1.03 - 11/10/93
Schumacher Candles / Tidd Flyash

Face Velocity 7 ft/min; Pressure 100 psig
Starting Cake 31 in. wg

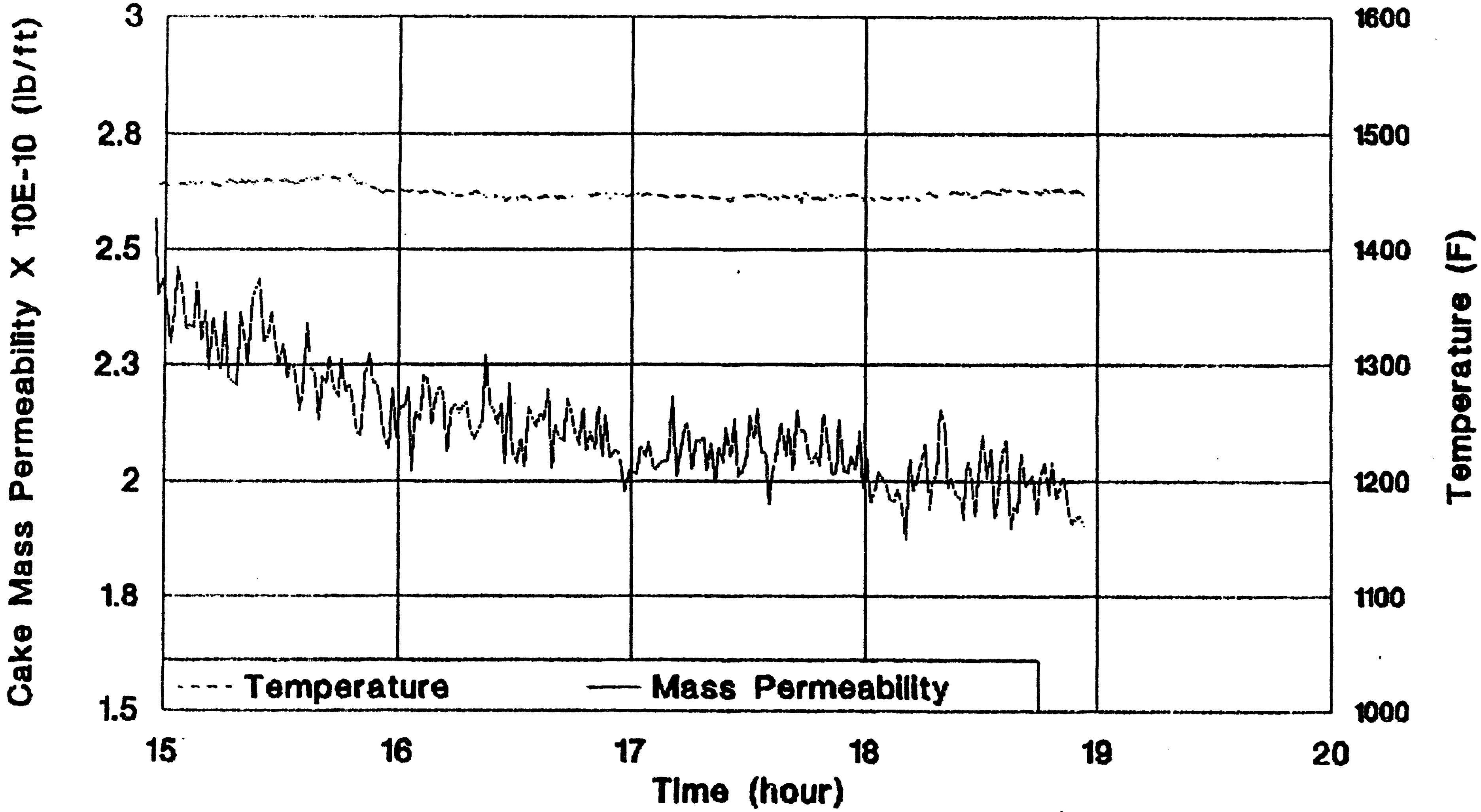


Test 1.04 - 11/11/93
