COLD SET CONCRETE

FINAL REPORT

by

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March, 1986

Prepared For:

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1.0 ABSTRACT

Chemical additives are currently available which will cause Portland cement concretes to react, set and cure at temperatures below 0°C (32°F). Mixes have been developed which will gain strengths as high as 5000 PSI when placed and cured at below freezing temperatures. The work to date has not determined the long term freeze-thaw durability of such concrete; however current state-of-the-art knowledge suggests that satisfactory long term durability should be achievable, with typical mixes. Such mixes contain standard cements and commercially available air-entraining agents and additives. The mechanism utilized to obtain hydration appears to be partially freezing point depression and partially ice crystal growth suppression. It is the investigator's opinion that when the exact mechanism is determined, additional means will be available to enhance the end result into a practical, functional product which will allow utilization of Portland cement concretes without the benefit of a plus 4°C (40°F) placing and curing environment.

2.0 INTRODUCTION

The purpose of this investigation was to seek information into the practical utilization of a Portland cement concrete which will set, cure and develop usable compressive strength at temperatures below 0°C (32°F). One requirement for a workable mix design is that it have a practical application and be achievable under average field conditions, i.e., not a laboratory oddity. Portland cement concretes utilizing proprietary chloride containing water-reducing accelerators were used during the construction of the Trans-Alaska Oil Pipeline to backfill damaged vertical support members installed in holes drilled into permafrost. These mixes set and developed strength at temperatures on the order of -4°C (25°F). The main objective of this investigation is to explore the mechanism which exists, to allow hydration and curing at temperatures below 0°C (32°F), to determine if this reaction may be enhanced, and to develop practical means to apply it to Portland cement concrete utilization in cold regions. Positive initial results have been achieved. More work needs to be done, particularly on determining the lower temperature limit for various mixes and on the durability of the cold set concrete.

3.0 METHOD OF INVESTIGATION

The performance of various mixes were evaluated in the laboratory in the following way. Various batches were prepared with a constant cement content of 600 lbs/cu.yd. (PCY). A majority of the mixes examined contained 242 lbs of water per cubic yard (PCY), although mixes with water as low as 200 PCY were tested (water-cement ratios of 0.40 to 0.33). All of the materials used were allowed to reach room temperature prior to mixing. The length of time between the introduction of the water to the cement and the sample being placed into the deep freeze varied from 10 to 15 minutes with the exception of two samples (#112 & #113) which were agitated to maintain fluidity for one (1) hour and then placed into the deep freeze. Time versus temperature data was obtained by inserting a copper-constant thermocouple into the center of a sample immediately prior to it being placed into a deep freeze adjusted to approximately -10°C (14°F). The thermocouples were connected to a chart recorder & monitored. Curves of time-temperature plots are shown on Figures 1 through 44.

The time temperature data was plotted on both arithmetic and semi-log scales. The semi-log plots reveal differences in the initial rate of reaction, the rate of cooling and the duration of the time of loss of the latent heat of fusion, while the arithmetic plots best show the cooling characteristics after the loss of the latent heat of fusion. By comparing the shape of these time-temperature curves, we are able to see if the reaction of hydration in a given mix continues to produce heat after the mass has cooled below 0°C (32°F).

The control mix which contained only Portland cement, water, sand and a neutralized vinsol resin, (air entraining agent) froze at 0°C (32°F) and exhibited little or no compressive strength after 14 days of curing at minus 10°C (14°F) temperatures. Strength determinations were made at room temperature after allowing the specimens to warm to room temperature. Some of the samples exhibited various degrees of thawing which would indicate that some amount of the mixing water had formed ice rather than chemically reacting with the cement. These mixes were deemed unsatisfactory for use at the test temperature. This does not preclude acceptable performance at a somewhat warmer temperature (say 25°F) or at a somewhat slower cooling rate, as some compressive strength was obtained (hydration products).

A ten point Leeds & Northrup thermocouple recorder with copper-constantan thermocouples was used to monitor the temperature with respect to time. A set of ten readings were made every 4.8 minutes. Point 1 measured the room temperature adjacent to the freezer, Point 2, the freezer air temperature at the level of the samples, Point 3 monitored a six (6) gallon insulated ice bath for temperature reference and Points 4 through 10 the various samples.

Data for Run 1 was only available to 15 hours due to a malfunction in the chart feed mechanism of the recorder.

All the temperature data, Figures 1 through 44 were corrected to the ice-bath temperature to compensate for instrument drift. The freezer air temperature thermocouple point was sensitive enough to record the temperature fluctuations created by the freezer compressor cycle. This amounted to only 0.8°C.

4.0 TESTS

Twenty-two different combinations were tested. The ingredients used are listed in Table I and the various batch combinations are presented in Table II.

The samples were prepared in 250 ml plastic disposable beakers. All tests utilized 150 grams of Type III Columbia Cement. A Mettler Model 4400 electronic digital scale was used to weigh all of the batches. Each of the various ingredients were allowed to reach room temperature equilibrium prior to mixing. The order of mixing was as follows: zero tare the beaker; weigh in water; add AEA with a micro-pipette and stir; add other liquid admixtures and stir; weigh in cement; quickly add preweighed other dry ingredients ($CaCl_2$, silica fume, activated alumina, etc) and mix vigorously with a spatula until completely blended; place in deep freeze and position a preassembled and calibrated type "T" thermocouple into the center of the sample. This sequence was continued until seven (7) samples were placed into the freezer. The samples were held in position 12 inches above the bottom of the 22 cubic foot, chest type freezer. Ten, one gallon cans of a 20% propylene glycol solution were located at the ends of the freezer to increase the thermal mass to reduce temperature fluctuations. The plastic beakers were supported in a rack made out of a peg-board section of masonite which had ¼ inch holes on a ½ inch grid.

The time-temperature plots of the tests are shown as Figures 1 through 44. Odd numbered figures are plots of temperature versus time on a three cycle Logarithmic scale. Even numbered figures show the same data only with the "time" plotted on an Arithmetic scale. The arithmetic plots best show the cooling rate after the "ice" point has been reached. The semi-log time plots better show the cooling rates during the first 100 minutes. They also more clearly show the freezing point depression. Figures 45 through 53 show multiple plots of various batches for comparison. All contain the control mix for base line comparison.

Previous tests have indicated that concretes with cement contents of 8 sacks per cubic yard or more and Master Builders Pozzolith 122 HE at the dosage rate of 64 fluid ounces per sack of cement will gain strength when 6" X 12" standard test cylinders are cast and then placed into a freezer set at -2°C (28°F). These mixes occasionally had indications of ice crystal growth although the mix gained compressive strength at the test temperature. In the latter instance, the gross water content was high due to the silty nature of the minus 3/8 sand used to produce the cold set grout. It was theorized that there was not enough calcium chloride ($CaCl_2$) present to adequately depress the freezing point of the mixing water to prevent ice crystal growth. In addition it was thought that the heat of hydration assisted in preventing the concrete from freezing prior to the initial set and strength being developed.

This series of tests was designed to show if the mechanism which enabled the mixes to hydrate and develop usable compressive strengths was, 'simple mixing water freezing point depression,' 'additional and prolonged chemical heat of reaction' delaying cooling to the freezing point or some other phenomenon.

It is the researcher's opinion that the results of these tests indicate that the mixes in this series of tests cooled below 0°C (32°F) prior to the initial set developing. It is further our opinion that mixes which harden are not dependent upon the heat of hydration and/or chemical heat produced by the reaction of calcium chloride with water. It would seem logical, based on the results observed, that any mechanism which adequately retards or prevents ice crystal growth in the concrete as it cools will prevent permanent damage to the concrete. This does not necessarily insure that adequate compressive strengths will be obtained.

5.0 RESULTS AND CONCLUSIONS

The work described in this report is still experimental in terms of currently accepted state-of-the-art technology. Limited scope laboratory testing shows that concretes made of Portland cement, mineral aggregates, water, and certain chemical admixtures will develop usable compressive strengths when cured at temperatures below 0°C (32°F). This phenomena is achievable in mixes which are placed into a below 0°C (32°F) environment, in a fluid condition, without any heat loss protection. We acknowledge that this information is contrary to current, Portland cement technology.

For the purpose of clarity in the discussion of the analysis of the data presented by the graphs and this report, the following definitions shall apply.

Cold Set Concrete - Concrete made with water, Portland cement, mineral aggregates and chemical admixtures which will develop usable compressive strength and durability when placed and cured at temperatures below 0°C (32°F). The strength gain is not dependent on preventing the concrete temperature from falling below 0°C (32°F) prior to the cement developing an initial or final "set."

Freezing Point Depression - The lowering of the freezing point of the free water in the mix below 0°C as depicted by the descending time-temperature plot crossing the 0°C temperature line in a somewhat vertical direction prior to the sharp break horizontally in most instances to a constant temperature with respect to time.

Ice Point - The temperature at which there was no decrease in temperature with an increase in time; i.e., the "break" in the curves generally occurring about 67 to 85 minutes after the placing of the sample into the freezer. Some of the samples examined showed no visible evidence of the formation of ice crystals even though the curves illustrate the loss of the latent heat of fusion of the water in the mix.

The data gathered from this series of tests provides answers to some of the questions which existed prior to the initiation of these tests. Some of the facts gained by these tests are:

Some freezing point depression of the mixing water does occur, perhaps 3°C in these tests. This does not appear to be the mechanism which makes possible the strength gain in the cold set concrete.

The mixes cool below 0°C prior to the cement developing its initial set.

The cooling rate to a temperature of 0°C for samples of the size tested is not appreciably affected by the heat generated by the chemical reaction of the cement, water, calcium chloride and/or other admixtures or chemicals.

Hydration and strength gain of the Portland cement can, and does, occur at temperatures below the freezing point of the mixing water (0°C or cooler) in those mixes which exhibit strength gain.

Usable compressive strengths can be achieved without the concrete being warmed to produce curing. This assumes that the concrete was not cooled to a point where ice crystal growth occurred, either by extremely rapid cooling or by cooling to some temperature colder than -12.5°C (9.0°F).

The Master Builders high range water reducer, Pozzolith 400N is valuable in controlling the flash set generated by the addition of dry, finely powered calcium chloride to a plastic P.C. concrete mix. This admixture appears to function partially as a retarder and partially as a fluidizer in the limited testing accomplished to date. It should be noted that the cold set mixes tend to set very rapidly at normal concrete temperatures e.g., 10°C to 27°C (50° to 80°F). Since some of the admixtures used to obtain the cold set reaction act as accelerators at warmer temperatures, careful planning is needed before the ingredients are batched to avoid mixes setting before they are placed, consolidated and properly finished. Non-chloride set accelerators such as the Master Builders Pozzoliths 500A or 555A do not protect by accelerating the initial set although they do modify the shape of the temperature curve beyond the ice point. These admixtures by themselves do not appear to provide cold set characteristics.

Materials and/or other commercially available products other than those examined may work as well or better. The funding for this project did not support an effort to investigate more materials.

Additional research needs to be performed. This project just scratches the surface. Since the whole concept of concrete curing at below freezing temperatures is contrary to currently accepted thinking and published criteria, much inertia will need to be overcome before usage will become wide spread.

Additional tests should be performed to determine the relationship of cure temperature to compressive strength and whether the water-cement ratio versus compressive strength relationship is valid or altered when concretes cure at cold temperatures. Other data that needs to be determined is the optimum value of entrained air, what the durability of cold cured concrete is and how it compares to warm cured concrete, as well as establishing the relationship of the quantity of admixture required to promote the cold set phenomena to the temperature at which curing and protection are desired. Electron microscopy of samples of cold set concrete performed at various ages could possibly reveal the physical structure of the water and whether or not ice crystal growth takes place. This information would be essential to the formulation of a general use admixture.

Until much additional work is done to establish the performance of the cold cured concrete when it is compared to warm cured material each application will have to be individually evaluated. This will require batching trial mixes and curing test cylinders at a temperature equivalent to the conditions anticipated for the application. Corrosion of embedded reinforcing steel should also be considered and evaluated on an individual basis.

6.0 STARTING POINT RECOMMENDATIONS

Portland Cement Concretes utilizing either Type I or Type III ASTM C-150 cements can be designed to produce usable compressive strengths when cured at below 0°C (32°F) temperatures by the addition of chemical admixtures. Experimental laboratory tests have shown that the inclusion of Master Builders Pozzolith 122HE, a chloride containing ASTM C-494 Type "E", water-reducing and accelerating admixture at a dosage rate of 64 fluid ounces per sack of cement will result in mixes which have cold-set characteristics. Similar, but not duplicate, results can be obtained using aqueous solutions of the various salts mentioned, in place of the 122HE Pozzolith admixture. Since most of the additives act as set accelerators in normal temperature concrete mixes, super-plasticizers and/or retarding admixtures will probably be necessary to control the mix until it can be placed in its final location. Admixtures which are not compatible in normal concrete mixes will not be compatible in cold-set mixes.

The water-cement ratio/compressive strength relationship for cold cured mixes differs somewhat from the relationship obtained for warm (+5°C, +40°F) cured mixes. For this reason it is desirable to keep the total unit water content as low as possible both in terms of the water/cement ratio and the total water content per cubic yard of mix. For this reason it is desirable to utilize a water-reducing admixture if the Pozzolith 122HE is not used.

The specific materials proposed for use must be lab tested on an individual basis as some combinations have not produced satisfactory results at the curing temperatures evaluated. This is not to say that they may not prove acceptable at a warmer curing temperature.

It is recommended that any of the chemicals proposed for use be dissolved in a portion of the mixing water and cooled prior to combining them with the Portland Cement in the mixer. This is to avoid flash sets and cement lumps. Admixtures must not be combined prior to introduction to the mixer. They should be introduced individually along with a portion of the mixing water to avoid detrimental inter-reaction.

7.0 SUMMARY

Practical mixes can be batched using a commercially available chloride containing ASTM C-494 Type E admixture which will set, cure and develop usable levels of compressive strength at temperatures as low as -9°C (15°F). Other additives, disodium ethylenedinitrilotetraacetate, magnesium silica fluoride, silica fume and possibly activated alumina show potential for producing low temperature enhancement. Super plasticizers appear to have value in regulating the set and controlling the fluidity of a given mix prior to placement into forms or bore holes.

Mixes for practical use will have to be laboratory designed and evaluated on a job-by-job basis, considering the minimum temperature anticipated, the ultimate compressive strength needed, whether or not the concrete will be subjected to warmer temperatures at some future time, aggregates available, freeze-thaw durability and corrosion of embedded reinforcing materials.

Once the commonly accepted concept that "concrete does not gain usable compressive strengths at temperatures below 0°C (32°F)" is overcome, rapid progress in the perfection of acceptable admixtures and techniques should follow.

TABLE I

INGREDIENTS USED IN TEST BATCHES

Cement: Columbia Type III ASTM C-150

Water: Well water run through a Water-Softner

Air Entraining Agent: Master Builders AE-10 and Microair

Admixtures: ASTM C-494 Types A, C, E, F

Type: Master Builders Pozzolith 322N (Type A)
Master Builders Pozzolith 400N (Type F)
Master Builders Pozzolith 500A (Type C)
Master Builders Pozzolith 122HE (Type E)
Master Builders Pozzolith 555A (Type C)

Other Chemicals: Anhydrous Calcium Chloride
Anhydrous "Activated Alumina"
Anhydrous Drierite (V.W.R. Scientific Cat No. 22890-284)
Disodium ethylenedinitrilotetraacetate
Magnesium Fluosilicate ($MgSiF_6$)

TABLE II

COMPOSITION OF TEST BATCHES

BATCH AMOUNTS - POUNDS AND FLUID OUNCES

Run #I

Batch Number		100	101	102	103	104	105	106
Type III Cement	Pounds	600	600	600	600	600	600	---
Water	Pounds	252	252	237.4	225	225	210	210
Air Entraining Agent	Fluid Ounces	5.1	5.1	5.1	5.1	5.1	5.1	5.1
M.B. Pozzolith 122HE	Fluid Ounces		409					
M.B. Pozzolith 322N	Fluid Ounces			32	32	32	32	32
M.B. Pozzolith 400N	Fluid Ounces					64	64	64
M.B. Pozzolith 500A	Fluid Ounces				32		32	32
M.B. Pozzolith 555A	Fluid Ounces		32					

Run #II

Batch Number		107	108	109	110	111	112	113
Type III Cement	Pounds	600	600	600	600	600	600	600
Water	Pounds	242	200	242	242	242	225	200
Air Entraining Agent	Fluid Ounces	5.1	5.1	5.1	5.1	5.1	5.1	5.1
M.B. Pozzolith 122HE	Fluid Ounces							
M.B. Pozzolith 322N	Fluid Ounces	32	32	32	32	32	32	32
M.B. Pozzolith 400N	Fluid Ounces		96				64	96
M.B. Pozzolith 555A	Fluid Ounces		128					128
Anhydrous $CaCl_2$	Pounds			12				
Anhydrous Drierite	Pounds				12			
Anhydrous Activated Alumina	Pounds					12		
Disodium EDTA	Pounds						12	
SSD Sand	Pounds						2703	1681

COMPOSITION OF TEST BATCHES

BATCH AMOUNTS - POUNDS AND FLUID OUNCES

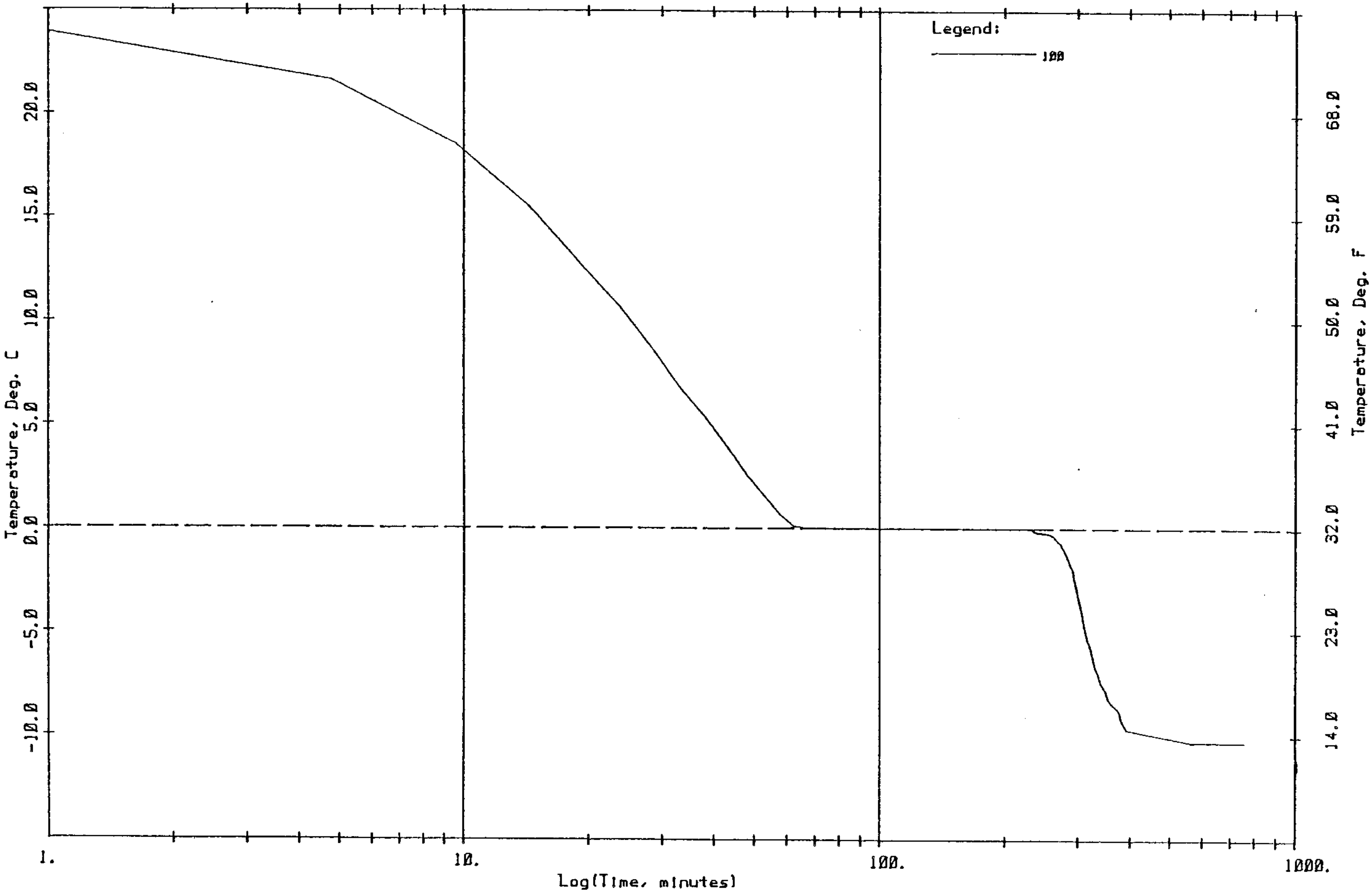
Run# III

Batch Number		114	115	116	117	118	119	120
Type III Cement	Pounds	600	600	600	600	600	600	600
Water	Pounds	242	242	242	242	242	242	242
Air Entraining Agent	Fluid Ounces	5.1	5.1	6.4	6.4	9.6	6.4	6.4
M.B. Pozzolith 122HE	Fluid Ounces						204	
M.B. Pozzolith 322N	Fluid Ounces		32	32				32
M.B. Pozzolith 400N	Fluid Ounces			64	96	128		
M.B. Pozzolith 500A	Fluid Ounces							
M.B. Pozzolith 555A	Fluid Ounces							
Dry $CaCl_2$	Pounds	12	12	12	12	12		
Disodium EDTA	Pounds						6	
Magnesium Silica Fluoride	Pounds							12

Run #IV

Batch Number		121
Type III Cement	Pounds	600
Water	Pounds	292
Air Entraining Agent	Fluid Ounces	
M.B. Pozzolith 122HE	Fluid Ounces	409
M.B. Pozzolith 322N	Fluid Ounces	
M.B. Pozzolith 400N	Fluid Ounces	96
M.B. Pozzolith 555A	Fluid Ounces	
Silica Fume	Pounds	24

FIG. 1



BATCH #100; 600# CEM; 242# (29)GAL) H2O
0.8 OZ/SK AE-10 (CEM = TYPE III)

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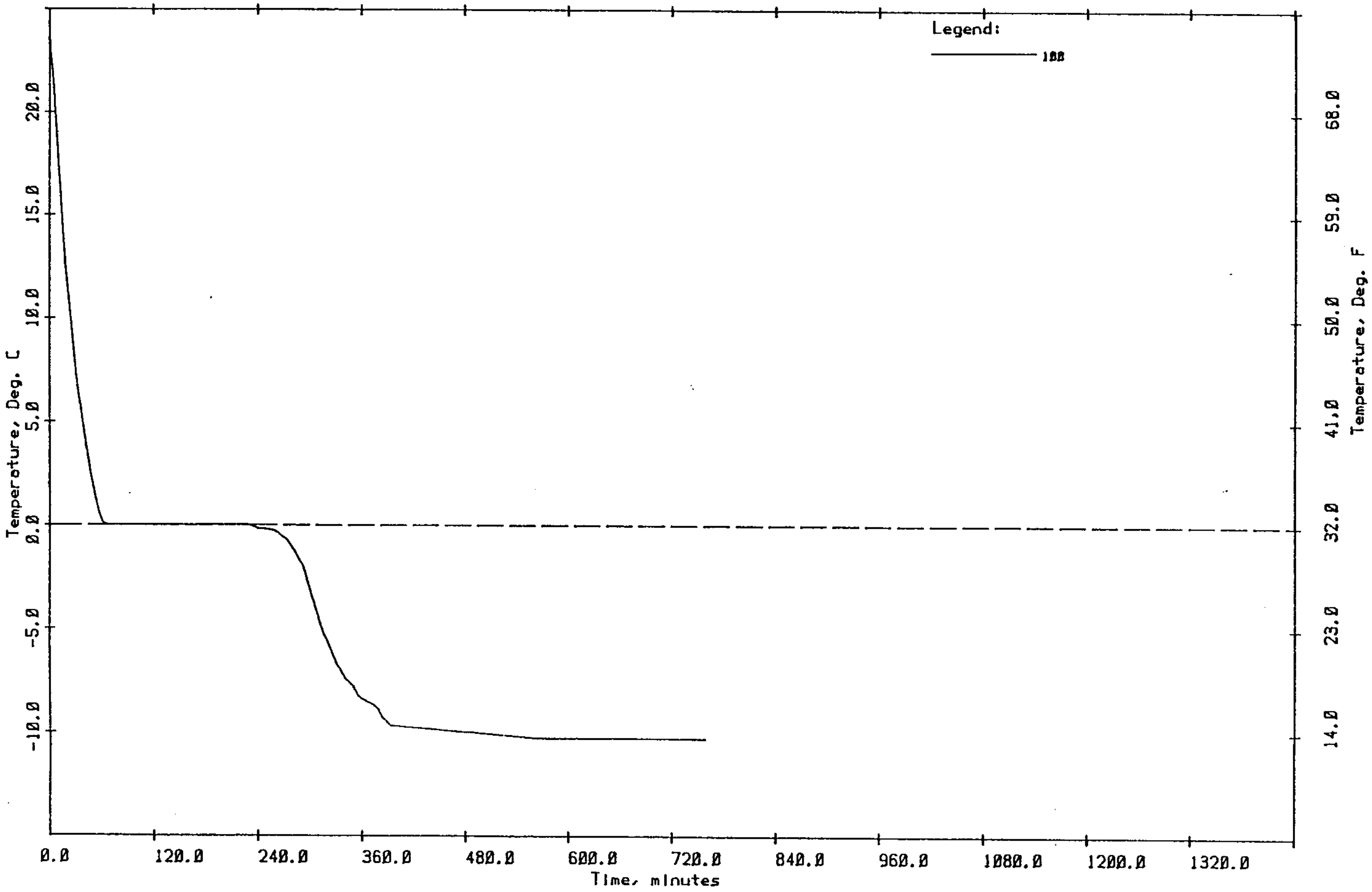
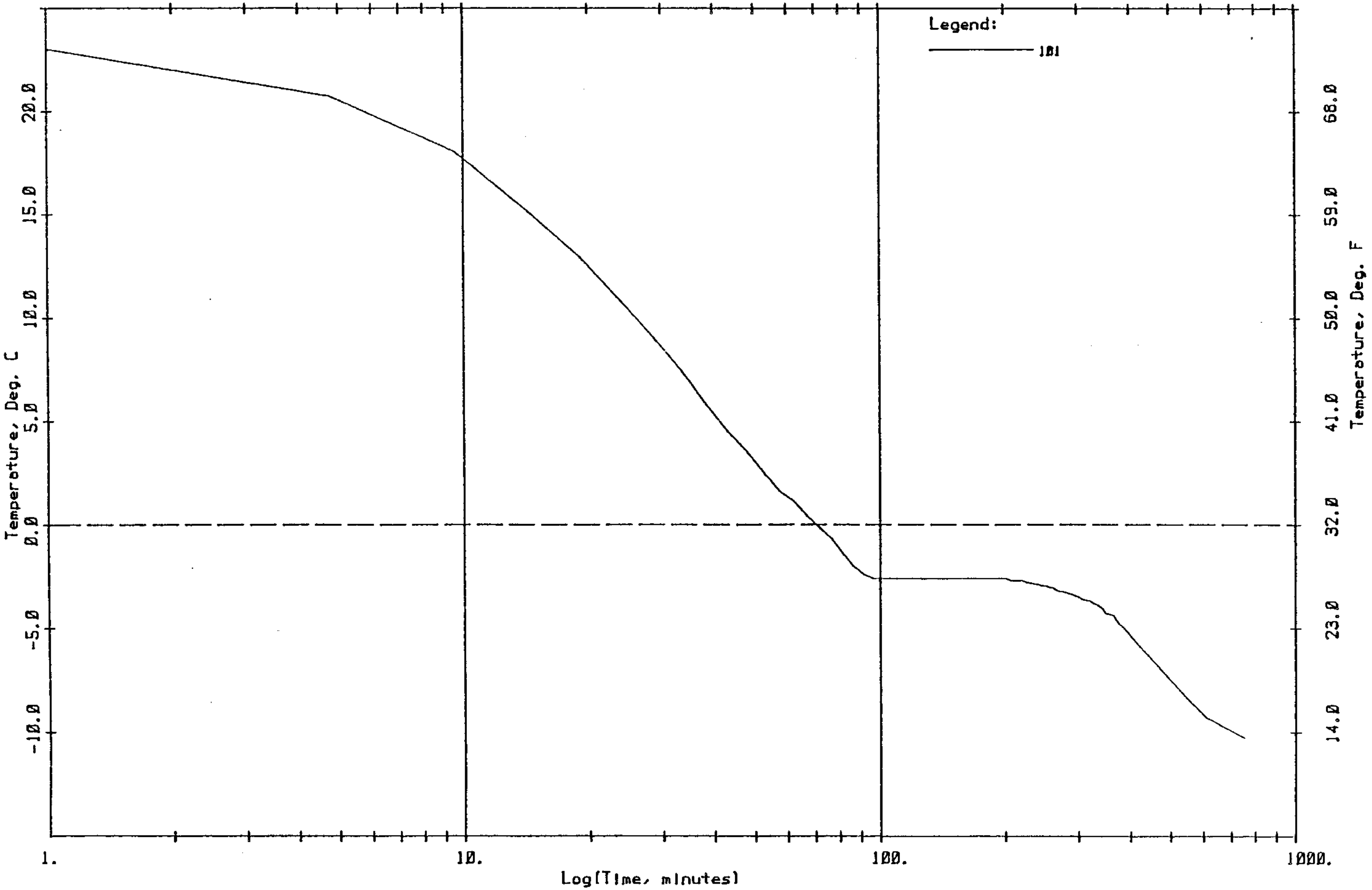
FIG. 2



