A COMPARISON OF A SPECIAL CORED BRAKE DRUM WITH ONE OF CONVENTIONAL DESIGN

by

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INTRODUCTION

The development of the cored brake drum tested in connection with this project was one of many attempts to improve the braking facilities on logging equipment and other types of vehicles. Because of difficult operating conditions the logging industry is particularly interested in these developments.

The general operating conditions and loads vary considerably, with approximate maximum conditions of 20 per cent grades, with trailer and log load of 47,000 pounds, and with a speed of about 16 miles per hour. In order to just control the velocity of the vehicle under these conditions, each drum would have to exert about 2,000 lb-ft of torque. This problem would not be so great if all or most of the water which is applied to cool the brake drum could be turned to steam in order to absorb this energy.

Another problem is that of drum breakage, which occasionally occurs in the conventional type of drum leaving the vehicle either without brakes or with braking seriously impaired. One manufacturer, Page and Page Company of Portland, Oregon, developed a special cored brake drum not as an answer to the braking problems but to improve the heat dissipating properties of the conventional design. The special cored brake drum was constructed with 100 one-fourth inch cored holes in the circumference of the drum on each side of the center, Figure 5, page 27. These holes were cored and at an angle of 30 degrees with the axis of the drum so that the receiving vanes at the center of the drum lead the outside edges. This cored system allows more surface area, giving more efficient heating of applied coolant than the conventional system using a smooth drum, such as that shown in Figure 4, page 25.

The purpose of this research was first to determine satisfactory methods and angles of coolant application, and second, to determine if use of the special brake drum brings about an increase in the heat dissipation. Since cooling by water presents several major problems, it was also desired to determine if the use of forced air as a coolant would be practical.

CURRENT LITERATURE

Basically the brake drum is part of a mechanism that converts energy of motion into heat. The brake linings are good insulators (1, p 41), therefore the brake drum has to dissipate the heat through conduction, convection, and radiation regardless of design. (10, p 256)

One of the main fields to be concentrated on should be increased braking through improved cooling methods. (12, p 57) The amount of torque developed by the brake is a minor problem, as the maximum braking of a vehicle occurs when sliding of wheels is impending; from this point an increase or decrease in braking pressure reduces the effective braking. An increase of braking pressure causes sliding and the kinetic coefficient of friction is less than the static coefficient of friction. (9, p 387)

Service reports and development projects on brake drums bring out the following facts: (3, p 33)

1. Cast iron apparently produces the best combination of relatively high coefficient of friction and resistance to heat checking.

2. Most drums removed from heavy duty service failed by heat checking.

3. Many drums are removed due to excessive wear.

4. Some failures have been due to insufficient strength either at elevated or atmospheric temperatures. Brake drum failures result from a number of causes which are difficult to separate.

Service reports indicate that the two main problems in braking are heat dissipation and material. Most brakes used at present dissipate their heat to the surrounding air (11, p 212), but one of the main trends is toward forced cooling (8, p 186). The maximum safe speed of a vehicle is governed by the amount of heat the brakes can dissipate. Since wheel brakes cannot conveniently be much larger to provide more surface area, the enormous amount of air needed to dissipate so much heat cannot be circulated through a wheel brake.(7, p 44)

The logging industry is one of the few industries that has made widespread use of applying water to the brake drums to aid cooling. Logging vehicles are subject to severe service conditions and the brake drums are subject to frequent overheating. Overheating may cause scoring, distortion, thermal cracks or heat checks, and finally it may cause fracture.(10, p 259) Overheating also makes the lining subject to rapid disintegration. As the temperatures increase the tensile strength, the thermal conductivity, the modulus of elasticity, and the wear resistance are reduced and thermal checking becomes critical.

This thermal checking or cracking is a visible network of cracks on the surface of the drum. The cracking is due to the rapid heating on the braking surface of the drum as the brake is applied while the outside is still cold. This action sets up stresses within the metal which may exceed the tensile strength of the metal. (10, p 260) As the metal becomes hotter the braking surface may undergo an uneven volume change in passing from alpha to gamma iron, and this may set up stresses within the metal. (3, p 33)

The degree of thermal checking in drums subject to rigid heating and cooling is in direct relationship to the quantity and form of the graphite; the graphitic irons being superior for resistance to thermal cracking, but subject to rapid wear.

Alloys of cast iron containing carbon (3.0 to 3.8 per cent), nickel, copper, molybdenum, and small amounts of chromium, with a minimum amount of cementite, are recommended for heavy duty drums which require high strength and high resistance to thermal checking and scoring. The above is true even though steel has approximately 22 per cent greater conductivity than cast iron. (10, p 406, 595) However, no material seems to be ideally suited and requirements are difficult to satisfy with any composition or structure. (3, p 32)

The following requisites must be considered before attempting to recommend or produce a suitable material for heavy duty brake drums: (3, p 33)

1. Relatively high coefficient of friction.
2. Ability to resist scoring.
3. Good wear resistance.
4. High strength at all temperatures.
5. High modulus of elasticity.
6. Resistance to thermal checking.
7. Ability to retain its original characteristics.
8. Resistance to plastic deformation.

Brake drums on logging trailers being operated in mountainous areas require hard, long-wearing cast iron. The difficult service produces severe wear and premature thermal cracking. These drums should have a fine pearlitic structure, which is thermally stable, and a uniform, well-distributed graphite content. (10, p 598) The special brake drum used in these tests was one of a series that was made with varying compositions. This particular one contained the following:

Copper - - - - 2.88 per cent

Carbon - - - - 2.57 per cent

Silicon - - - 1.40 per cent

Chromium - - - 0.43 per cent

Manganese - - 0.39 per cent

Phosphorus - - 0.310 per cent

Sulphur - - - 0.088 per cent

There are various methods of measuring temperatures in the braking systems with rotating drums, some of which are outlined in the following paragraphs.

In one experiment on brake drums and tires, the temperatures in the rotating parts were obtained by means of copper-constantan thermocouples, the leads of which were soldered to corresponding pairs of copper and constantan slip rings carried on a fixed frame outside the wheel assembly. A pair of copper-constantan brushes on the appropriate pair of slip rings was coupled to a potentiometer by means of copper and constantan leads. (14, p 38) This system gave a continuous copper and a continuous constantan lead from the welded point of the thermocouple to the cold junction at the potentiometer. This was, however, unnecessary and the commutators could have been of a different material since it may be shown that the insertion of a different metal in a thermoelectric circuit produces no effect upon the total emf if both ends of the introduced metal are at the same temperature. (4, p 21) No indication of accuracy was given for the method, however the author apparently assumed it was quite satisfactory.

Another method was indicated but the author suggested that it was inaccurate. This was rotating the drum in a liquid and recording the temperature of the liquid.

The change in microstructure due to heating the metal of the drum may be used to give an indication, within limits, of the temperature attained by a brake drum as a result of service in the field or in the laboratory. (10, p 261)

One set of tests on brake drums was conducted by taking the temperature through the shoes.(2, p 51) This system, however, would not give very accurate results since the brake linings are good insulators and the temperatures reached in the shoes are much lower than those reached in the drums. (2, p 52)

The heat dissipating ability of drums might be improved by cladding the outer surface with aluminum or copper (12, p 73) or by banding aluminum fins on the cast iron drums. (13, p 6)

Other improvements in braking might be brought about with different types of brakes. One type that might be used could be a disk brake similar to the one developed by the Budd Company for railway equipment. In railway service the main problem was also that of heat dissipation. The brake was designed not to exceed a certain temperature to prevent heat checking and disintegration of the brake lining. The disk was made with a large cooling area inside with multiple fins that served as a centrifugal blower and the heat was dissipated with air. (1, p 41) This brake was designed for high speed operation and since logging equipment is usually operated at slow speeds the brake would not be satisfactory.

An eddy-current brake might be of value to assist the present type of braking system. (7, p 44)

The fact that this brake has no slip rings, brushes, or rotating windings provides for low maintenance costs. The brake can increase the maximum safe speed. The eddy-current brake can dissipate heat more easily since it may be mounted in the open and the rotor can be made to act as a fan. The main disadvantage is the original cost of mounting the eddy-current brake on the trailer.

DEVELOPMENT OF TEST EQUIPMENT

The development of testing equipment used in this work was an evolutionary process. The setup consisted of three main sections, the power unit, the gear reduction unit, and the test stand. (Figure 1, p 11) Power was developed by a 6 cylinder $4\frac{1}{2}$ x $5\frac{1}{2}$ Buda Diesel engine rated at about 50 hp and was transmitted through a truck transmission for speed reduction and then applied to the hub and brake drum mounted on the test stand.

The testing stand (Figure 1, p 11) was constructed of heavy I-beams to insure minimum distortion under operating conditions. Since the Diesel engine was mounted on 6" x 6" I-beams, the test stand base was made of the same size material to facilitate alignment and connection.

The "A" sections of the test stand were made of 3" x 5" I-beams. The brake drums were mounted on a 17,000 pound Timken trailer axle, complete with braking and bearing setup as if it were mounted upon a trailer. The 17,000-pound axle is round heavy-gage pipe five inches in diameter, with considerable camber which introduced a problem of alignment.

The brake drum and hub were free to rotate on the axle when the brake was off. The brake shoes were of the internal expanding type, expanded by an operating cam