Schumacher Candles / Tidd Flyash

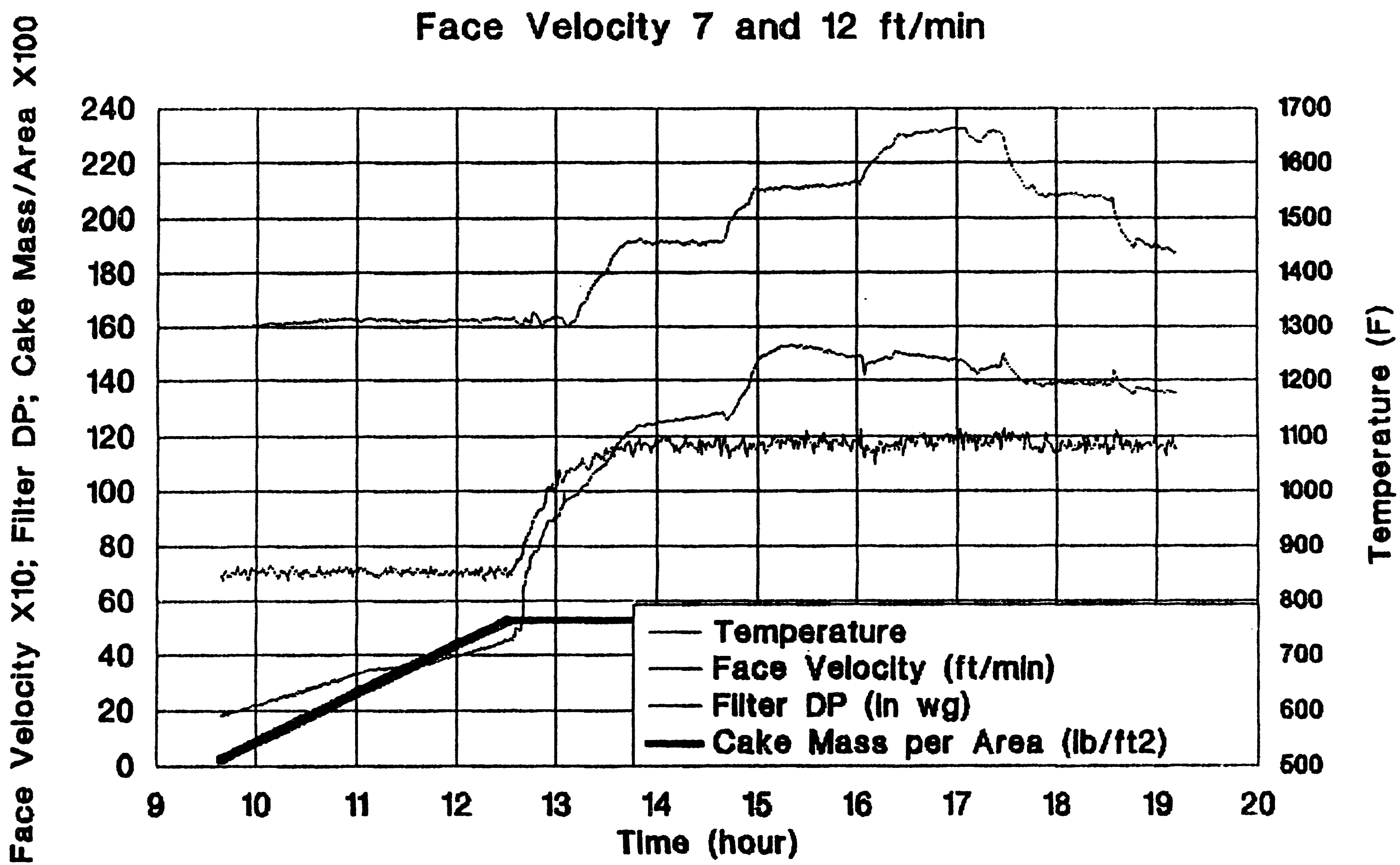


Test 1.04 - 11/11/93
Schumacher Candles / Tidd Flyash

Face Velocity 7 ft/min; Pressure 100 psig
