Thermal Conductivity Measurement Study of Refractory Castables

API PUBLICATION 935
FIRST EDITION, SEPTEMBER 1999

American
Petroleum
Institute

Helping You
Get The Job
Done Right.SM

Thermal Conductivity Measurement Study of Refractory Castables

Downstream Segment

API PUBLICATION 935
FIRST EDITION, SEPTEMBER 1999

American Petroleum Institute

Helping You Get The Job Done Right.SM

SPECIAL NOTES

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect five years after its publication date as an operative API standard or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Downstream Segment [telephone (202) 682-8000]. A catalog of API publications and materials is published annually and updated quarterly by API, 1220 L Street, N.W., Washington, D.C. 20005.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this standard or comments and questions concerning the procedures under which this standard was developed should be directed in writing to the general manager of the Downstream Segment, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

API standards are published to facilitate the broad availability of proven, sound engineering and operating practices. These standards are not intended to obviate the need for applying sound engineering judgment regarding when and where these standards should be utilized. The formulation and publication of API standards is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

FOREWORD

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to the general manager of the Downstream Segment, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

CONTENTS

CONTENTS

Thermal Conductivity Measurement Study of Refractory Castables

1 Executive Summary

Thermal conductivity is a physical property that provides guidance in designing refractory systems for equipment in which heat loss and/or thermal behavior are important. The accuracy of reporting and understanding thermal conductivity is vital to developing the most cost effective, efficient, and reliable equipment.

The refractory industry uses various methods for measuring and reporting thermal conductivity that contribute to confusion in interpreting thermal conductivity data. The presence of chemically combined moisture in unfired castable masses complicates the measurement of thermal conductivity. The moisture contributes to higher thermal conductivity values until it is removed. Improper removal of the moisture during initial heat-up can also contribute to incorrect thermal conductivity data.

Temperatures associated with refining of petroleum products are considerably lower than other industries such as steel, foundries, aluminum, etc. At low operating temperatures (1000°F — 1400°F), removal of chemically combined water from refractory castable linings is incomplete, and castable products do not achieve the optimum thermal characteristics. Removal of chemically combined water is a function of temperature. The majority of chemically combined water—approximately 70%—is removed between 500°F and 850°F, with the remainder dissociating up to 1250°F. This is illustrated in a Thermo-Gravimetric Analysis (TGA), shown in Appendix A. Historically, thermal conductivity of castables was represented as a single value. More representative multi-point curves were later introduced as heat loss became more important but captured data while cooling a specimen fired to within 100°F of its use limit. Data collected during cooling of specimens is classified as descending data.

Thermal conductivity measured during initial heating of specimens is defined as ascending data and produces significantly different data than descending data. Ascending data provides a more accurate representation of a product's thermal conductivity for low temperature application typical in most hydrocarbon processing industry (HPI) applications.

A study was initiated to compare the thermal conductivity developed by different measurement techniques and assess the relationship between ascending and descending data. The study was designed to evaluate six products in six laboratories with five measurement techniques. The castable products were chosen to represent a specific category, including: lightweight, medium weight, moderate erosion resistant, dense, dense-extreme erosion resistant, and fused silica castables. The study was designed to show differences in measurement techniques and ascending and descending data. *There was no attempt to rank, classify, or assign accuracy to each of the measurement techniques*.

The study concluded that the different thermal conductivity procedures/apparatuses yield very different results. Thermal conductivity of lightweight and medium weight insulating castables varied by 100%, depending on the measuring technique. As density increased, differences in thermal conductivity values attributed to measuring technique decreased but were still significant. Test results also indicate that differences in ascending and descending thermal conductivity data, for the castables studies, are considerable and worthy of design consideration.

It is recommended that users and designers utilize ascending thermal conductivity curves (data) in designing refractory lining systems, where heat transfer is a major consideration for applications below 1500°F. It is also recommended that users and designers evaluate thermal conductivity data and the method of measuring the data before using the data in designs when heat transfer and skin temperatures are important to successful equipment operation.

2 Introduction

Thermal conductivity is defined as the amount of heat transferred through a unit area of a material in a unit time, through a unit thickness, with a unit of temperature difference between the surfaces of the two opposite sides.

Thermal conductivity of refractory castables is difficult to measure accurately due to the presence of moisture (chemically combined water) in the matrix. When heated the first time, cementitious castables expel water (dehydration) from the hydrated cement. The moisture is responsible for affecting the identification of heat flowing through the refractory mass.

Manufacturers of refractory products use various measurement techniques to develop thermal conductivity of refractory castables. The following list identifies commonly used procedures.

a. Water Calorimeter—ASTM C-201 apparatus; C-417 procedure.
b. Calorimeter—Pilkington Method.
c. Hot Wire Method—ASTM C-1113.
d. Comparative Thermal Conductivity Method—Dynatech.
e. Panel Test.

Each procedure addresses unique concerns about measuring thermal conductivity of unfired castable refractories.

This study was initiated to compare differences in the five test methods at six laboratories. The scope of the study was limited to one set of data for each of six products. Therefore, numeric relationships and direct evaluations between the various methods were not desired nor achieved.

The study concentrated on products with high to moderate cement contents. These products have distinct thermal conductivity curves during initial heating (ascending) and cooling (descending). Low and No Cement products were not evaluated and may or may not follow the same trends developed for the cementitious products.

Cement bonded castables develop physical properties through proper hydration of the cement. Upon heating, the hydrated cement dehydrates as the chemically bonded water dissociates from the calcium aluminate cement. Use of Thermo-Gravimetric Analyses (TGA) provides a good understanding of the dehydration process. Figure A-1 shows a TGA curve for a cement bonded castable refractory. Dehydration begins at approximately 425°F and continues through 1250°F. However, approximately 70% of the water loss due to dehydration occurs between 500°F and 850°F.

3 Test Methods

Thermal conductivity is a measure of heat flow through a medium. Various techniques of measuring thermal conductivity are employed by manufacturers and laboratories. The following is a brief description of the measurement techniques evaluated in this study.

3.1 WATER CALORIMETER

3.1.1 ASTM C-201 Apparatus (Conducted in Accordance with ASTM C-417)

3.1.1.1 The C-201 apparatus consists of a heating chamber, calorimeter assembly, water circulating system, and instrumentation. The heating chamber is capable of being heated electrically over a temperature of 400°F to 2800°F in a neutral or oxidizing atmosphere. Heating is controlled to ± 5°F. A silicon carbide slab 13½ x 9 x 1 in., with the 13½ x 9-in. faces plane and parallel, is placed above the sample for the purpose of providing uniform heat distribution. A layer of insulation equivalent at least to 1-in. Group 20 insulating firebrick is placed below the calorimeter and guard plates.

A copper calorimeter assembly is used for ensuring the quantity of heat flowing through the test specimen. The water circulation is such that adjacent passages contain incoming and outgoing streams of water. The calorimeter is 3 x 3 in.^{2} and has one inlet and one outlet water connection. An inner and outer guard surrounds the calorimeter.

The water-circulating system provides the calorimeter assembly with water at constant pressure and at a temperature that is not changing at a rate greater than 1°F per hour. Instrumentation for measuring temperatures includes:

a. Specimen temperature.
b. Calorimeter water temperature.
c. Temperature difference between calorimeter and inner guard.

The apparatus is modified for the C-417 procedure to reduce the affect of moisture released from the specimen. Ceramic fiber is used to ensure there is no contact between the specimen and calorimeter. Copper tubes are inserted through the furnace wall to the perimeter of the outer guard to facilitate removal of moisture during heating of the specimen. Compressed air supply with a flowmeter is also a part of this apparatus.

Thermal conductivity is determined by measuring the temperatures of the furnace and specimen, water temperature rise, and calculating thermal conductivity with the following formulation.

$$k = \frac{QL}{[A(t_1 - t_2)]} \qquad (1)$$

where

- k = thermal conductivity in Btu in./hr ft^2°F,
- Q = Btu/hr flowing into the calorimeter,
- L = thickness (distance between hot junctions at which t_1 and t_2 are measured) in in.,
- t_1 = higher of two temperatures measured in the test specimen in °F,
- t_2 = lower of two temperatures measured in the test specimen in°F,
- A = area of center calorimeter in ft^2.

3.2 CALORIMETER

3.2.1 Pilkington Apparatus MTP-103

3.2.2 The Pilkington apparatus is composed of a heating chamber, calorimeter assembly, and instrumentation. The refractory specimen is placed 2 in. above and parallel to the silicon carbide heating elements. The calorimeter is located in direct contact with the top surface of the specimen. The 2¼-in. diameter calorimeter is surrounded by an inner and outer guard. Heating chamber temperature is controlled by a platinum-platinum/13% rhodium thermocouple located between the specimen and the heating elements. Platinum-platinum/13% rhodium thermocouples are attached to the calorimeter to measure the temperature gradient.

The refractory specimen is cut to form a solid octagon, 4.4 in. to 4.5 in. between parallel sides. The specimen should be cut/ground to a thickness between 1 in. and 3 in. based on density. The octagonal surfaces must be flat and parallel within ± 0.01 in. Platinum-platinum/13% rhodium thermocouples are cemented into grooves in the hot and cold face of the specimen to measure the temperature gradient.