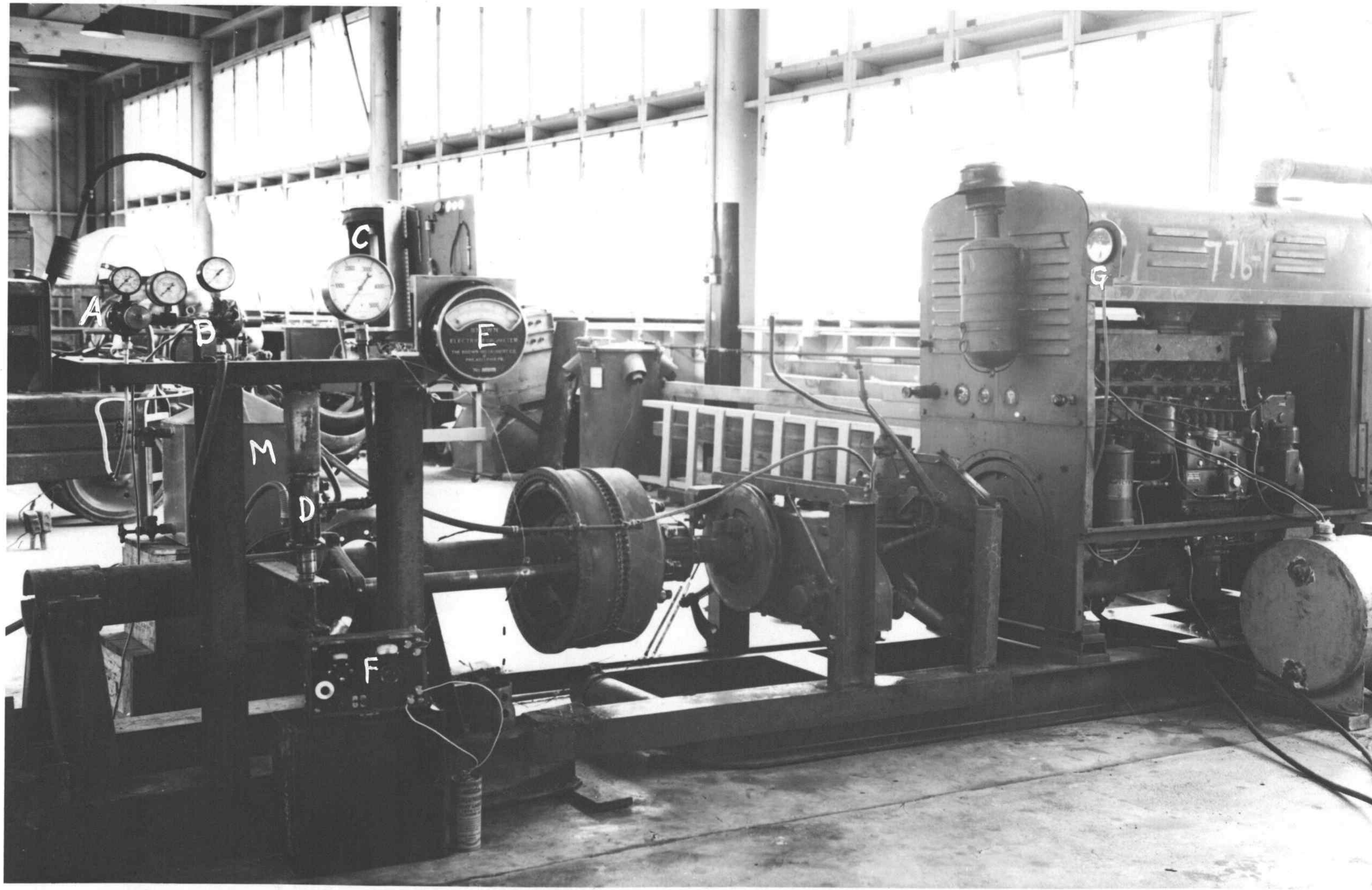


Figure I. General View of Test Equipment which in turn was actuated by an air cylinder mounted on the axle. The brake shoes were mounted on the axle and when the brake was applied it produced a tendency for rotation in the axle. The torque in the axle was used to measure the torque exerted by the brake. An arm was welded to the axle and the rotation of the axle was restrained by a hydraulic piston and cylinder assembly ("D," Figure 1, p 11) held by an inverted "U" made of a pair of 3" x 5" I-beams with a 1 3/4" x 5" channel across the top. (Figure 2, p 13) A 2" x 4" piece of lumber was bolted in this channel and used for mounting several of the instruments. The hydraulic system included a pressure gage ("C," Figure 1, p 11) which indicated the amount of torque. The illustration on page 13 shows a close-up view of the torque system. Before installation the pressure system, which included a Peacock Brothers steel tube gage, was calibrated on a 30,000-pound Tinius Olsen testing machine. The calibration data are included in the Appendix, page 85.

On top of each pair of I-beams which made the "A" parts of the test stand was mounted a piece of heavy gage pipe cut in half to cradle the axle and to act as a bearing surface. This surface was kept oiled to produce a minimum of friction. Each half of each section of the split pipe had a piece of steel welded to either side to

Figure 2. Torque System

allow for bolting the pieces of pipe together. The bolts could be tightened to hold the axle and thus facilitate working on the apparatus.

The brake was applied with air pressure which was available in the building. An oxygen regulator ("B,", Figure 1, p 11) was used to give a constant pressure, but the pressure used was determined by the torque as shown on the hydraulic pressure gage. The safety valve was removed from the regulator and a petcock installed as an exhaust for releasing the brake.

The speed of the drum was determined by knowing the gear ratio of the transmission and by having a tachomoter on the engine. Thus, by knowing the torque and speed the horsepower could be calculated and power conditions could be held fairly constant for the comparison of the two types of drums.

The water was applied to the brake drum under air pressure up to 40 psi. Air pressure applied to the water tank was governed by another oxygen regulator ("A", Figure 1, p 11), forcing the water through a hose from the pressure tank ("M," Figure 1, p 11) to the drum. The water height in the pressure tank was regulated with a float valve and could be checked by the glass level gage. In testing at 40 pounds per square inch, however, the system was soon out of water, as the air pressure exceeded that of the incoming water.

The preliminary tests showed that the high pressure was unnecessary and that very close to maximum cooling could be obtained with about 2½ psi when the drum was absorbing approximately 38 horsepower. This led to abandoning the oxygen regulator and using the height of the water as the head. This was done by venting the top of the pressure tank, then raising and lowering the pressure tank to obtain the desired pressures. The water line leading to the pressure tank was made flexible by using a piece of hose to allow for lowering and raising the tank easily. A water hose from the pressure tank ended with a 1/8" pipe. This pipe was held in place for application of the water with an adjustable iron stand which had sufficient adjustments in any direction. The original holding device as shown in the illustration (Figure 1, p 11) was not rigid enough and later had to be changed.

The measurement of the temperatures of the rotating drum presented a major problem. This problem was first attacked by attempting to take the temperature of the drum by having a spring loaded thermocouple ride on the drum through the brake shoe. This proved to be inaccurate and very slow in reacting because of the low conductivity and insulating qualities of the brake linings and the indefinite heat transfer from the drum to the thermocouple capsule. Also, very shortly the brake lining dust "welded" or packed around the thermocouple capsules so that there was no force on the drum, finally making this system inoperative.

The readings were indicated on the Brown electric pyrometer ("E," Figure 1, p 11), reading directly in degrees Fahrenheit.

The system of measuring drum temperatures was changed to include thermocouples drilled down through the drum and welded on the inside, then the potential was taken through slip rings mounted on the universal joint shaft (about 3 inches in diameter) which was between the transmission and the brake drum hub. The universal joint came with the transmission and bolted directly on the hand brake disk. The other end of the universal joint was welded to a flat plate 1 inch larger than the bolt circle of the brake drum hub. This allowed bolting of the universal joint to the brake drum hub. (Figure 3, p 17)

The slip rings (Figure 3, p 17) were made by placing mica sheets around the universal joint shaft and winding heavy copper wire around these and filling the spaces between the wires with solder. Two bands were made in this fashion with a lead wire passing under the one closer to the drum, thus attaching one lead of the thermocouple to the ring furthest from the drum. The bands were insulated

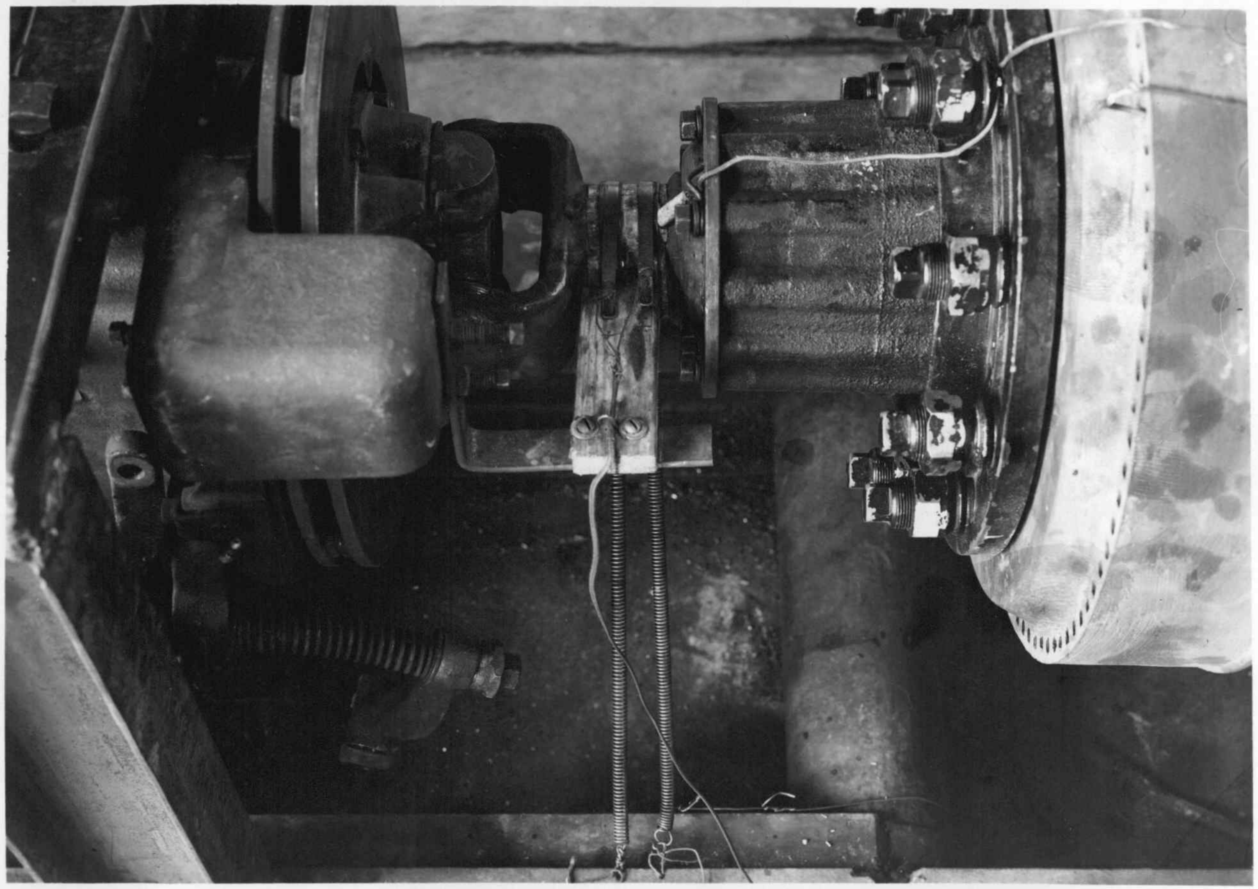


Figure 3. Slip Ring Assembly

from each other and from the universal joint in this manner.

The brushes used were copper strips (Figure 3, p 17) and were spring loaded, with about 4 pounds pull, to insure constant contact and wear, to prevent corrosion, and to keep contacts clean. The length of contact was about 120 degrees around the slip rings. The introduction of different material is permissible as long as the two ends of the introduced material are at the same temperature, and since they were close together and not fastened solidly to any material, but stood in free air, the readings should be acceptable. (4, p 21)

The upper ends of the straps were held by a bracket. Thus, in operation the iron-constantan thermocouple had a lead going to each ring and there the voltage from each ring went to a strap, and from each strap back to an iron or constantan wire and over to the cold junction in a thermos bottle. From the thermos bottle copper leads went to the potentiometer. Thus the materials on one leg from the welded tip to the cold junction were iron, copper, then iron. The other circuit was made up of constantan, copper, then constantan, and copper finished the circuit to the potentiometer in each case. The potentiometer indicated the temperature in millivolts and had a compensator for the cold junction, so all readings could be converted into degrees Fahrenheit directly the same as if the cold junction was at 0 degrees Fahrenheit. This fact aided in plotting the curves.