Starting Cake 20 in. wg

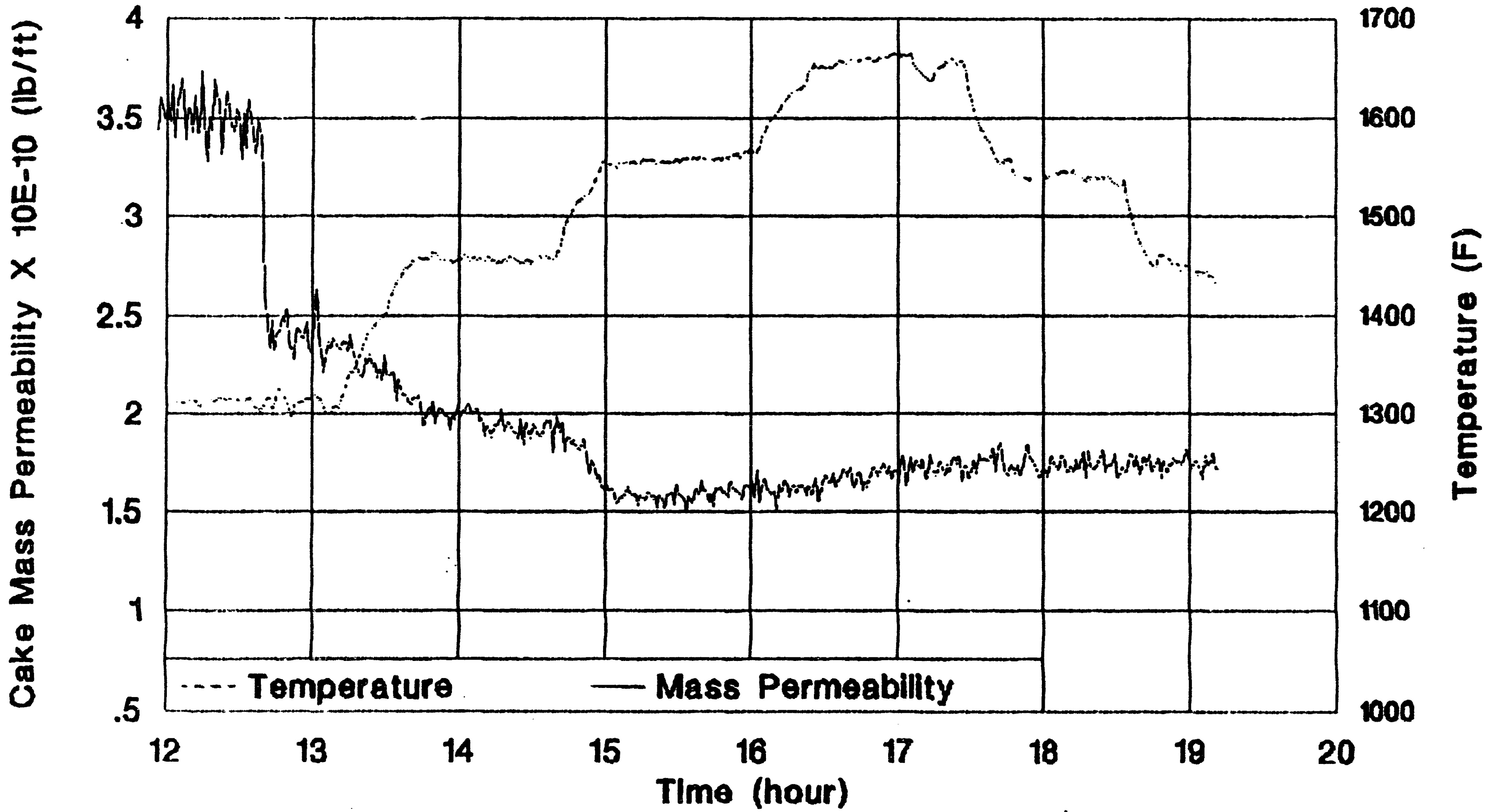


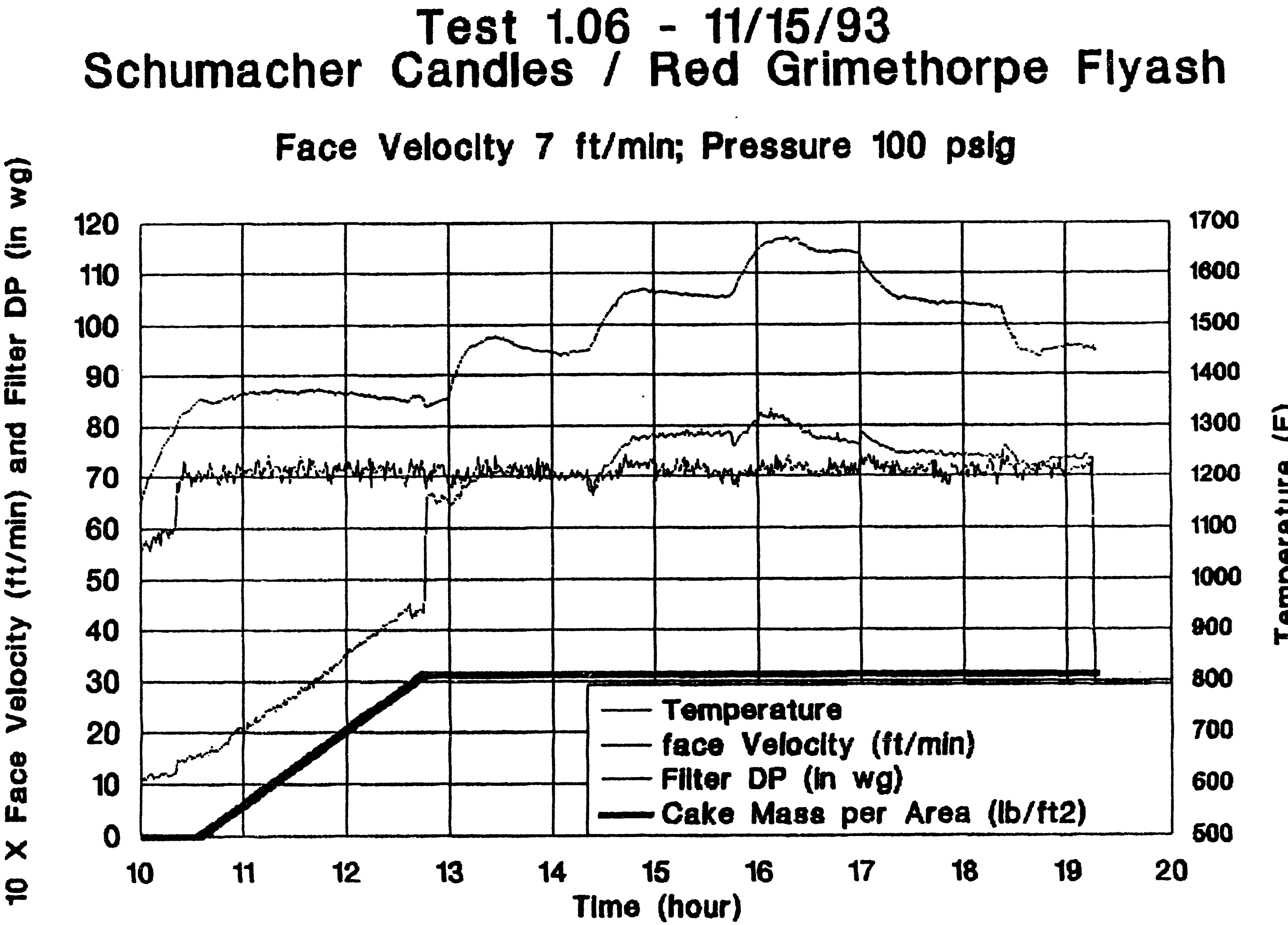
TEST 1.05 - 11/12/93
Schumacher Candles / Tidd Flyash