Thermal conductivity is calculated with the following equation:

$$K(s) = \frac{K(c) \times T(c) \times d(s)}{T(s) \times d(c)} \tag{2}$$

where

$K(s)$ = thermal conductivity of sample in Btu in./hr ft^2°F,

$K(c)$ = thermal conductivity of calorimeter determined by interpolation of the known thermal conductivity values of the calorimeter in Btu in./hr ft^2 °F,

$T(s)$ = temperature drop across sample in °F,

$T(c)$ = temperature drop across calorimeter in °F,

$d(s)$ = distance between the hot junction thermocouple beads in the sample in inches,

$d(c)$ = distance between the hot junction thermocouple beads in the calorimeter in inches.

3.3 HOT WIRE C 1113-90

3.3.1 The hot wire method of determining thermal conductivity is described in ASTM Procedure C-1113-90, Volume 15.01. A constant electrical current is applied to a pure platinum wire placed between two brick. The rate at which the wire heats is based on how rapidly the temperature flows from the wire into the constant temperature mass of the refractory brick. The rate of temperature increase of the platinum wire is accurately determined by measuring its increase in resistance in the same way a platinum resistance thermometer is used. A Fourier equation is used to calculate the *k* value based on the rate of temperature increase of the hot wire and the power input.

3.3.2 Refractory castables can be cut into brick shapes or cast into special molds. A step and several grooves are utilized to position the platinum wire. A furnace with a heating chamber capable of supporting two 9-in. straight brick is used to heat the brick shapes. Thermocouples are embedded into the grooves and monitored with a computer which also serves to control the power supply, voltmeter, and scanner.

3.4 COMPARATIVE THERMAL CONDUCTIVITY TESTER

3.4.1 The Model TCFCM comparative thermal conductivity instrument is designed for testing medium-to-high thermal conductivity materials, such as ceramics, plastics, glass, metals, metal alloys, epoxies, composites, and geological materials. The thermal conductivity of the unknown specimen is determined by comparing this property to the known thermal conductivity of a reference material. The reference materials is chosen to match, as closely as possible, the expected thermal conductance of the unknown sample. Best results are obtained by using a reference material with a thermal conductivity with an order of magnitude of that of the test specimen. This test method requires the use of a relatively small test specimen. Low thermal conductivity materials (thermal insulation) that are nonhomogeneous require a larger test specimen.

3.4.2 A single specimen is tested at one time. The specimen is instrumented with two thermocouples near or at each surface to measure the temperature gradient through the sample during a test. Two materials of known thermal conductivity are placed, one above, and one below the test specimen to form a column. These reference materials are similarly instrumented with thermocouples. A heater is placed at each end of this column. The temperature of each heater is regulated by an automatic temperature controller; and each heater is regulated at a different temperature to impose a temperature gradient across the three components. A spring-loaded pad applies a force on the test stack to assure stability of the column and good contact between the samples. This column rests on a heat sink cooled with water or some other cooling liquid, thus permitting operation at or below ambient temperatures. A guard furnace, which is designed to allow the operator to impose a linear temperature gradient through it that closely matches the gradient through the samples, and thereby minimizes radiant heatflow from the samples, also surrounds the test column. The temperature gradient through the furnace is regulated by two automatic temperature controllers.

3.4.3 The thermal conductivity of the test specimen is determined from the knowledge of the thermal conductivities of the reference materials, the temperature gradient through the reference and the test samples, and the geometry of each sample with the equation:

$$k(\text{test sample}) = \frac{1}{2}\left(\frac{\Delta T}{\Delta T}\right)\text{test sample} \left[k\left(\frac{\Delta T}{\Delta x}\right)\text{top ref} + k\left(\frac{\Delta T}{\Delta x}\right)\text{bottom ref}\right] \tag{3}$$

where

k = thermal conductivity,

Δx = distance between the thermocouples mounted in each sample,

ΔT = temperature gradient through a sample as measured with thermocouples.

3.5 FURNACE PANEL

3.5.1 The test panel procedure uses an electrically heated furnace and two walls fabricated with the test specimens. The furnace accommodates two test panels 18 x 18 x 3½ in., which can be brick, rammed, cast, or gunned from the test materials, depending on the method of application. All test panels except fired brick are dried to a constant weight at 230°F, prior to installing in the furnace.

3.5.2 A parallel series of four electrically heated SiC globars are used as the heat source in the furnace. SiC plates are positioned between the furnace chamber and the test panels to evenly distribute the heat onto the hot face of the panel.

3.5.3 Three thermocouples are positioned between the SiC plate and test panel near the center of the panel to measure the hot face temperature. The cold face temperature is measured on a 6 x 6 in. steel plate in contact with the cold face at the center of the refractory test panel, using both a surface thermometer and thermocouples. The ambient temperature is measured with a bulb thermometer, and the thickness of the panel is determined at the center of the panel where the temperature readings are taken.

3.5.4 The procedure for the thermal conductivity test is to heat the furnace to several programmed temperatures (usually 500°F/1000°F/1500°F/2000°F) and hold for 18 hours to ensure a steady state of heat flow. Temperatures are then recorded for hot face temperature, cold face temperature, and ambient air temperature.

K value is calculated as follows:

$$K = \frac{QL}{(T_{hf} - T_{cf})} \tag{4}$$

where

Q = heat loss in Btu/ft^2/hr,

L = thickness of test panel in in.,

T_{hf} = temperature of hot face in °F,

T_{cf} = temperature of cold face in °F.

Q is calculated by adding $QR + QC$,

where

QR = heat loss due to radiation

$$= 0.174e\left(\left(\frac{T_{cf}}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4\right) \tag{5}$$

where

T_{cf} = temperature of cold face in °R,

T_a = temperature of ambient air in °R,

e = emissivity of surface.

QC = heat loss due to convection

$$= 0.25(T_{cf} - T_a)^{1.25} \tag{6}$$

where

T_{cf} = temperature of cold face (°F),

T_a = temperature of ambient air (°F)

4 Materials

4.1 The thermal conductivity study was designed to evaluate a cross section of products used in the petroleum refining industry. The following is a list and description of the products evaluated.

4.1.1 lightweight castable: A lightweight castable, density of 56 lb/ft^3 and compressive strength of 350 psi was selected for this category.

4.1.2 medium weight castable: A castable, density of 74 – 78 lb/ft^3, compressive strength of 1,500 – 2,200 psi was selected for this category.

4.1.3 moderate density castable: The product chosen had a density of 110 lb/ft^3, a compressive strength of approximately 7,000 psi and erosion losses of less than 15 cm^3.

4.1.4 dense castable: Product has a density of 135 – 140 lb/ft^3, compressive strength of 7,500 – 9,000 psi and erosion losses of less than 12 cm^3.

4.1.5 dense erosion resistant castable: Product has a density of 165 lb/ft^3, compressive strength of 9,000 – 12,000 psi, and erosion losses of less than 7 cm^3.

4.1.6 fused silica castable: This product has a fused silica aggregate system with a density of 124 lb/ft^3.

All product categories are cement rich castables that use water to hydrate the cement and develop appropriate physical properties.

5 Sample Preparation

Each of the six participating manufacturers of refractory products supplied samples to each company conducting thermal conductivity testing. Sample preparation was performed to maximize uniformity in the samples supplied. Sample sizes for each test method were communicated to each manufacturer.

Samples were cured and dried under laboratory conditions. Samples were subsequently sealed and shipped to participating companies for testing.

6 Data

Thermal conductivity data, developed by each participate and reported in English units, Btu in./hr ft^2°F., is shown in Tables A1 – A6. Data from the tables is shown graphically in Figures A1 – A7.

Thermal conductivity measured during the initial heating of conventional cementitious bonded castable products, shown in Figures 1A – 6A, decreases with increasing temperature. The fused silica castable did not follow this trend because the affect of dehydration was basically overshadowed by the thermal conductivity of the aggregate system. The trends were consistent with all test procedures; however, the magnitude of change varied.

Thermal conductivity measured during the cooling cycle of the test decreased with decreasing temperatures as shown in Figures A-1B – A-6B. This trend was apparent in all data developed during this study and is consistent with manufacturers' published thermal conductivity data.

A total of six apparatuses, representing five measurement techniques, show a wide variation in measured thermal conductivity. Differences range from 20% to 100%; however, differences of 50% – 70% were typical.

7 Conclusions

7.1 DIFFERENT PROCEDURES YIELD DIFFERENT RESULTS

The measurement of thermal conductivity for cement-bonded castable products vary considerably. Differences between test methods are more significant than originally considered. The testing program was not designed to evaluate accuracy of each test method; however, results show the relationships of each test method was generally consistent.

7.2 ASCENDING THERMAL CONDUCTIVITY CURVES DIFFER FROM DESCENDING THERMAL CONDUCTIVITY CURVES

Thermal conductivity for cement bonded castable products is generally higher during the initial heating. The ascending data, developed during the initial heating, consistently produces higher thermal conductivity, except for the fused silica product. The significance in this data is apparent in higher heat transfer for equipment operating at low (1000°F – 1400°F) temperatures, where optimum thermal conductivity is not developed.

7.2.1 Descending thermal conductivity data is valid for applications where operating temperatures are sufficiently high to remove moisture in the castable, and the affect moisture has on thermal conductivity.