The transmission was connected to the engine through the flexible coupling that came with the engine. The transmission input shaft was splined. An internal splined fitting was used to bolt to an adapter to make the connection between the splined fitting and the hole in the flexible coupling. The transmission mounting was made with a base of 3" x 5" angle irons which were bolted to the engine frame and supported the brackets for the transmission. Also, they were welded to the test stand and helped to hold it in alignment and steady it under load. The base angle irons later had to be tacked to the engine base for greater rigidity.

The front brackets were uprights made of 3" x 5" angle iron and the bell housing of the transmission was bolted to slotted holes in the uprights. The back transmission mount was constructed of 3" x 5" I-beams for the uprights and 1 3/4" x 5" channel across the top. Two mounting bolts were on top of the transmission and these were used by putting them through slotted holes in the channel. The slotted holes of the transmission mounting made it possible to adjust the transmission while alignment was being made. After the alignment the washers on the front uprights were welded to the uprights for greater rigidity.

The adapter for attachment of transmission to the engine and the plate on the universal joint were both turned true on a lathe and the bolt circles were inscribed on each at the time of turning to insure greater accuracy.

The transmission was rented for the purpose of running these tests and was definitely stated to have torque capacity exceeding the 2,000 lb-ft torque desired, but during preliminary runs the output shaft failed. This failure was partly due to a bending moment because of inadequate holding down of the test stand, and partly due to seizing of the brakes which caused the torque to vary as much as 1,000 lb-ft, however it was mainly due to the fact that the transmission was too light. The broken parts of the shaft were sent away for repair. The shaft came back improperly repaired with not all the fractured material removed, and it also was crooked. The crookedness was in the overhang outside the bearings, so the plate that bolted on the shaft was turned true with the bearing surfaces and the bolt circle rerun. This operation provided a true running universal joint and would have been satisfactory if the checks in the shaft had not caused a second failure. A replacement shaft was obtained and not stressed above 1,000 lb-ft in accordance with calculations for the 1 5/8 inch splined shaft and no further trouble with this part was encountered. Also, the front side of the test stand was bolted to the concrete floor and two 3" x 5" I-beams were placed on the back end and weighted down.

The plate that was bolted to the brake drum hub and welded to the universal joint was left partly loose to act as a second universal joint by not tightening the bolts. During the alignment period and preliminary runs it was discovered that threads were pressed into the plate by the bolts thus holding the plate firm with respect to the hub. This caused a slight misalignment to show up by giving a wobble to the axle and the transmission. The bolts were replaced by bolts that had 1/2 inch next to the head unthreaded. This gave a smooth bearing surface for the plate, correcting the previous condition.

During the preliminary runs it was discovered the Diesel engine would develop a maximum of about 40 horsepower instead of the desired 100 horsepower. The engine was checked to determine the cause of the low power output but everything checked out normally. However, the fuel injector pump was a combined pump that is not ordinarily used on engines over 50 horsepower. (5, p 227) The engine was probably designed for efficiency in the operation of the 30 kilowatt generator that had been connected to it.

For the above reasons the original plan of running the tests at the horsepower approximately equivalent to field conditions had to be abandoned.

TESTING PROCEDURE

Many check runs were made to determine if and where changes were needed in equipment and instrumentation.

The adjustments of equipment consisted mainly of alignment of units. The rough unfinished surfaces of the equipment and the great amount of rigidity needed made the alignment particularly troublesome.

The method of applying water to the special drum was determined experimentally by constructing various sizes of jets. These jets were made by drilling 1/8-inch pipe caps with different angles between the divided stream. A single stream was found to be unsatisfactory at the outset. Various angles before top center and various angles with respect to the horizontal plane were tried. The best system found for all the conditions was that of using two 1/16-inch jets with the streams of water 90 degrees apart. The jet was placed about 100 degrees before top center, with streams of water set about horizontal.

Before tests could be made the water flow was calibrated. This was done by choosing water pressures of 15 inch head of water, about 2½ pounds per square inch, and about 5 pounds per square inch pressure. For the special drum, using the jet, water heads of 15 inches, 5.8 feet and 11.5 feet were metered to determine the rate of flow. The rates of flow were determined by the time of flow per gallon. These rates were determined with the aid of a stop watch and several check runs were taken. The rates were determined as being 0.20, 0.28, and 0.41 gallons per minute, respectively. The water was applied to the conventional brake drum through the 1/8-inch pipe at top center or up to 20 degrees before top center, either with the stream of water set parallel to the axis of the axle or slightly turned to direct the water stream against the direction of rotation. The position finally selected for the testing was about 20 degrees before top center and about parallel to the axis of the brake drum. The head for the 1/8-inch pipe with open end for application on the conventional drum was determined by trial and error to give an equivalent flow, and the heights were determined as 8 inches, 11½ inches, and 21 inches for rates of 0.20, 0.28 and 0.41 gallons per minute, respectively.

The speeds were chosen to include most operating conditions. The drum speeds used were 100 rpm and 164 rpm. This is approximately equal to 12½ miles per hour and 20 miles per hour, respectively, with a 10:00 x 20 tire (41.7 inches in diameter). The equivalent engine speeds were 1220 rpm and 2000 rpm, respectively. Twenty miles per hour is considered higher than most speeds used on the steep grades. It was decided that using this speed would be desirable, however, since the effect of the centrifugal force throwing off the coolant is a major factor. As more water is thrown off, less heat will be absorbed.

The brake drums were both 20,000 pound drums and were mounted on a 17,000 pound axle and hub, the only difference in the 20,000 and 17,000 pound brake drums being in the diameter of the large hole in the closed end of the drum which bears the load under operating conditions. The bolt circles are the same. The fact that there was some play around the mounting bolts may have caused the drum to be off center and contributed to the seizing of the brake lining. The seizing was counteracted by application of oil to the brake lining during operation. These applications smoothed out the operation of the brake but radically changed the coefficient of friction and the air pressure applied to the booster (air cylinder) had to be changed continually to keep the torque constant. This changing torque had its effect upon the engine speed.

The conventional drum is shown in Figure 4, page 26. The iron-constantan thermocouple may be seen mounted on the drum. The drum has an inside diameter of 16½ inches and a braking width of 7 inches. Each of the two brake shoes covered an area of about 7 x 18 inches.

The special cored brake drum is illustrated in Figure 5, page 28, showing the receiving vanes as originally

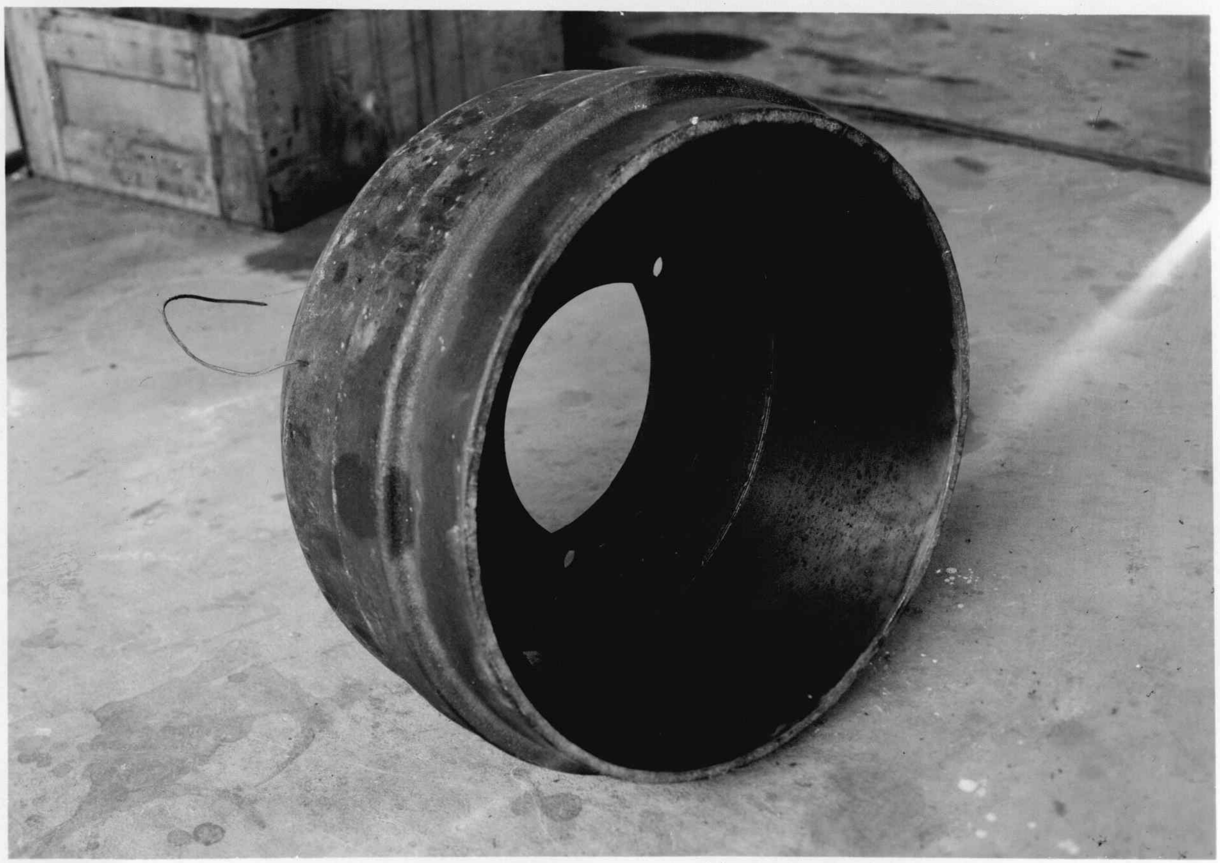


Figure 4. Conventional Brake Drum

constructed, the direction of rotation, the angle of the cored holes, and the mounted thermocouple wires.

The thermocouple wires in both drums were mounted in the same positions with respect to the brake shoes. Considerable trouble was encountered in attaching the thermocouples to the drums, since the thermocouple wires were of small diameter as compared to the thickness of the drums and attempts to weld the wires to the castings with the arc welder failed because the heat burned the wires off.