Test 1.05 - 11/12/93
Schumacher Candles / Tidd Flyash

Face Velocity 7 and 12 ft/min; Pressure 100 psig
Starting Cake 29 in. wg

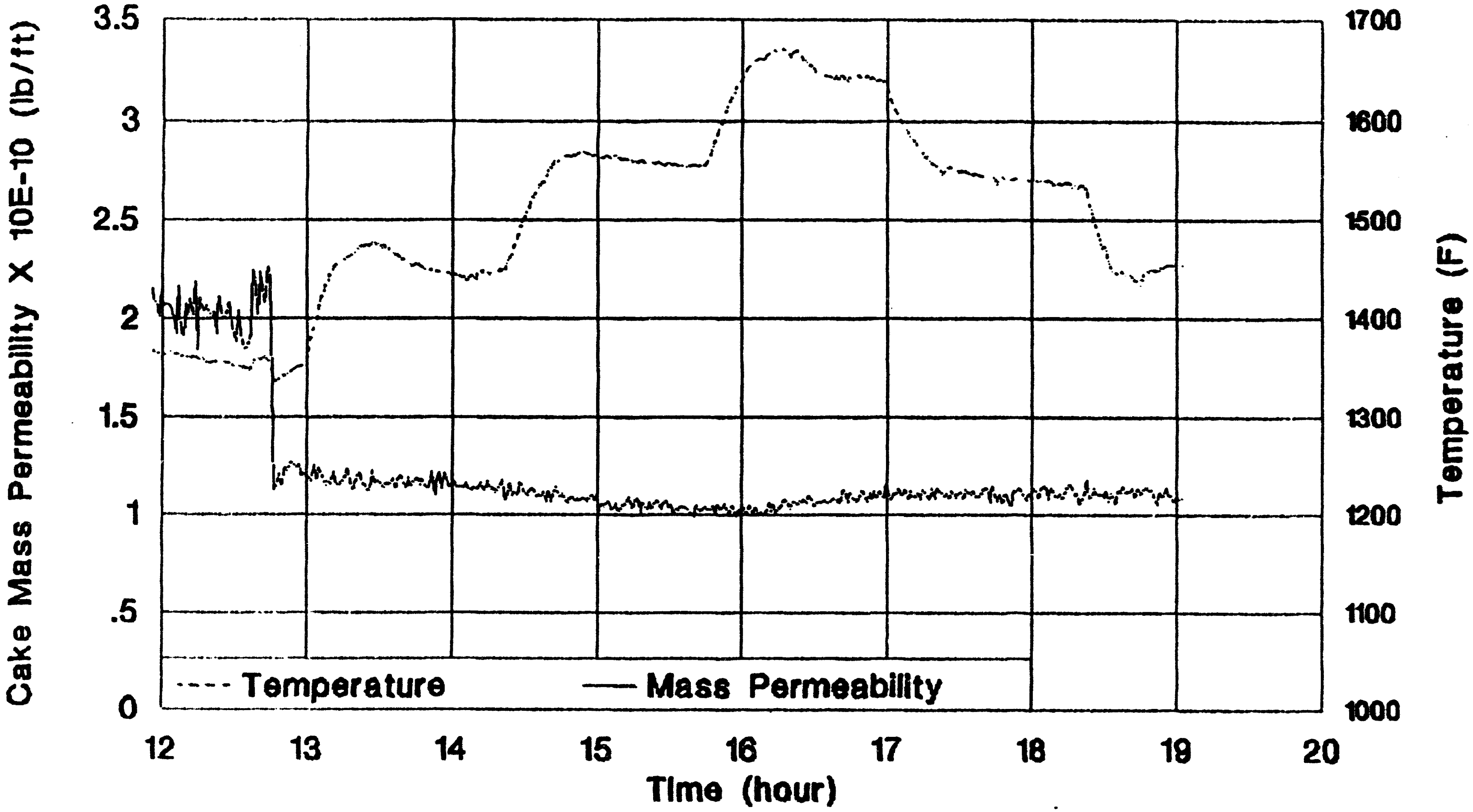




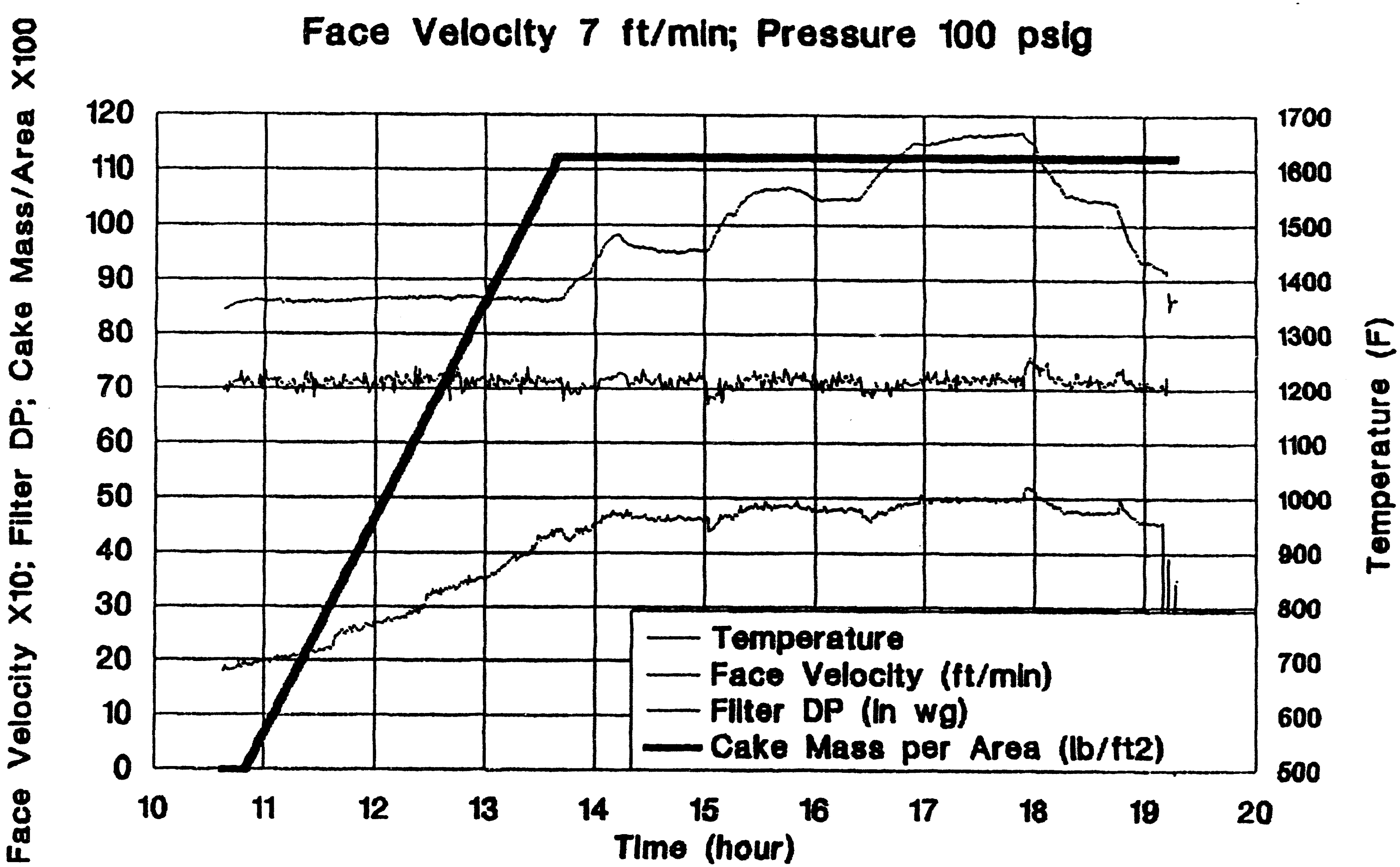
Test 1.06 - 11/15/93
Schumacher Candles / Red Grimethorpe Flyash
Face Velocity 7 ft/min; Pressure 100 psig
10 X Face Velocity (ft/min) and Filter DP (in wg)
Temperature (F)
Time (hour)
Temperature
face Velocity (ft/min)
Filter DP (in wg)
Cake Mass per Area (lb/ft2)
0
10
20
30
40
50
60
70
80
90
100
110
120
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
10
11
12
13
14
15
16
17
18
19
20