7.2.2 The differences in measuring thermal conductivity exposed in this test program were intended to help define the most accurate test method. Each test method has accuracies designed into the procedure. The differences are likely a result of the intent of each test method. In some instances, absolute thermal conductivity is not as important as more practical values. However, the designer must be aware of these differences and incorporate them into his design.

8 Recommendations

8.1 For applications where heat loss and/or skin temperatures are critical, review the thermal conductivity data source and type before assigning values in a design.

8.1.1 Heat transfer plays an important role in designing expansion provisions for heated equipment. Inaccurate thermal conductivity data will contribute to inadequacies in expansion joint design, hanger designs, and heat balances for process control. Lower-than-expected thermal conductivity yields lower shell temperatures and problems such as dew-point corrosion.

8.2 Standardize on the ascending thermal conductivity data castables in refining and petrochemical applications.

8.2.1 Operating temperatures in refining and petrochemical applications are lower than other many other industries. The lower temperatures (1000°F – 1400°F) do not remove all of the moisture in a castable lining; therefore, higher thermal conductivities are obtained. Ascending thermal conductivity curves provide more accurate data for developing heat transfer characteristics of fired equipment lining.

APPENDIX A—THERMO-GRAVIMETRIC ANALYSES

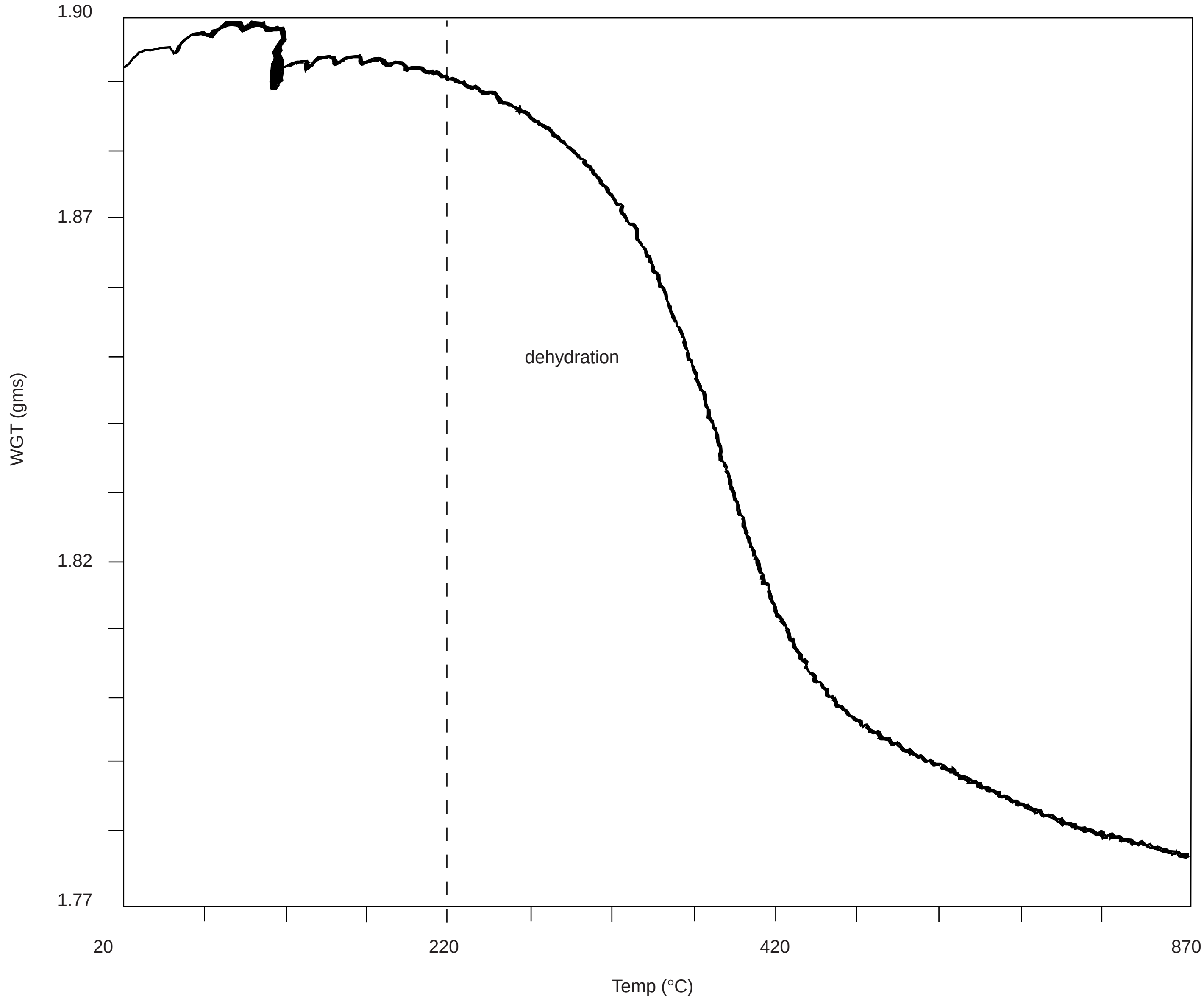

Figure A-1—Thermo-Gravimetric Analysis (TGA) Cement Bonded Castable

Table A-1—Thermal Conductivity
Dense (135 – 140 lb/ft^3) Erosion-Resistant Castable
Btu in./hr ft^2 °F

Mean Temperature °F	Pilkington Calorimeter	Water Calorimeter ASTM C-417	Water Calorimeter ASTM C-417	Hot Wire ASTM C-1113	Dynatech	Panel Test
200			12.57	12.90		
243		15.50				
300				12.46		7.01
400	9.70			12.02	14.70	6.83
500			10.06	11.59		6.65
572	8.60					
600		10.60		11.18		6.50
700				10.81		6.40
752	8.90				12.61	
800				10.49		6.38
900				10.25		6.36
932	9.00					
973			9.13			
1000				10.09		6.38
1025		9.46				
1100				10.02		6.40
1112	9.30				12.06	
1200				10.08		6.43
1312			9.00			
1410		9.36				
1472					12.00	
1657			9.13			
1788		9.44				
1398		9.58				
1299			8.87			
1112					11.93	
1100				10.03		
1000		9.79		10.00		6.35
932	8.80		8.76			
900				9.99		
800				10.00		6.25
752					11.65	
700				10.02		
621		10.00				
600				10.06		6.20
572	8.40					
531			8.66			
500				10.11		
400	8.50			10.18	10.75	6.20
300				10.27		
244		11.00				
200			8.79	10.37		6.20

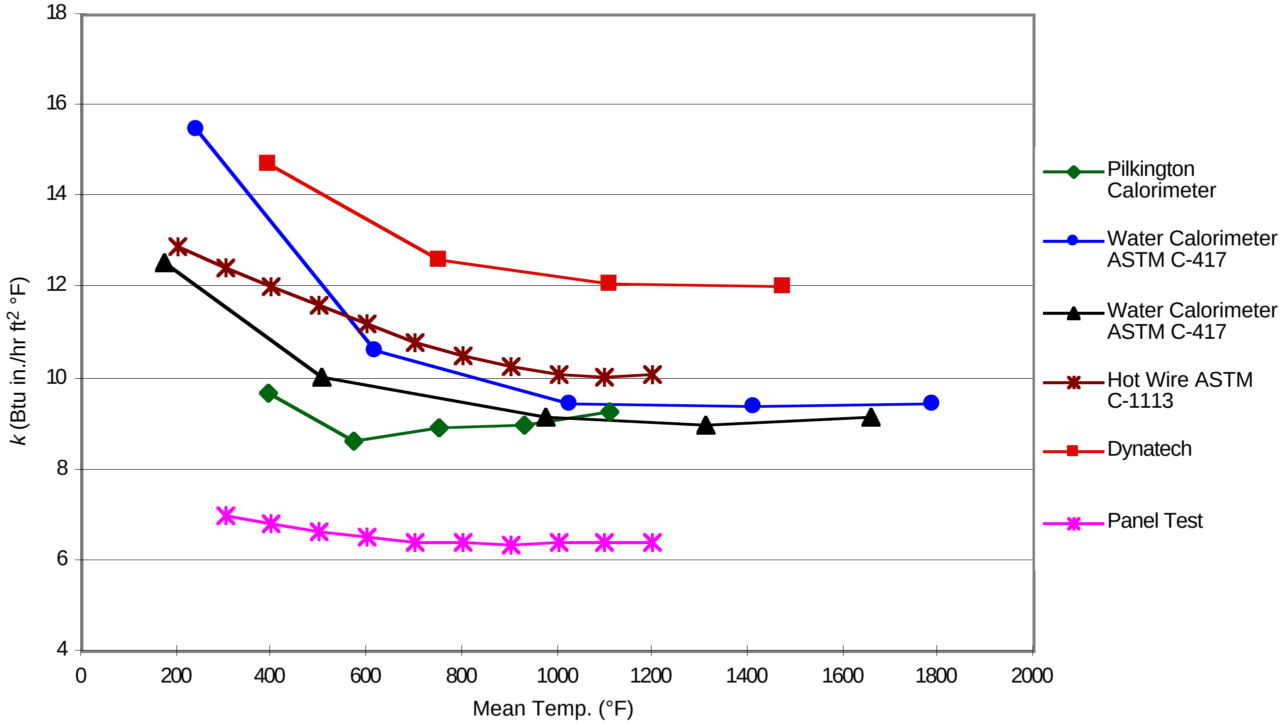

Figure A-2A—Dense (135 – 140 lb/ft^3) Erosion-Resistant Castable, Ascending Thermal Activity