The use of a carbon arc operated from a battery was attempted but this failed to stick the wires due to insufficient heat. The acetylene torch also created too much heat and the wires burned off. Therefore, a large area around the thermocouple was heated with the torch and the wires were silver soldered to the casting. This system was satisfactory and the depth of the silver solder in the hole was controlled by the insulation on the wires, although the depth probably was not extremely important since the temperature gradient within the metal along the thermocouple could not be great. The excess silver solder and an area about 2 inches in diameter were ground with a portable grinder to insure that only conducted heat in the drum would be recorded. Before installation the thermocouple wires and instruments were calibrated in the

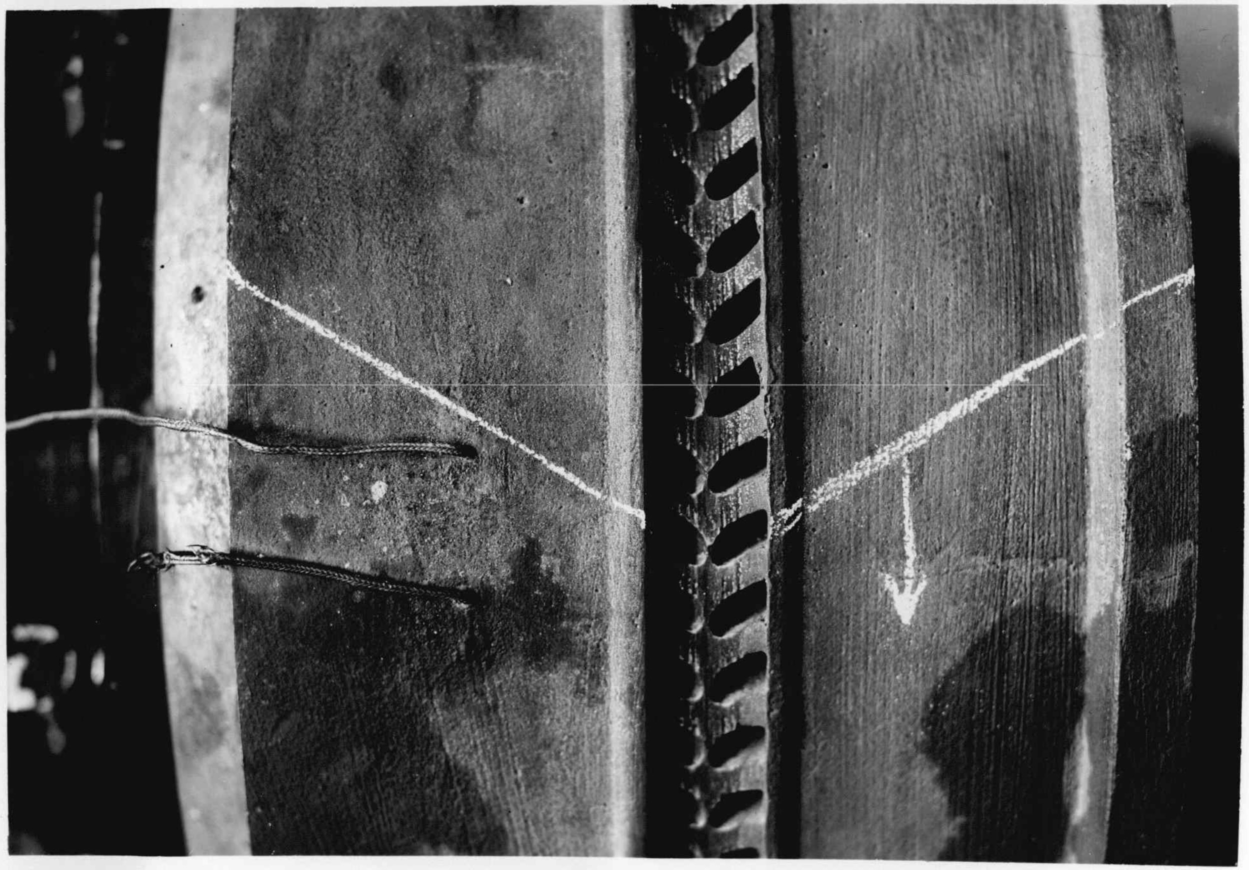


Figure 5. Special Brake Drum

laboratory by checking against the boiling point of water and freezing points of several pure metals.

Early in the preliminary tests it was determined that the cored special drum receiving vanes could be improved upon, since the lands and grooves were approximately the same area in the receiving groove at the center of the drum. (Figure 5, p 28) The application of the water was observed with a stroboscope and it seemed to splash on the lands. This greatly hindered the normal entrance of the water into the holes. The receiving vanes were modified to reduce the area between the holes. This was done by drilling with a portable drill and enlarging the openings. The modified brake drum is shown in Figure 6, page 30. This illustration shows the direction of rotation, the angle of the cored holes, and the results of drilling. The modification was made by drilling with three sizes of drills, 5/8 inch, 1/2 inch, and 11/32 inch, taking care to leave the back surface of the hole smooth to make less resistance for the entrance of the water.

The actual running of the tests was comparatively simple after the preliminary runs had ironed out many of the difficulties. After the rates, methods of water application, torques, and speeds had been standardized, the first series of tests was run at 100 rpm of the drums, or with an engine speed of 1220 rpm.

Figure 6. Modified Special Brake Drum

Conditions were held as nearly constant as possible, but there were many more or less variable factors. The engine speed was difficult to read; this condition was improved by moving the tachometer from the engine to reduce vibration. The torque at times was difficult to read and regulate. This was partially remedied by repeated addition of oil to the brakes. Accurate measurement of the water head was difficult due to unevenness of the floor.

The governor on the engine gave an occillating engine speed. This was partially corrected by taking it apart and cleaning.

The second set of readings was taken with an engine speed of 2,000 rpm. This speed was not within the range of the governor, therefore it had to be disconnected and the engine speed directly controlled by the hand throttle. This introduced another source of error since any change in torque would change the engine speed and vice-versa, therefore the conditions required constant attention.

All tests were run with conditions controlled as closely as possible, and each test continued until the temperatures appeared to have become stabilized.

The temperatures in the brake drums could not be checked accurately, however rough checks were taken occasionally with the thermocouple mounted in the shoes and

and with "Tempilsticks" manufactured by the Tempil Corporation. These sticks have definite melting points represented to be accurate within 1 per cent. They are available from 125 degrees Fahrenheit to 1600 degrees Fahrenheit. They were made use of by marking on the hot drum with a stick. If the line melted, the temperature of the drum was above the rating marked on the stick, and if it did not melt the temperature could be considered below that marked on the stick. In this manner the temperature could be approximated fairly closely. The temperature in the region adjacent to the thermocouple could not be checked very accurately, however, since it was difficult to get inside the drum that far and the temperature on the outside was of no value. Also, further indications of inaccuracy were noted by watching the galvanometer in the potentiometer. When there were any breaks or shorts in the circuit the galvanometer would not register or would fluctuate erratically. These effects were noted once when the thermocouple broke loose in the drum, and also when the contacts on the slip rings were corroded or oily.

In making these tests, three runs were made for each condition with each drum. The data for these runs are given in the appendix. The data for each test and for each drum were plotted, then a representative curve was drawn for use in the comparison of the drums.

RESULTS AND CONCLUSIONS

Maximum effectiveness in applying water to the special brake drum was obtained, with a maximum of 40 horsepower, by using two 1/16-inch jets of water 90 degrees apart, the jet being so placed that streams of water were directed horizontally and placed about 100 degrees before top center.

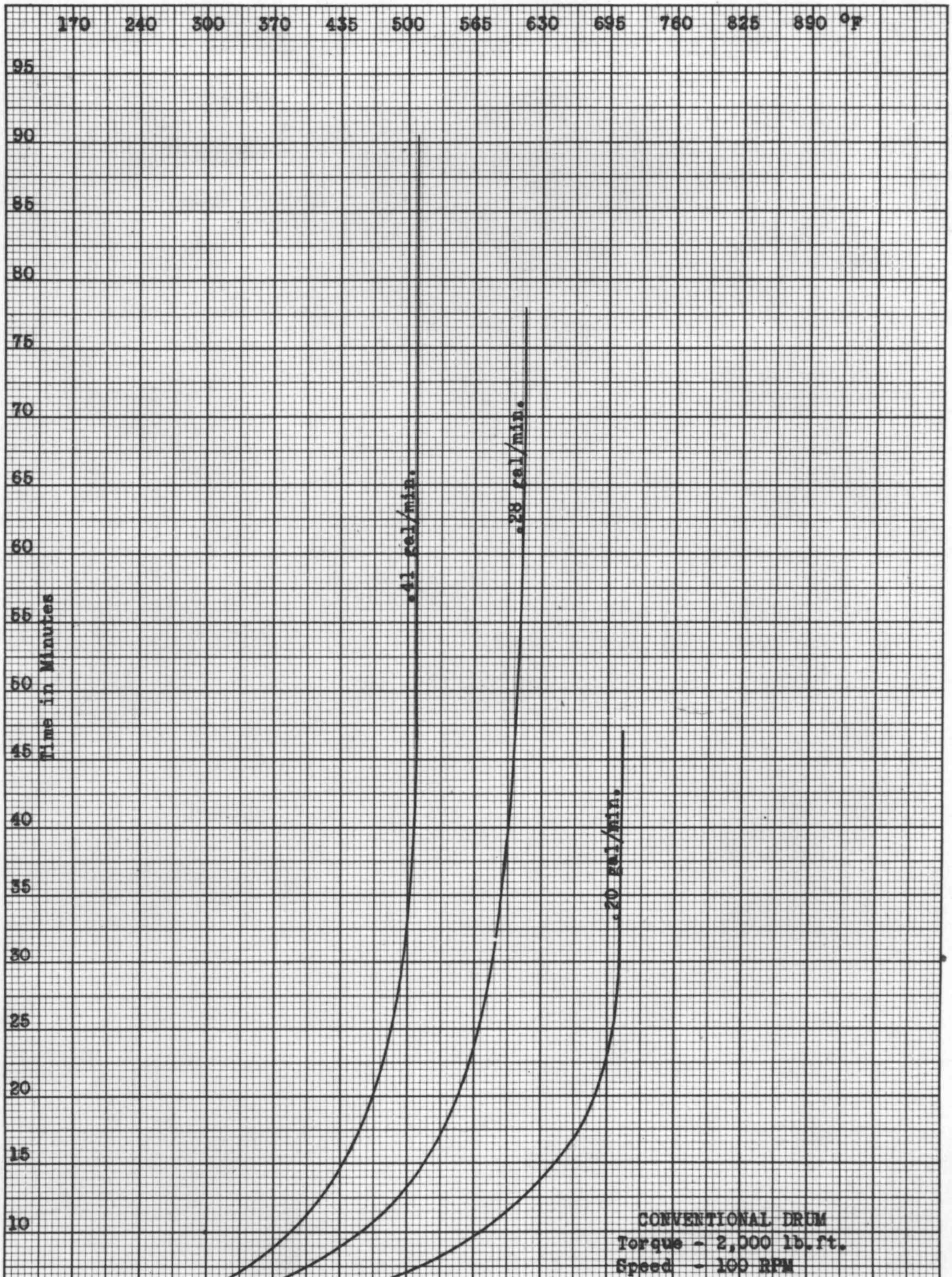
The water pressure applied to the special brake drum seemed to have very little increased advantage above 2.5 pounds per square inch, but heating increased very rapidly below 2.5 pounds per square inch.

Under actual field conditions a larger jet size would probably have to be used and the pressure increased to keep the same velocity, because more power would have to be absorbed.

The water when applied to the special brake drum went through the cored holes only when the drum was warm and the hotter the drum became the better the water seemed to flow through, largely independent of the pressure applied. This effect was probably brought about by the condensation of steam envelope on the surface of the holes reducing the resistance to the flow of the water.