Test 1.06 - 11/15/93
Schumacher Candles / Grimethorpe Flyash

Face Velocity 7 ft/min; Pressure 100 psig
Starting Cake 51 in. wg

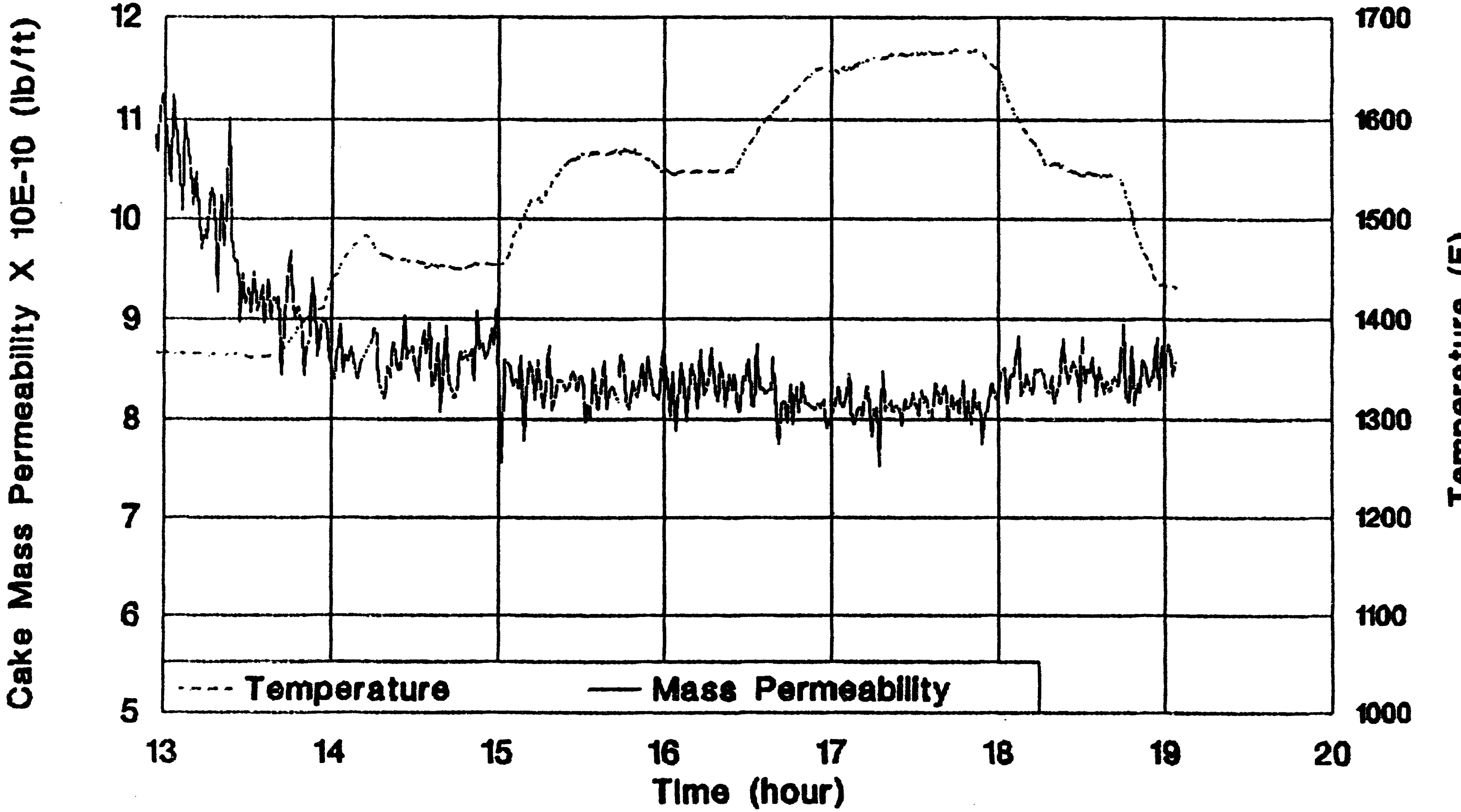


Test 1.07 - 11/16/93
Schumacher Candles / Karhula Flyash



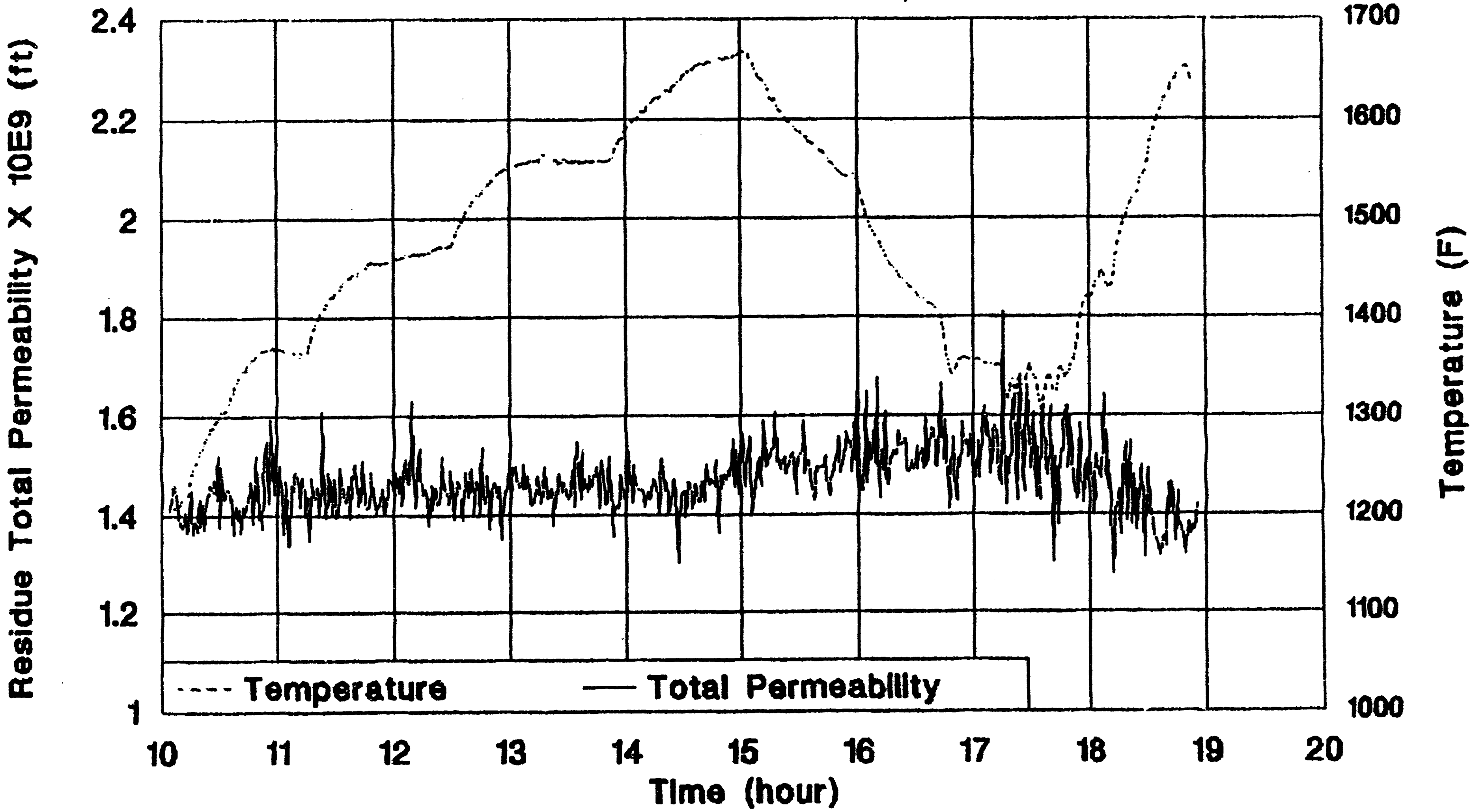
Test 1.07 - 11/16/93
Schumacher Candles / Karhula Flyash