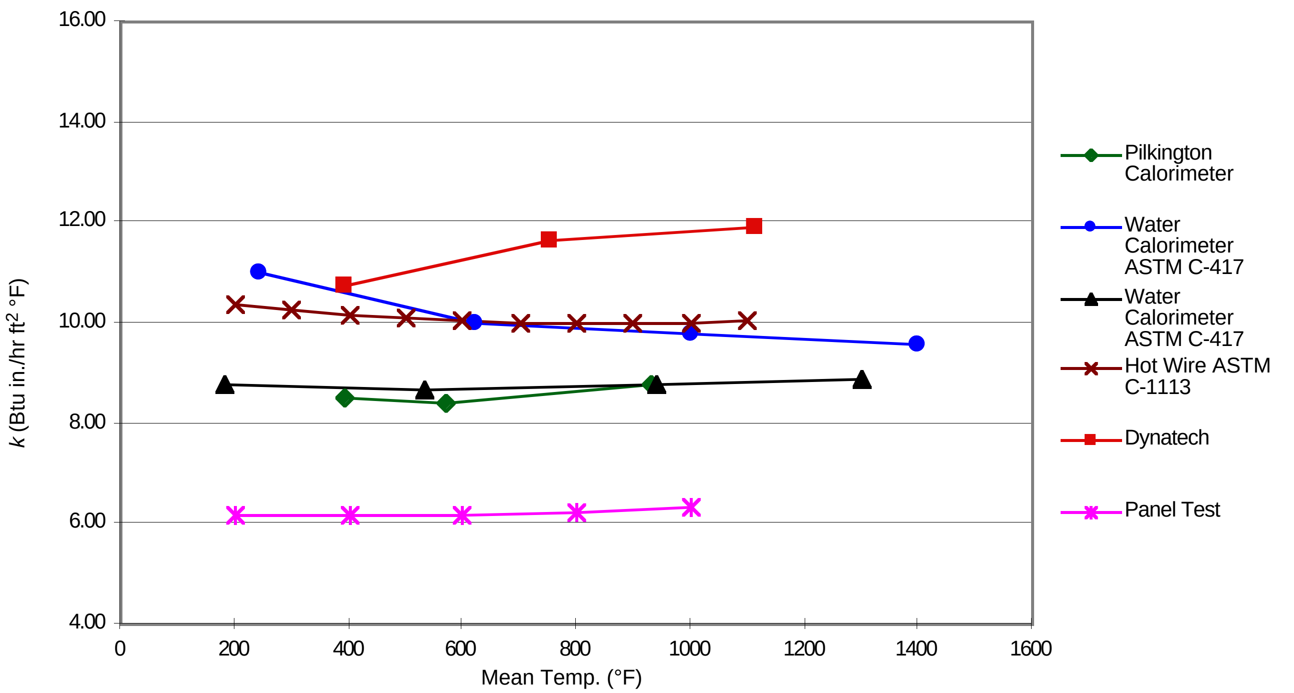

Figure A-2B—Dense (135 – 140 lb/ft^3) Erosion-Resistant Castable, Descending Thermal Conductivity

Table A-2—Thermal Conductivity
Dense (165 lb/ft^3) Extreme Erosion-Resistant Castable
Btu in./hr ft^2 °F

Mean Temperature °F	Water Calorimeter ASTM C-417	Dynatech	Hot Wire ASTM C-1113	Panel Test	Water Calorimeter ASTM C-417
200	15.50		20.34		
300	14.70		19.22		21.20
400	13.83	21.97	17.71	6.20	
500	12.92		15.95		
570				6.40	
600	11.99		14.14		
700	10.92		12.50		
752		16.90		6.55	
784					12.10
800	9.99		11.23		
900	9.37		10.44		
927				6.59	
1000	9.00		10.11		
1100	8.73		10.07	6.55	
1112		12.65			
1200	8.56		9.92		
1251					9.56
1300	8.48				
1400	8.51				
1472		12.06			
1812					9.68
1425					10.10
1300	8.68				
1200	8.73		9.89		
1112		12.65			
1105				6.40	
1100	8.81		9.95		
1028					10.90
1000	8.91		10.04		
927				6.25	
900	9.01		10.16		
800	9.13		10.38		
752		13.39		6.10	
700	9.25		10.47		
634					12.10
600	9.38		10.66		
570				5.95	
500	9.52		10.88		
400	9.67	14.48	11.13	5.85	
300	9.83		11.40		
253					14.40
200	9.98		11.70		

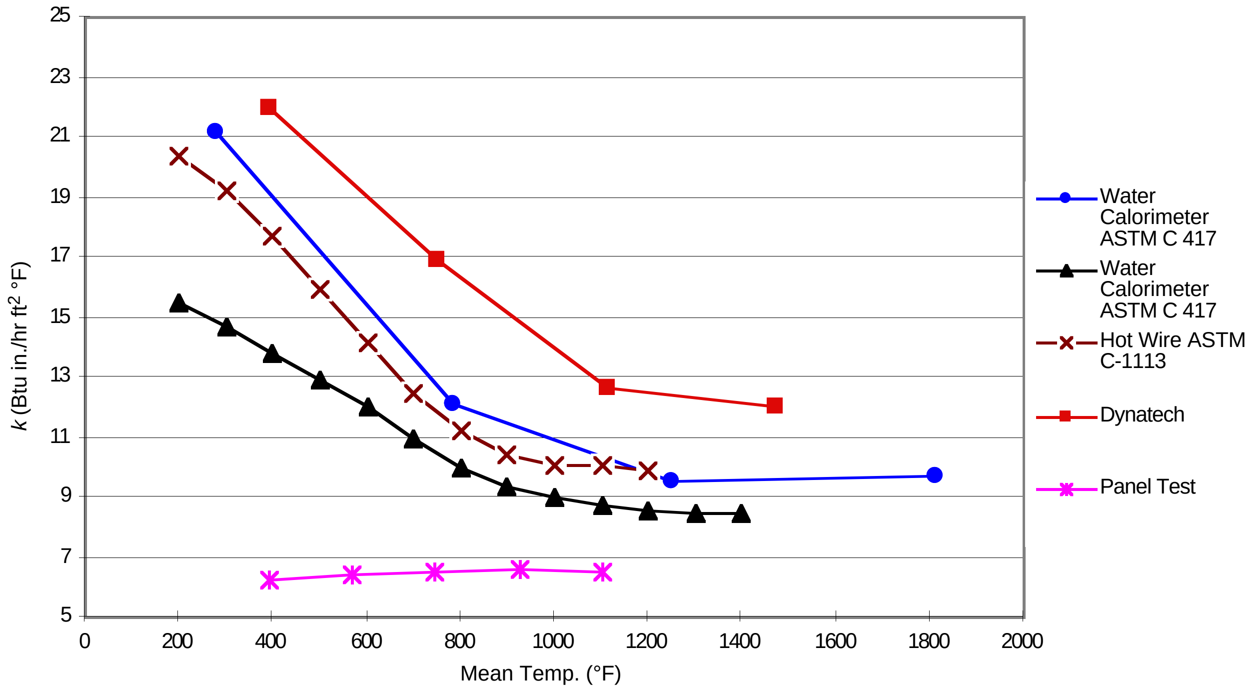

Figure A-3A—Dense (165 lb/ft^3) Extreme Erosion-Resistant Castable, Ascending Thermal Conductivity