BATCH #100; 600# CEM; 242# (29)GAL) H2O
0,8 OZ/SK AE-10 (CEM = TYPE III)

K-0698

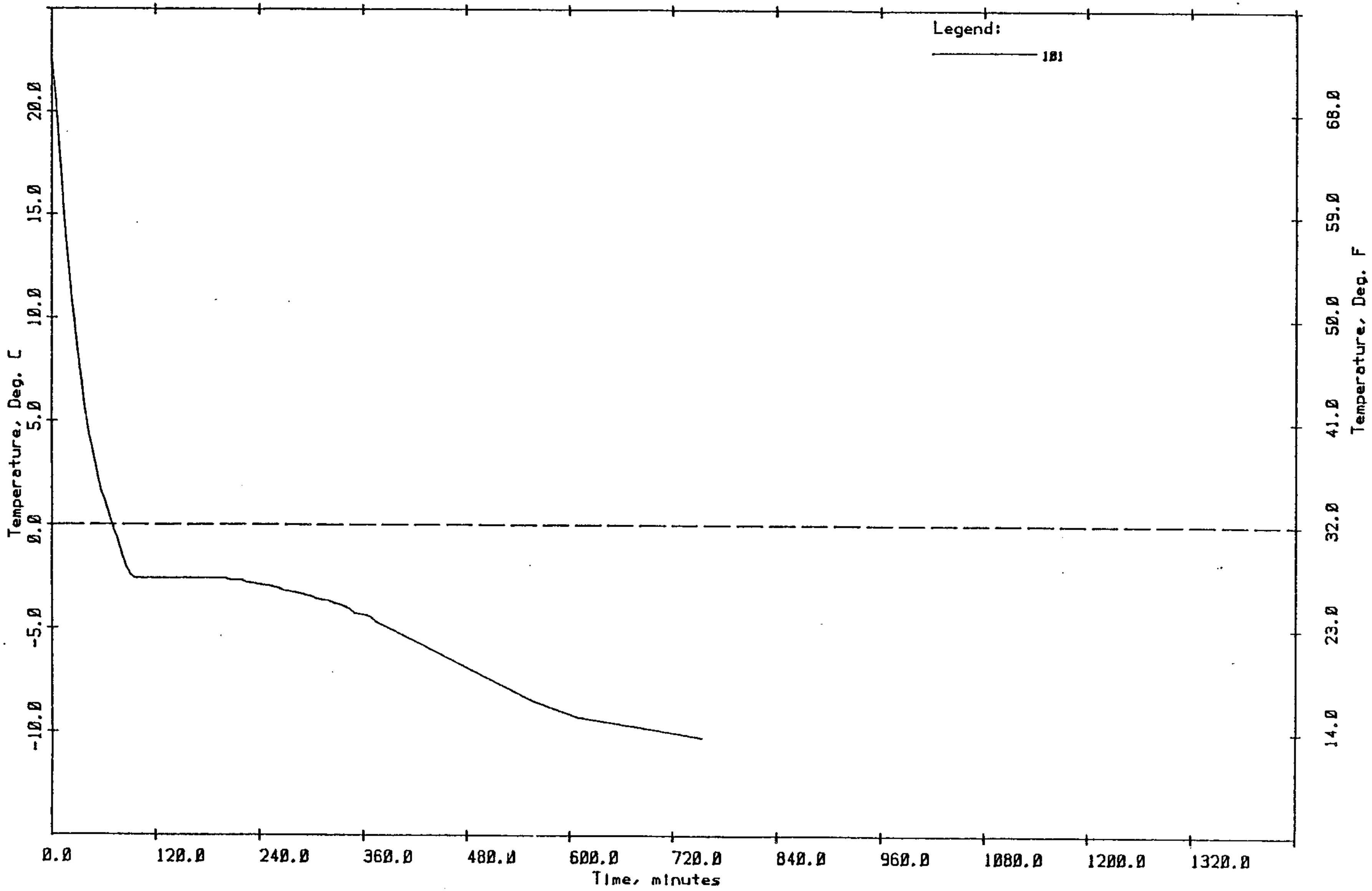
FIG. 3



BATCH #101 600# CEMENT, 242# H2O, 0.8 FL OZ MICRO-AIR/SK,
64 FL OZ 122HE/SK (EQUIVALENT TO 2% CALCIUM CHLORIDE)

K-0698

FIG. 4



BATCH #101 600# CEMENT, 242# H2O, 0.8 FL OZ MICRO-AIR/SK,
64 FL OZ 122HE/SK (EQUIVALENT TO 2% CALCIUM CHLORIDE)

K-0698

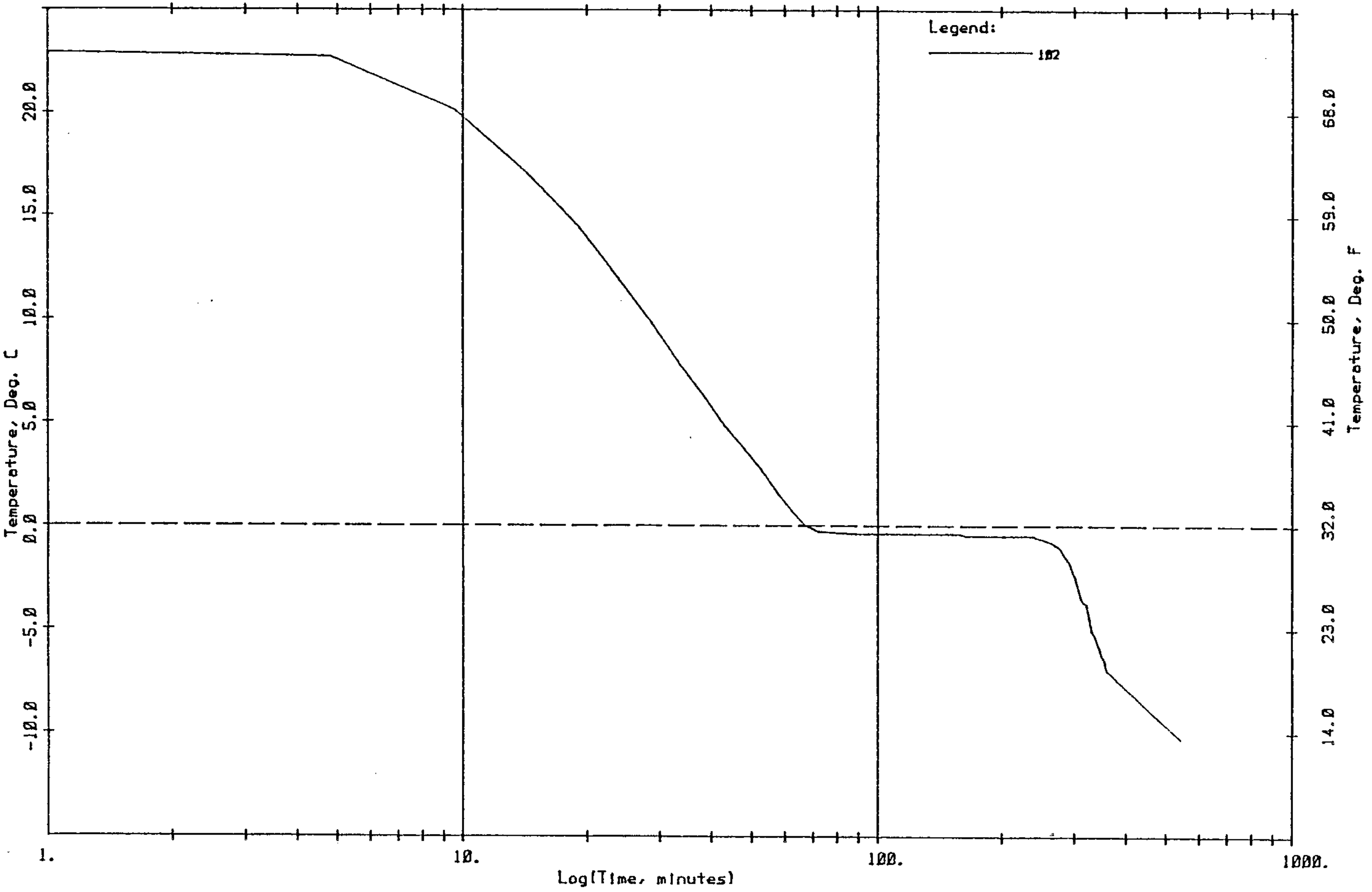
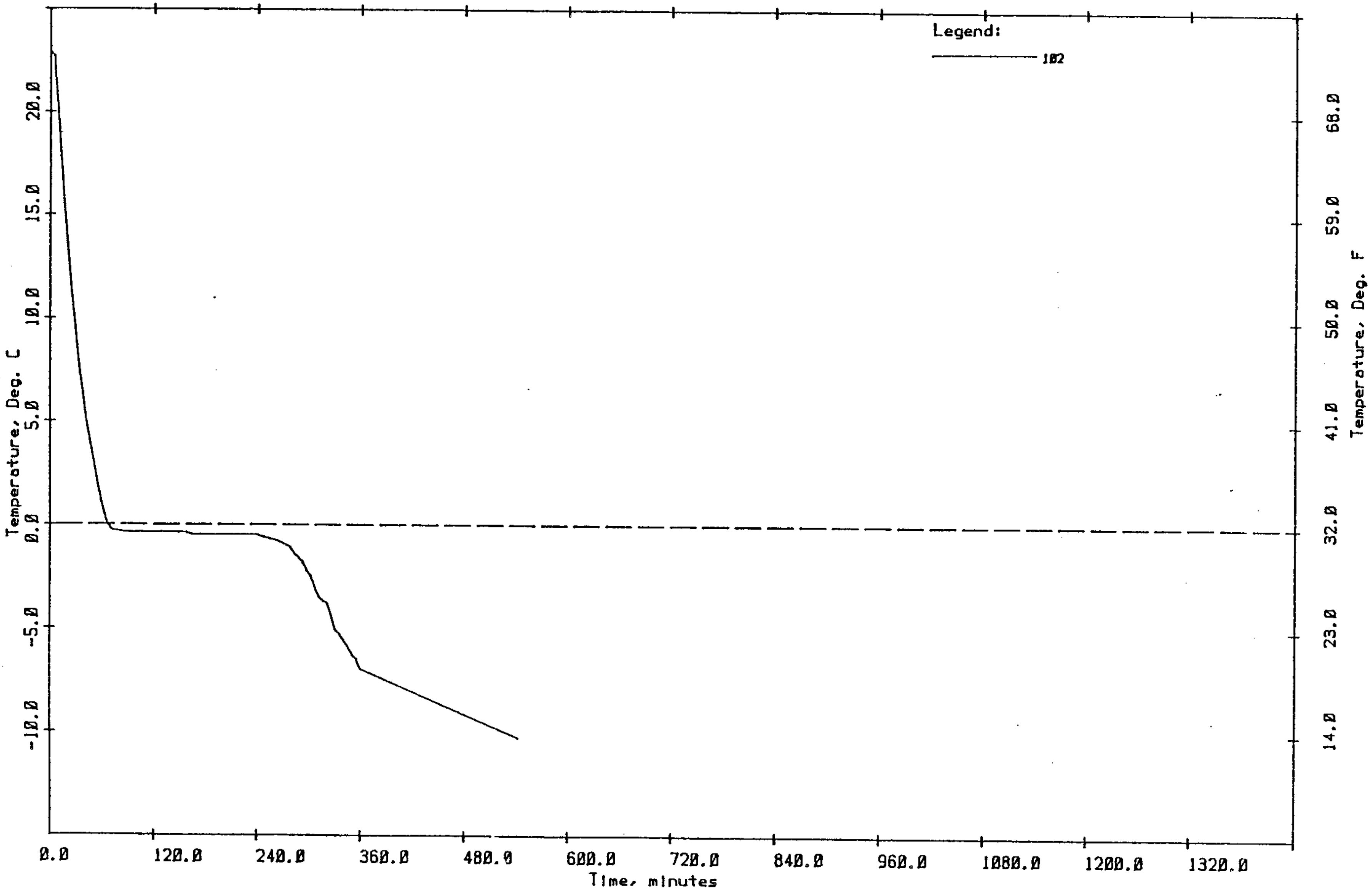


FIG. 5

600 # CEM; 28.5 GAL H2O; 5.0 FL OZ 322N POZZ/SK;
10.0 FL OZ 555N/SK; NO AIR

K0698

FIG. 6



600 # CEM, 28.5 GAL H2O, 5.0 FL OZ 322N POZZ/SK,
10.0 FL OZ 555N/SK, NO AIR

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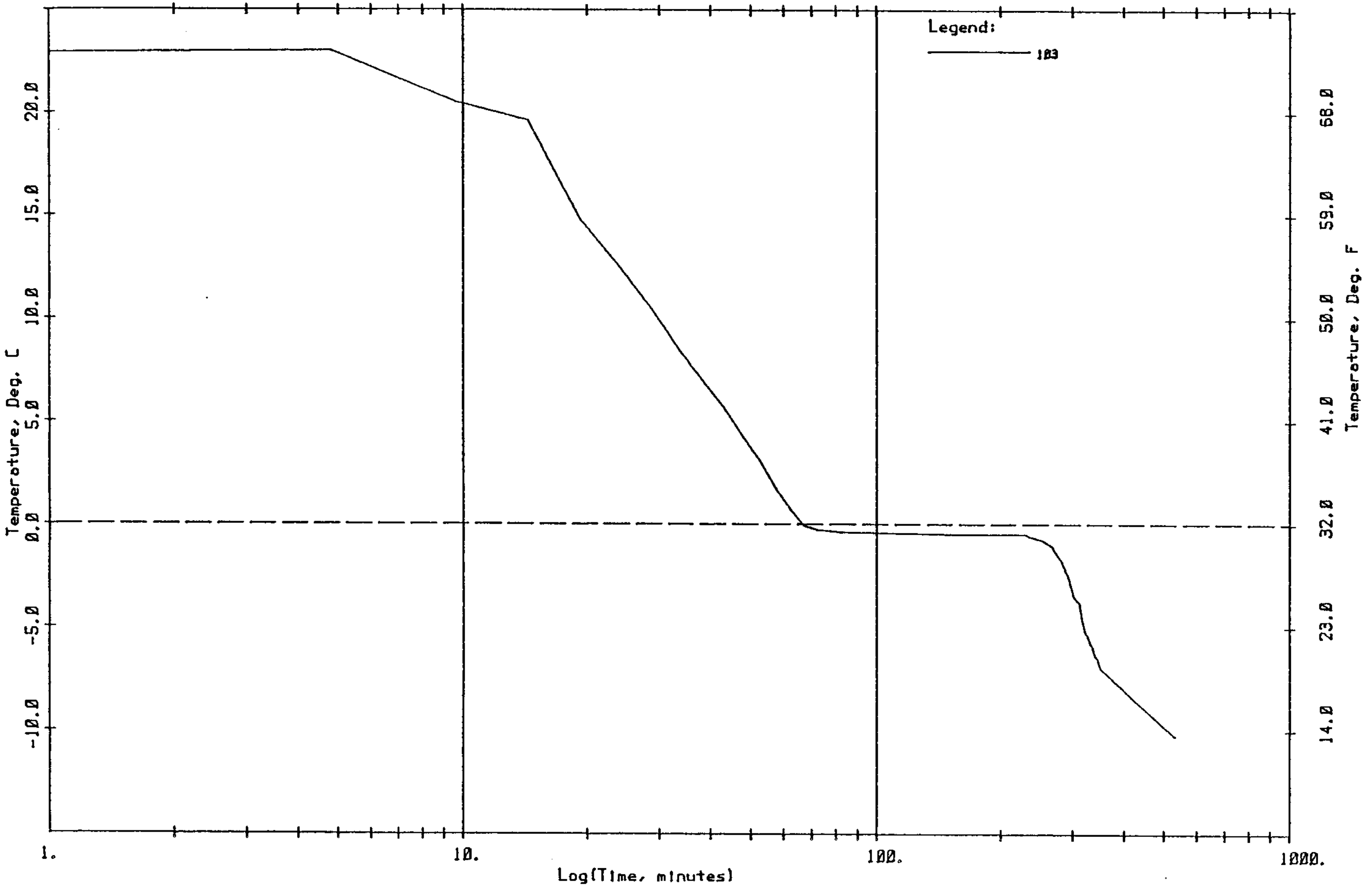
FIG. 7



600# CEM, 27.0 GAL H2O, 0.8 FL OZ/SK AE-10,
5.0 FL OZ 322N/SK, 5.0 FL OZ 500A/SK,

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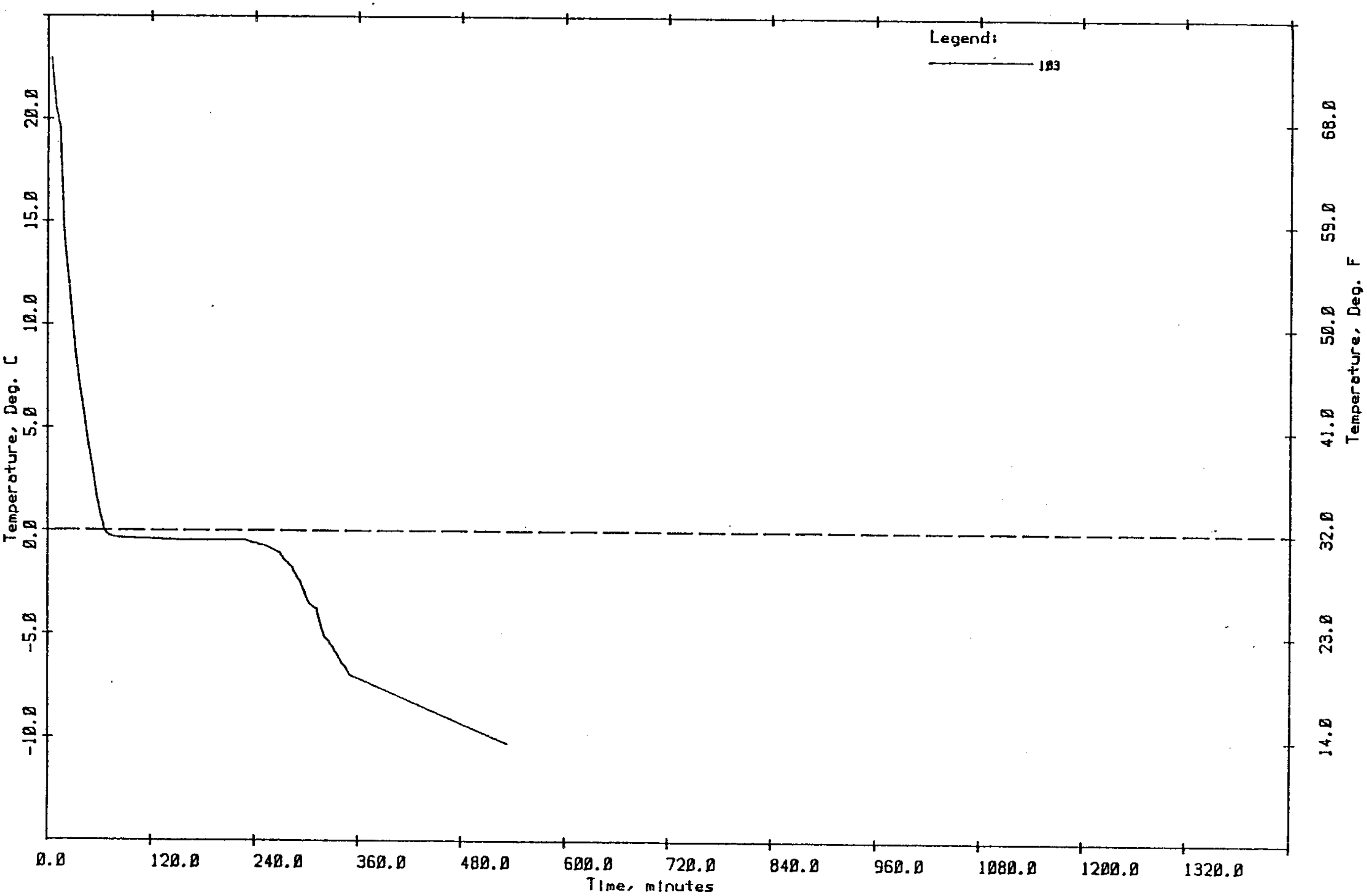
FIG. 8



600# CEM; 27.0 GAL H2O; 0.8 FL OZ/SK AE-10;
5.0 FL OZ 322N/SK; 5.0 FL OZ 500A/SK;

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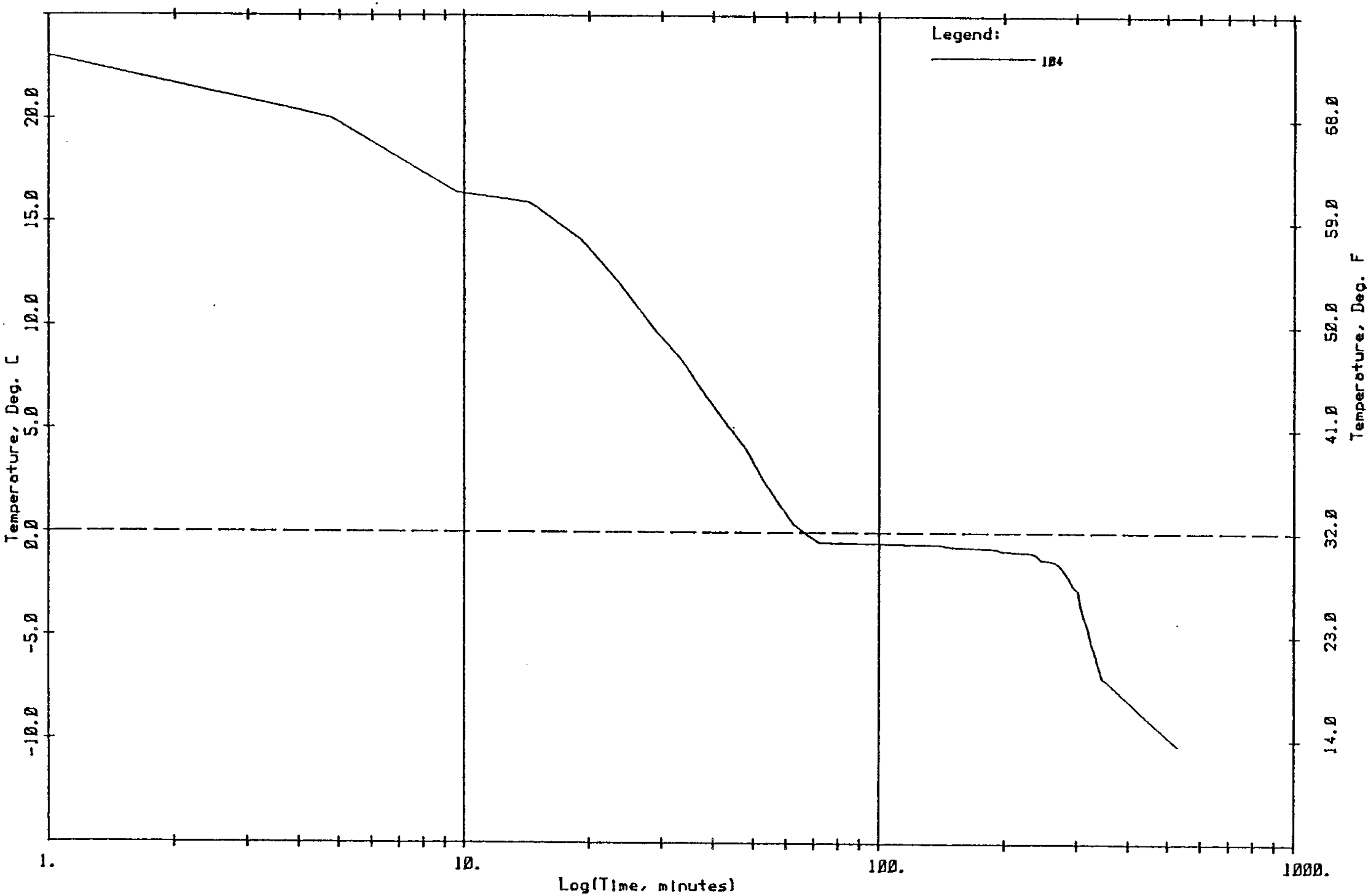
FIG. 9



BATCH # 104 600 # CEM; 27 GAL H2O; 0.8 FL OZ AE-10/SK
5 FL OZ 322N/SK; 10 FL OZ 400N/SK

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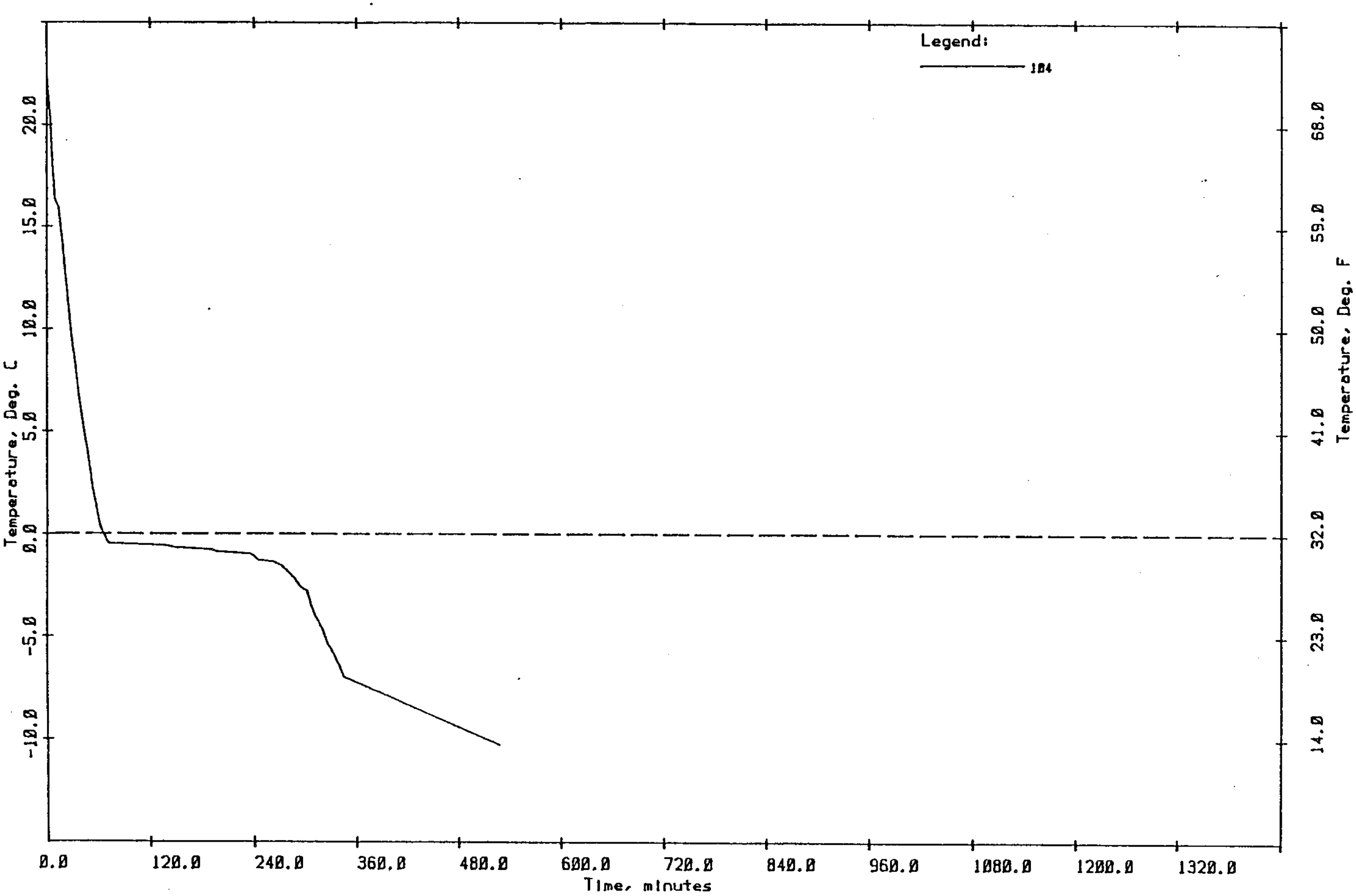
FIG. 10