Face Velocity 7 ft/min; Pressure 100 psig
Starting Cake 25 in. wg

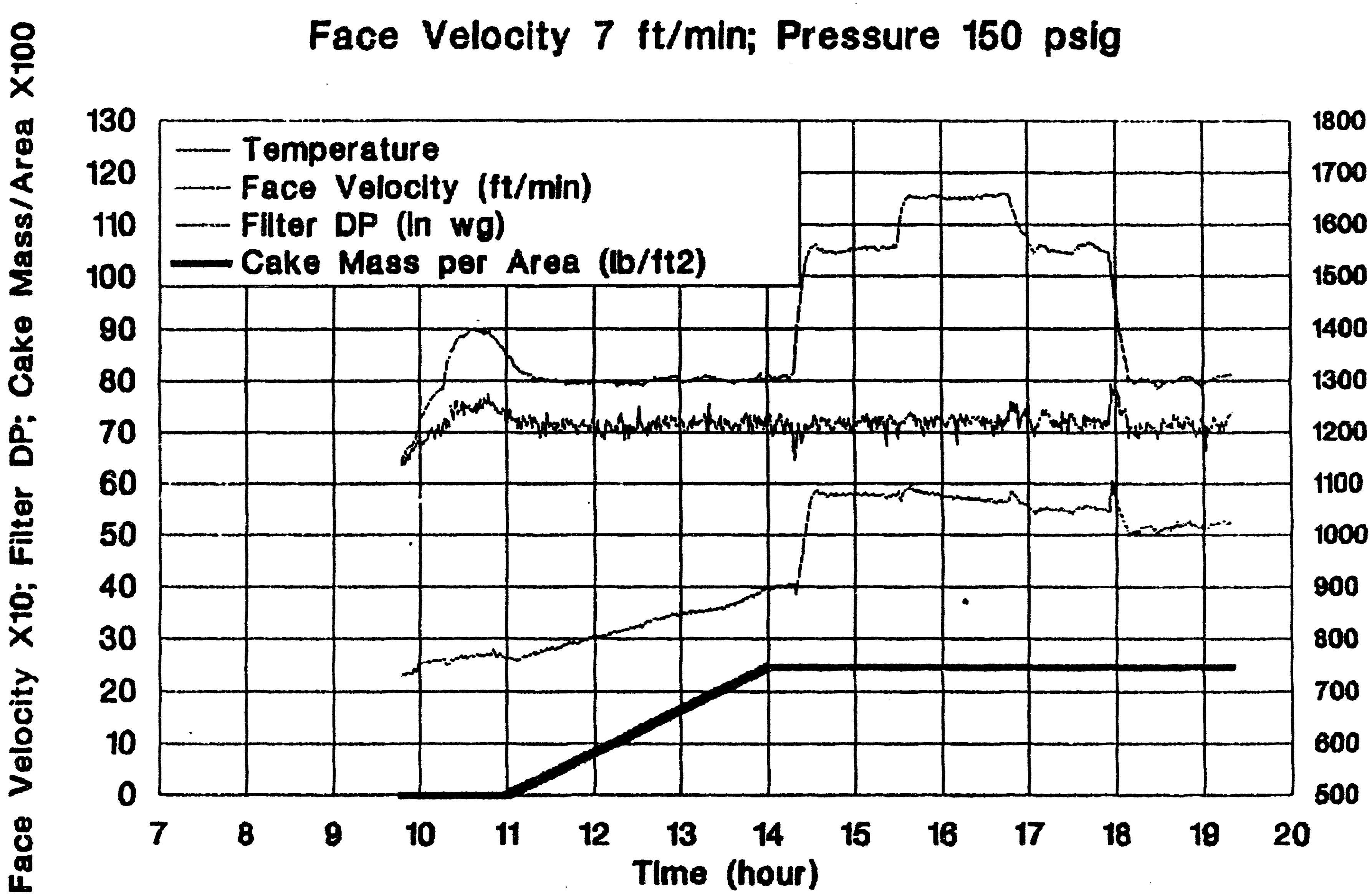


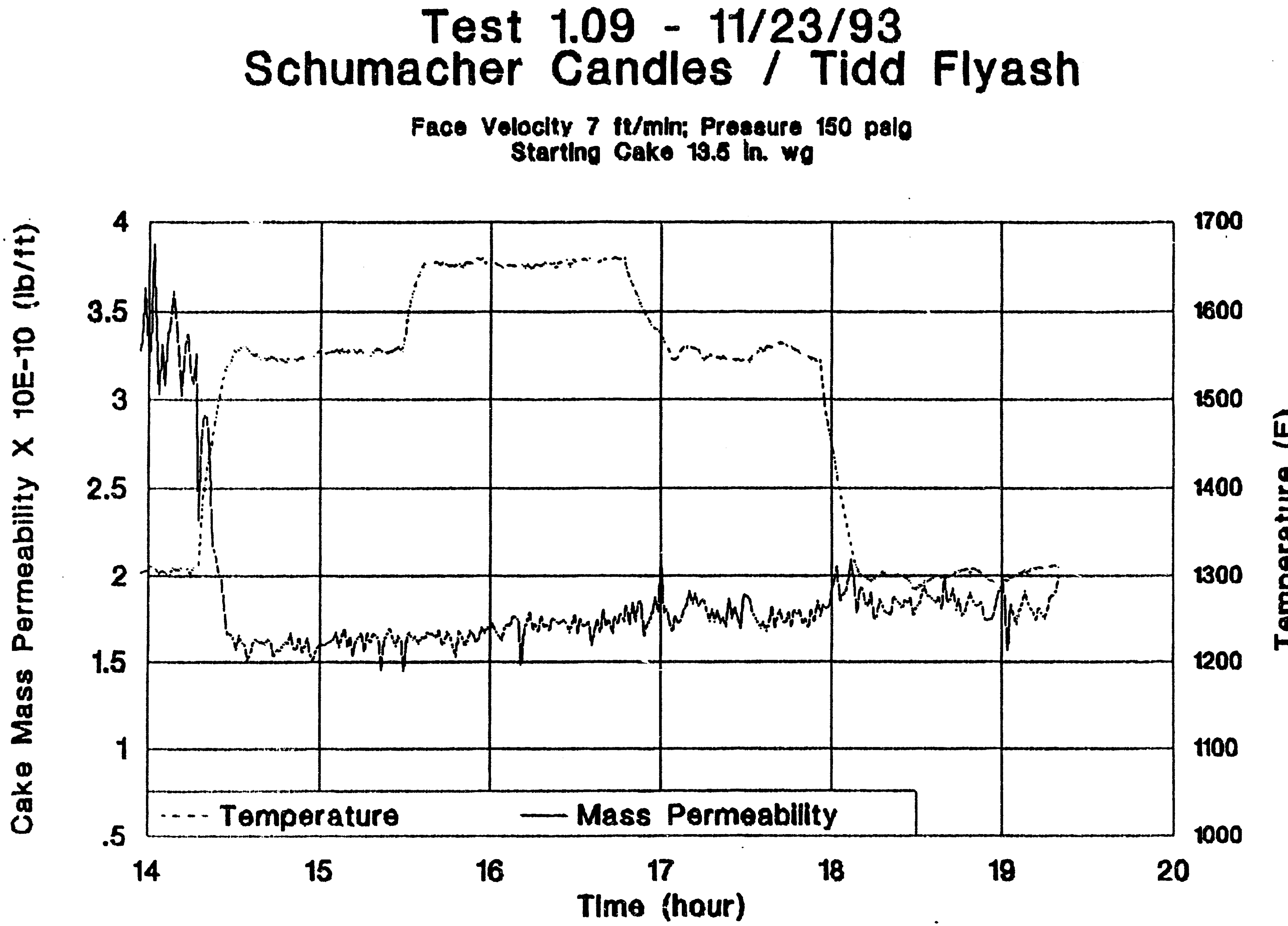
Test 1.08 - 11/17/93
Schumacher Candles / No Flyash