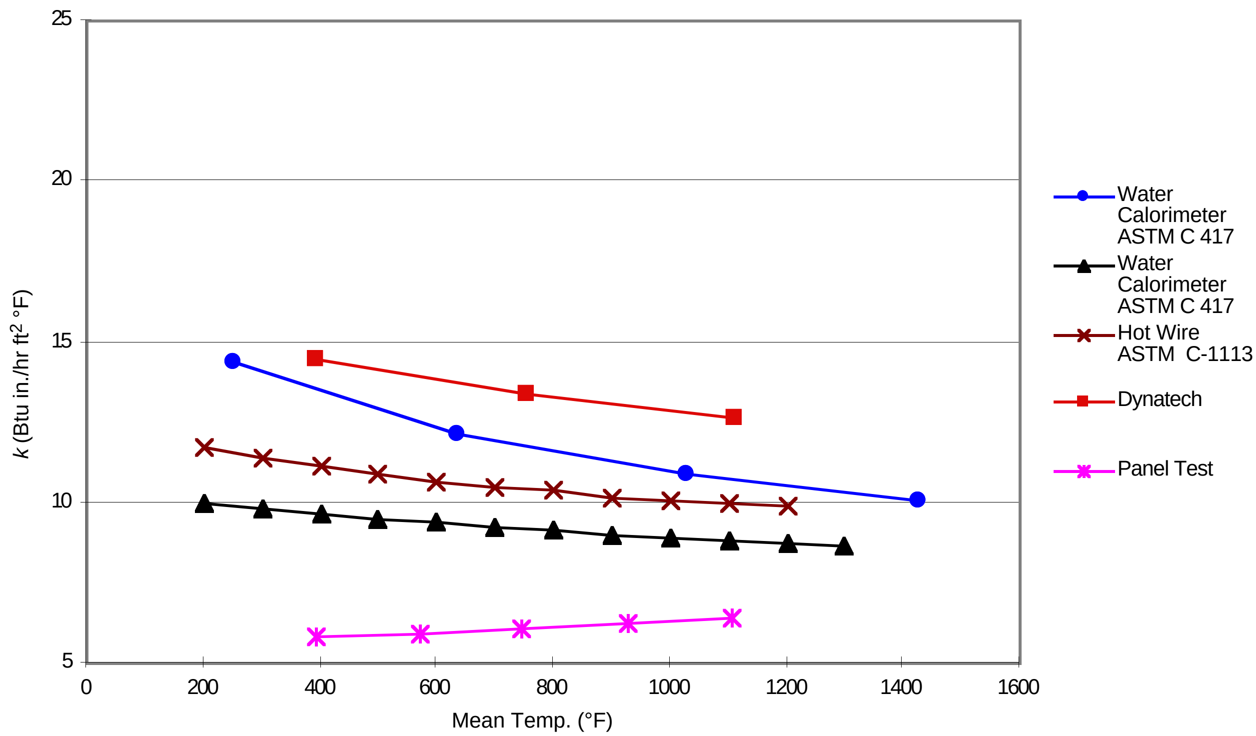

Figure A-3B—Dense (165 lb/ft^3) Extreme Erosion-Resistant Castable, Descending Thermal Conductivity

Table A-3—Thermal Conductivity
Fused Silica Castable
Btu in./hr ft^2 °F

Mean Temperature °F	Water Calorimeter ASTM C-417	Dynatech	ASTM C-1113	Panel Test	Water Calorimeter ASTM C-417
200	6.08		7.37		
300	6.21		7.75		
400	6.33	8.94	7.90		
461					7.19
500	6.45		7.92		
600	6.57		7.92		
700	6.68		8.00		
752		9.50			
800	6.81		8.16		
900	6.97		8.37		
1000	7.16		8.53		
1100	7.41		8.59		
1112		10.31			7.76
1200	7.72		8.60		
1472		11.34			
1642					9.64
1222					8.98
1200	7.77		8.62		
1112		10.42			
1100	7.59		8.61	8.73	
1000	7.41		8.49	8.59	
900	7.23		8.29	8.45	8.41
800	7.07		8.08	8.21	
752		9.60			
700	6.90		7.89	7.97	
640					
600	6.75		7.73	7.74	
500	6.60		7.61	7.57	7.89
400	6.42		7.55	7.11	
392		8.70			
300	6.21		7.52		
274					7.57
200	5.99		7.51		

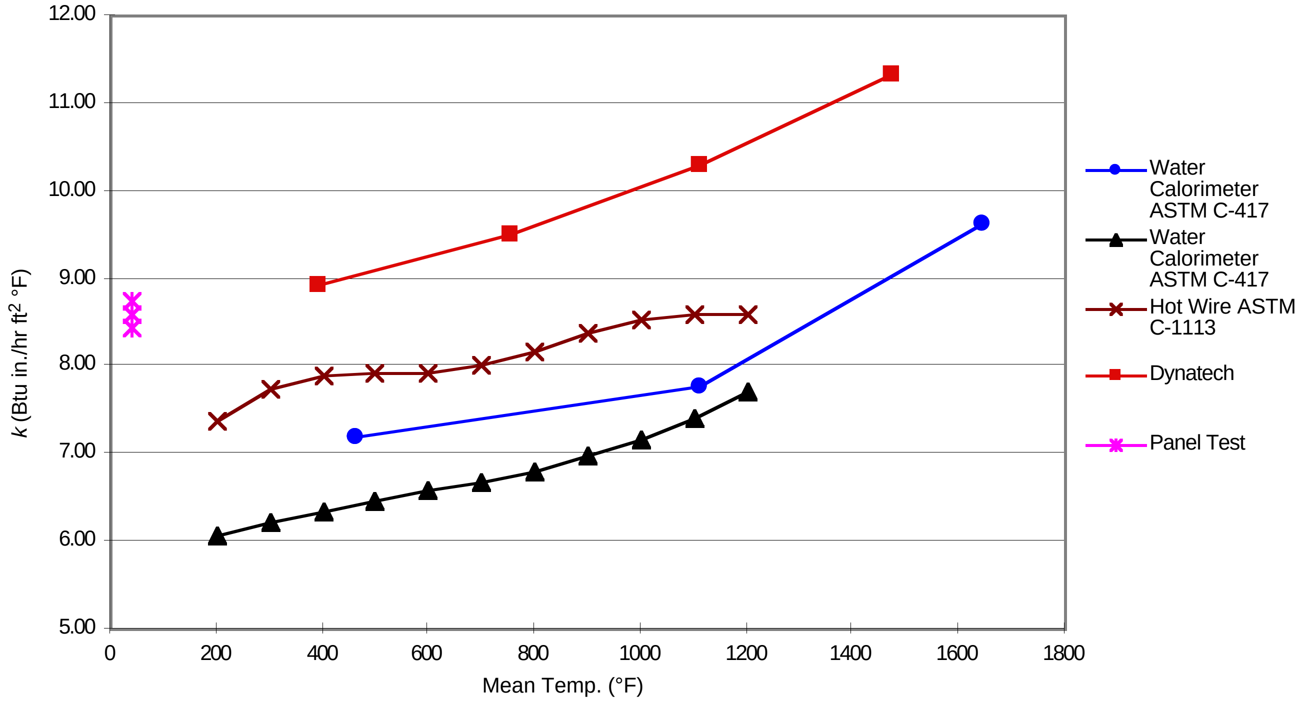

Figure A-4A—Fused Silica Castable,
Ascending Thermal Conductivity

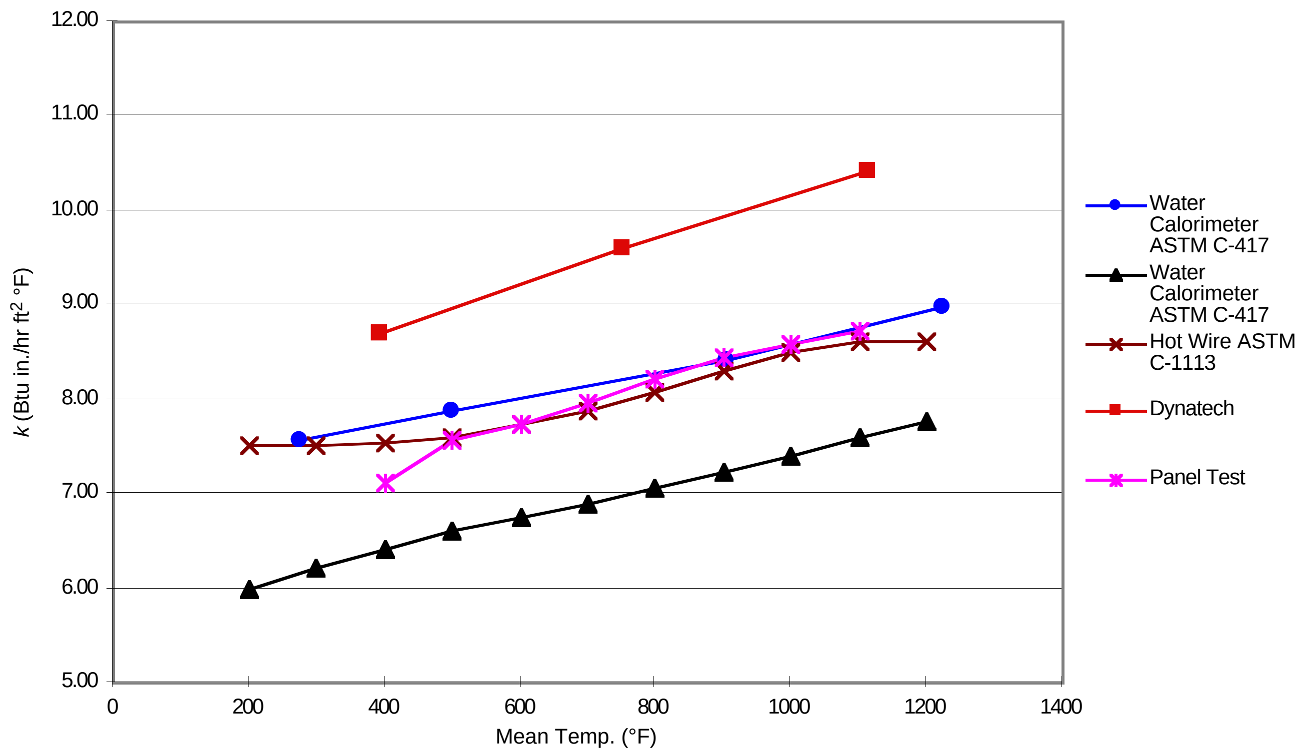

Figure A-4B—Fused Silica Castable,
Descending Thermal Conductivity

Table A-4—Thermal Conductivity
Lightweight (55 – 60 lb/ft^3) Castable
Btu in./hr ft^2 °F