BATCH # 104 600 # CEM, 27 GAL H2O, 0.8 FL OZ AE-10/SK
5 FL OZ 322N/SK, 10 FL OZ 400N/SK

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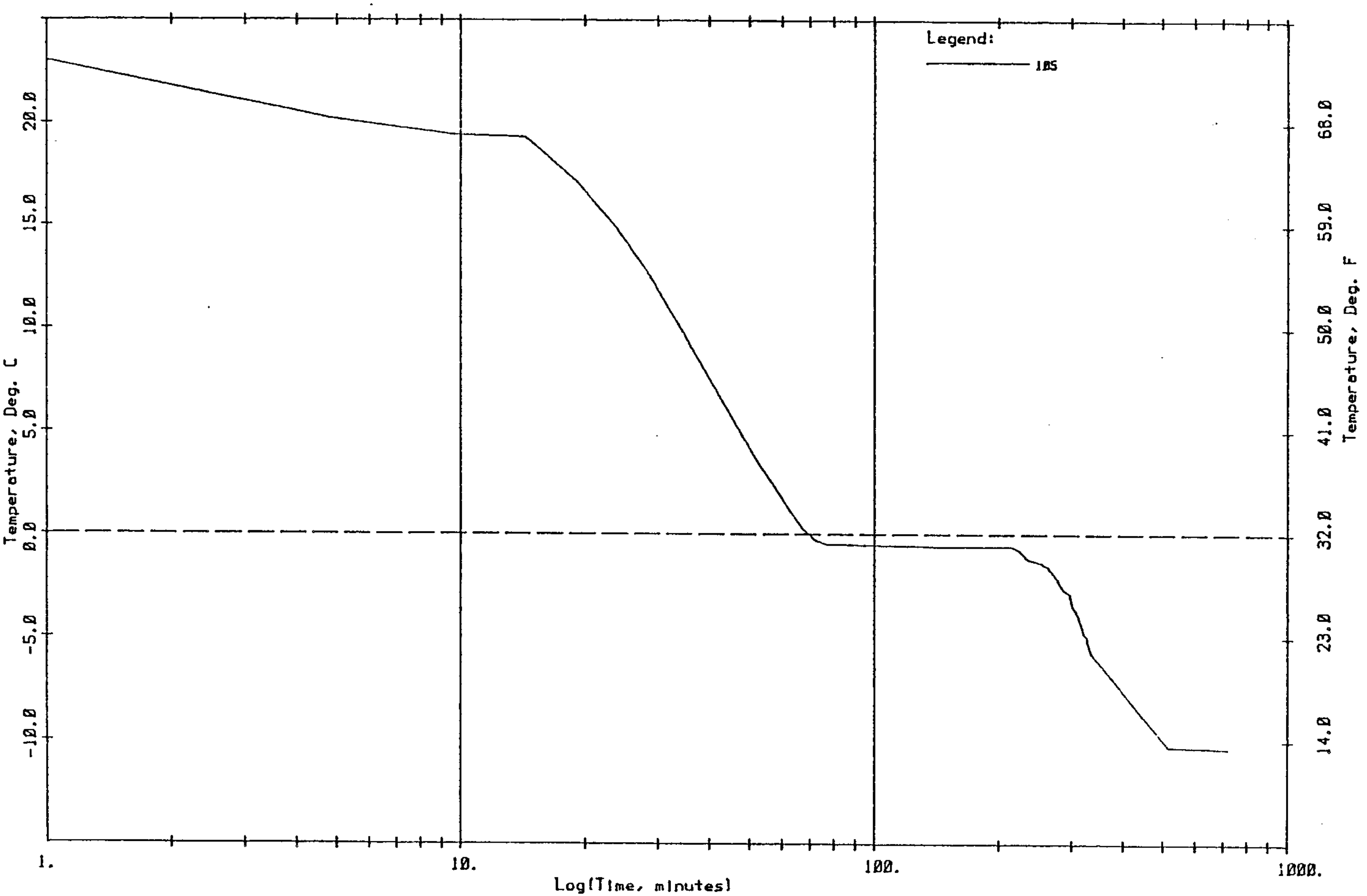
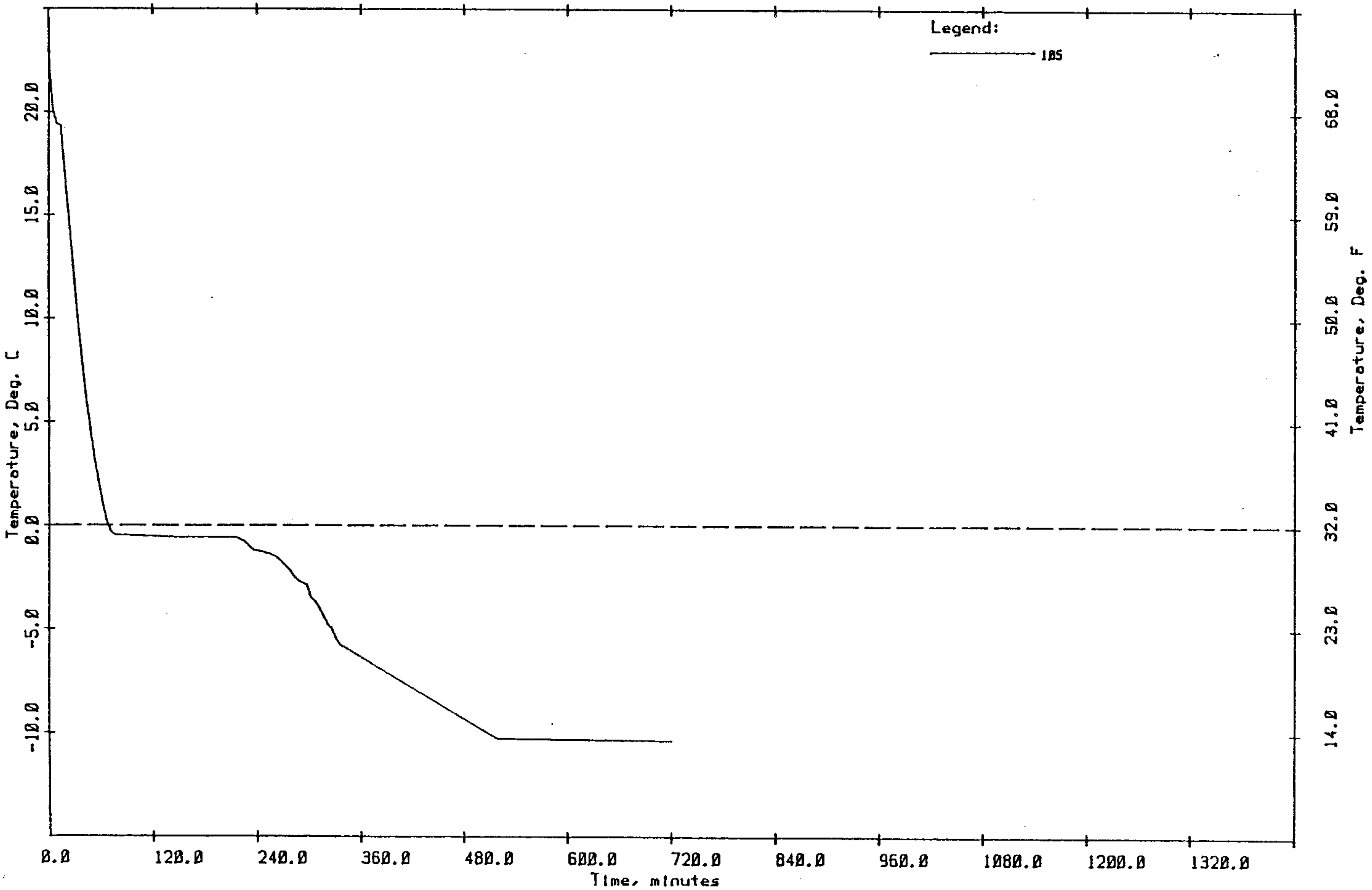


FIG. 11

BATCH # 105 600 # CEM, 25.2 GAL H20, 0.8 FL OZ AE-10/SK
5.0 FL OZ 322N/SK, 5.0 FL OZ 500A/SK, 10 FL OZ 400N/SK



BATCH # 105 600 # CEM, 25.2 GAL H20, 0.8 FL OZ AE-10/SK
5.0 FL OZ 322N/SK, 5.0 FL OZ 500A/SK, 10 FL OZ 400N/SK

FIG. 12

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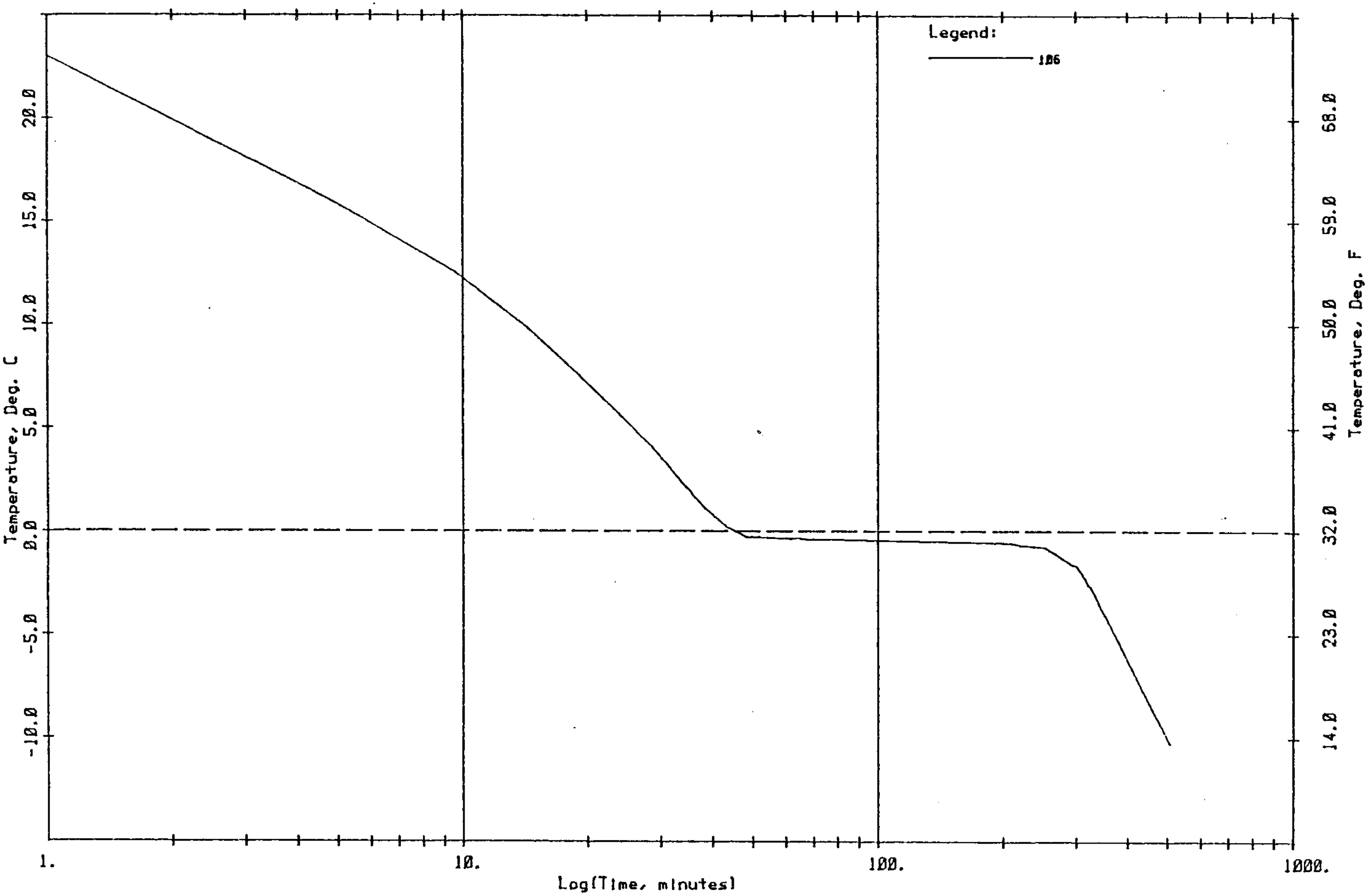
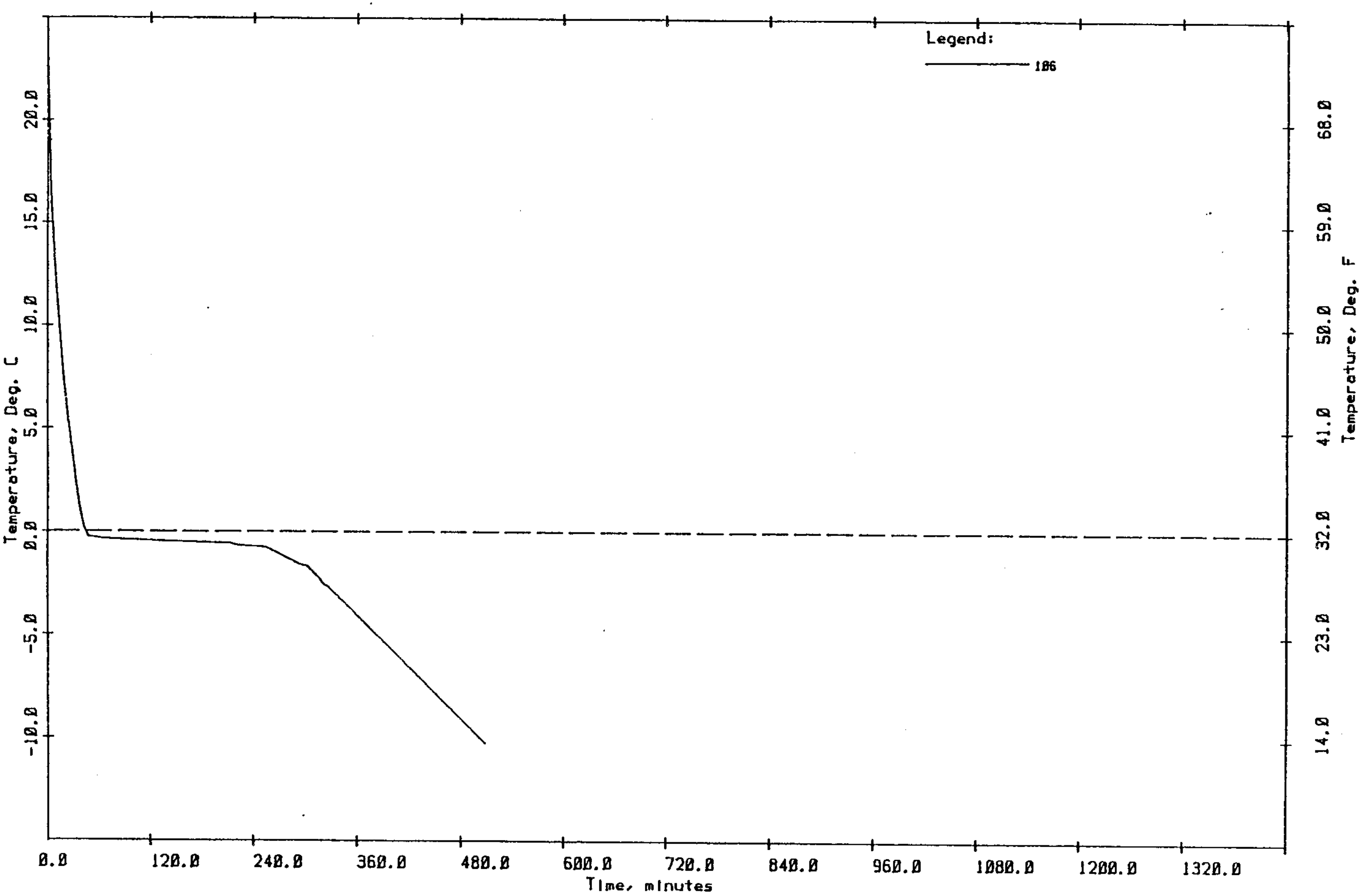


FIG. 13

BATCH # 106 25.2 GAL H2O, 0.8 FL OZ AE-10/SK (6.383 SKS)
5 FL OZ 322N/SK, 5 FL OZ 500A/SK, 10 FL OZ 400N/SK
(NO CEMENT - ALL LIQUID)

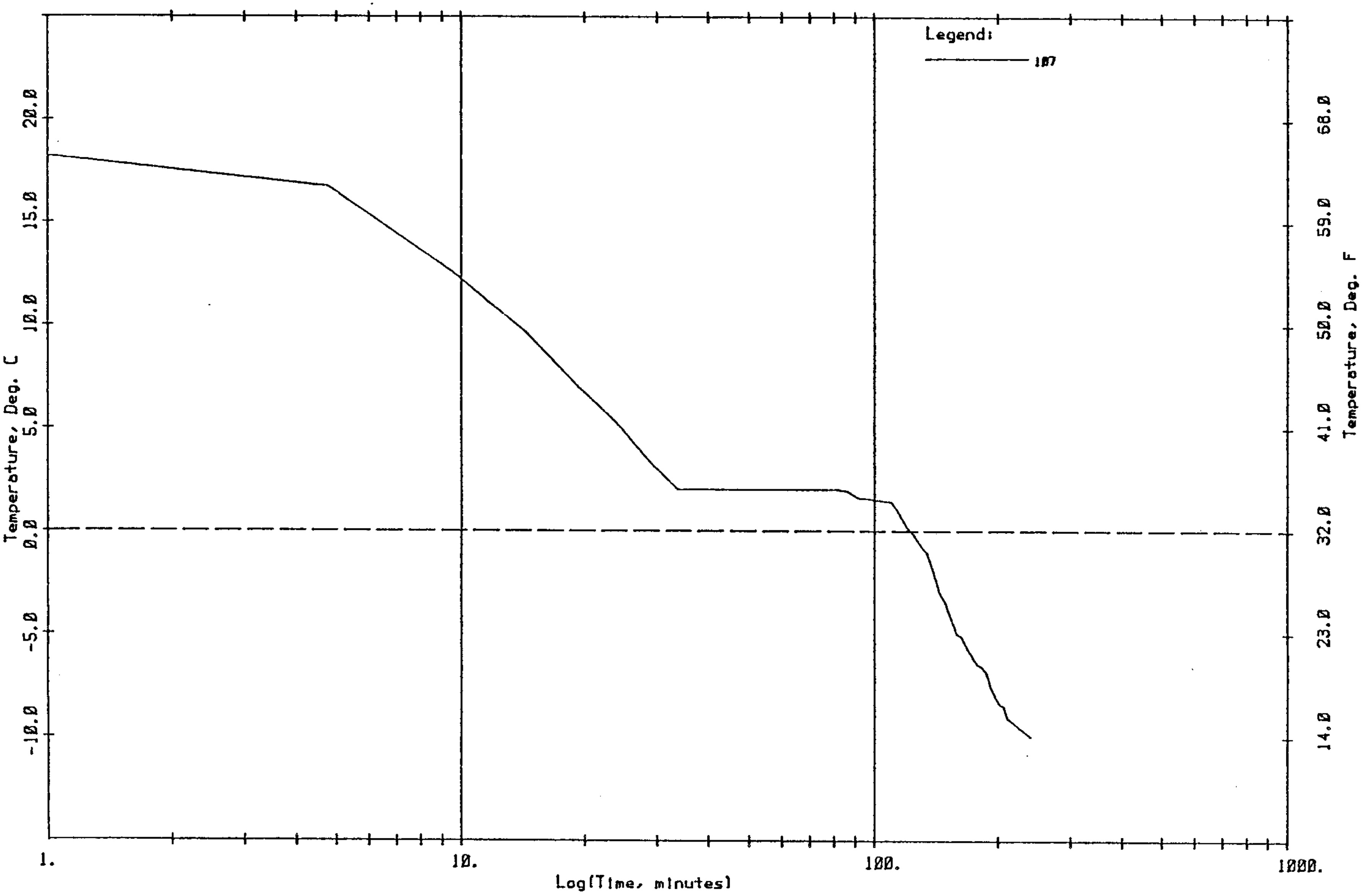
K0698

FIG. 14



BATCH # 106 25.2 GAL H2O, 0.8 FL OZ AE-10/SK (6.383 SKS)
5 FL OZ 322N/SK, 5 FL OZ 500A/SK, 10 FL OZ 400N/SK
(NO CEMENT - ALL LIQUID)

K0698



BATCH #107, 600##CEMENT, 242# H2O, 5 FL OZ 322N/SK,
2% BY WEIGHT CALCIUM CHLORIDE

FIG. 15

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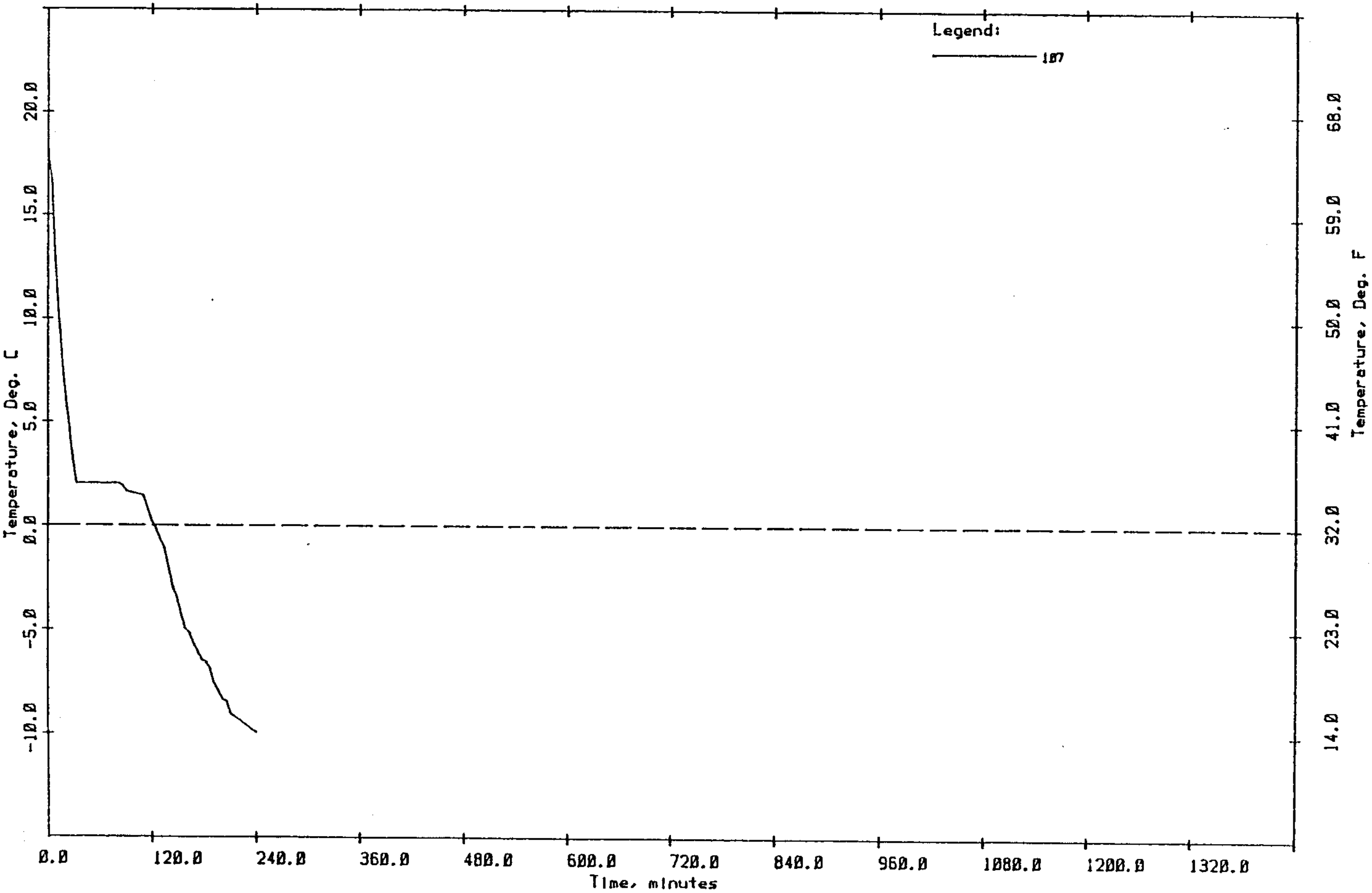
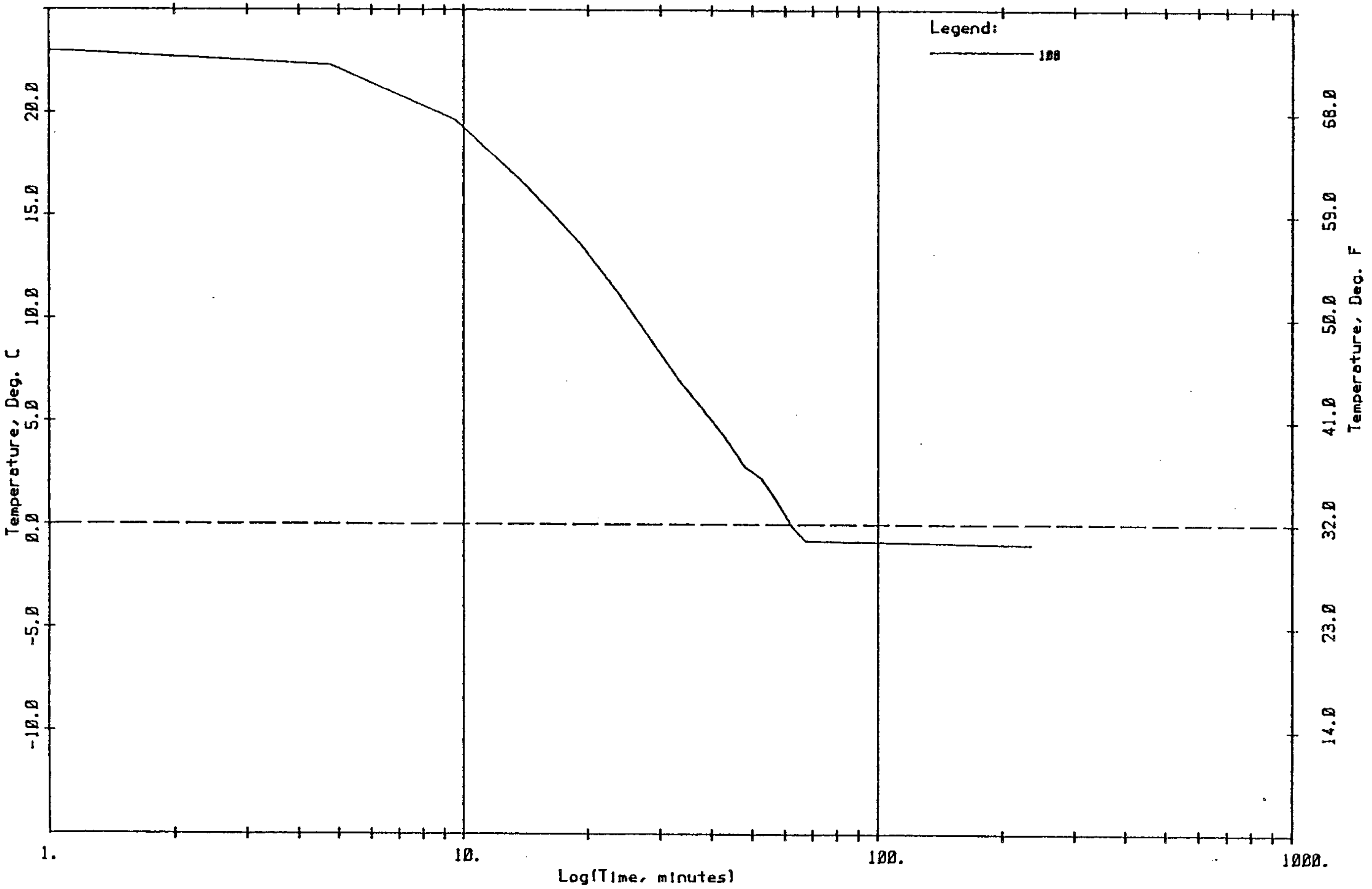
FIG. 16