Face Velocity 7 and 12 ft/min
Pressure 100 psig



Test 1.09 - 11/23/93
Schumacher Candles / Tidd Flyash

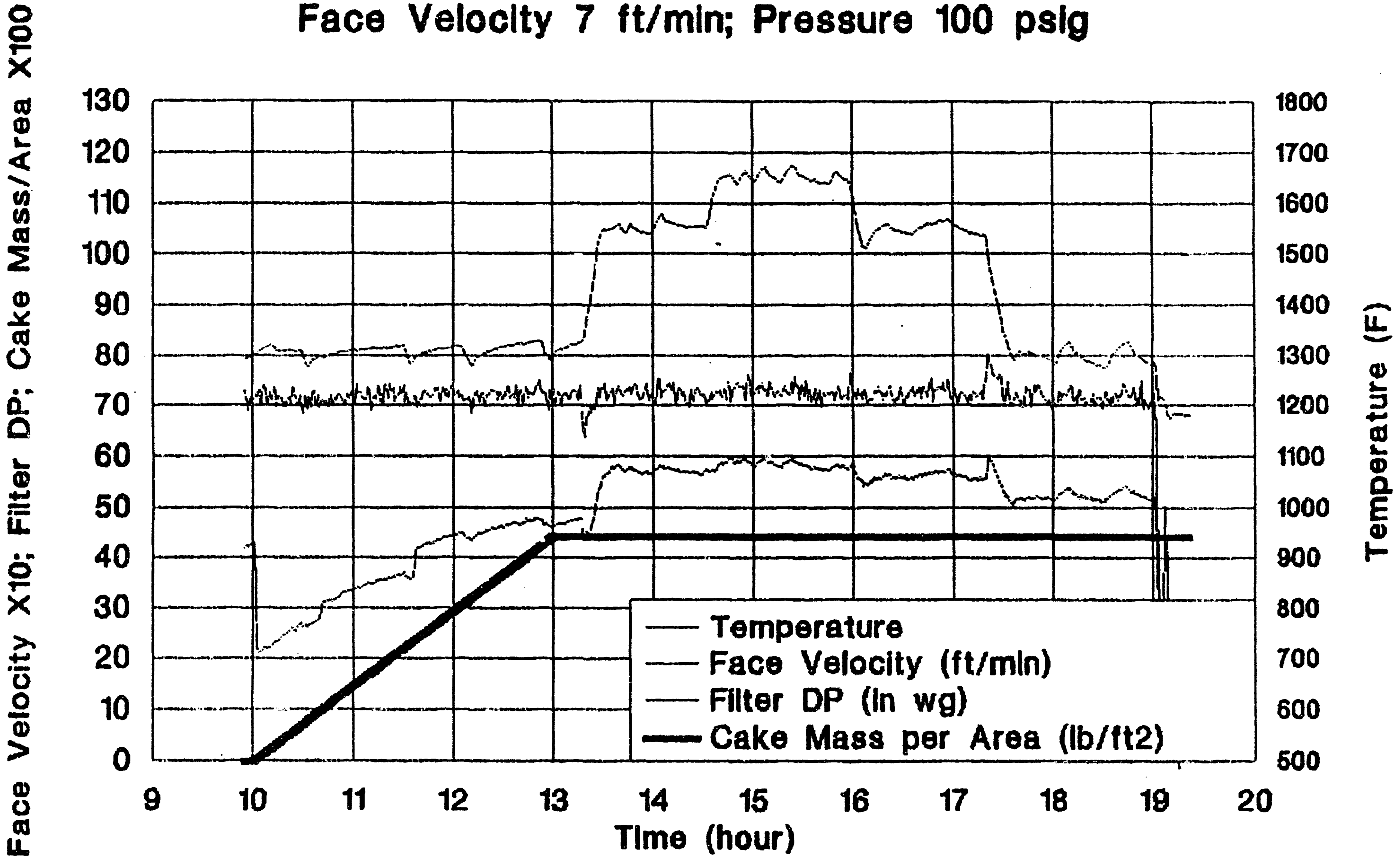


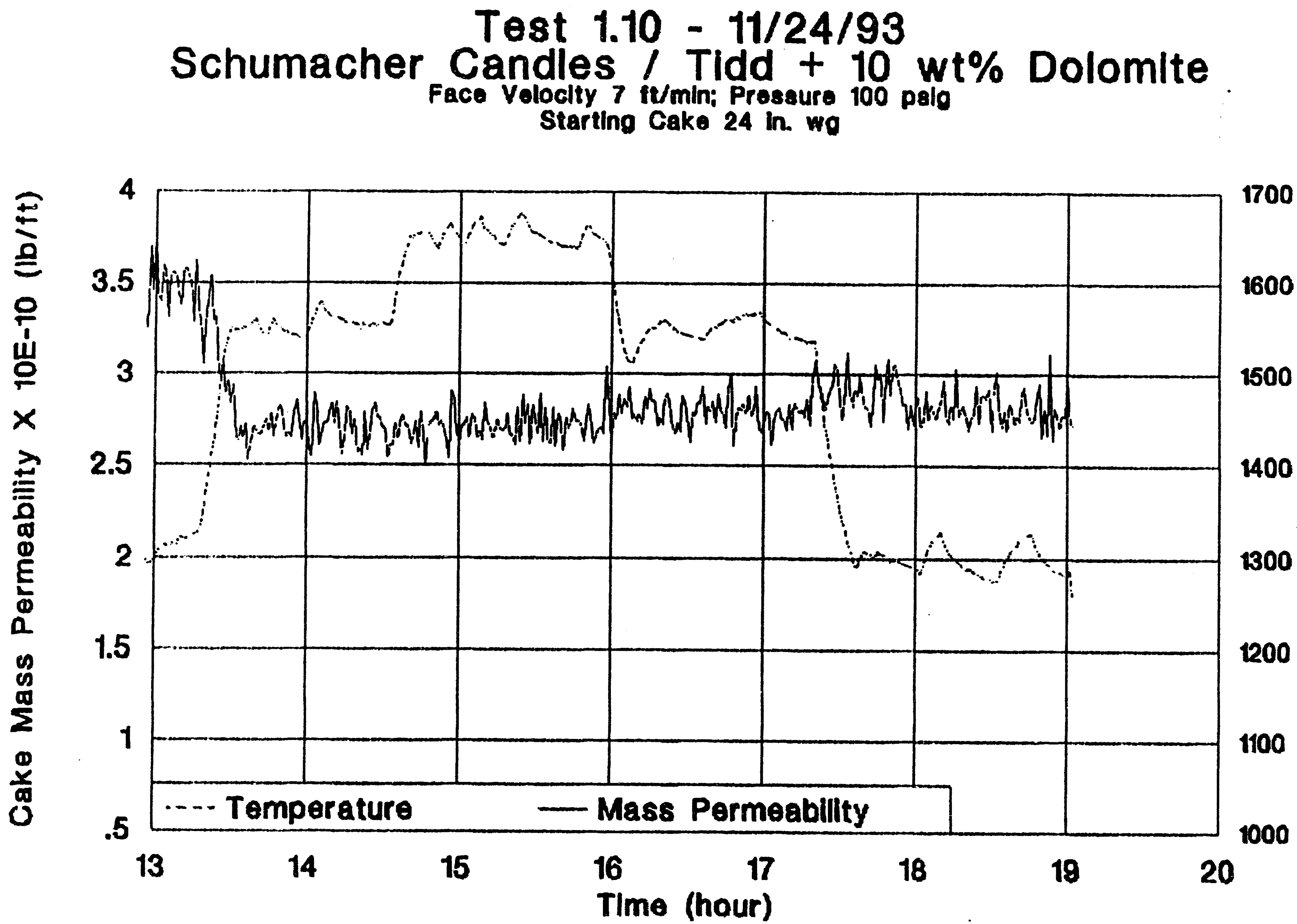


Test 1.09 - 11/23/93
Schumacher Candles / Tidd Flyash
Face Velocity 7 ft/min; Pressure 150 psig
Starting Cake 13.5 in. wg
Cake Mass Permeability X 10E-10 (lb/ft)
Temperature (F)
Time (hour)
Temperature
Mass Permeability
4
3.5
3
2.5
2
1.5
1
.5
1700
1600
1500
1400
1300
1200
1100
1000
14
15
16
17
18
19
20

Test 1.10 - 11/24/93