Mean Temperature °F	Water Calorimeter ASTM C-417	Dynatech	Hot Wire ASTM C-1113	Panel Test	
200	2.07		2.84		
300	1.95		2.82		
392		3.77			
400	1.85		2.43		
435					2.00
500	1.77		2.02		
600	1.73		1.84		
700	1.70		1.87		
745					1.75
752		3.29			
800	1.68		1.93		
900	1.67		1.87		
1000	1.68		1.78		
1070					1.67
1100	1.70		1.86		
1112		3.47			
1200	1.72		1.97		
1300	1.76				
1349					1.76
1472		3.82			
1300	1.76				
1200	1.72				
1112		3.50			
1100	1.69		1.86	1.64	
1005					1.66
1000	1.66		1.82	1.60	
900	1.63		1.77	1.55	
800	1.60		1.73	1.51	
752		3.22			
700	1.57		1.69	1.47	
640					1.63
600	1.54		1.65	1.41	
503	1.51		1.62	1.35	
400	1.49		1.60	1.29	
392	1.46	3.06			
300	1.43		1.59	1.22	
274					1.62
200			1.57		

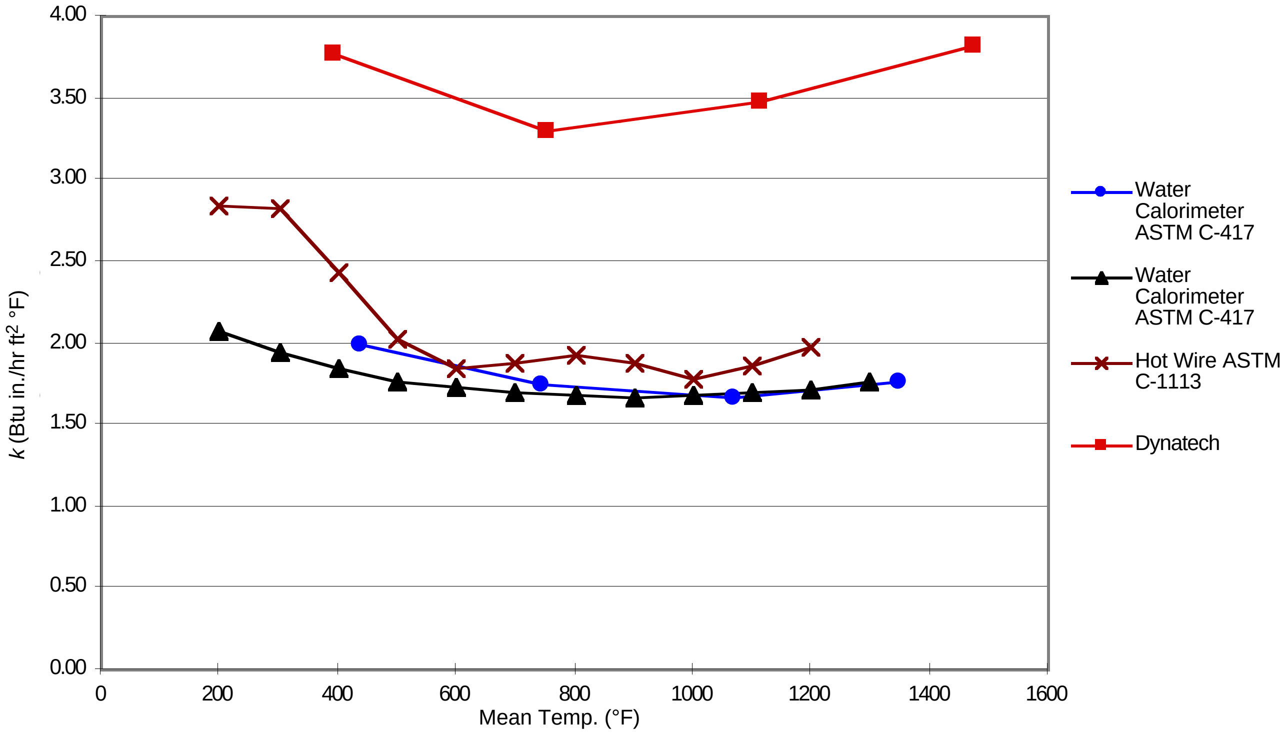

Figure A-5A—Lightweight (55 – 60 lb/ft^3) Insulating Castable, Ascending Thermal Conductivity

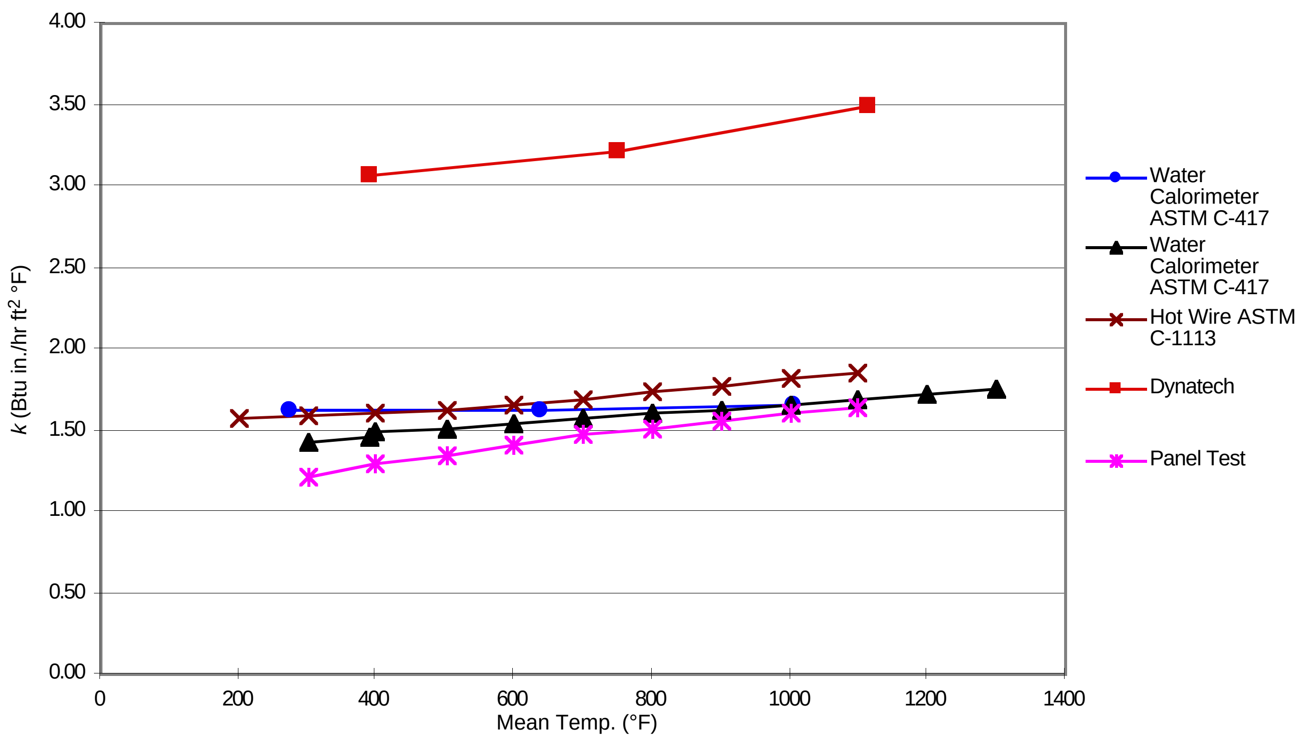

Figure A-5B—Lightweight (55 – 60 lb/ft^3) Insulating Castable, Descending Thermal Conductivity

Table A-5—Thermal Conductivity Medium Weight (70 – 85 lb/ft^3) Insulating Castable

Mean Temperature °F	Pilkington Calorimeter	Water Calorimeter ASTM C-417	Water Calorimeter ASTM C-417	Hot Wire ASTM C-1113	Dynatech	Panel Test
200				4.80		
229		4.50	3.55			
300				4.67		2.48
400	2.90			3.97	5.29	2.35
500				3.30		2.22
514			3.01			
536		3.32				
572	3.00					
600				2.99		2.08
700				3.00		2.03
752	2.60				4.25	
800				3.09		2.00
854		3.05	2.77			
900				3.08		1.95
932	2.80					
1000				3.04		2.00
1100				3.16		2.03
1112	2.90				4.52	
1135			2.72			
1200				3.25		2.04
1235		2.89				
1449			2.91			
1472					4.78	
1588		3.14				
1255		3.02				
1200				3.17		
1131			2.80			
1112					4.56	
1100				3.12		2.01
1000				3.08		1.97
932	2.80	3.07				
900				3.03		1.93
800			2.71	2.98		1.92
752	2.60				4.20	
700				2.93		1.91
600		3.03		2.88		1.90
572	2.60					
500			2.64	2.83		1.89
400	2.80			2.77	3.89	1.88
300				2.72		1.87
258		3.04				
228			2.51			
200				2.66		