BATCH #107, 600##CEMENT, 242# H_2O, 5 FL OZ 322N/SK,
2% BY WEIGHT CALCIUM CHLORIDE

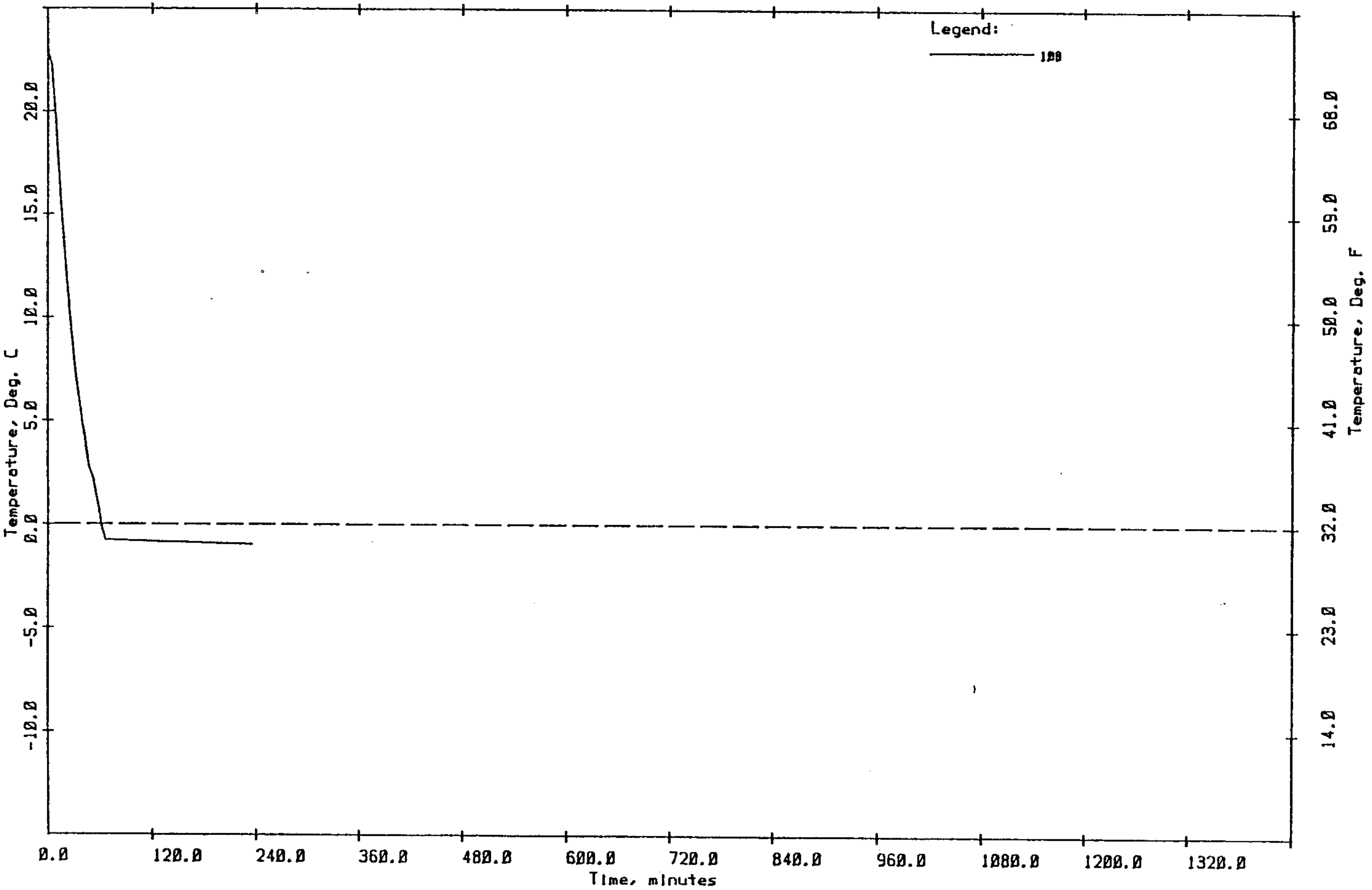
K-0698

FIG. 17



BATCH #108 600# CEMENT, 200# H2O, 5 FL OZ 322N/SK,
15 FL OZ 400N/SK, 20 FL OZ 555N/SK, 1 FL OZ MICRO-AIR/SK

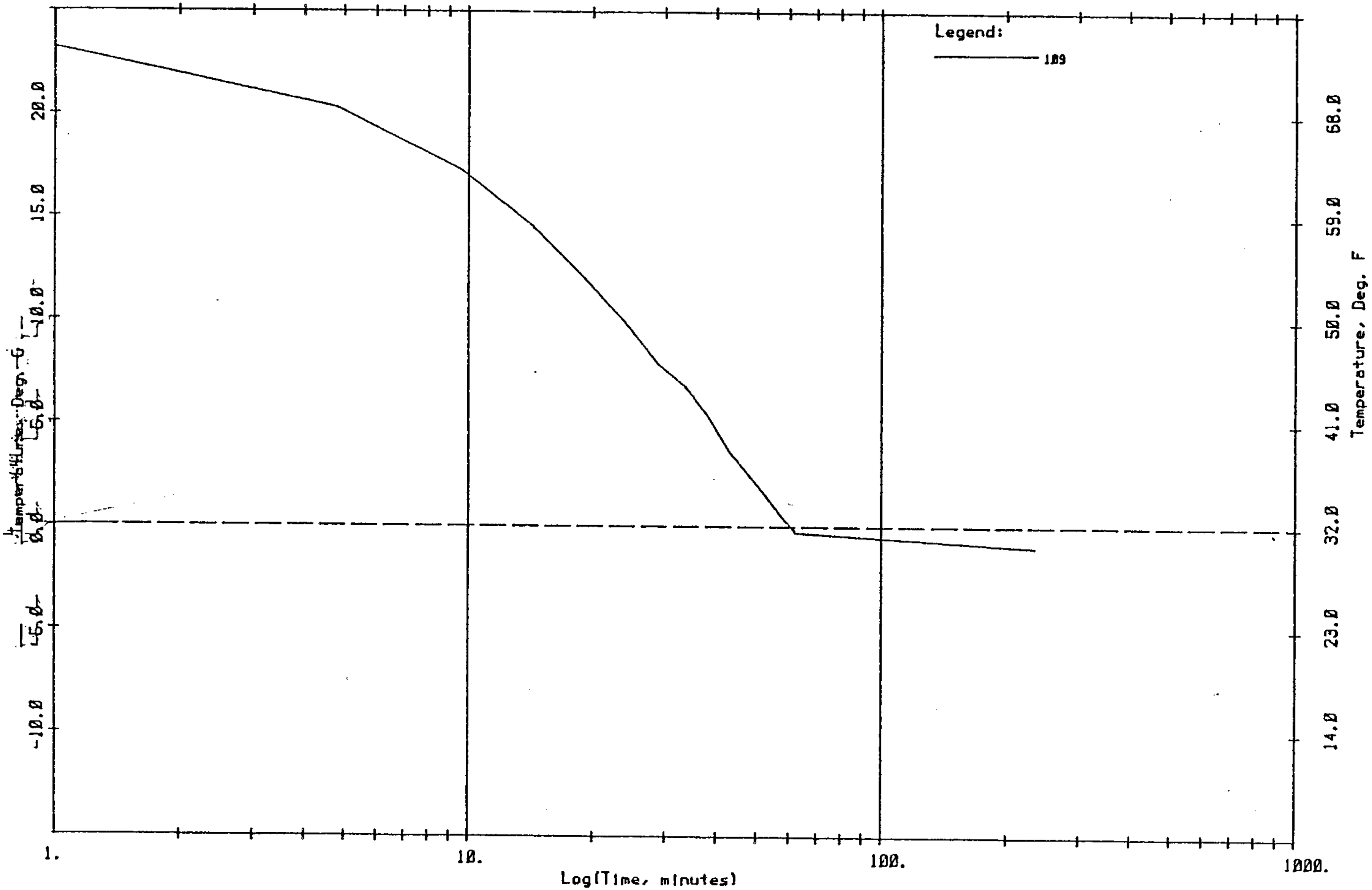
FIG. 18



BATCH #100 600# CEMENT, 200# H2O, 5 FL OZ 322N/SK,
15 FL OZ 400N/SK, 20 FL OZ 555N/SK, 1 FL OZ MICRO-AIR/SK

K-0698

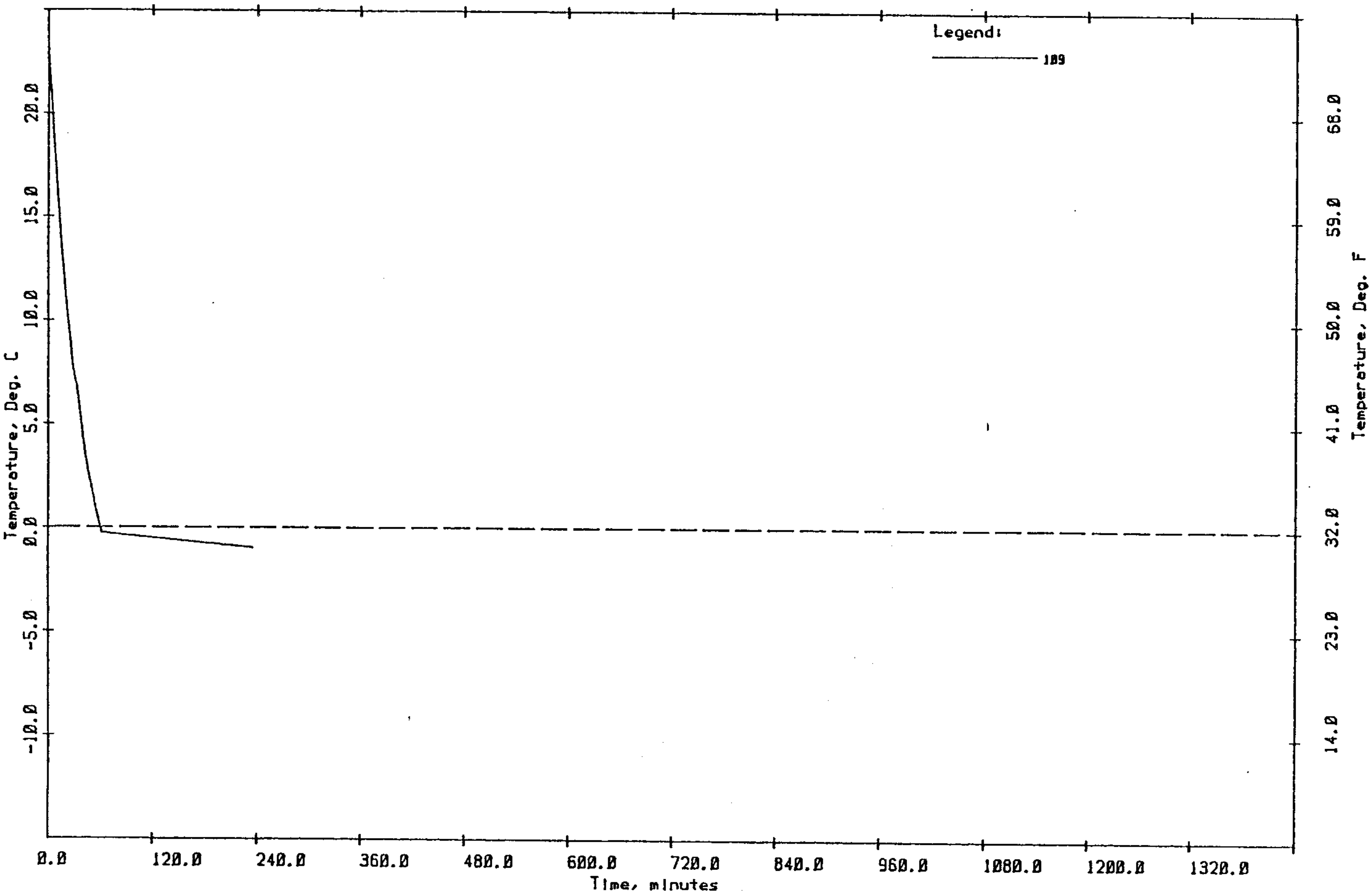
FIG. 19



BATCH #109 600# CEMENT, 242# H2O, 5 FL OZ 322N/SK,
0.8 FL OZ MICRO-AIR/SK, 2% BY WEIGHT OF CEMENT -- DRIERITE

K-0698

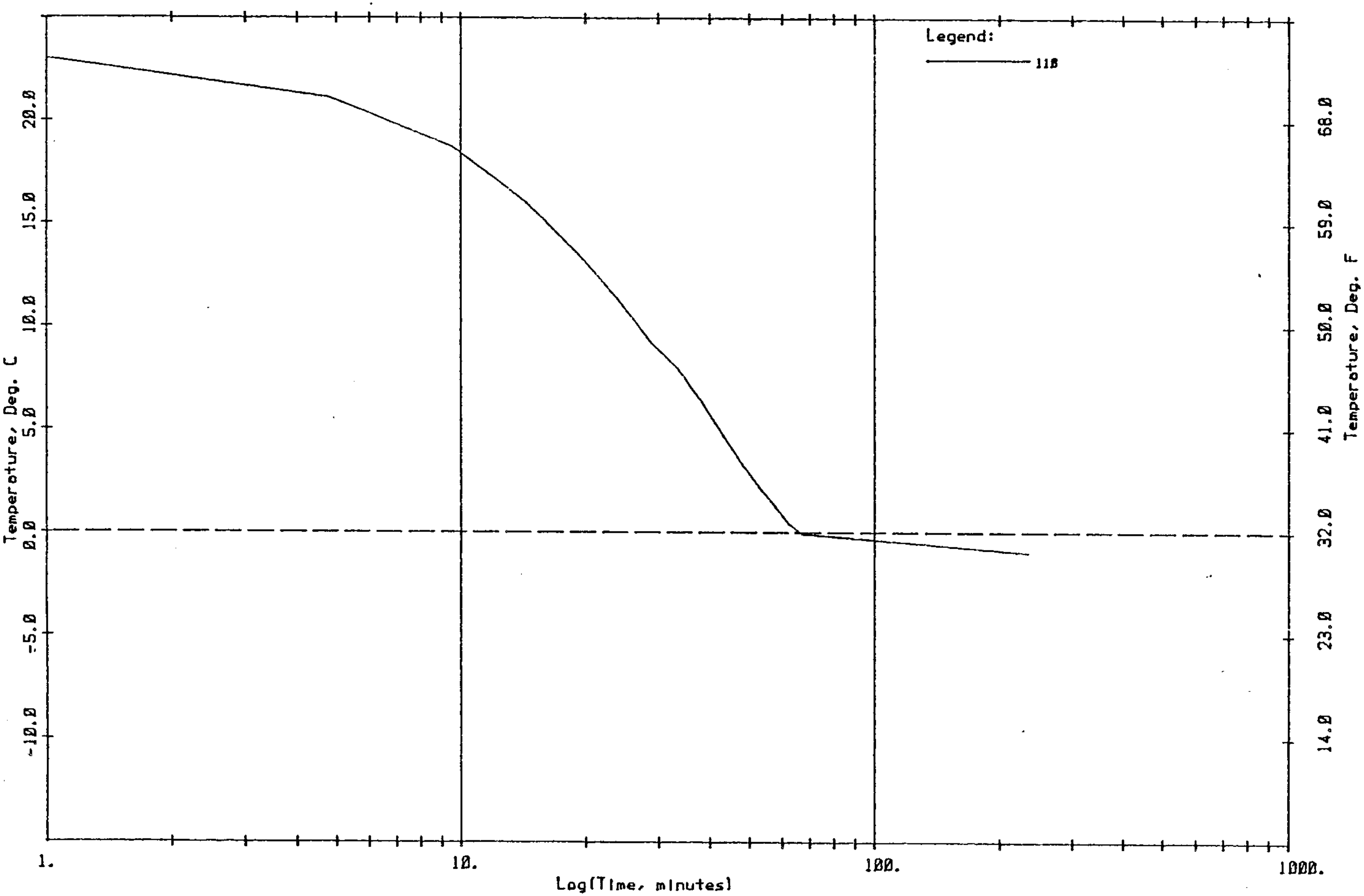
FIG. 20



BATCH #109 600# CEMENT, 242# H2O, 5 FL OZ 322N/SK,
0.8 FL OZ MICRO-AIR/SK, 2% BY WEIGHT OF CEMENT - DRIERITE

K-0698

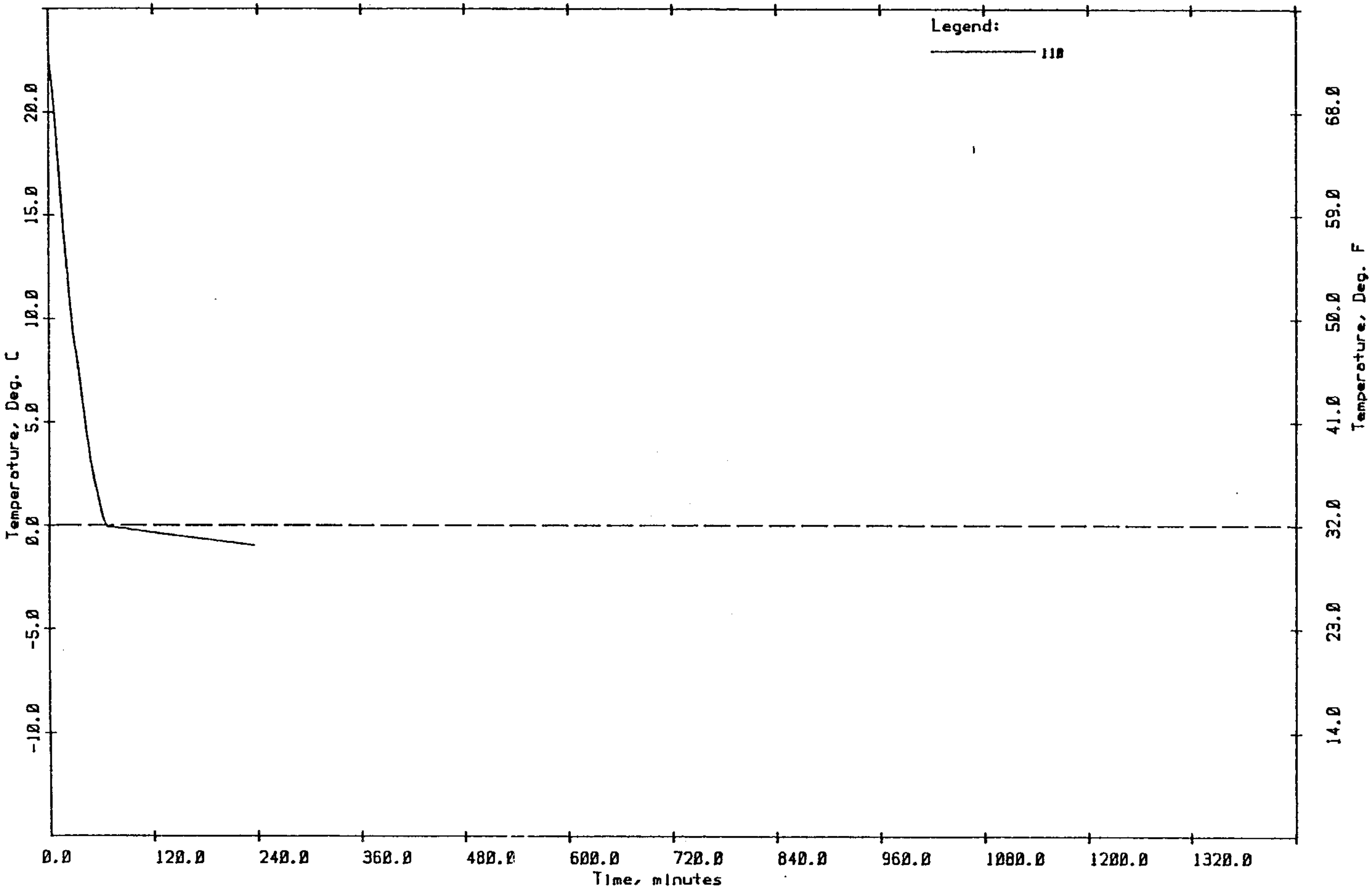
FIG. 21



BATCH #110 600# CEMENT, 242# H2O, 5 FL OZ MICRO-AIR/SK,
2% ACTIVATED ALUMINA BY WEIGHT OF CEMENT
TENDED TO FLASH SET

K-0698

FIG. 22



BATCH #110 600# CEMENT, 242# H2O, 5 FL OZ MICRO-AIR/SK,
2% ACTIVATED ALUMINA BY WEIGHT OF CEMENT
TENDED TO FLASH SET

K-0698

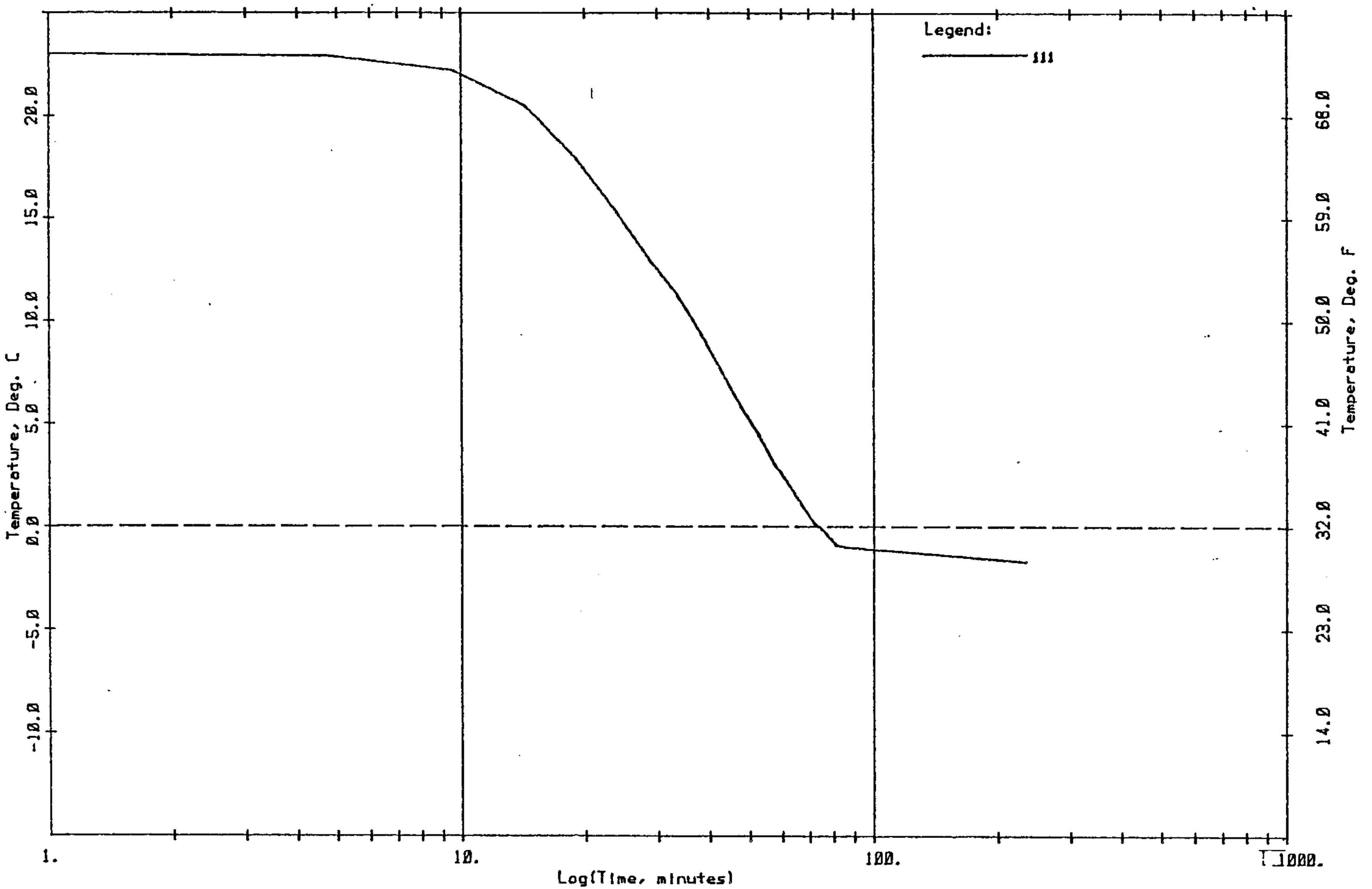
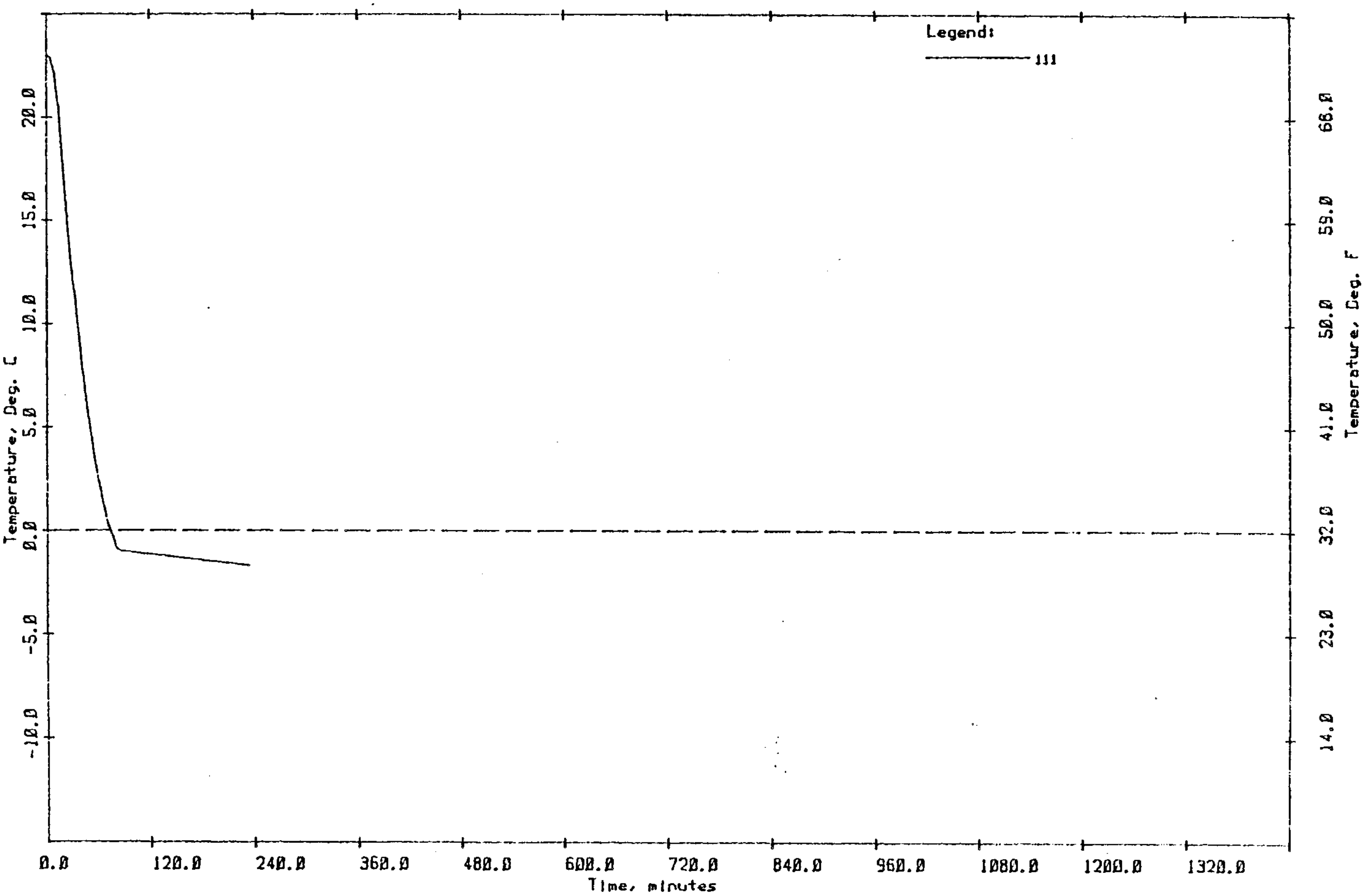