The temperatures recorded in the metal of the special drum for the 0.28 and 0.41 gallons per minute tests are below the boiling point of water in both sets of runs, although steam was produced in all cases. (See curves, pages 38 and 39.) This condition was due to the method of mounting the thermocouples. The inside of the drum was ground out around the thermocouple so that the indicated heat would have to be conducted heat. The thermocouple was mounted about 1.5 inches from the edge of the brake shoe and the ground area was about 2 inches in diameter, so for practical purposes no heat could be developed on that side of the thermocouple. The thermocouple was mounted in the web between two cored holes and the ground area was under two holes on each side of the thermocouple. This condition probably caused most of the heat coming from the sides perpendicular to the axis of the drum to be absorbed by the water passing through the holes. Therefore, for all practical purposes the conducted heat would have to come from one direction and since two holes carrying water were 1/8 inch on either side of the thermocouple, the apparent temperature gradient is to be expected.

The thermocouples in both drums were mounted in the same relative position and both drums were made of approximately the same material with about equal thermal conductivity, therefore the relative temperatures between the two drums for purposes of the comparison should be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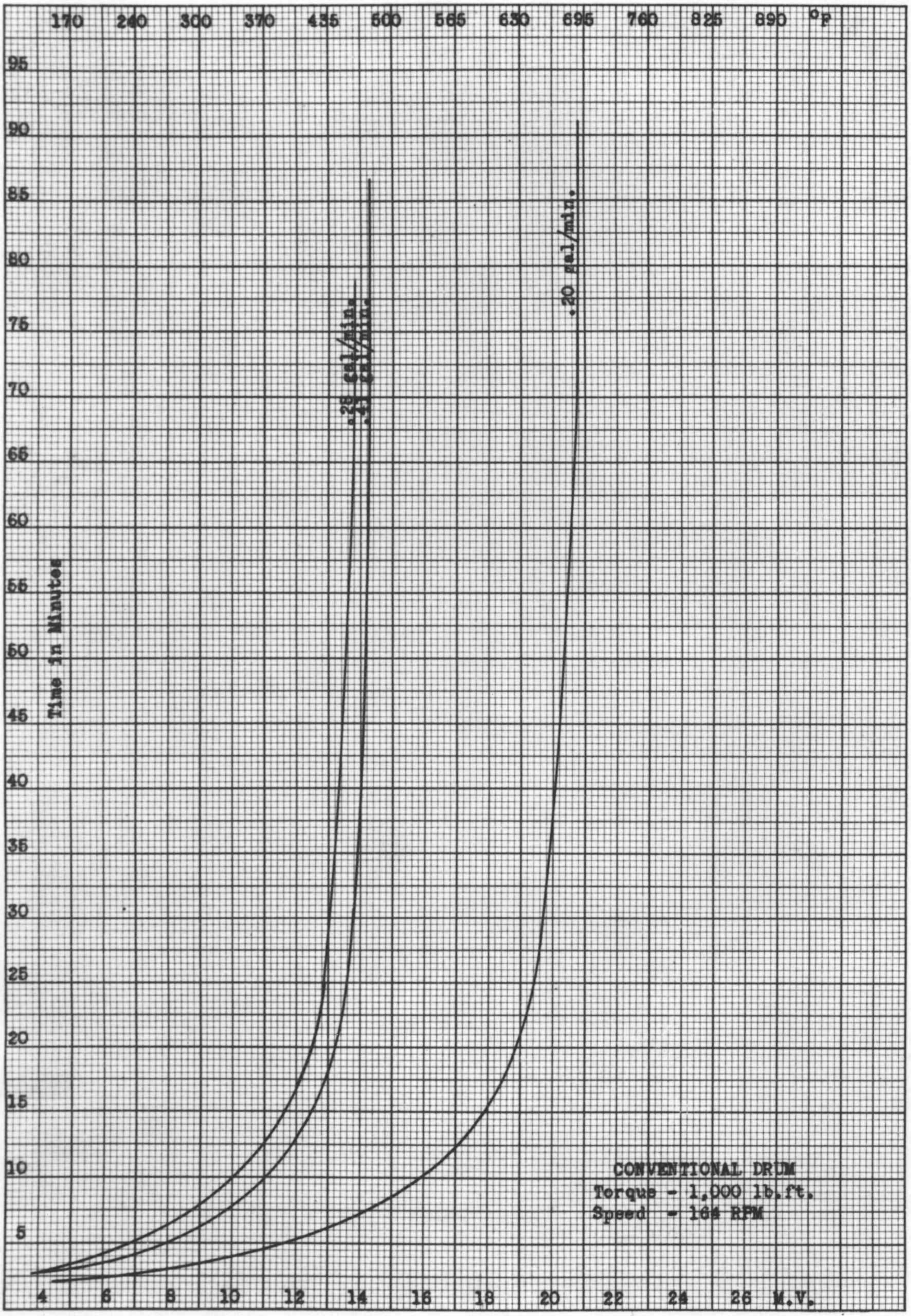
55
50
45
40
35
30
25
20
15
10
5
Time in Minutes
.41 gal/min.
.28 gal/min.
.20 gal/min.
CONVENTIONAL DRUM
Torque - 2,000 lb.ft.
Speed - 100 RPM
4
6
8
10
12
14
16
18
20
22
24
26 M.V.


170 240 300 370 435 500 565 630 695 760 825 890 °F
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Time in Minutes
.25 gal/min.
.45 gal/min.
.20 gal/min.
CONVENTIONAL DRUM
Torque - 1,000 lb.ft.
Speed - 164 RPM
4 6 8 10 12 14 16 18 20 22 24 26 M.V.

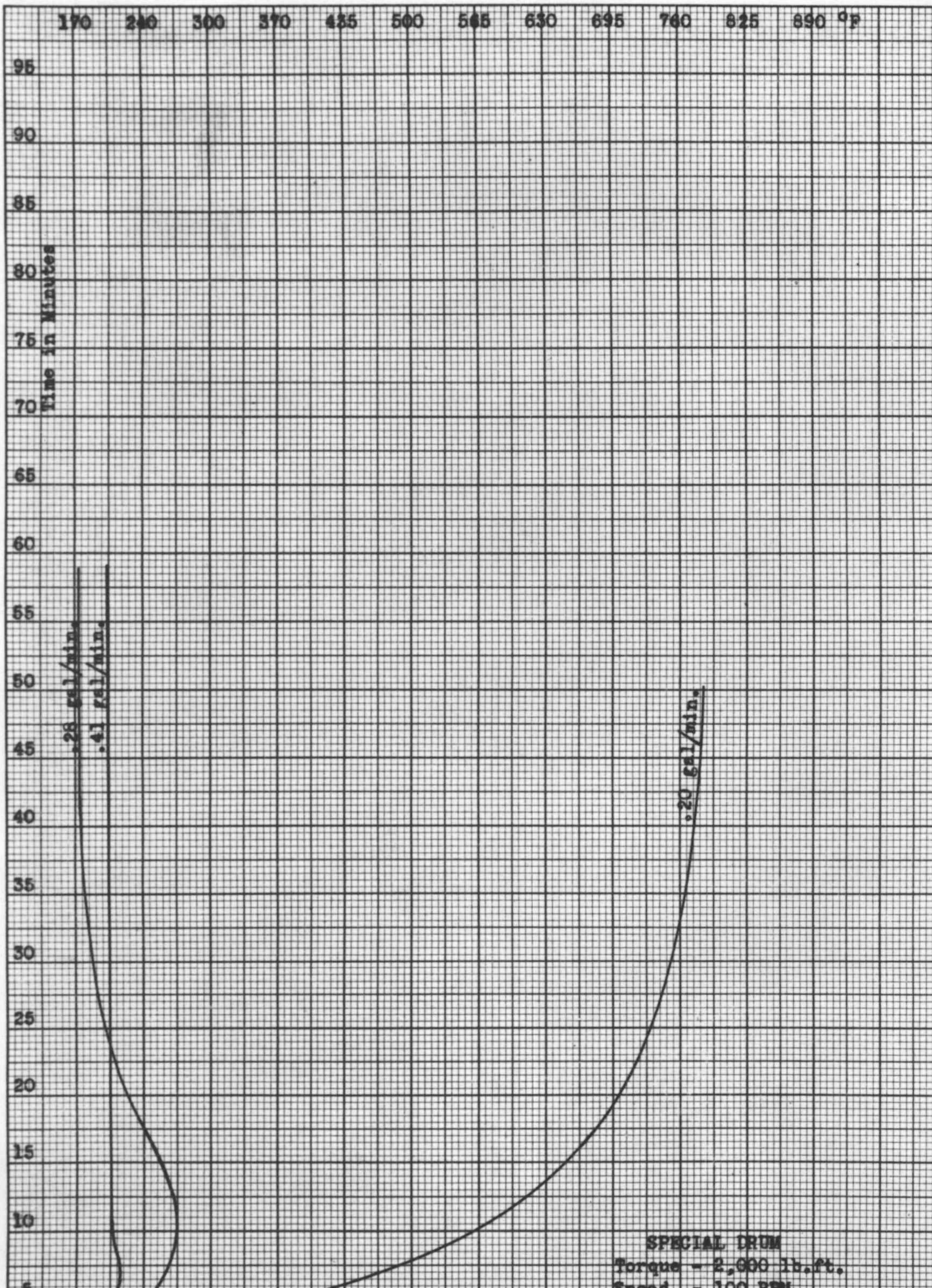
acceptable.