chumacher Candles / Tidd Flyash + 10 wt% Dolomit

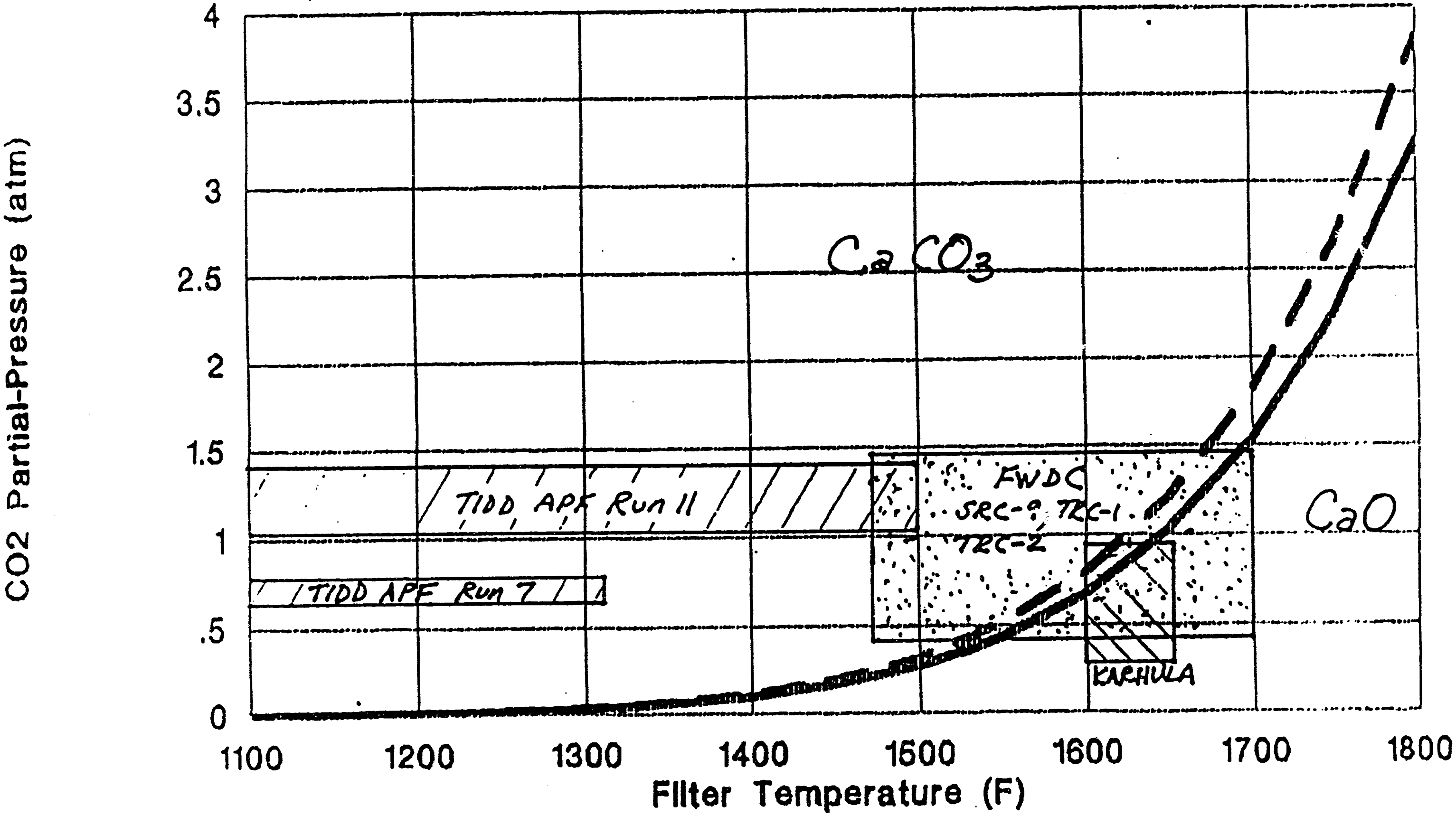
Face Velocity 7 ft/min; Pressure 100 psig





Test 1.10 - 11/24/93
Schumacher Candles / Tidd + 10 wt% Dolomite
Face Velocity 7 ft/min; Pressure 100 psig
Starting Cake 24 in. wg
Cake Mass Permeability X 10E-10 (lb/ft)
4
3.5
3
2.5
2
1.5
1
.5
1700
1600
1500
1400
1300
1200
1100
1000
Temperature (F)
13
14
15
16
17
18
19
20
Time (hour)
Temperature
Mass Permeability

PFBC Filter Cake Conditions
Calcination Equilibrium



DATE FILMED

5/5/94

END