FIG. 23

BATCH #111 242# H20, 5 FL OZ 322N/SK, 0.8 FL OZ MICRO-AIR/SK
2% DISODIUM ETHYLENEDINITRILOTETRAACETATE BY WT OF CEMENT

K-0698

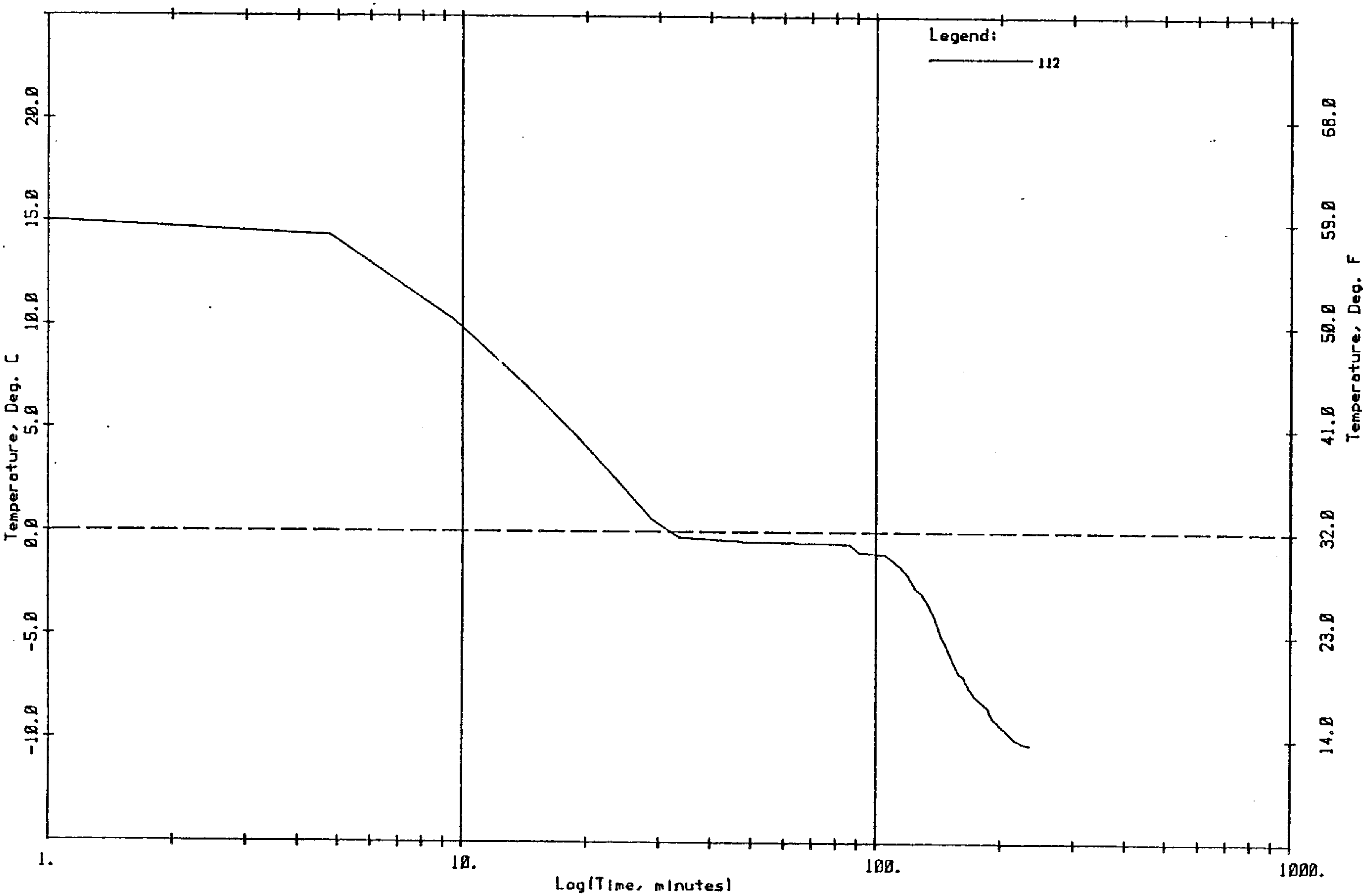
FIG. 24



BATCH #111 242# H2O, 5 FL OZ 322N/SK, 0.8 FL OZ MICRO-AIR/SK
2% DISODIUM ETHYLENEDINITRILOTETRAACETATE BY WT OF CEMENT

K-0698

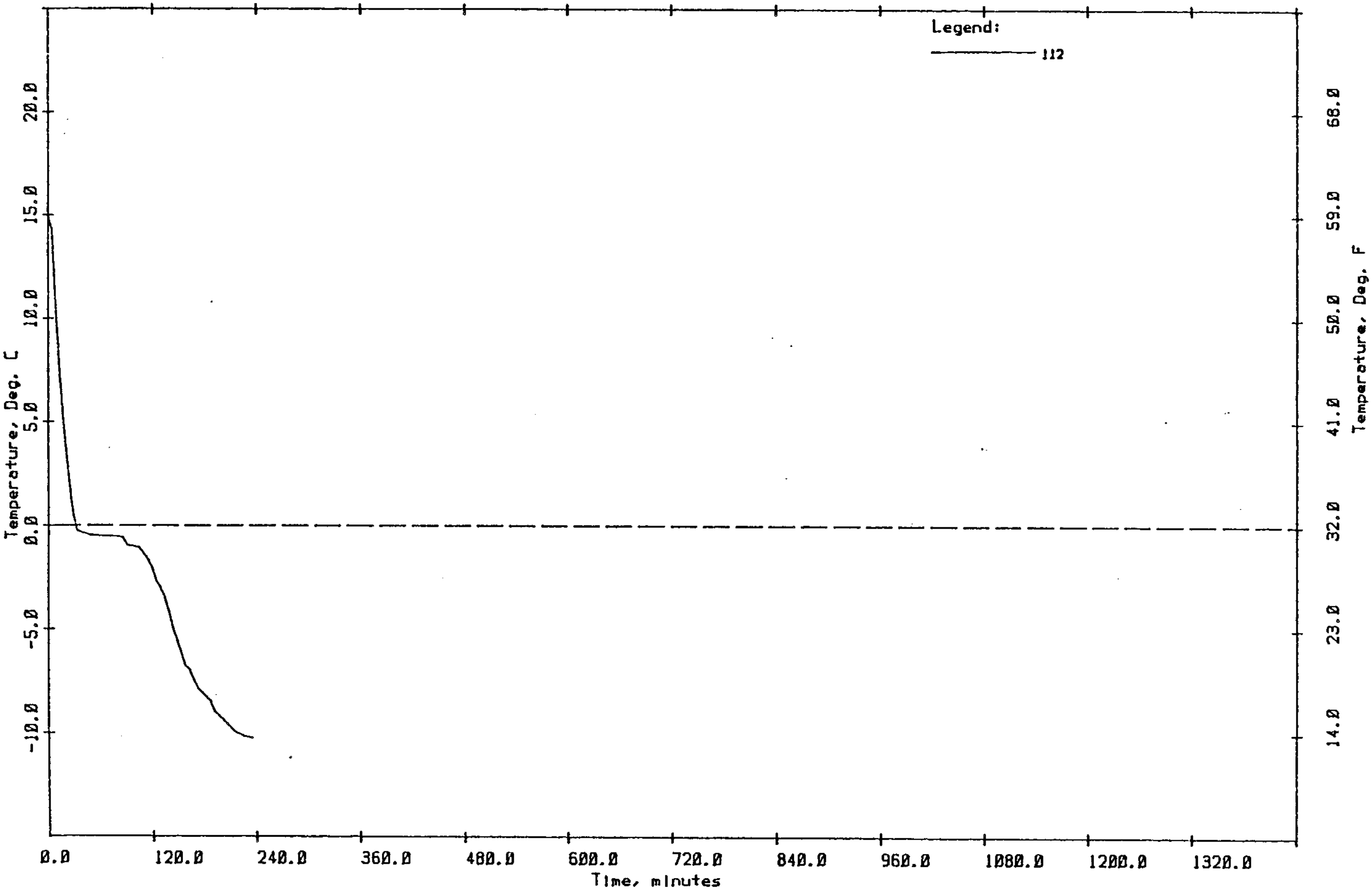
FIG. 25



BATCH #112 600# CEMENT, 242# H2O, 5 FL OZ 322N/SK,
10 FL OZ 400N/SK, 1.6 FL OZ MICRO-AIR/SK, 2,703# SAND/CU YD.
BATCH MIXED, FLASH SET, THEN ADD'L 10 FL OZ 400N/SK ADDED.

K-0698

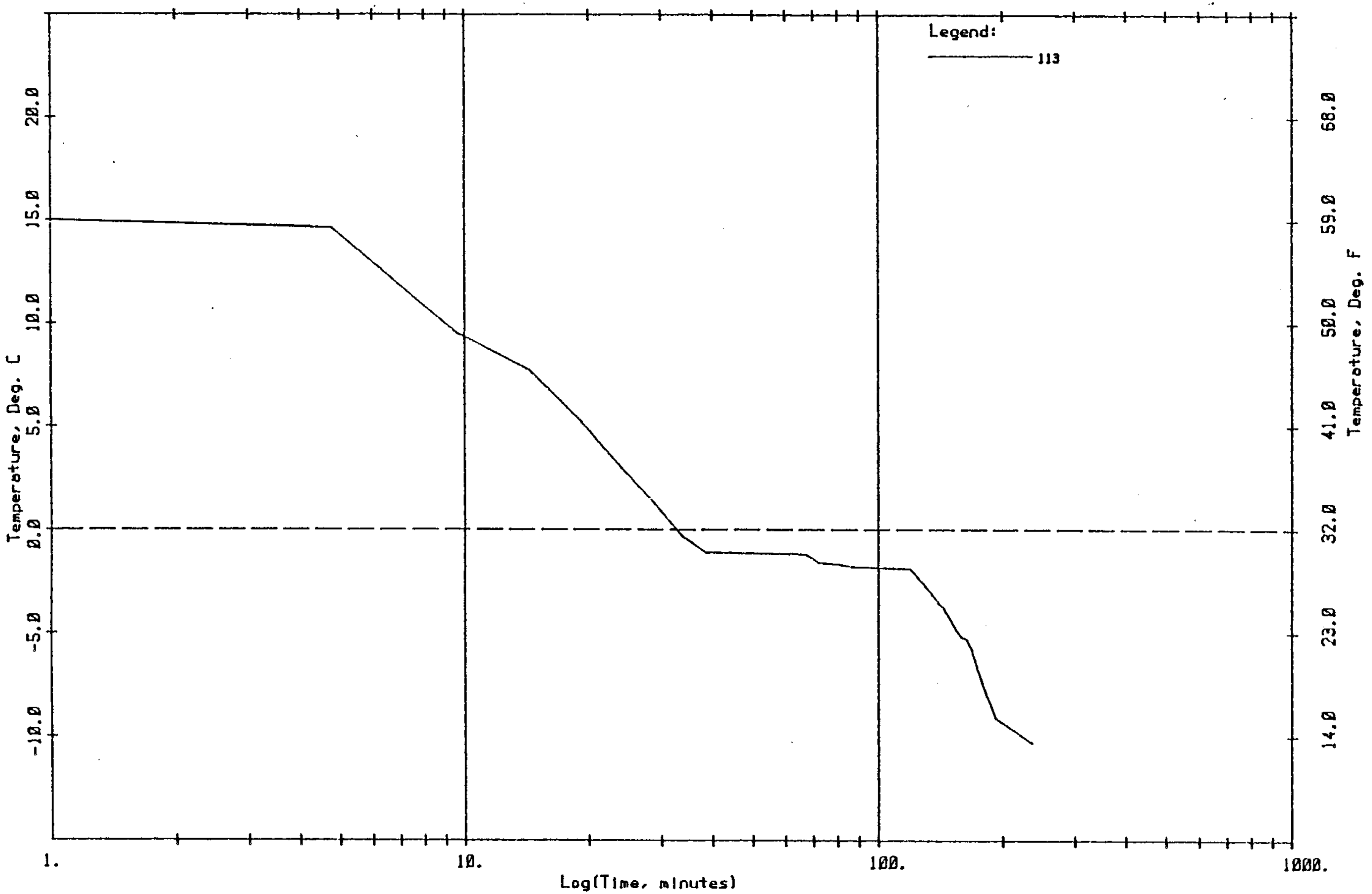
FIG. 26



BATCH #112 600# CEMENT, 242# H2O, 5 FL OZ 322N/SK,
10 FL OZ 400N/SK, 1.6 FL OZ MICRO-AIR/SK, 2,703# SAND/CU YD.
BATCH MIXED, FLASH SET, THEN ADD'L 10 FL OZ 400N/SK ADDED.

K-0698

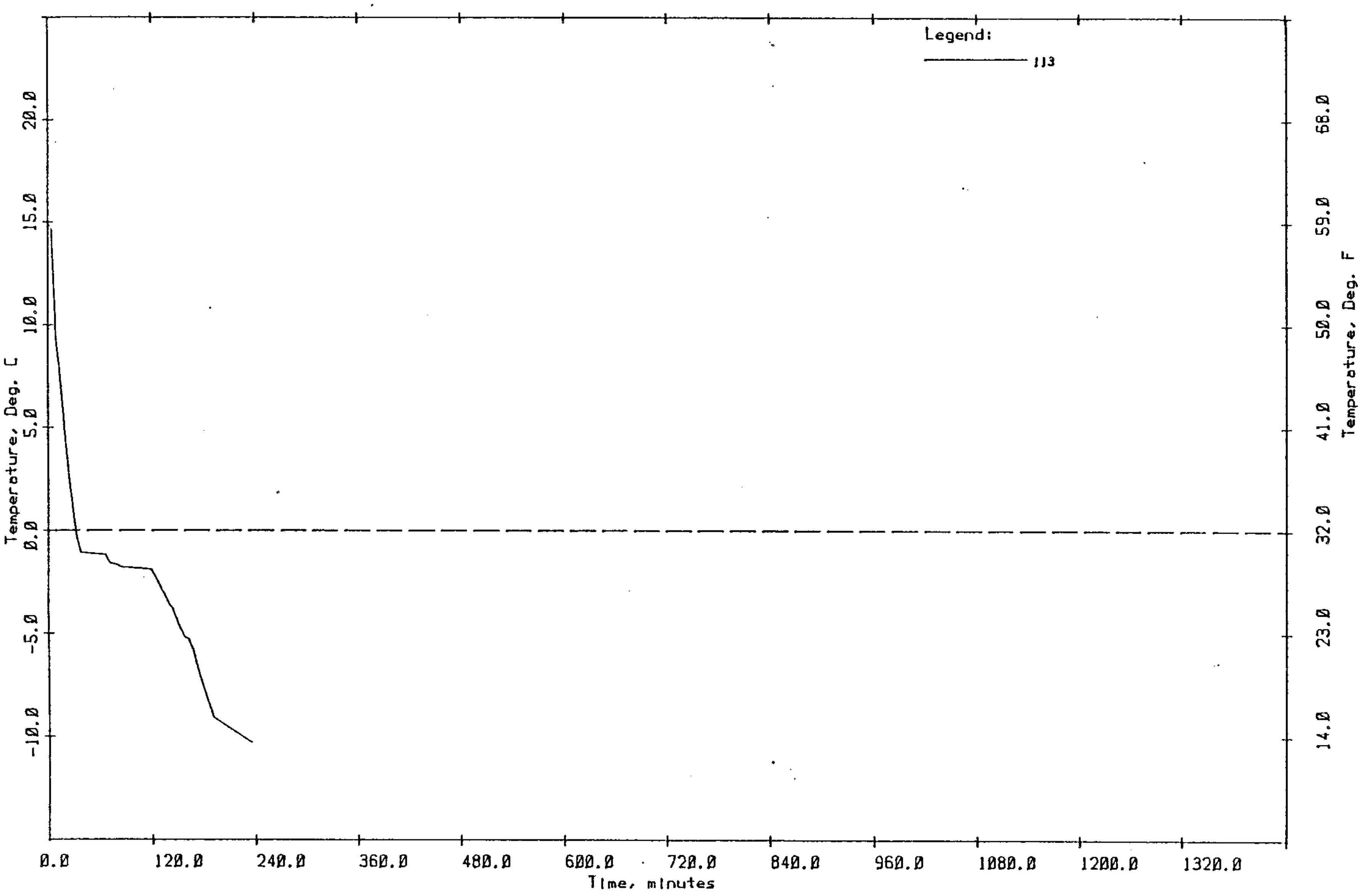
FIG. 27



BATCH #113, SAME AS BATCH 108 WITH ADDN OF 1681 LBS OF SAND
600# CEM, 200# H2O, 5 OZ 322N/SK, 15 OZ 400N/SK 20 OZ 555N/SK
1 FL OZ MICRO-AIR/SK

K-0698

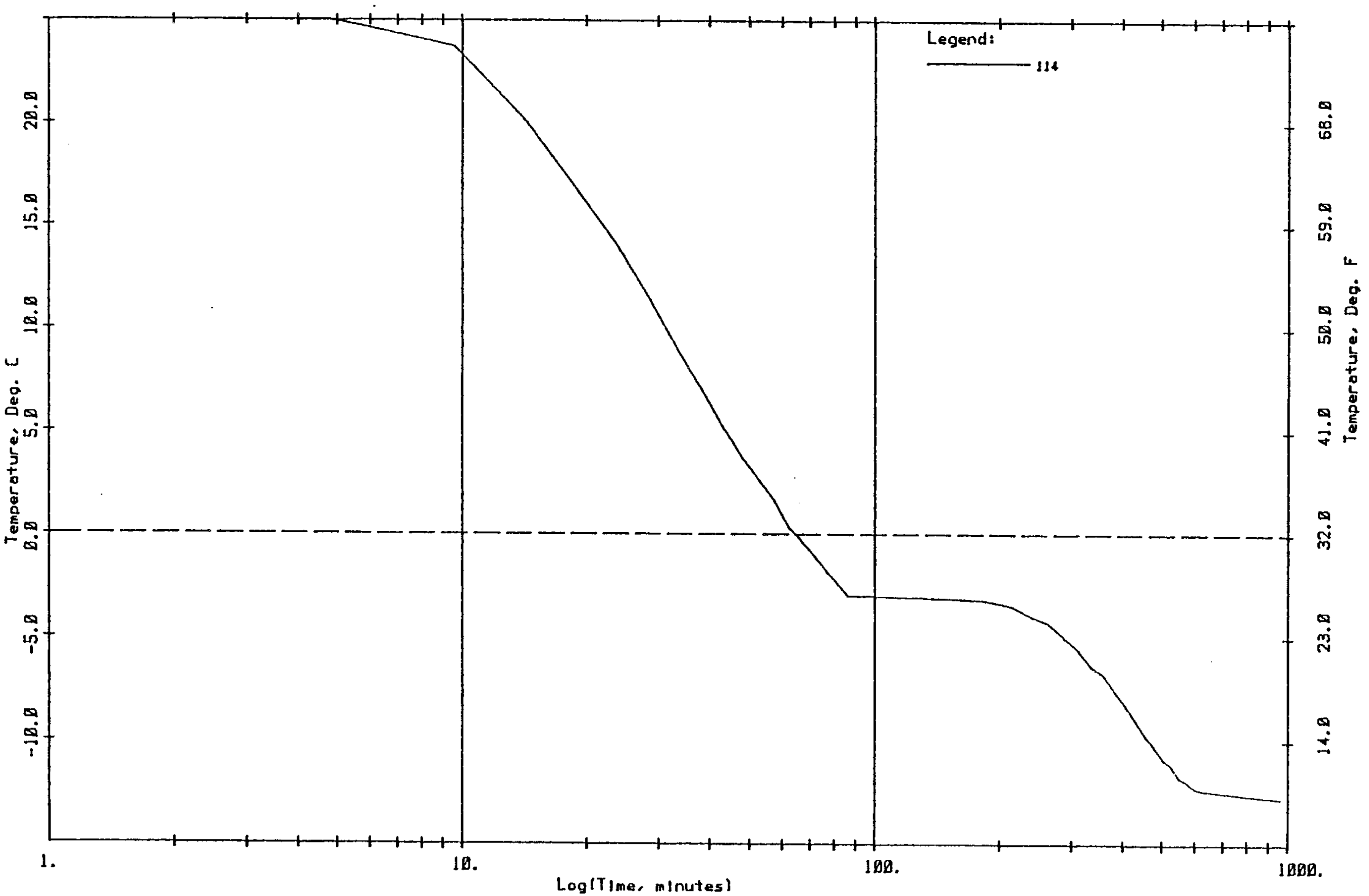
FIG. 28



BATCH #113, SAME AS BATCH 108 WITH ADDN OF 1681 LBS OF SAND
600# CEM, 200# H2O, 5 OZ 322N/SK, 15 OZ 400N/SK 20 OZ 555N/SK
1 FL OZ MICRO-AIR/SK

K-0698

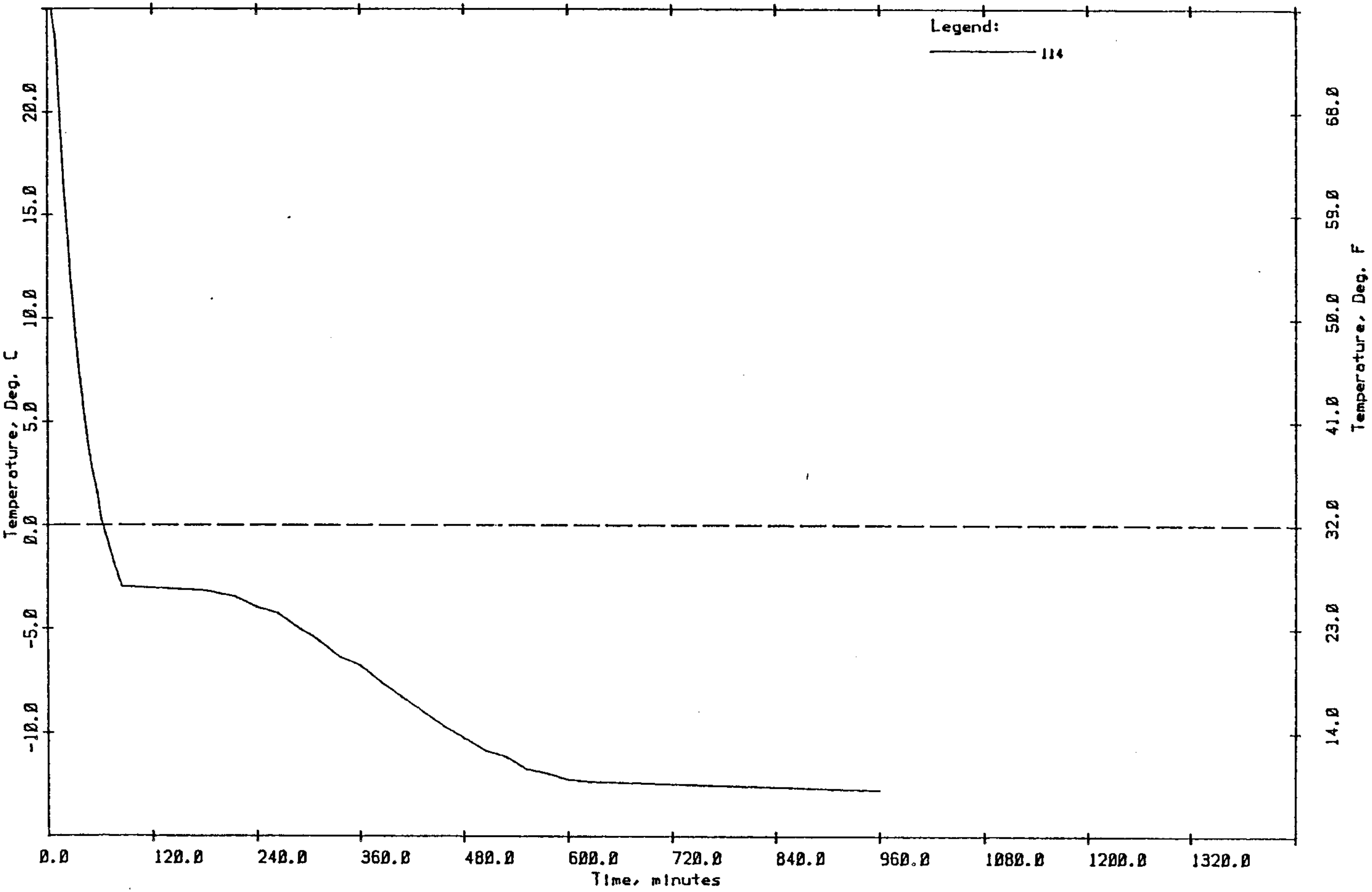
FIG. 29



BATCH #114 600# CEMENT, 242# H2O, 12# DRY CALCIUM CHLORIDE,
0.8 FL OZ MICRO-AIR, CACL2 FINELY GROUND OVEN DRY,
HOT - FLASH SET BROKEN BY STIRRING,

K-0698

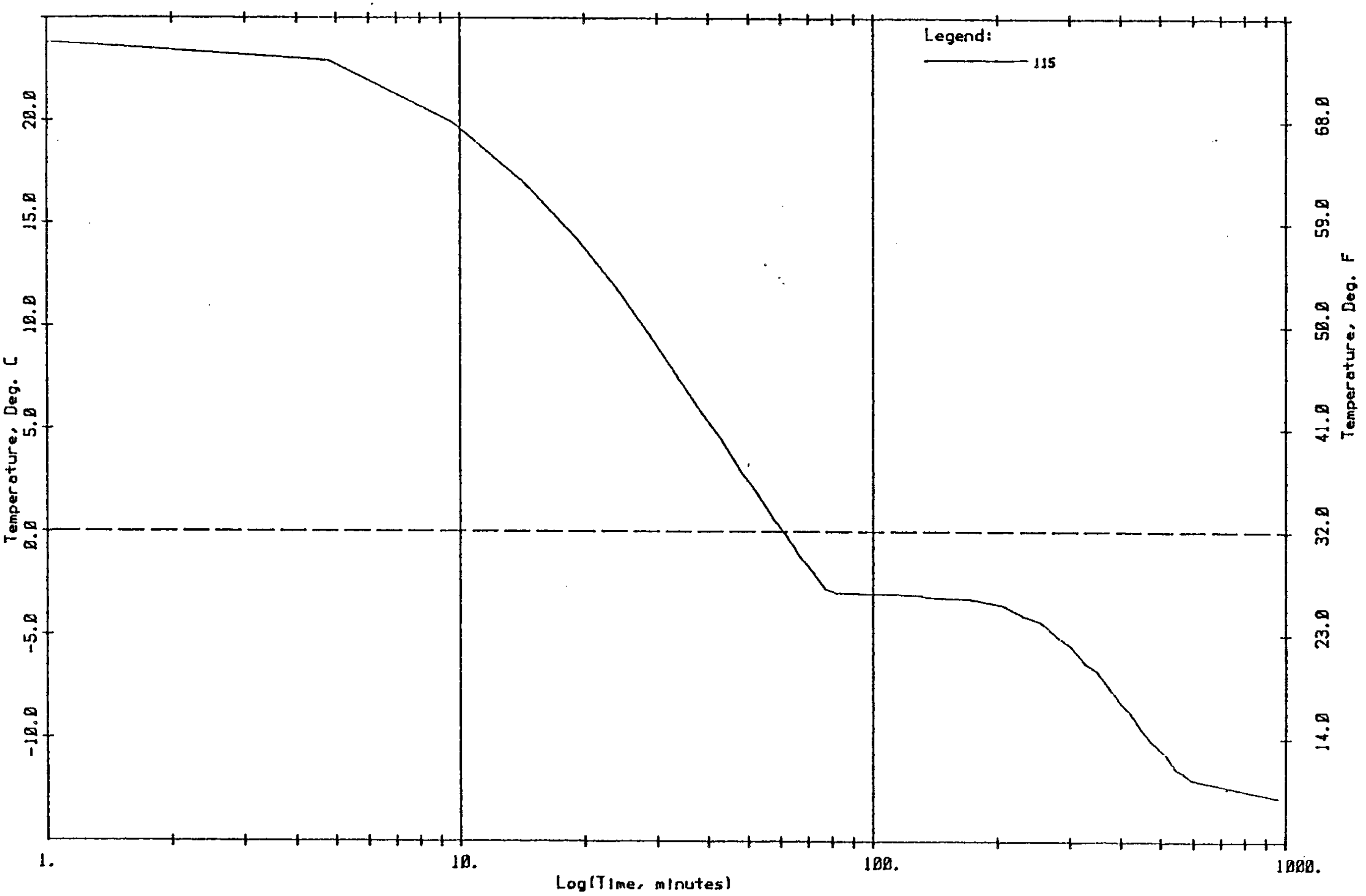
FIG. 30



BATCH #114 600# CEMENT, 242# H2O, 12# DRY CALCIUM CHLORIDE,
0.8 FL OZ MICRO-AIR, CACL2 FINELY GROUND OVEN DRY,
HOT - FLASH SET BROKEN BY STIRRING,

K-0698

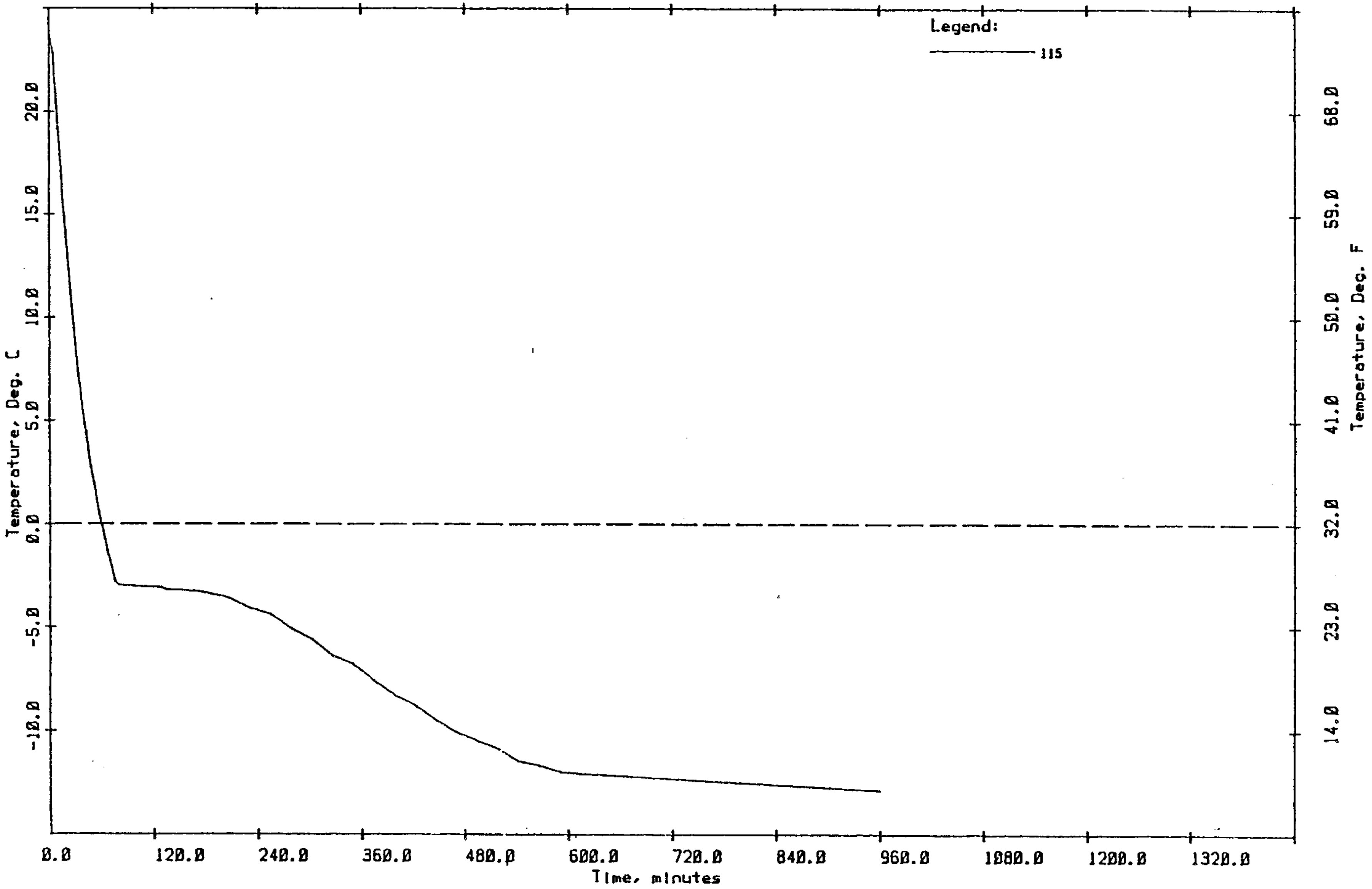
FIG. 31



BATCH #115 600# CEMENT, 242# H2O, 12# DRY CALCIUM CHLORIDE,
5 FL OZ 322N/SK, 0.8 FL OZ MICRO-AIR/SK, CACL2 MIXED INTO
MIXING WATER AFTER 322N.