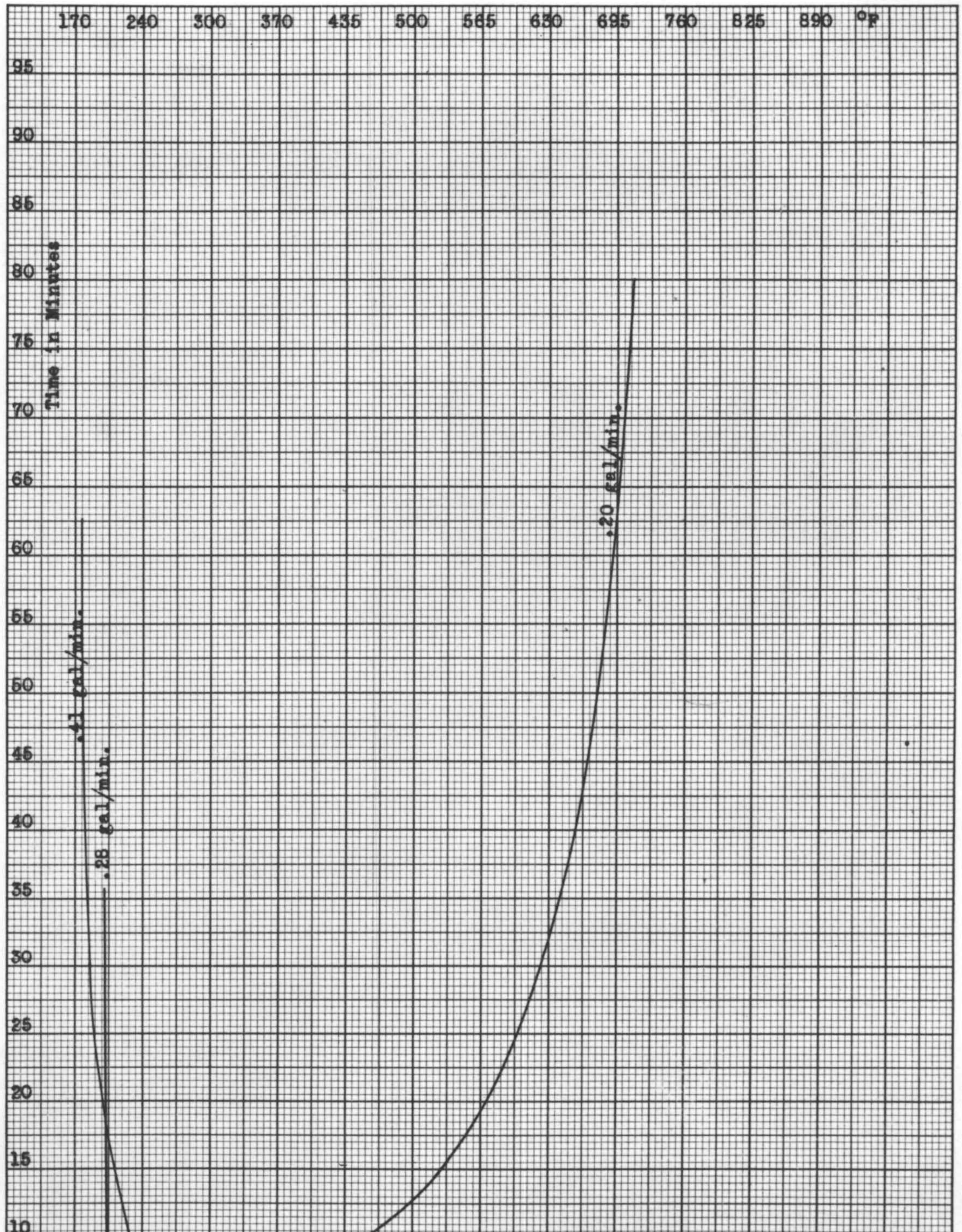
The curves on pages 35 and 36 are the representative curves of the runs made with the conventional brake drum showing the effects of different amounts of water applied with all other conditions held constant.

The apparent inconsistency in the set of curves on page 36 is the product of a mistake in the head of water, as $21\frac{1}{2}$ inches of head was used instead of the required $11\frac{1}{2}$ inches, giving a somewhat greater water flow than the 0.41 gallons per minute. This made the run come out with a lower temperature than the run when using 0.41 gallons per minute. This mistake was not noticed until after the set-up had been torn down, but the curve can be used for a comparison since the amount of water is on the conservative side.

The curves on pages 38 and 39 are the representative curves of the runs made with the special brake drum, also showing the effects of applying different amounts of water with other conditions constant.

There is another apparent inconsistency shown in the curves on page 38. The application of 0.28 gallons of water per minute shows a lower final temperature than does the curve of the application of 0.41 gallons per minute. This was not due to a mistake and was verified by running a check run at 0.28 gallons per minute with other


170 240 300 370 435 500 565 630 695 760 825 890 °F
Time in Minutes
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
.28 gal/min.
.41 gal/min.
.20 gal/min.
SPECIAL DRUM
Torque - 2,000 lb.ft.
Speed - 100 RPM
4 6 8 10 12 14 16 18 20 22 24 26 M.V.


170
240
300
370
435
500
565
630
695
760
825
890
°F
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Time in Minutes
.41 gal/min.
.28 gal/min.
.20 gal/min.
SPECIAL DRUM
Torque - 1,000 lb.ft.
Speed - 164 RPM
4
6
8
10
12
14
16
18
20
22
24
26 M.V.

conditions held constant. The water head, after the temperature had stabilized, was then raised to give the flow of 0.41 gallons per minute and the temperature rose instead of lowering. The condition is probably brought about by reaching a critical value of the amount of water and the surface velocity of the brake drum. It is probable that the increased amount of water caused a higher percentage to be thrown off due to increased impact. It is likely that if the speed of the drum had been changed for this set of tests the results would have been more consistent.

The special brake drum, due to the thinner sections and large surface area, was subject to a more severe quenching effect than the conventional drum and therefore is subject to easier cracking. Such cracking did occur between the cored holes and the braking surface. The cracks allowed the applied oil to seep into the cored holes and to plug and insulate them. One of these cracks appeared next to the thermocouple during the preliminary tests. This may have caused the temperatures in the special drum to be recorded slightly higher than would have occurred normally, but for purposes of the comparison this condition is also on the conservative side.

In practice the special brake drum would prove to be safer even though the metal is subject to a more severe quench due to the larger surface area. This severe quench is more likely to produce cracks, however, the cracks seemed to be confined to the areas between the braking surface and the cored holes. This leaves the operation of the brake unimpaired since the metal on the circumference of the drum outside of the cored holes apparently is cooled more uniformly with less likelihood of cracking and the remaining metal apparently is strong enough to withstand fracturing from the braking pressure.

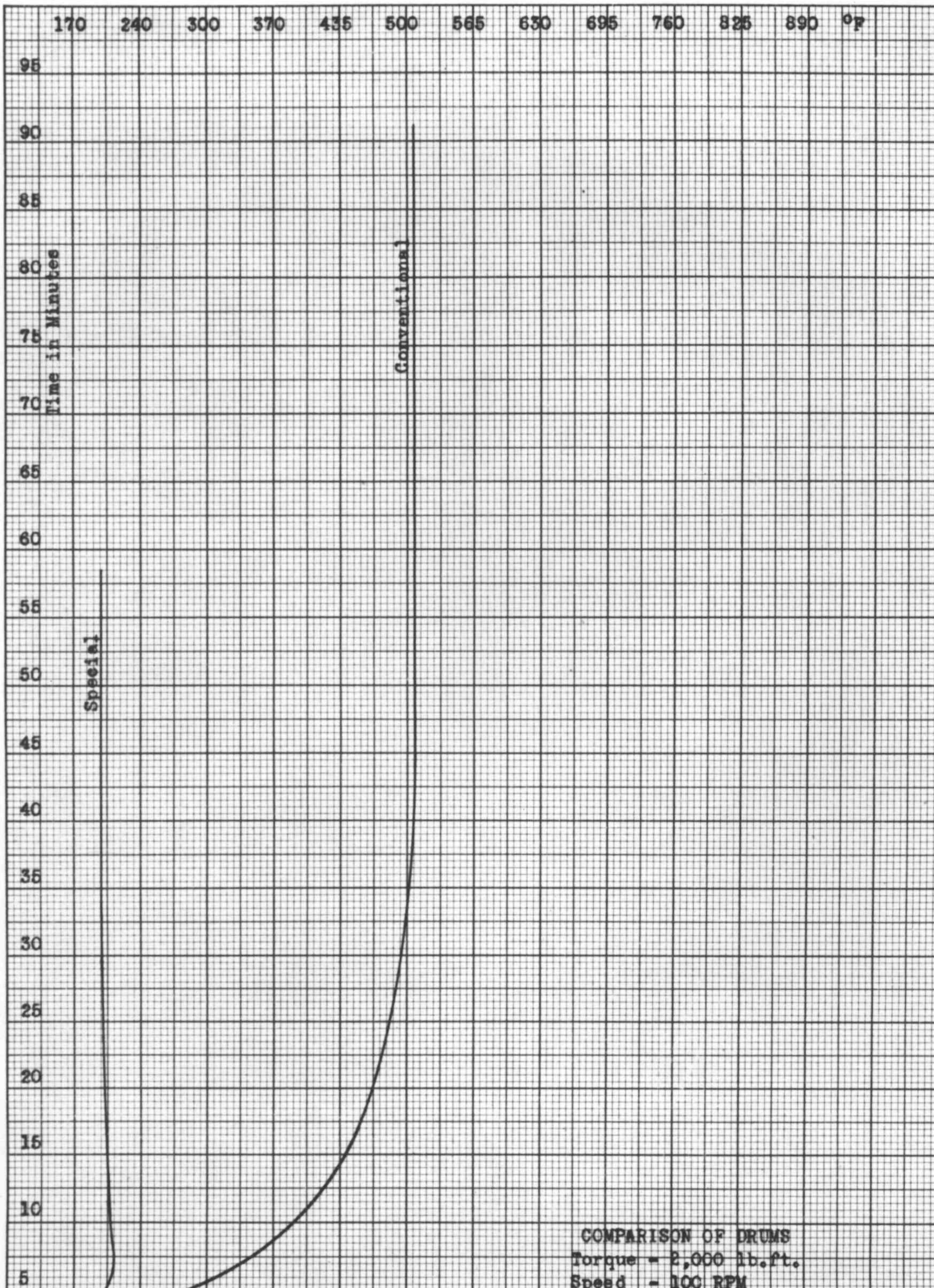
Air was tried as a coolant for the special brake drum. The first trial was through the water jet with two 1/16 inch holes with the full 120 pounds per square inch in the system. This gave a flow of approximately 14 cubic feet per minute. (6, p 1-15) This run was not plotted because the cooling effect was apparently negligible and a satisfactory run without coolant could not be obtained. The runs made with air and the run made without coolant had to be interrupted for brake adjustment.

The run with air was made again with a 1/8 inch pipe directed into the holes. This also was unsatisfactory because the storage of 21 cubic feet, or 192 cubic feet at 120 pounds per square inch was reduced to 63.8 cubic feet at 30 pounds per square inch in 8 minutes. This gave an average of 16 cubic feet of air per minute. The cooling effect was only slightly greater than in the first run made with air. The data, for comparison, are included in the appendix, page 84, but they were not plotted as the curves would not represent the true heating curves with respect to time, since the tests were interrupted for brake adjustment. Also, the air pressure fell off considerably during these runs.

The curves on pages 43, 44, 45, and 46 are the ultimate results of the project. The curves of the comparisons of the brake drums all show definitely lower temperatures for the special brake drum, indicating a much greater percentage of the applied coolant was being turned to steam. This should indicate that the drum will possibly be of great value in service.

The comparison of the drums with the application of 0.20 gallons per minute was not made, since the amount of water was so slight that the already mentioned variables made too great a difference in the readings. Changes in any of the variables produced discrepancies in the curves. The water did not spread on either drum, therefore no apparent reason exists for any differences between the two drums for these runs.