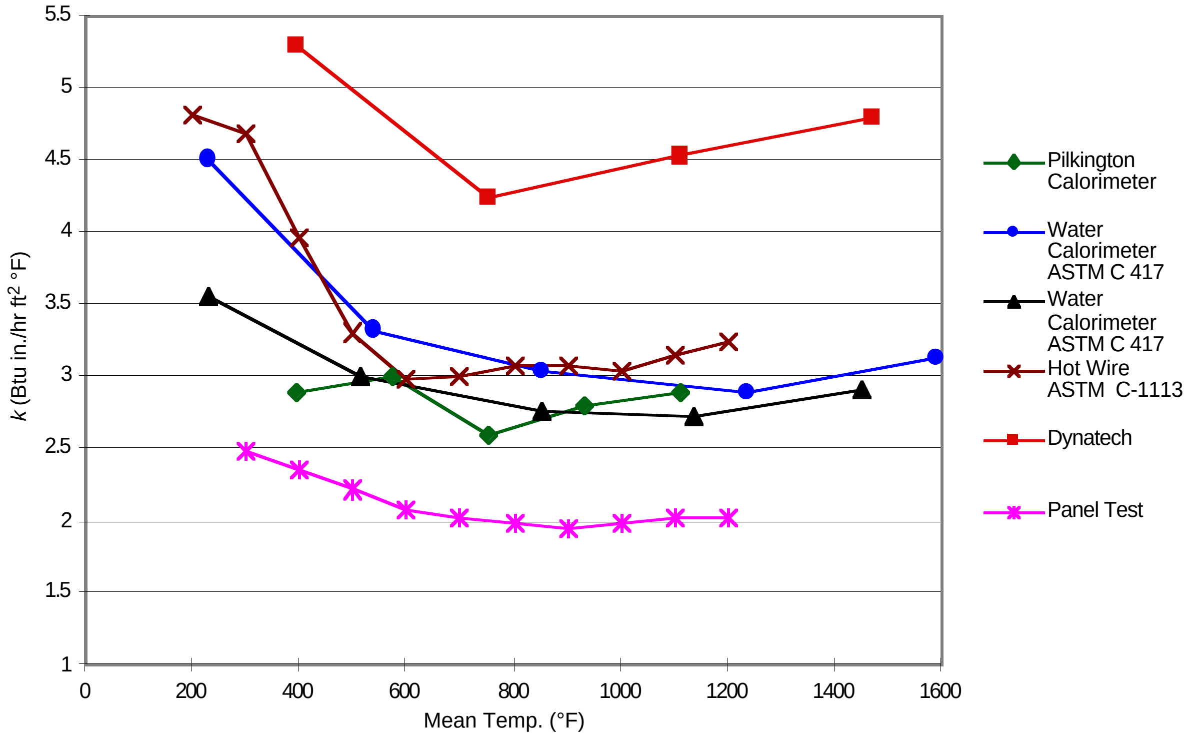

Figure A-6A—Medium Weight (70 – 85 lb/ft^3) Insulating Castable, Ascending Thermal Conductivity

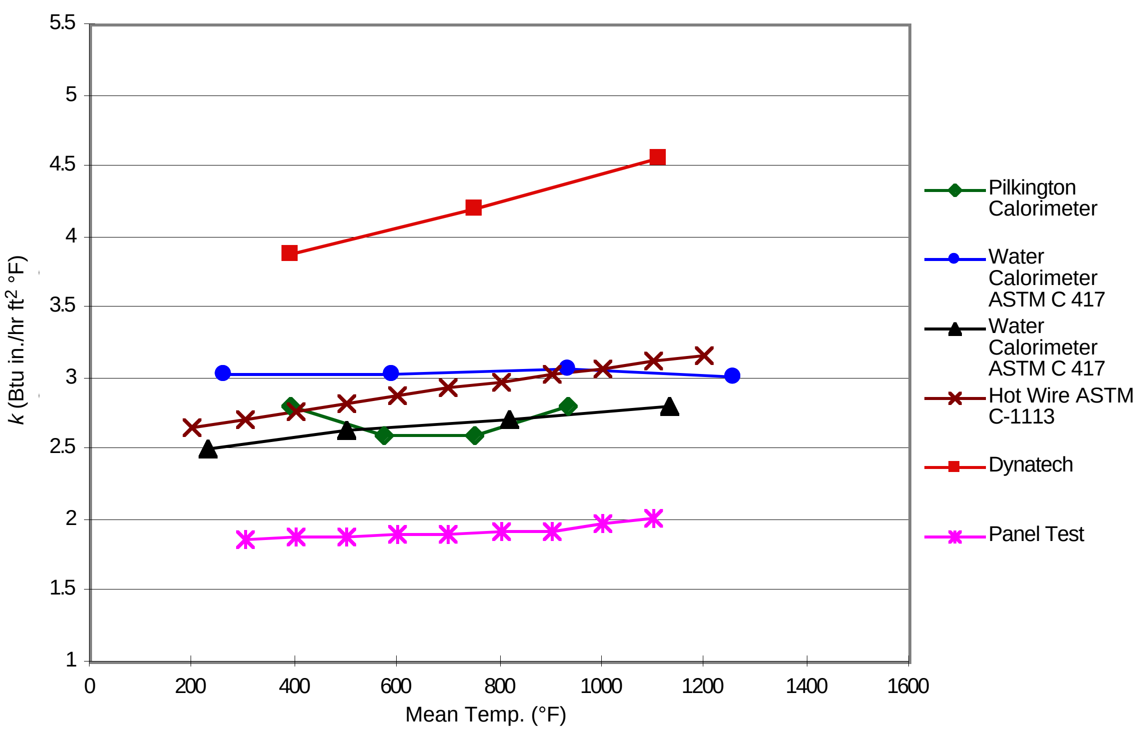

Figure A-6B—Medium Weight (70 – 85) lb/ft^3 Insulating Castable, Descending Thermal Conductivity

Table A-6—Thermal Conductivity
Moderate Density/Erosion Resistant Castable (110 lb/ft^3)
Btu in./hr ft^2 °F

Mean Temperature °F	Water Calorimeter ASTM C-417	Dynatech	Hot Wire ASTM C-1113	Panel Test	Water Calorimeter
200	6.36				
300	6.01		7.72		
392		8.37	7.35	4.36	
400	5.70		6.94		
500			6.55		
570				4.13	
600	5.19		6.24		
700	5.00		6.02		
745				4.02	
752		6.89			
800	4.84		5.98		
900	4.78		5.87		
930				4.01	
1000	4.74		5.90		
1100	4.74		5.95		
1112		6.87		4.14	
1200	4.76		5.94		
1300	4.78				
1400	4.83				
1472		7.01			
1500	4.87				
1400	4.86				
1300	4.84				
1200	4.83				
1112		6.94		4.18	
1100	4.83		5.87		
1028					
1000	4.83		5.83		
930				4.05	
900	4.84		5.81		
800	4.85		5.80		
752		6.77			
745				3.94	
700	4.87		5.80		
600	4.88		5.80		
570				3.86	
500	4.90		5.81		
400	4.92		5.81		
392		6.63		3.76	
300	4.94		5.80		
200	4.95		5.77		

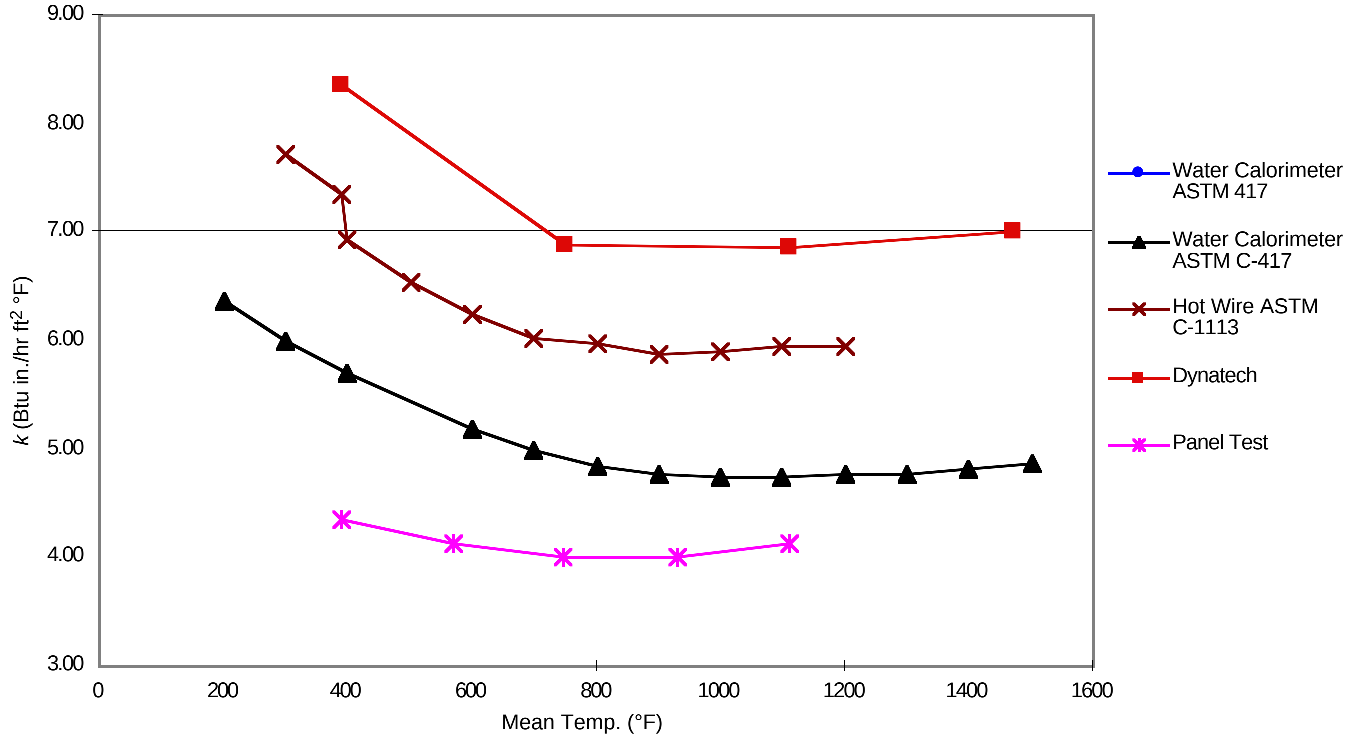

Figure A-7A—Moderate Density (100 – 120 lb/ft^3) Moderate Erosion-Resistant, Castable Ascending Thermal Conductivity