K-0698

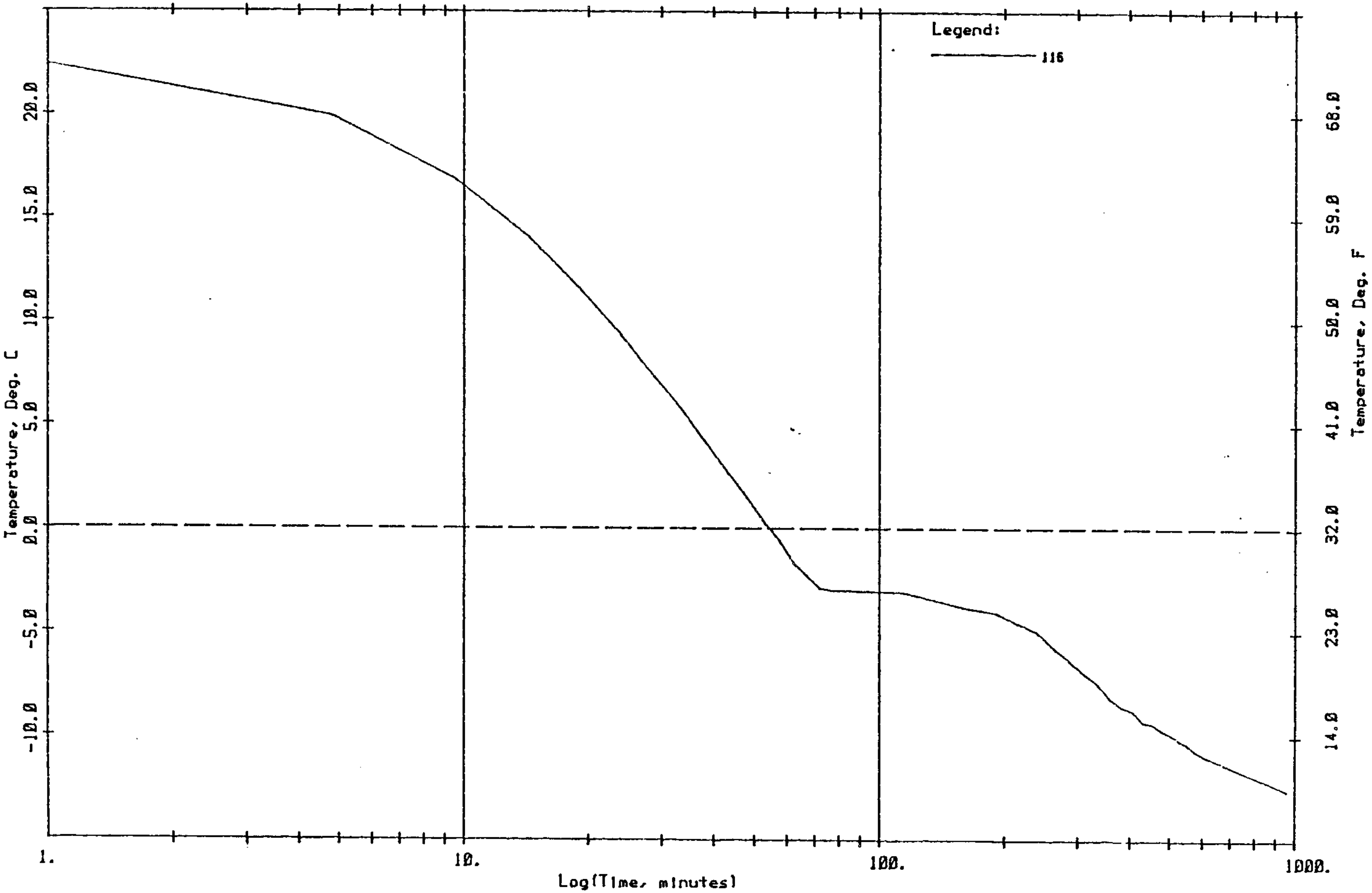
FIG. 32



BATCH *115 600* CEMENT, 242* H2O, 12* DRY CALCIUM CHLORIDE,
5 FL OZ 322N/SK, 0.8 FL OZ MICRO-AIR/SK, CACL2 MIXED INTO
MIXING WATER AFTER 322N.

K-0698

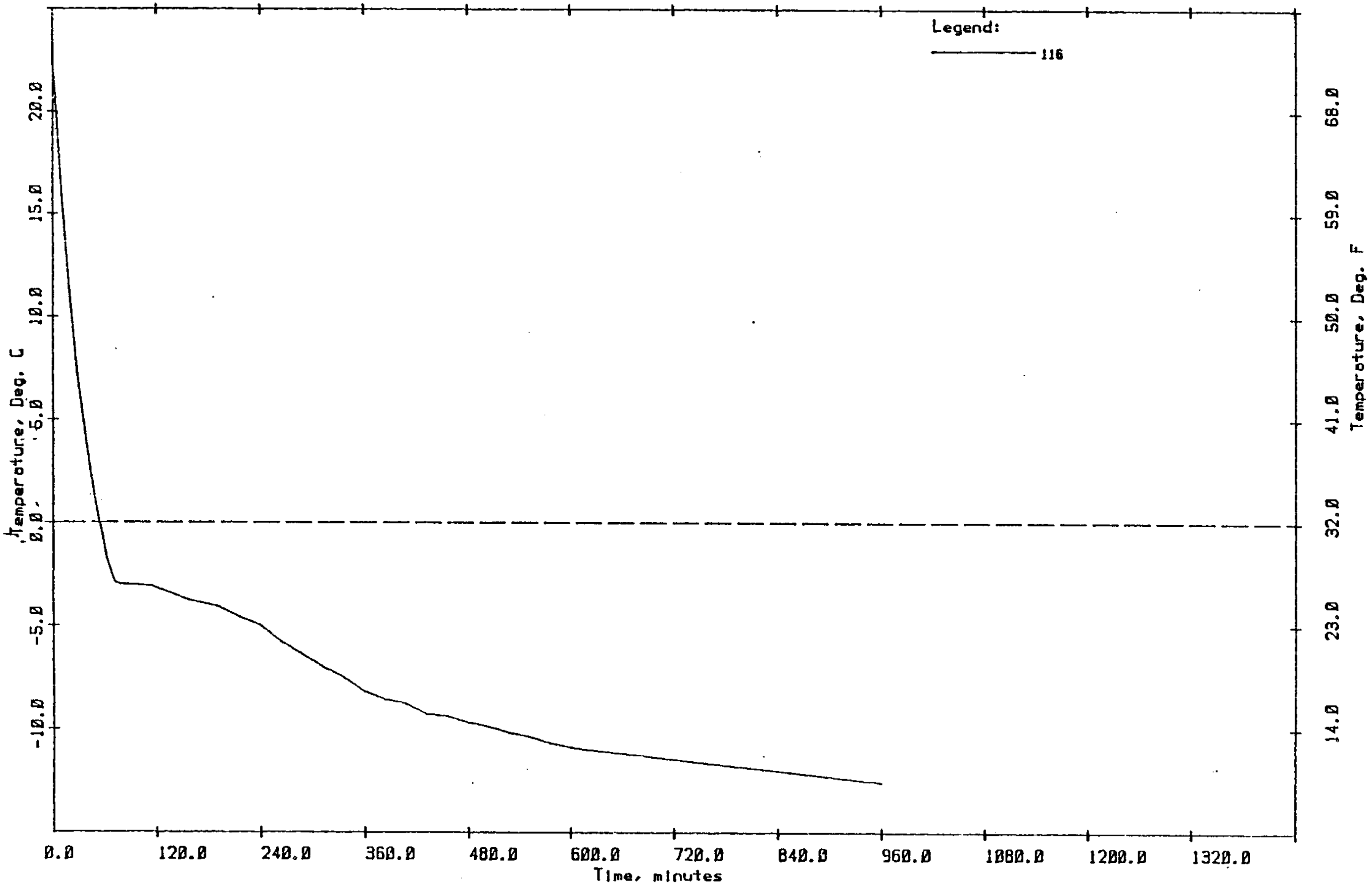
FIG. 33



BATCH #116; 600# CEMENT, 242# H2O, 12# DRY CALCIUM CHLORIDE,
5 FL OZ 322N/SK, 10 FL OZ 400N/SK, 1.0 FL OZ MICRO-AIR/SK,

K-0698

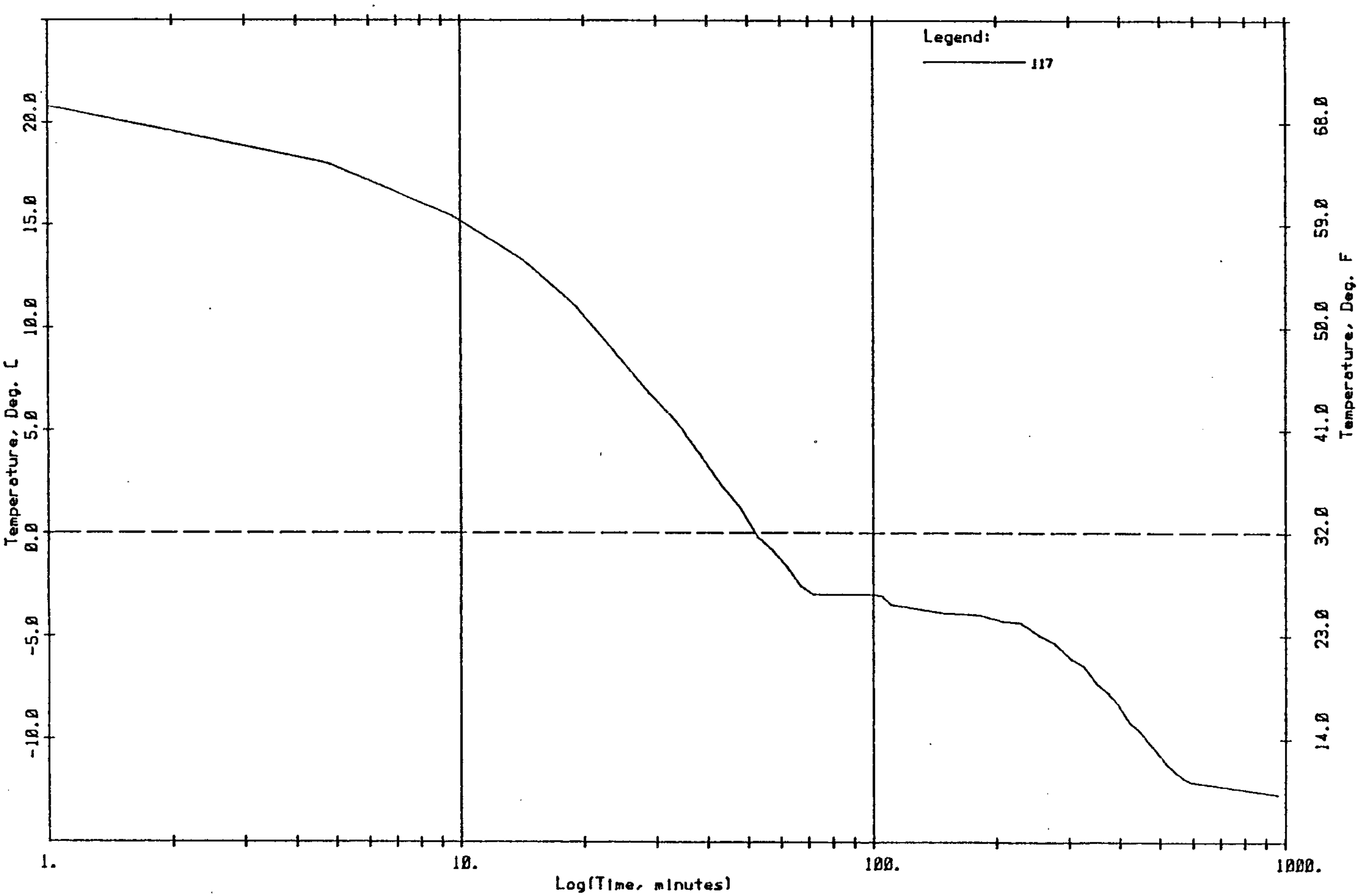
FIG. 34



BATCH #116, 600# CEMENT, 242# H2O, 12# DRY CALCIUM CHLORIDE,
5 FL OZ 322N/SK, 10 FL OZ 400N/SK, 1.0 FL OZ MICRO-AIR/SK,

K-0698

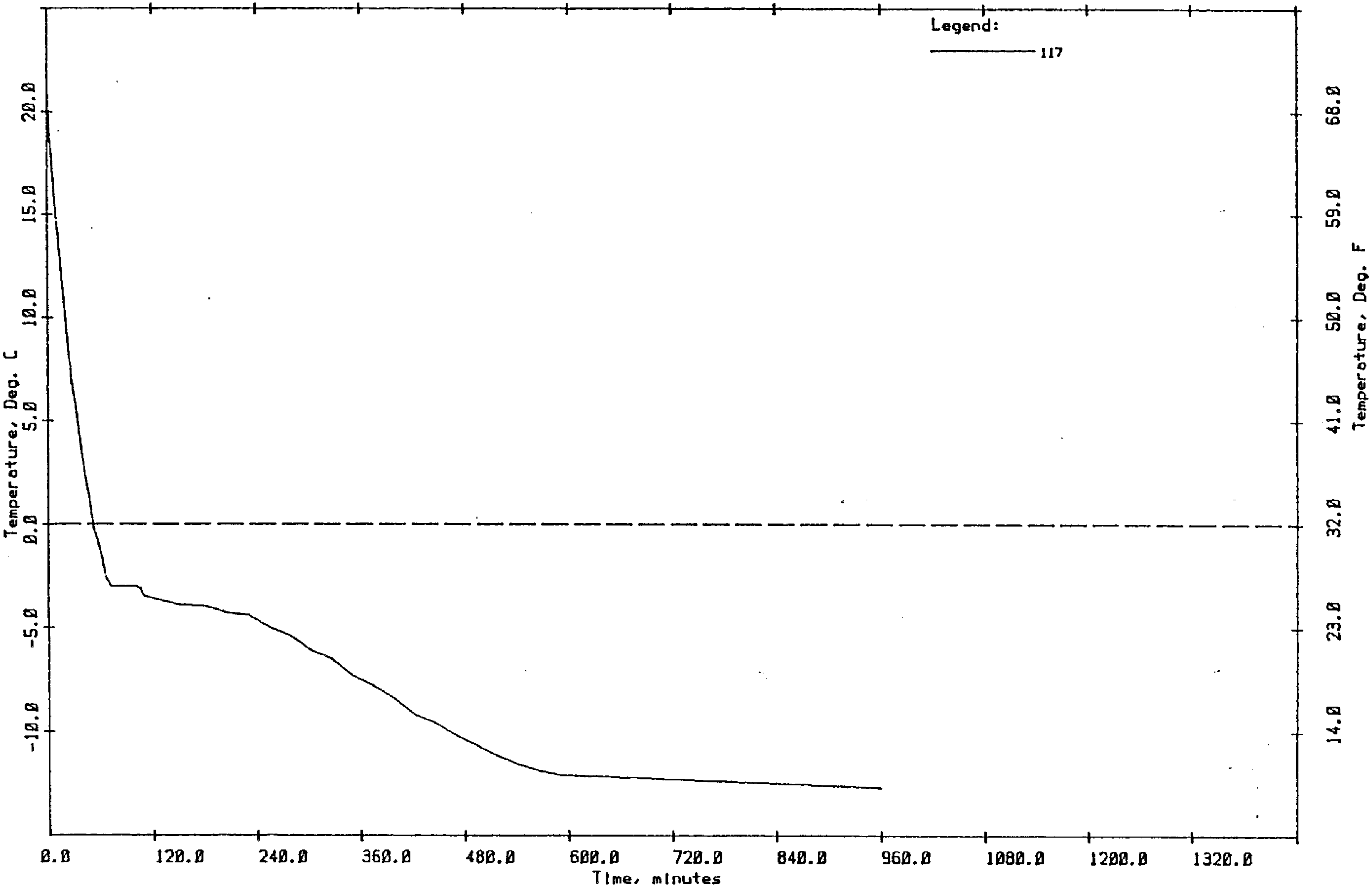
FIG. 35



BATCH #117 600# CEMENT, 242# H20, 12# DRY CALCIUM CHLORIDE,
15 FL OZ 400N/SK, 1 FL OZ MICRO-AIR/SK,

K-0698

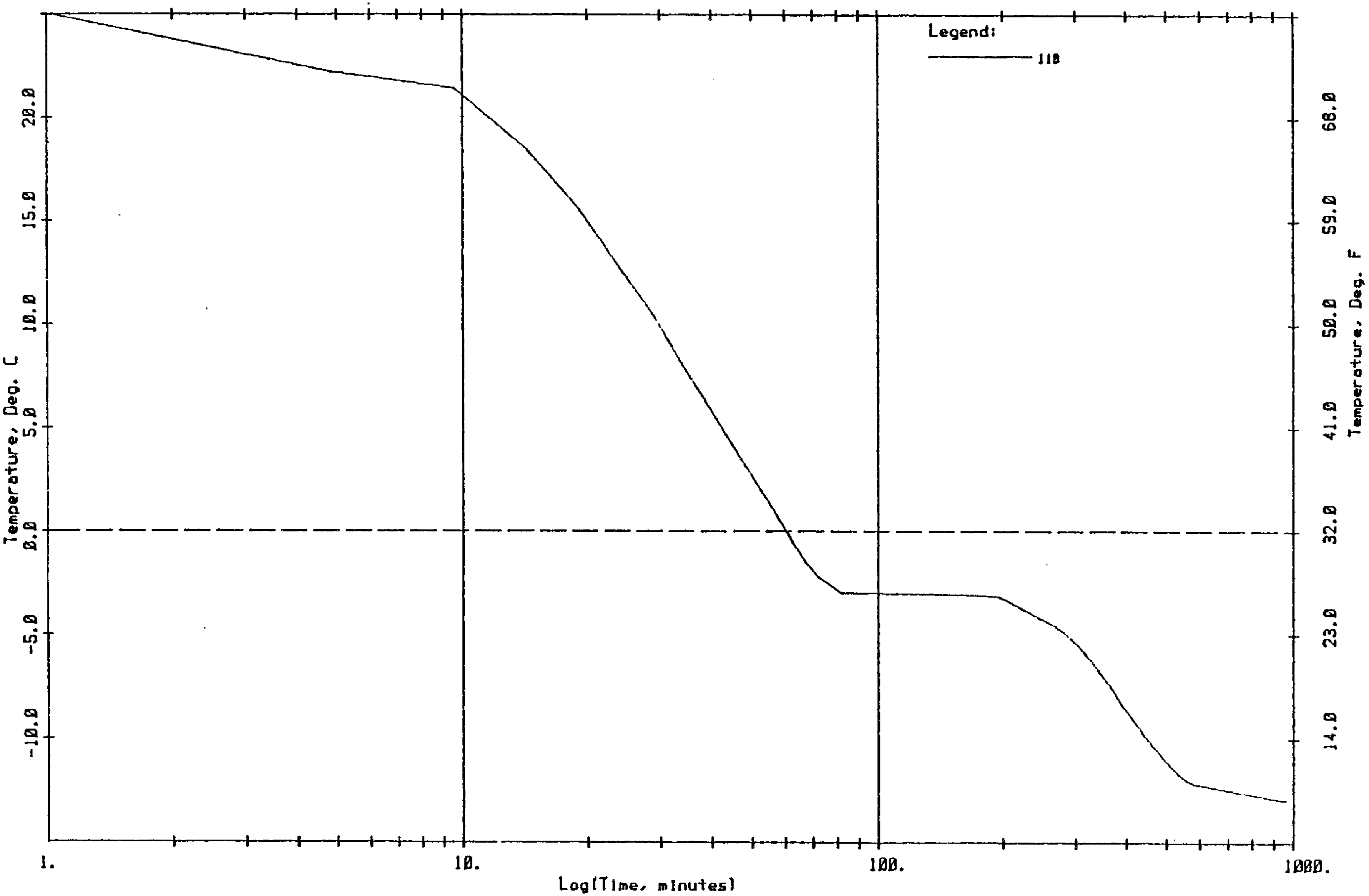
FIG. 36



BATCH #117 600# CEMENT, 242# H20, 12# DRY CALCIUM CHLORIDE,
15 FL OZ 400N/SK, 1 FL OZ MICRO-AIR/SK,

K-0698

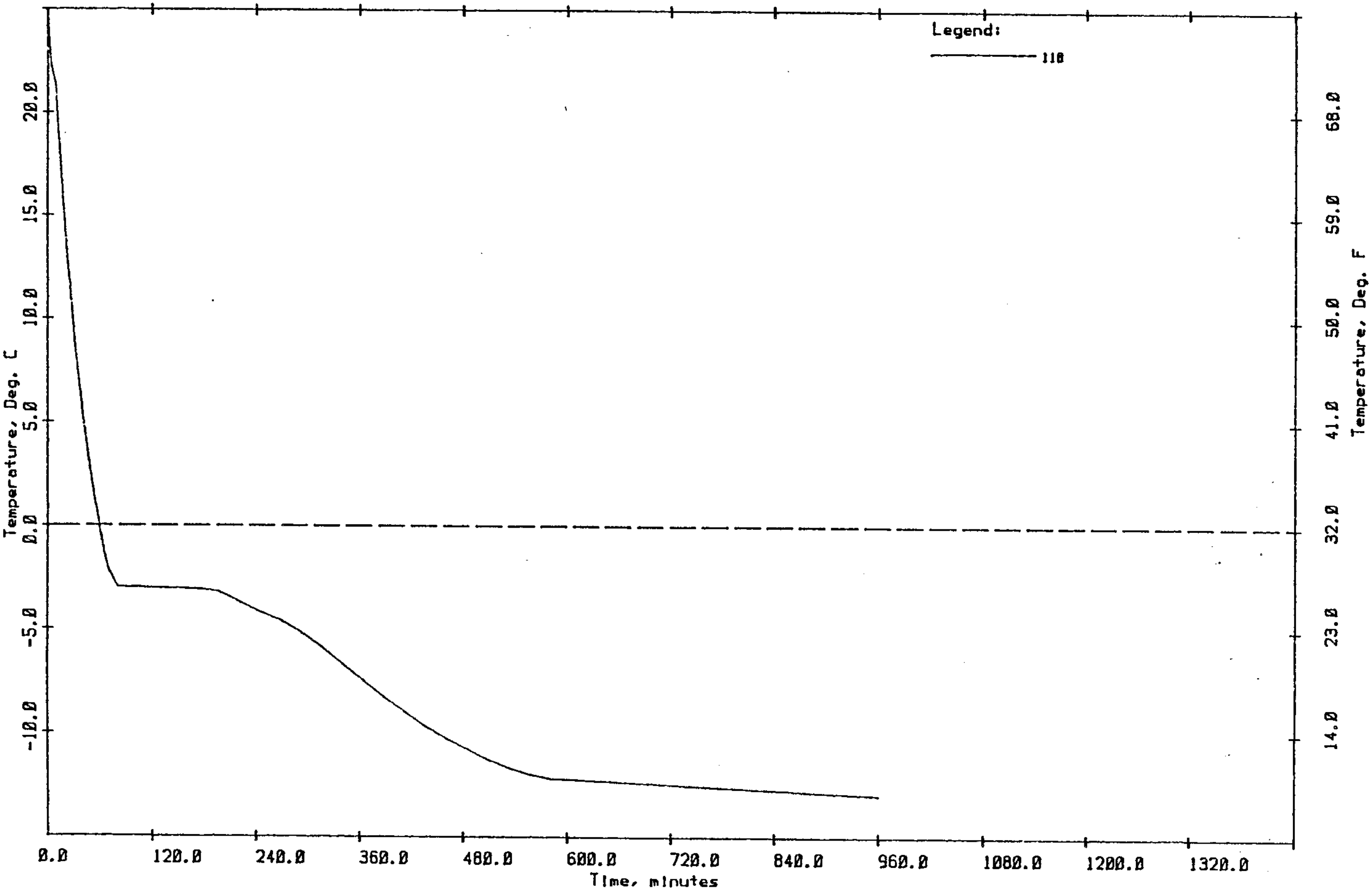
FIG. 37



BATCH #118 600# CEMENT, 242# H2O,, 12# DRY CALCIUM CHLORIDE,
20 FL OZ 400N/SK, 1.5 FL OZ MICRO-AIR, SOUPY!

K-0698

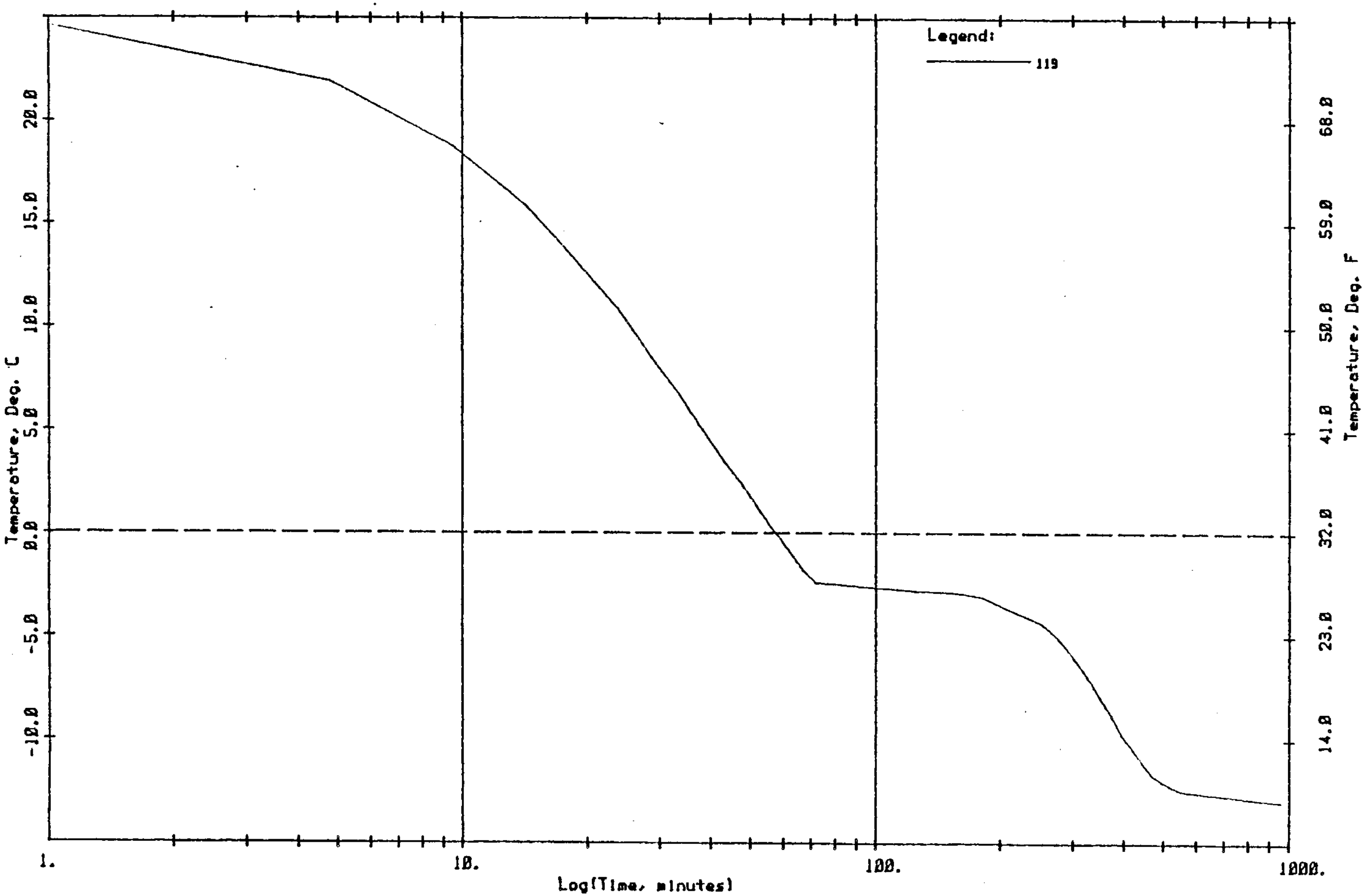
FIG. 38



BATCH #118 600# CEMENT, 242# H2O,, 12# DRY CALCIUM CHLORIDE,
20 FL OZ 400N/SK, 1.5 FL OZ MICRO-AIR, SOUPY!