There are several possible improvements in the special cored brake drum which would probably make the drum even more valuable. One of these would be to move the water admitting ring at the center toward the open side of


170
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435
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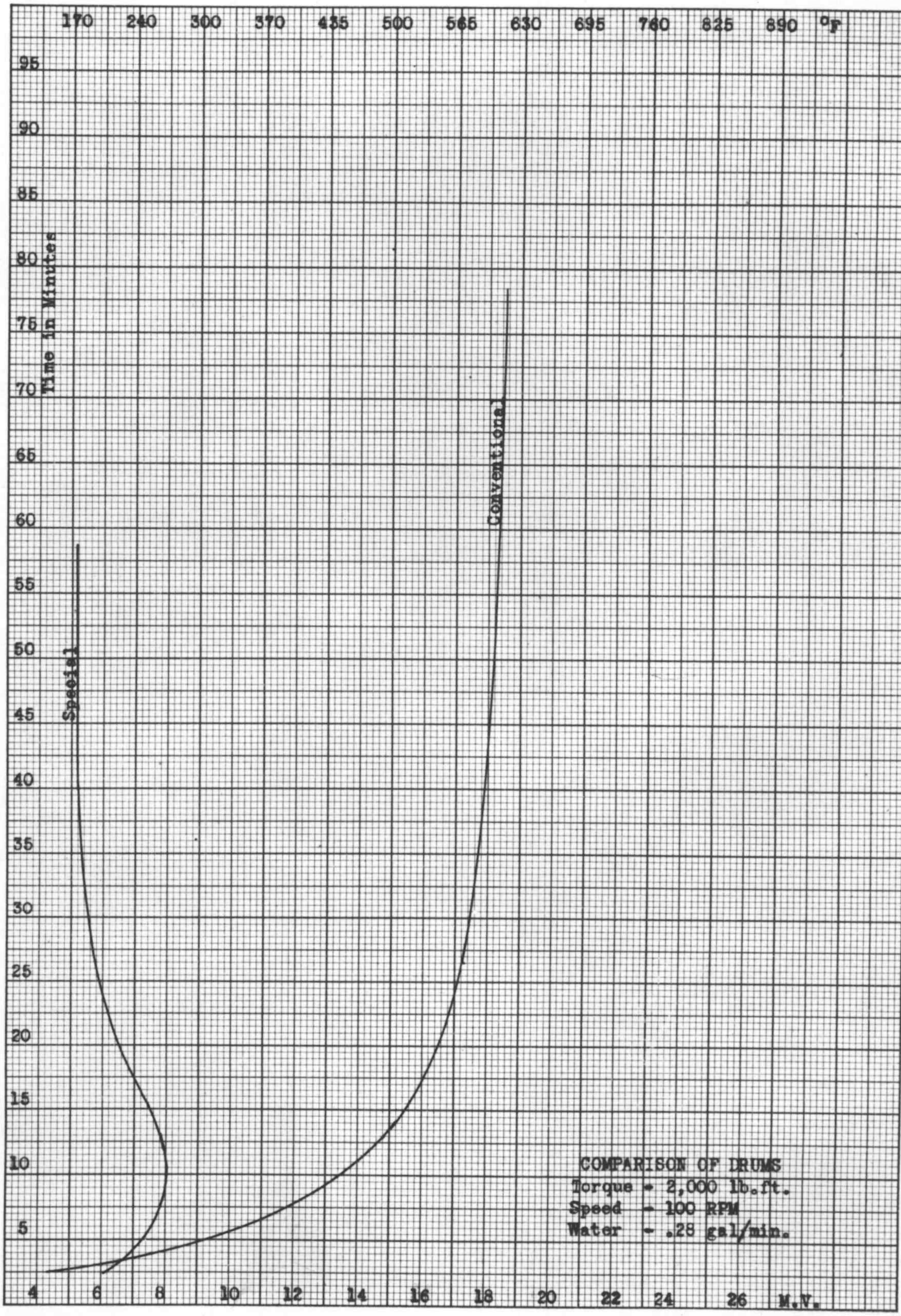
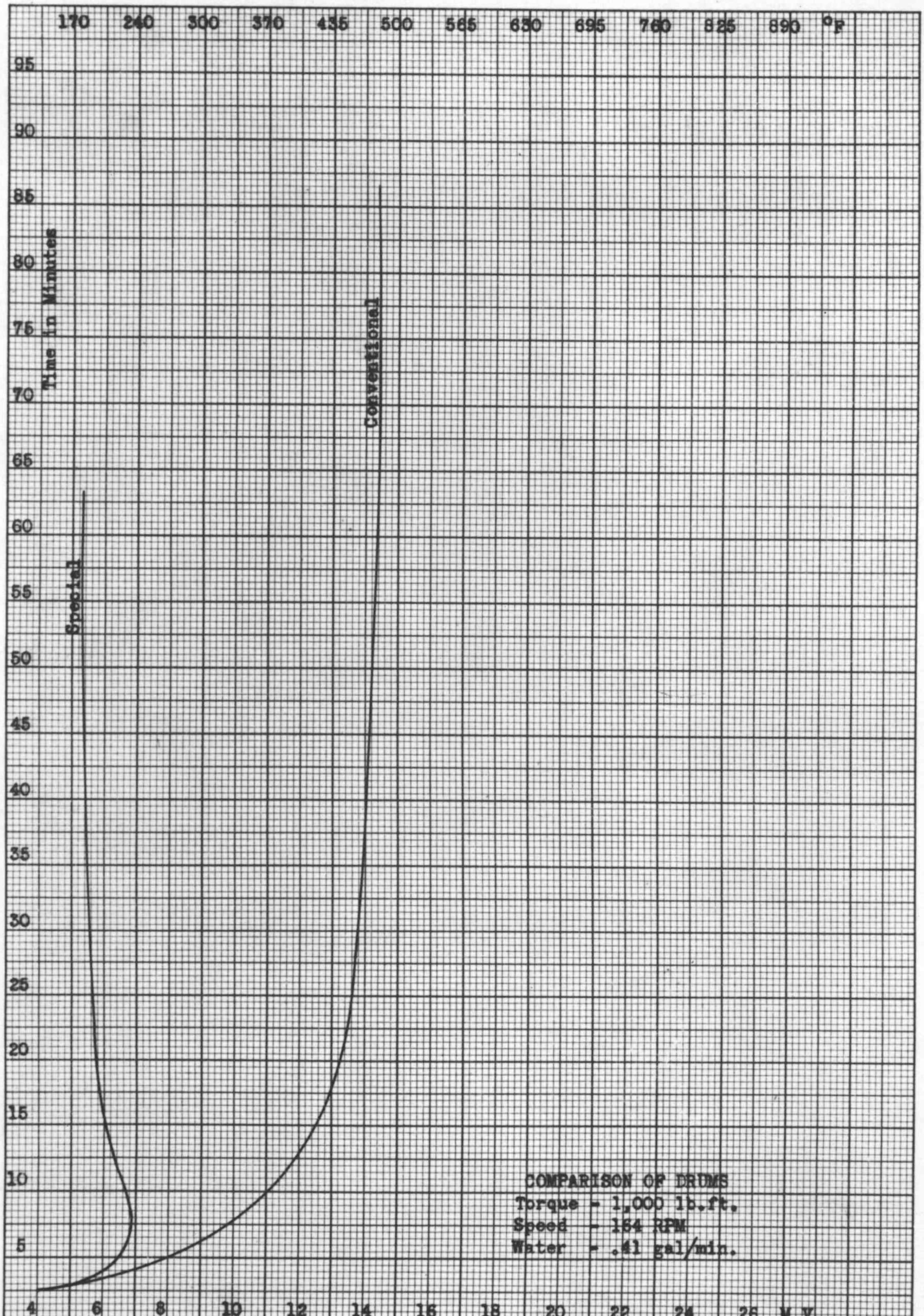
695
760
825
890
°F
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Time in Minutes
Conventional
Special
COMPARISON OF DRUMS
Torque - 2,000 lb.ft.
Speed - 100 RPM
Water - .41 gal/min.
4
6
8
10
12
14
16
18
20
22
24
26
M.V.



170 240 300 370 435 500 565 630 695 760 825 890 °F
95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
Time in Minutes
Special
Conventional
COMPARISON OF DRUMS
Torque - 2,000 lb.ft.
Speed - 100 RPM
Water - .28 gal/min.
4 6 8 10 12 14 16 18 20 22 24 26 M.V.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890
°F
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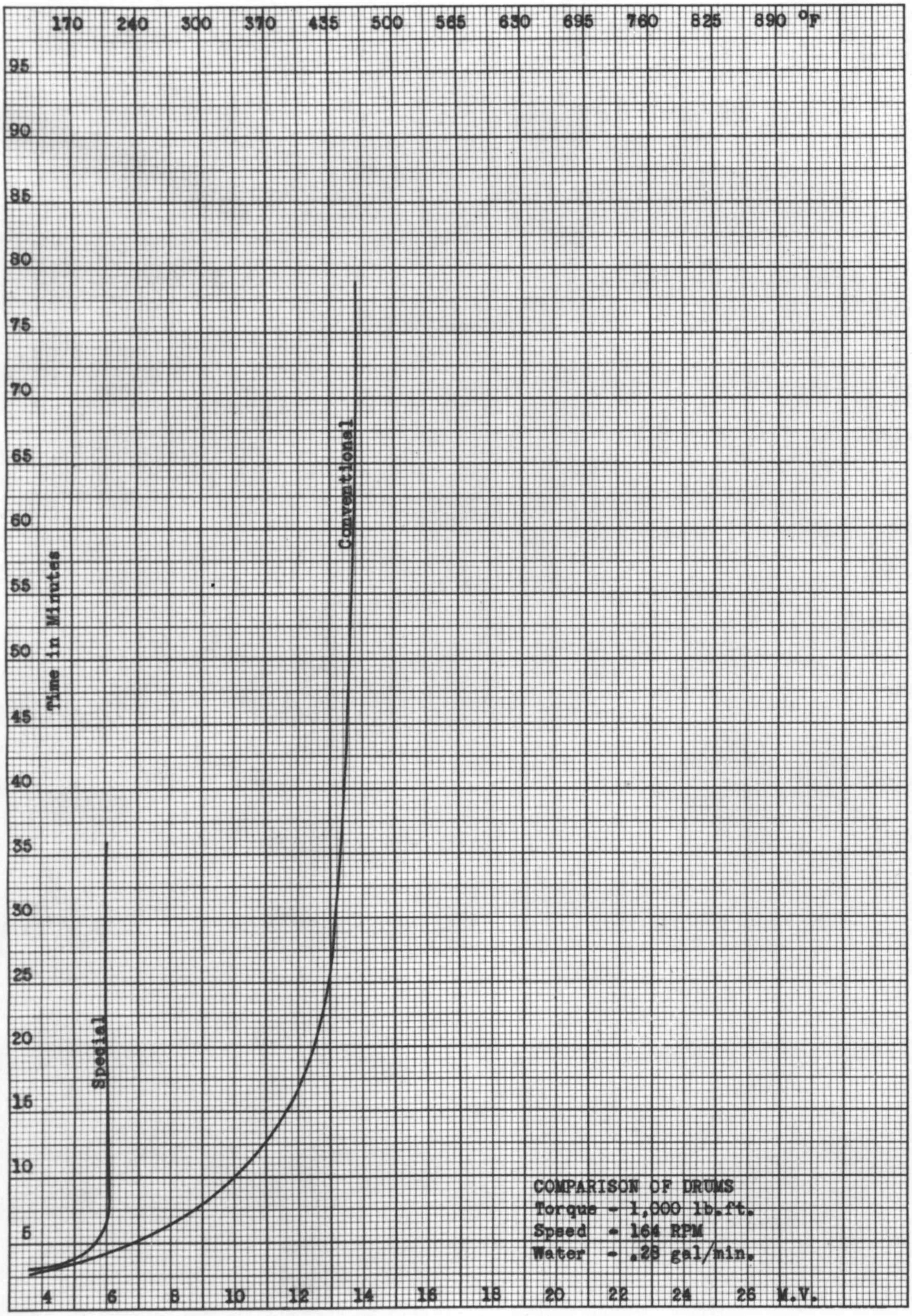
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Time in Minutes
Conventional
Special
COMPARISON OF DRUMS
Torque - 1,000 lb.ft.
Speed - 164 RPM
Water - .41 gal/min.
4
6
8
10
12
14
16
18
20
22
24
26
M.V.