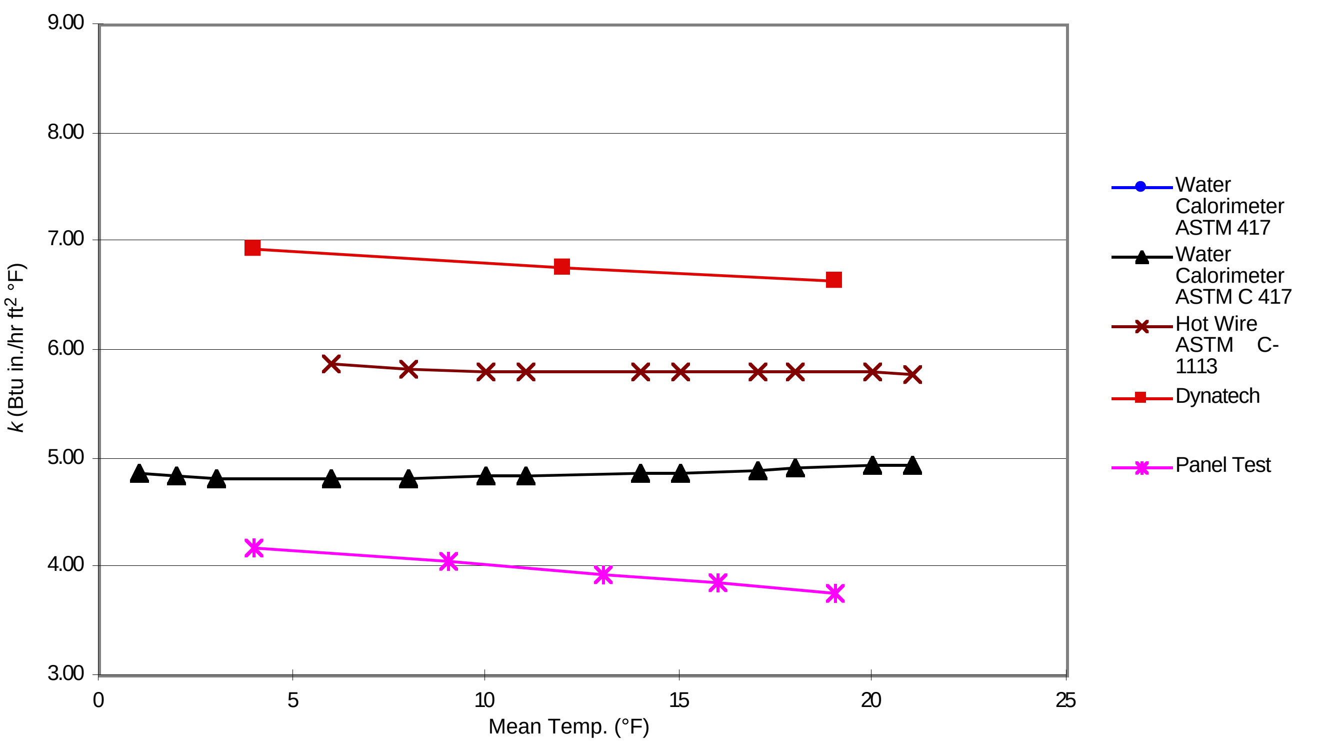

Figure A-7B—Moderate Density (100 – 120 lb/ft^3) Moderate Erosion-Resistant, Castable Descending Thermal Conductivity

The American Petroleum Institute provides additional resources and programs to industry which are based on API Standards. For more information, contact:

• Training/Workshops	Ph:	202-682-8490
	Fax:	202-682-8222
• Inspector Certification Programs	Ph:	202-682-8161
	Fax:	202-962-4739
• American Petroleum Institute Quality Registrar	Ph:	202-682-8130
	Fax:	202-682-8070
• Monogram Program	Ph:	202-962-4791
	Fax:	202-682-8070
• Engine Oil Licensing and Certification System	Ph:	202-682-8233
	Fax:	202-962-4739
• Petroleum Test Laboratory Accreditation Program	Ph:	202-682-8129
	Fax:	202-682-8070

In addition, petroleum industry technical, patent, and business information is available online through API EnCompass™. Call 1-888-604-1880 (toll-free) or 212-366-4040, or fax 212-366-4298 to discover more.

To obtain a free copy of the API Publications, Programs, and Services Catalog, call 202-682-8375 or fax your request to 202-962-4776. Or see the online interactive version of the catalog on our web site at www.api.org/cat.

American Petroleum Institute

Helping You Get The Job Done Right.℠

API Related Publications Order Form

Date: ____________________ *(Month, Day, Year)*

❏ API Member *(Check if Yes)*

Invoice To – ❏ Check here if same as "Ship To"

Company:

Name/Dept.:

Address:

City: State/Province:

Zip: Country:

Customer Daytime Telephone No.:

Fax No.:

(Essential for Foreign Orders)

Ship To – (UPS will not deliver to a P.O. Box)

Company:

Name/Dept.:

Address:

City: State/Province:

Zip: Country:

Customer Daytime Telephone No.:

Fax No.:

(Essential for Foreign Orders)

❏ Payment Enclosed $ ____________________

❏ Payment By Charge Account:

❏ MasterCard ❏ Visa ❏ American Express

Account No.:

Name (As It Appears on Card):

Expiration Date:

Signature:

❏ Please Bill Me

P.O. No.:

Customer Account No.:

State Sales Tax – The American Petroleum Institute is required to collect sales tax on publications mailed to the following states: AL, AR, CT, DC, FL, GA, IL, IN, IA, KS, KY, ME, MD, MA, MI, MN, MO, NE, NJ, NY, NC, ND, OH, PA, RI, SC, TN, TX, VT, VA, WV, and WI. Prepayment of orders shipped to these states should include applicable sales tax unless a purchaser is exempt. If exempt, please print your state exemption number and enclose a copy of the current exemption certificate.

Exemption Number: State:

Quantity	Order Number	Title	SO*	Unit Price	Total
	C93601	RP 936, *Refractory Installation Quality Control Guidelines*		$ 55.00	
	C56002	Std 560, *Fired Heaters for General Refinery Services*		$ 110.00	
	C66000	Std 660, *Shell-and-Tube Heat Exchangers for General Refinery Services*		$ 53.00	
	C66104	Std 661, *Air-Cooled Heat Exchangers for General Refinery Service*		$ 95.00	
	C66201	Std 662, *Plate Heat Exchangers for General Refinery Services*		$ 53.00	

Subtotal	
State Sales Tax *(see above)*	
Rush Shipping Charge *(see left)*	
Shipping and Handling *(see left)*	
Total *(in U.S. Dollars)*	

Shipping and Handling – All orders are shipped via UPS or First Class Mail in the U.S. and Canada. Orders to all other countries will be sent by Airmail. U.S. and Canada, $5 per order handling fee, plus actual shipping costs. All other countries, for Airmail (standard service) add 25% of order value. All other countries, for UPS Next Day, add an additional 10% of order value.

Rush Shipping Charge – FedEx, $10 in addition to customer providing FedEx account number: ____________________. UPS Next Day, $10 plus the actual shipping costs (1-9 items). UPS Second Day, add $10 plus the actual shipping costs (1-9 items).

Rush Bulk Orders – 1-9 items, $10. Over 9 items, add $1 each for every additional item. *NOTE: Shipping on foreign orders cannot be rushed without FedEx account number.*

Returns Policy - Only publications received in damaged condition or as a result of shipping or processing errors, if unstamped and otherwise not defaced, may be returned for replacement within 45 days of the initiating invoice date. A copy of the initiating invoice must accompany each return. Material which has neither been damaged in shipment nor shipped in error requires prior authorization and may be subject to a shipping and handling charge. **All returns must be shipped prepaid using third class postage. If returns are due to processing or shipping errors, API will refund the third class postage.**

**To be placed on Standing Order for future editions of this publication, place a check mark in the space provided.*

Pricing and availability subject to change without notice.

Mail Orders: American Petroleum Institute, Order Desk, 1220 L Street, N.W., Washington, DC 20005-4070

Fax Orders: (202) 962-4776

Phone Orders: (202) 682-8375

To better serve you, please refer to this code when ordering: L A 4 4 4 8 0 1 9 9

Additional copies available from API Publications and Distribution:
(202) 682-8375

Information about API Publications, Programs and Services is available on the World Wide Web at: http://www.api.org

American
Petroleum
Institute

1220 L Street, Northwest
Washington, D.C. 20005-4070
202-682-8000

Order No. C93501