K-0698

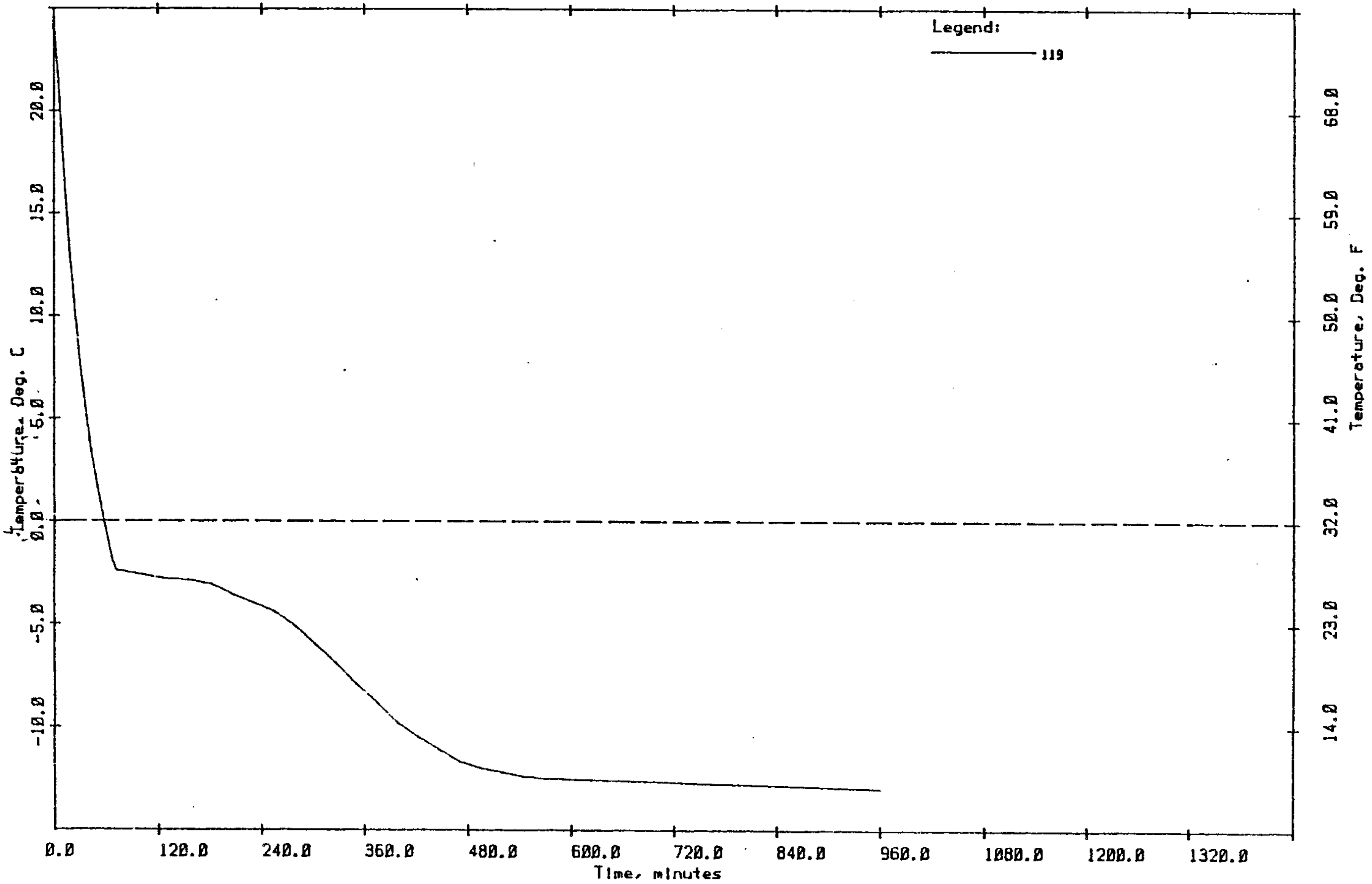
FIG. 39



BATCH #119 600# CEMENT, 242# H2O, 32 FL OZ 122HE/SK,
6# (1%) DISODIUM EDTA, 1 FL OZ MICRO-AIR/SK, WATER,122HE,
DIS EDTA, AIR ON CEMENT.

K-0698

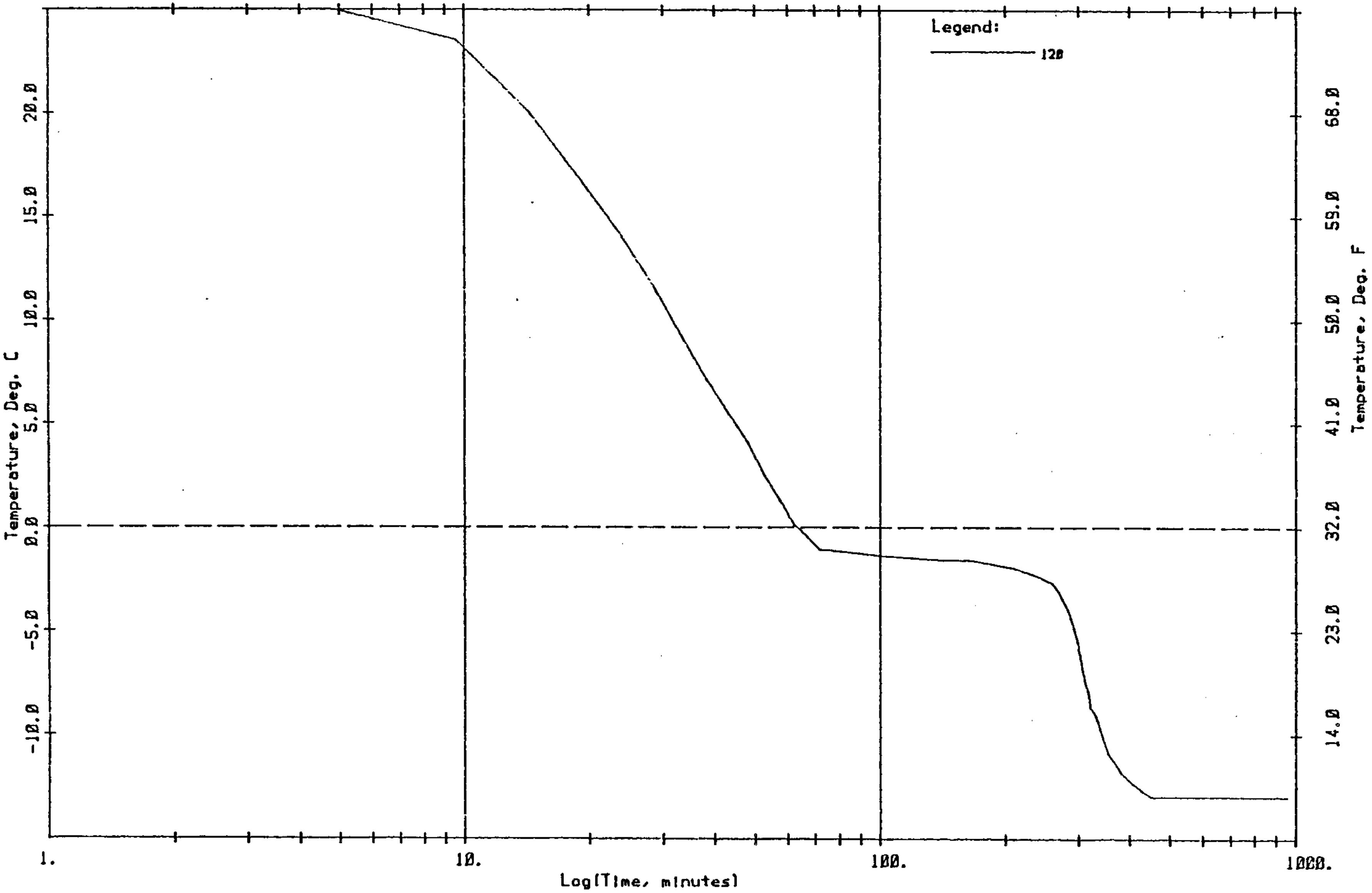
FIG. 40



BATCH #119 600# CEMENT, 242# H2O, 32 FL OZ 122HE/SK,
6# (1%) DISODIUM EDTA, 1 FL OZ MICRO-AIR/SK, WATER,122HE,
DIS EDTA, AIR ON CEMENT.

K-0698

FIG. 41



BATCH #120 600# CEMENT, 242# H2O, 5 FL OZ 322N/SK,
12# (2%) MAGNESIUM SILICA FLUORIDE, 1 FL OZ MICRO-AIR/SK,

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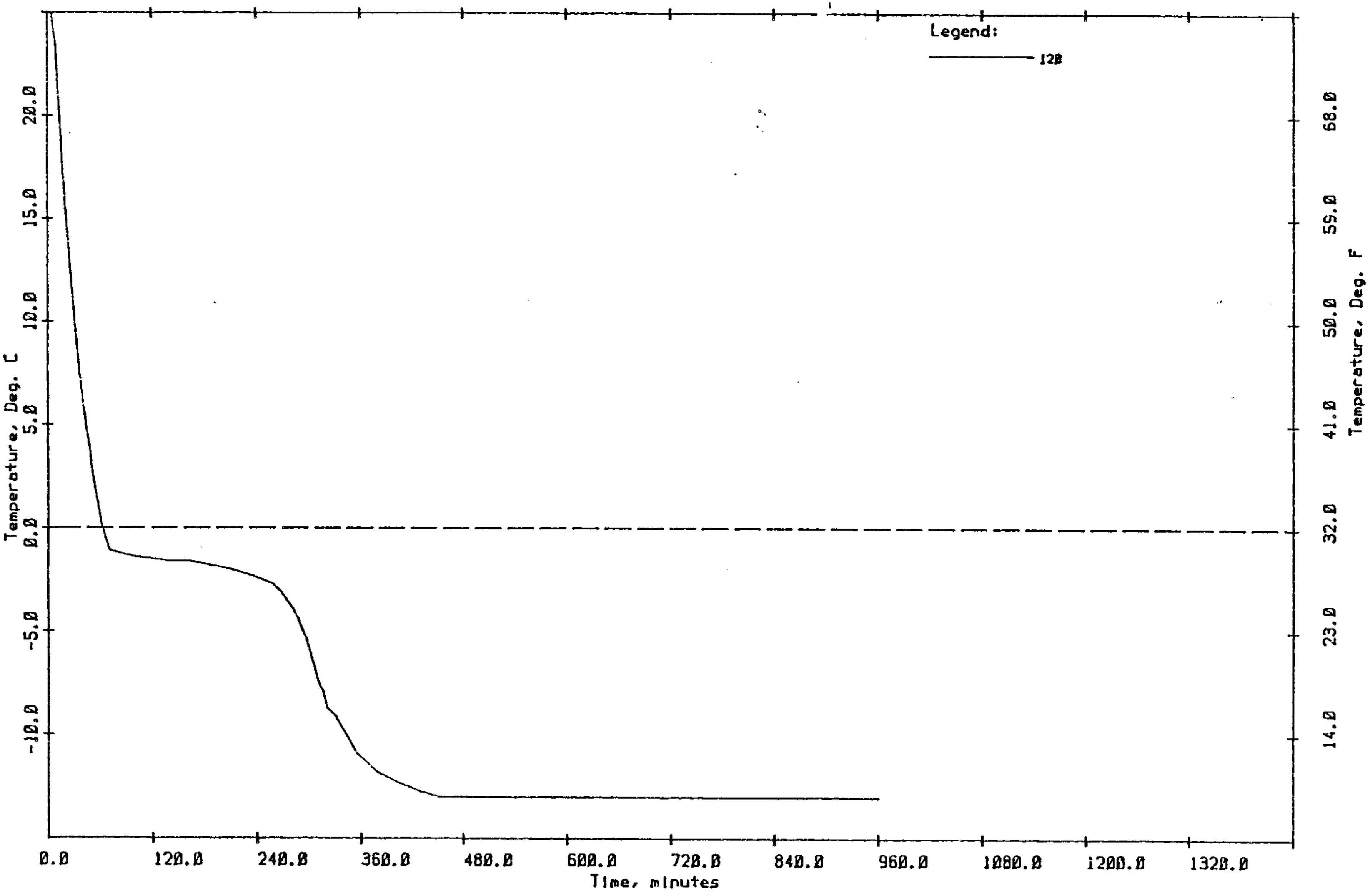

BATCH #120 600# CEMENT, 242# H2O, 5 FL OZ 322N/SK,
12# (2%) MAGNESIUM SILICA FLUORIDE, 1 FL OZ MICRO-AIR/SK,

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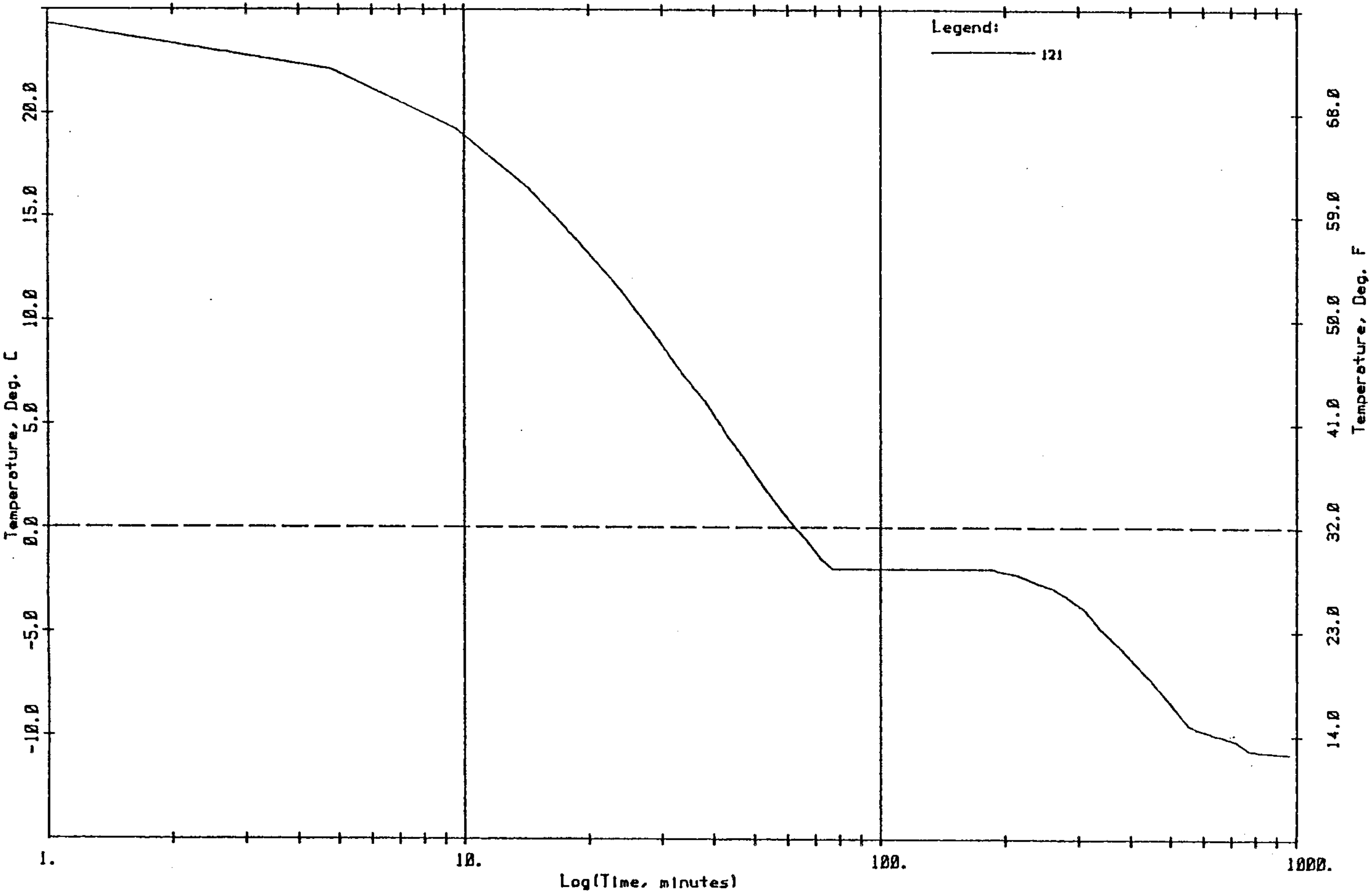
FIG. 42

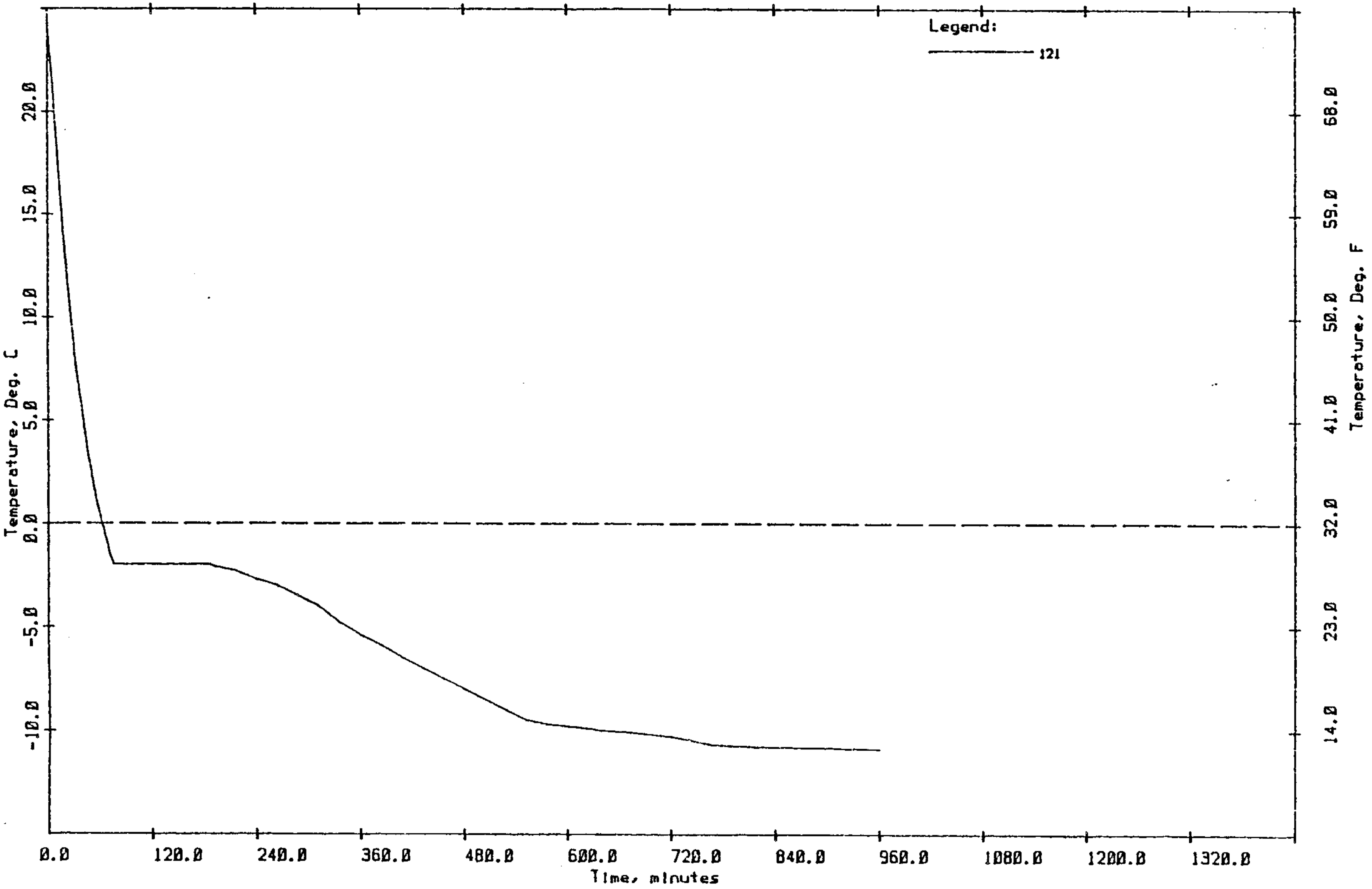
FIG. 43



BATCH #121 600# CEM, 291# H2O, 120# SILICA FUME
64 FL. OZ. 122HE/SK, 15 FL.OZ. 400N/SK, 3 FL. OZ. MICROAIR

K-698

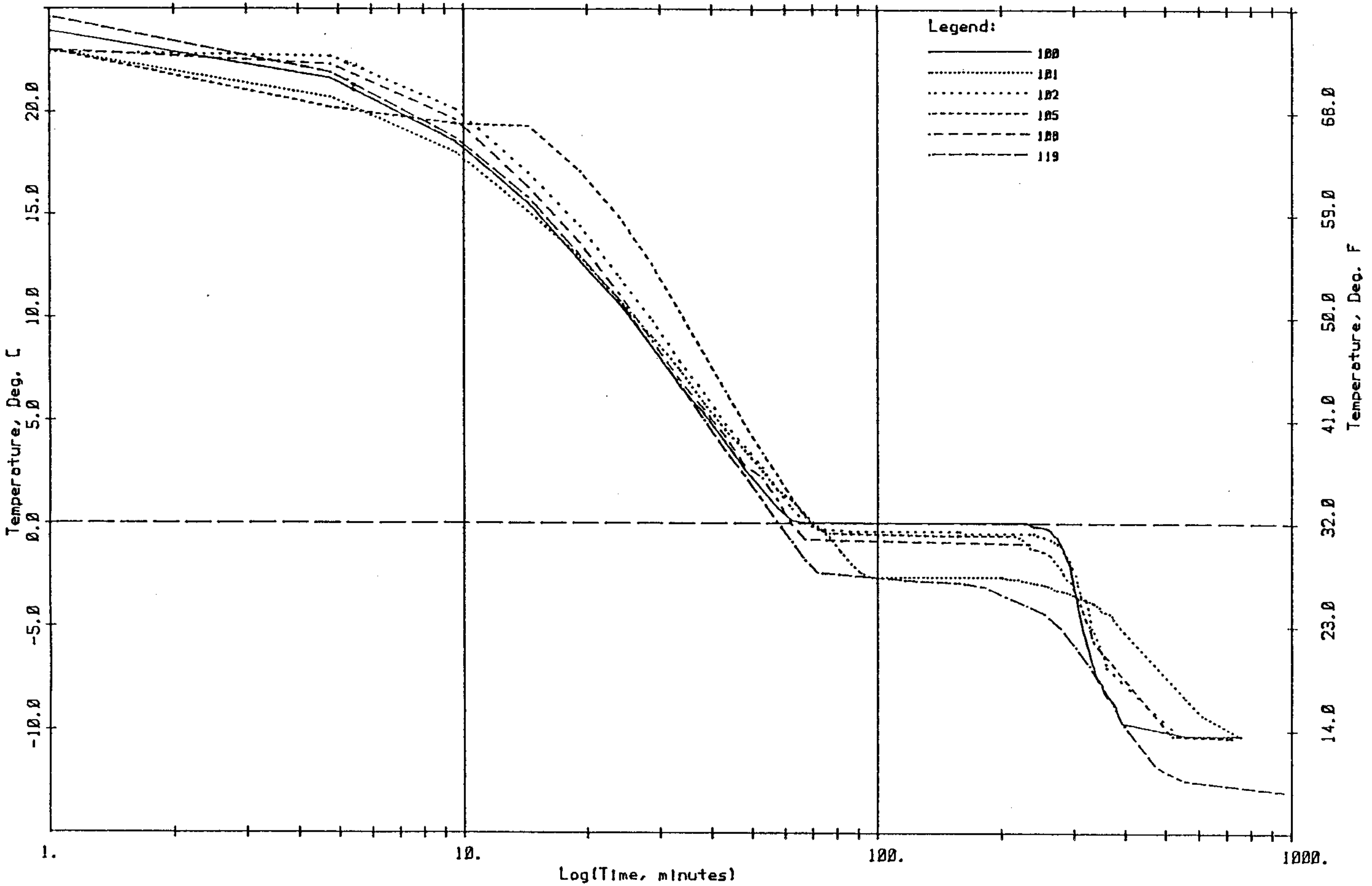
FIG. 44



BATCH #121 600# CEM, 291# H2O, 120# SILICA FUME
64 FL. OZ. 122HE/SK, 15 FL.OZ. 400N/SK, 3 FL. OZ. MICROAIR

K-698

FIG. 45



BATCH #119 600# CEMENT; 242# H20; 32 FL OZ 122HE/SK;
6# (1%) DISODIUM EDTA; 1 FL OZ MICRO-AIR/SK; WATER,122HE,
DIS EDTA, AIR ON CEMENT.

K-0698

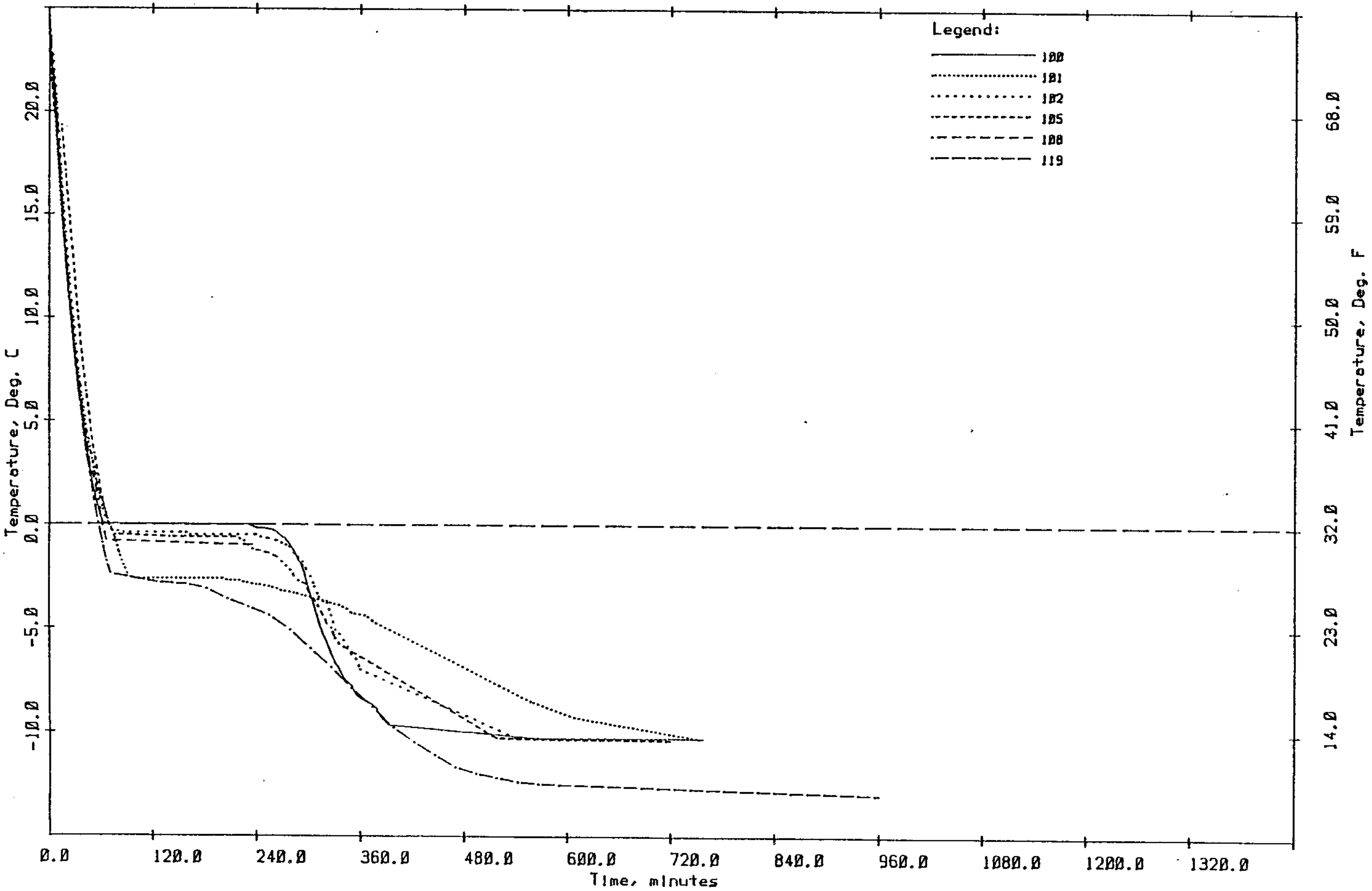
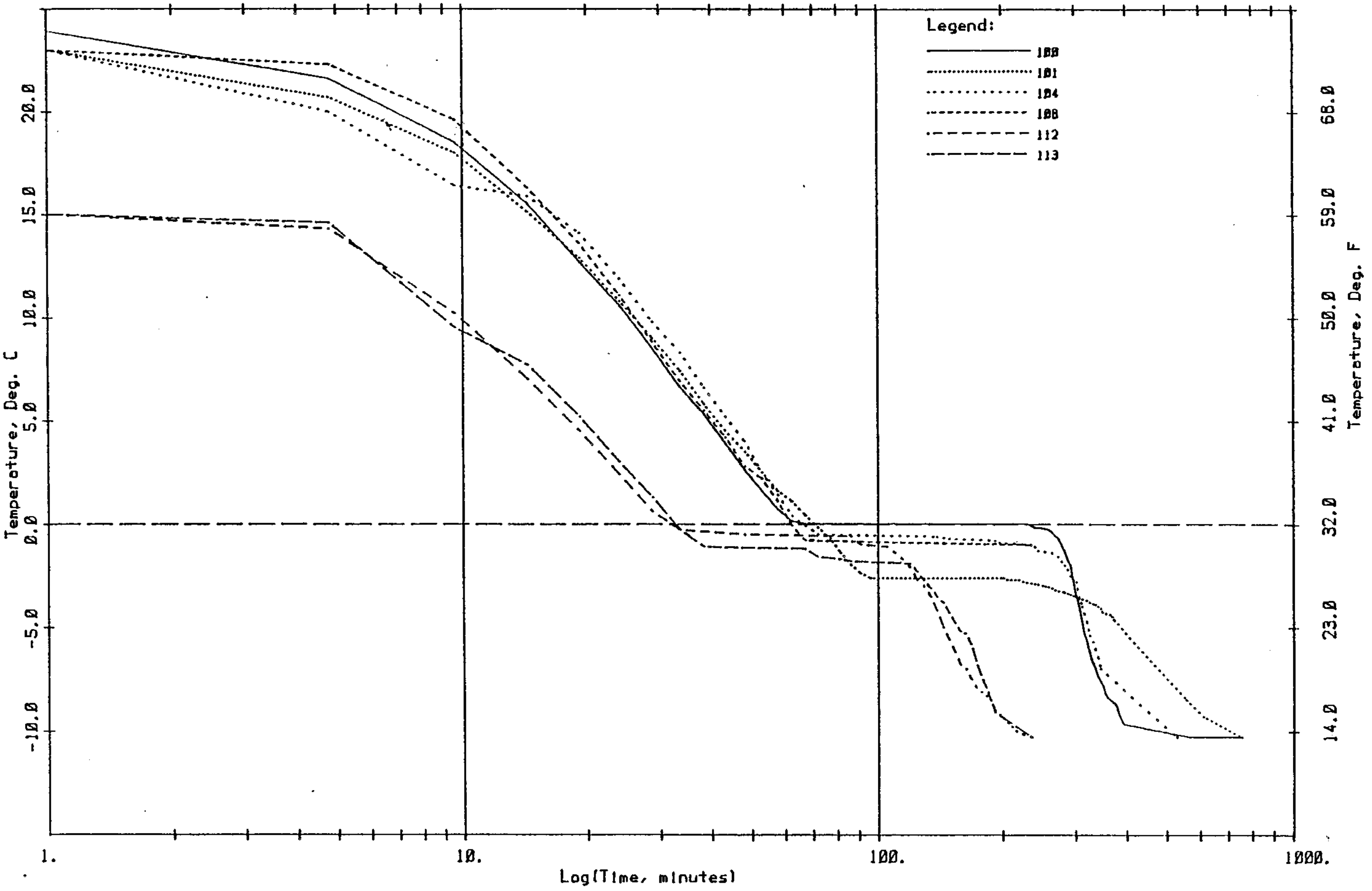


FIG. 46

BATCH #119 600# CEMENT, 242# H2O, 32 FL OZ 122HE/SK,
6# (1%) DISODIUM EDTA, 1 FL OZ MICRO-AIR/SK, WATER,122HE,
DIS EDTA, AIR ON CEMENT.

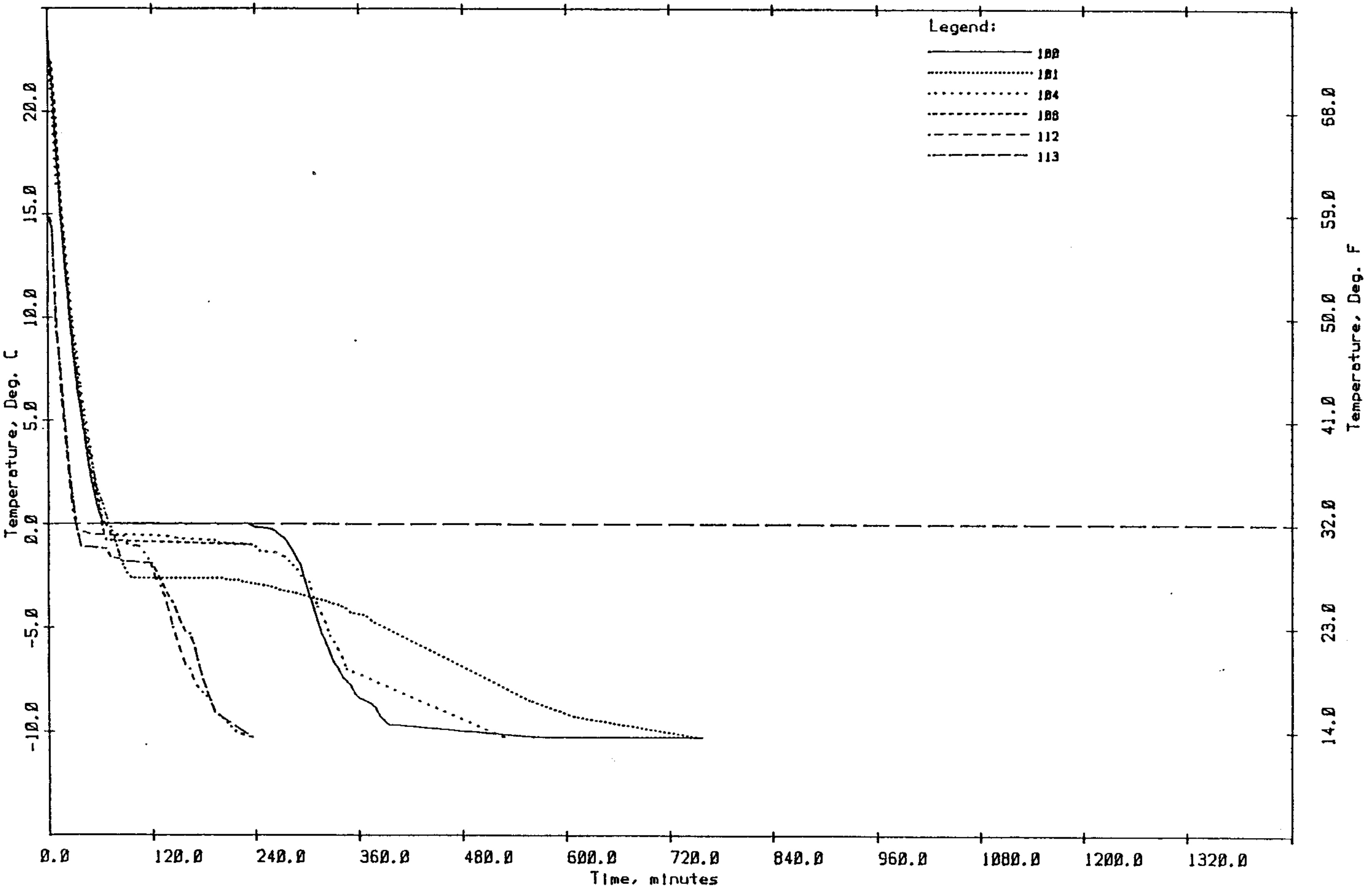
K-0698

FIG. 47



BATCH #113 SAME AS BATCH 108 WITH ADDN OF 1681 LBS OF SAND,
600# CEM, 200# H2O, 5 OZ 322N/SK, 15 OZ 400N/SK, 20 ZO 555N/S
K1 FL OZ MICRO-AIR/SK

K-0698

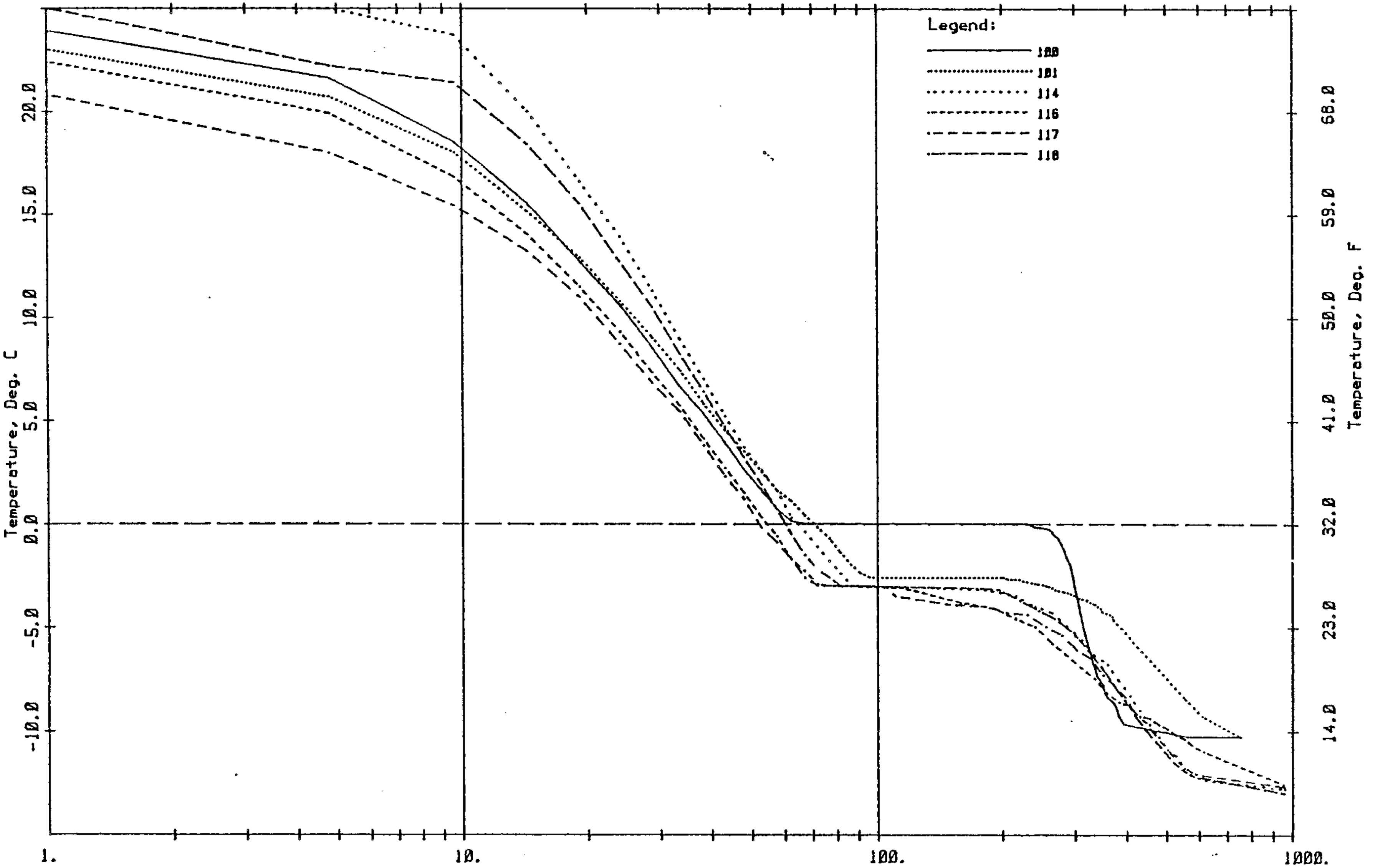


BATCH #113 SAME AS BATCH 108 WITH ADDN OF 1681 LBS OF SAND,
600# CEM, 200# H2O, 5 OZ 322N/SK, 15 OZ 400N/SK, 20 ZO 555N/S
K
1 FL OZ MICRO-AIR/SK

K-0698

FIG. 48

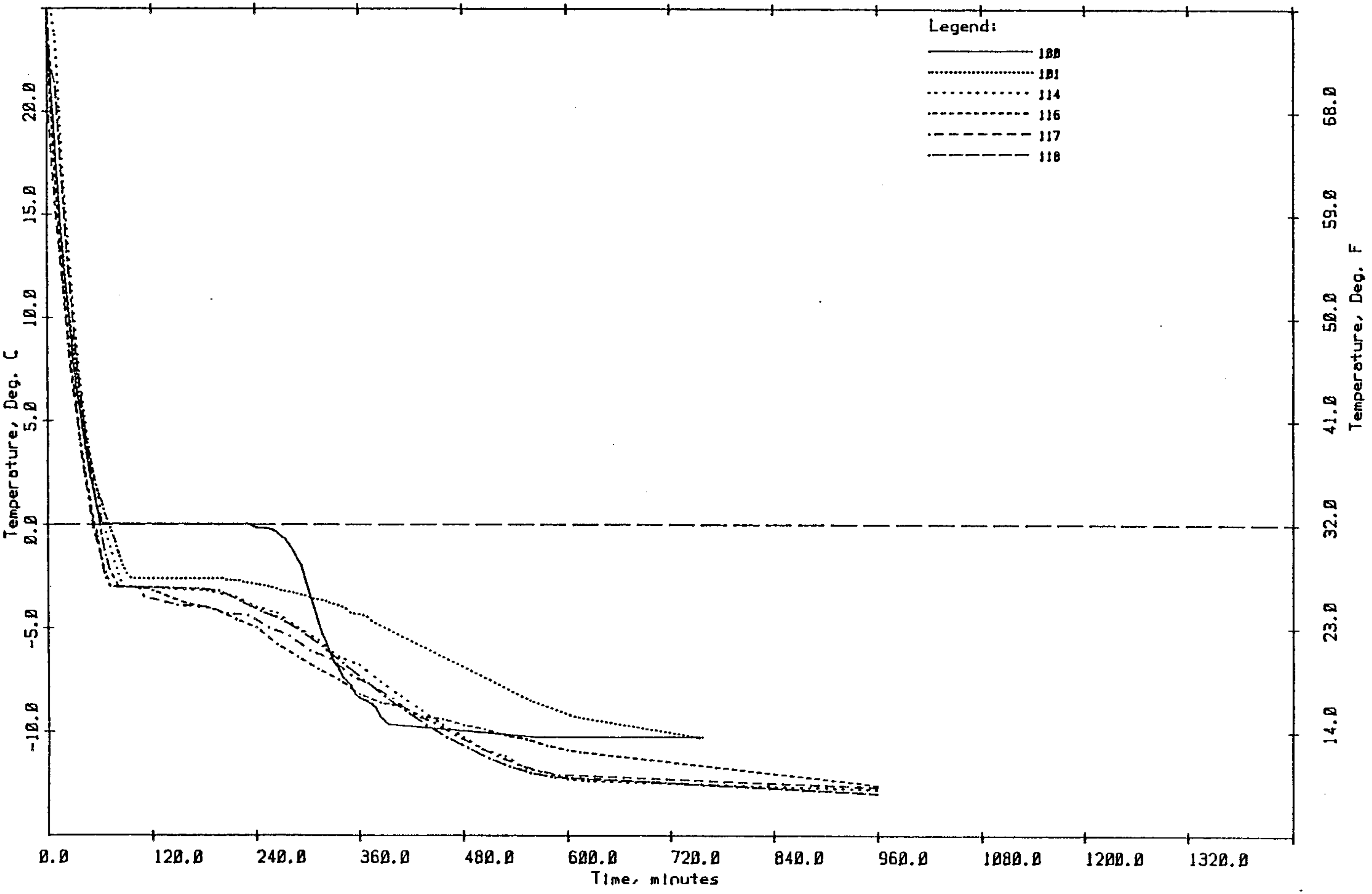
FIG. 49



BATCH #118 600# CEMENT, 242# H2O,, 12# DRY CALCIUM CHLORIDE,
20 FL OZ 400N/SK, 1.5 FL OZ MICRO-AIR, SOUPY!

K-0698

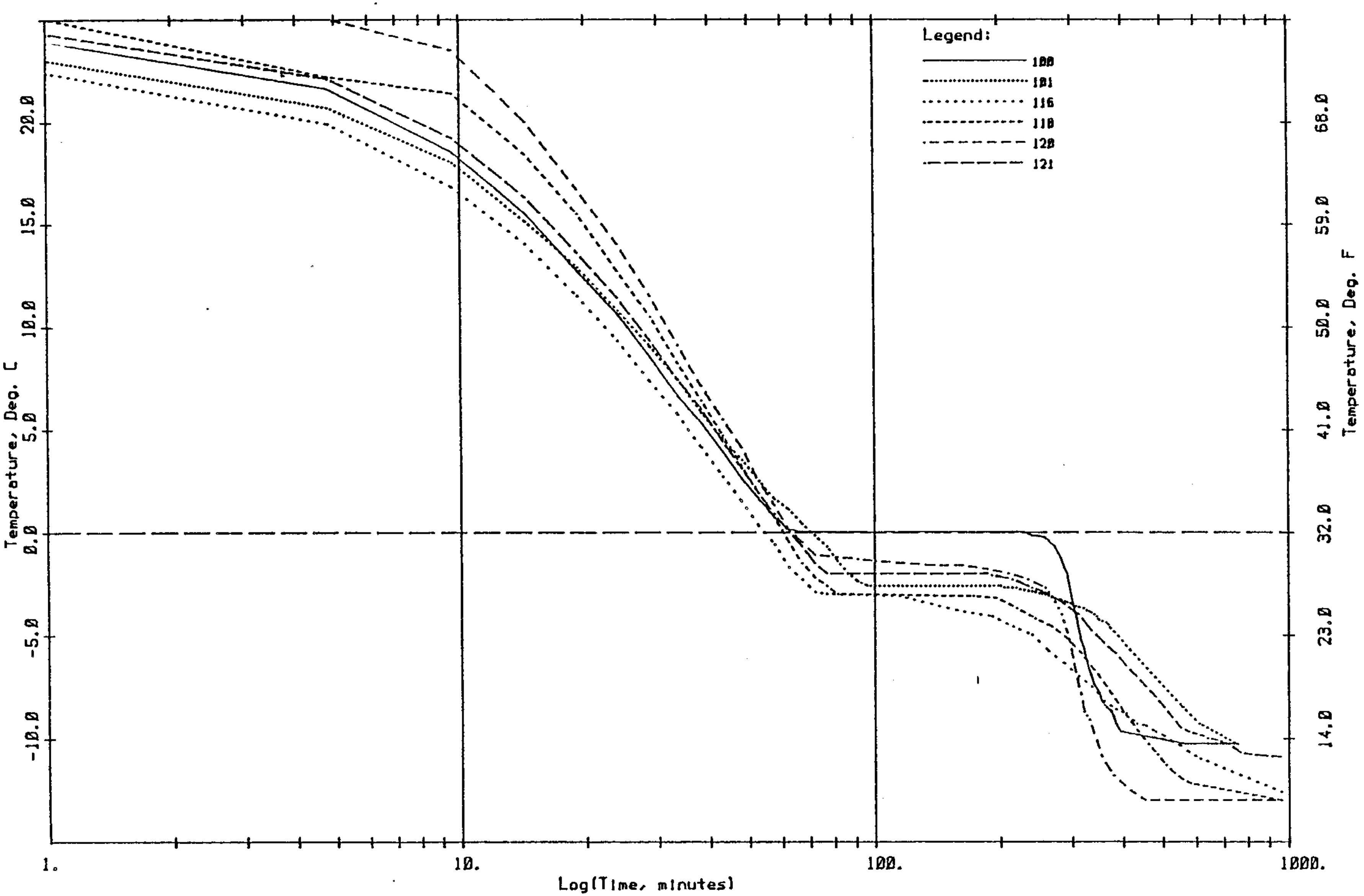
FIG. 50



BATCH #118 600# CEMENT, 242# H2O,, 12# DRY CALCIUM CHLORIDE,
20 FL OZ 400N/SK, 1.5 FL OZ MICRO-AIR, SOUPY!

K-0698

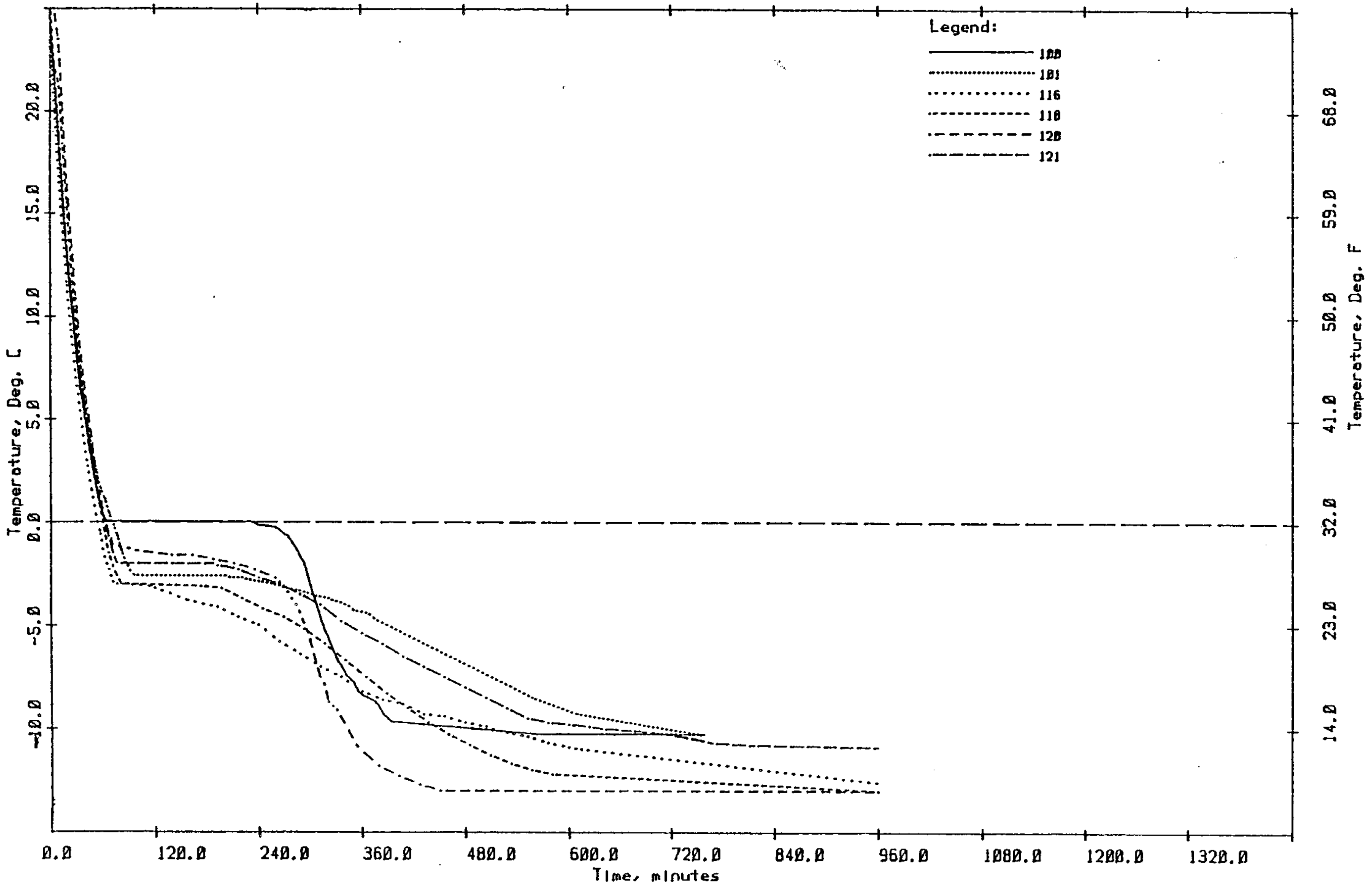
FIG. 51



BATCH #121 600# CEM, 291# H2O, 120# SILICA FUME
64 FL. OZ. 122HE/SK, 15 FL.OZ. 400N/SK, 3 FL. OZ. MICROAIR

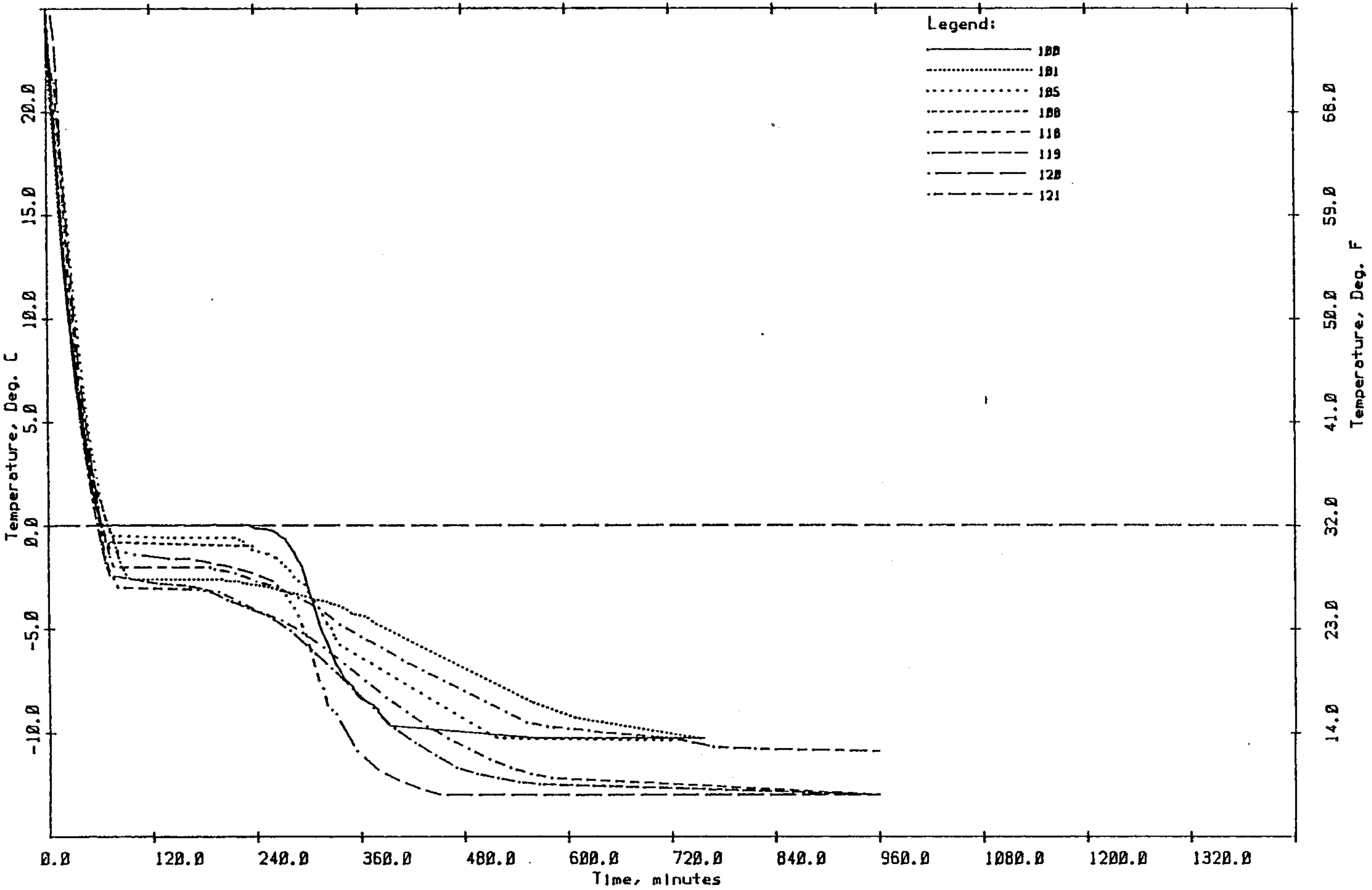
K-698

FIG. 52



BATCH #121 600# CEM, 291# H2O, 120# SILICA FUME
64 FL. OZ. 122HE/SK, 15 FL.OZ. 400N/SK, 3 FL. OZ. MICROAIR

K-698



BATCH #121 600# CEM; 291# H2O; 120# SILICA FUME
64 FL. OZ. 122HE/SK; 15 FL.OZ. 400N/SK; 3 FL. OZ. MICROAIR

K-698

FIG. 53