170
240
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435
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630
695
760
825
890 °F
95
90
85
80
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60
55
50
45
40
35
30
25
20
15
10
5
Time in Minutes
Conventional
Special
COMPARISON OF DRUMS
Torque - 1,000 lb.ft.
Speed - 164 RPM
Water - .28 gal/min.
4
6
8
10
12
14
16
18
20
22
24
26 M.V.

the drum 1/2 to 3/4 inch. This would help because the open end of the drum has less metal and surface to dissipate the heat, thus a more uniform temperature probably would be maintained across the drum. Temperature differences across the drum were noted by the use of "Tempilsticks" as described on page 31.

Also, if the receiving vanes were cast in instead of being drilled the water would have easier access to the holes and would be affected less by the centrifugal force. The cast-in vanes could have a greater angle from the axis of the drum than the cored holes and the outside edges of the holes could be parallel to the axis of the drum instead of sloping as they are when drilled.

The water admitting ring, with the receiving vanes, could be made inside the drum and the water injected inside the drum between the shoes or through one of the shoes. The water injection point would be changed with this method to 90 or 180 degrees after top center. The effect of centrifugal force when using such a system would be advantageous instead of detrimental.

The special drum will, because of its thinner sections, have to be used differently. With the conventional system an operator frequently saves the water until the brake drums are quite hot before applying. This would be unsatisfactory for the special drum because of the severe quenching possible due to the large amount of surface area. The water should be applied concurrently with the brakes to have coolant on the drums all of the time they are heating. This would prevent excessive temperatures and would tend to keep heat checking at a minimum. This procedure would also aid in prolonging the life of the lining.

In general, these tests seem to indicate that the principle of cored holes in brake drums as an aid in cooling could be of considerable importance. The lower operating temperatures would tend to permit higher operating speeds with a possible decrease in lining wear, scoring, heat checking, cracking, and complete failure of drums.

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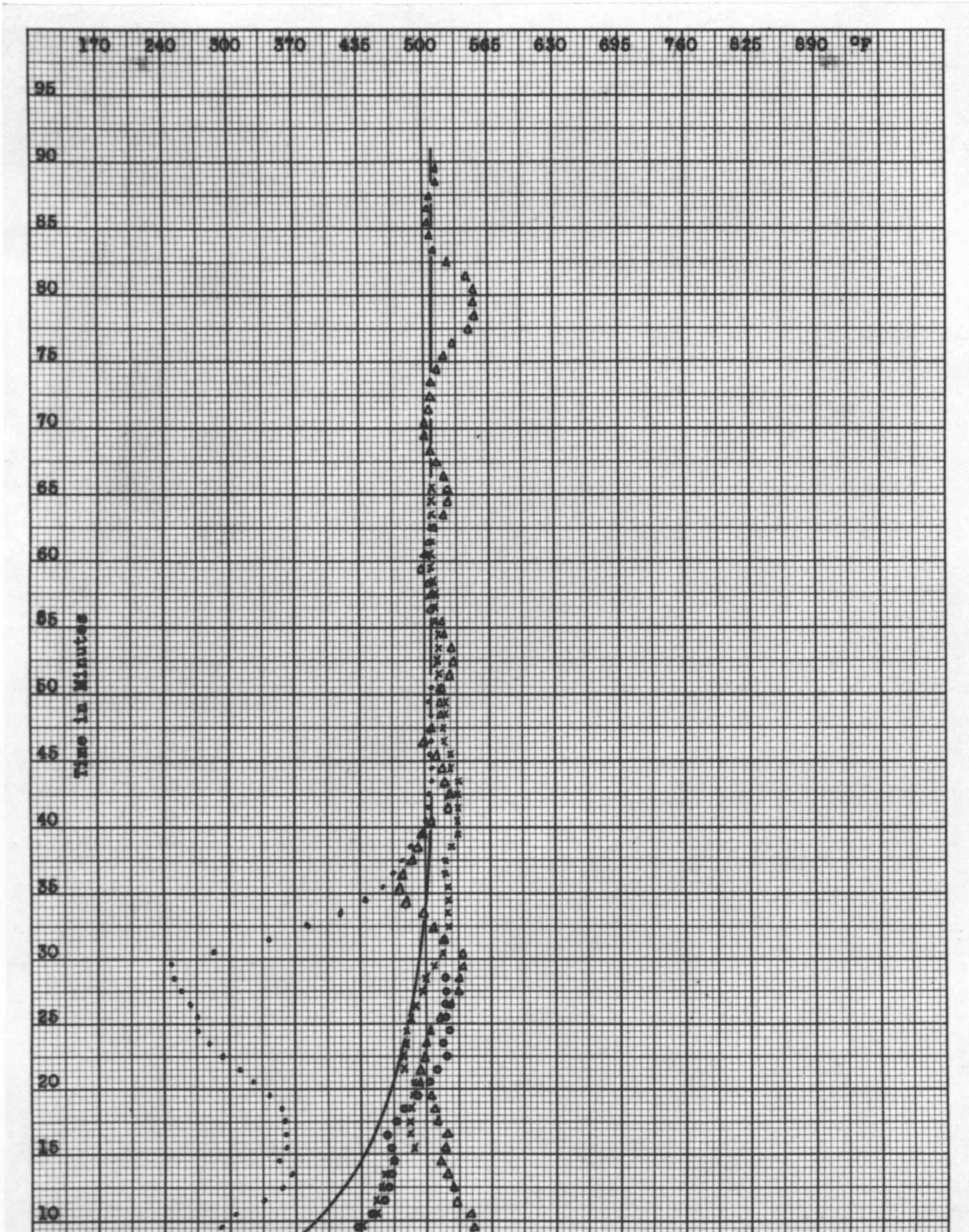
A P P E N D I X

TEMPERATURE RECORD FOR TEST ON CONVENTIONAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 2,000 lb-ft — Water Pressure - 0.41 gal/min
Drum Speed - 100 rpm — Water Outlet - 1/8" pipe

Run No. 1			Run No. 2		Run No. 3	
2.8	8.2	15.2	3.3	15.7	4.5	14.4
3.3	8.0	15.2	4.6	15.6	5.4	14.4
4.3	7.9	15.2	5.9	15.6	6.8	14.5
5.7	8.0	15.2	7.0	15.6	8.3	14.5
6.6	7.9	15.2	8.7	15.5	9.7	14.7
7.4	7.8	15.2	9.8	15.6	10.4	14.8
8.0	7.7	15.1	10.5	15.6	11.0	14.9
8.3	7.5	15.2	10.9	15.6	11.6	15.0
8.2	7.4	15.2	11.4		11.7	15.0
8.0	7.3		11.9		11.8	15.1
7.9	7.3		12.0		12.2	15.2
7.9	7.2		12.2		12.3	15.3
8.0	7.0		12.4		12.5	15.5
8.3	8.5		12.6		12.7	15.6
8.5	9.5		12.8		13.0	15.6
8.7	10.2		12.9		13.2	15.6
8.9	10.7		13.1		13.3	15.7
9.1	11.4		13.3		13.4	15.7
9.6	11.9		13.4		13.4	15.7
10.0	12.4		13.7		13.5	15.7
10.5	11.9		13.7		13.6	15.7
10.6	12.4		13.8		13.6	15.7
10.8	12.7		13.8		13.7	15.7
10.9	13.1		13.9		13.8	15.7
11.1	13.3		14.0		14.0	15.6
10.5	13.7		14.0		14.2	15.6
10.5	13.9		13.9		14.6	15.6
10.7	14.0		13.9		14.6	15.6
10.8	14.2		13.9		14.5	15.7
10.7	14.3		13.8		14.5	15.8
10.7	14.4		14.0		14.5	15.9
10.7	14.6		14.1		14.4	16.0
10.7	14.8		14.3		14.5	16.1
10.6	14.9		14.5		14.5	16.0
10.4	14.9		14.7		14.6	15.9
10.2	15.0		15.0		14.6	16.0
9.9	15.1		15.1		14.6	16.0
9.7	15.1		15.3		14.6	16.0
9.4	15.1		15.3		14.3	15.9
9.3	15.2		15.3		14.3	15.8
9.0	15.2		15.6		14.3	15.8
8.8	15.1		15.6		14.4	15.8
8.5	15.2		15.5		14.4	15.7
8.4	15.2		15.7		14.4	15.6

Run No. 3 (Con't.)	Run No. 4			
15.6	1.9	15.6	15.5	15.4
15.6	4.8	15.7	15.5	15.4
15.6	5.8	15.8	15.6	15.5
15.6	6.6	16.0	15.7	15.6
15.6	8.8	16.0	15.9	15.6
15.6	10.7	16.0	15.9	15.9
15.6	11.8	16.1	15.8	16.1
15.5	13.3	16.1	15.8	16.4
15.5	14.8	16.1	15.8	16.5
15.4	16.7	16.1	15.6	16.5
15.4	17.0	16.0	15.6	16.5
15.4	16.7	15.6	15.4	16.5
15.4	16.7	15.3	15.4	16.5
15.4	16.7	15.2	15.2	16.5
15.4	16.4	15.1	15.3	16.5
15.3	16.4	14.9	15.2	16.3
15.3	16.5	15.6	15.1	16.0
15.3	16.3	14.4	15.1	15.7
15.3	16.2	14.4	14.9	15.5
15.3	15.9	14.2	14.9	15.3
15.3	15.8	14.3	15.0	15.2
15.2	15.8	14.3	15.0	15.2
15.2	15.7	14.4	15.0	15.2
15.2	15.6	14.6	15.1	15.1
15.2	15.4	14.6	15.2	15.1
15.2	15.4	14.7	15.3	15.1
15.2	15.4	14.8	15.5	15.1
15.2	15.5	14.9	15.6	15.2
15.2	15.5	15.0	15.8	15.2
15.2	15.6	15.2	15.7	15.4
15.2	15.4	15.4	15.7	15.4
15.2	15.3	15.7	15.7	15.4
	15.3	15.7	15.7	
	15.2	15.7	15.6	
	15.2	15.7	15.6	
	15.1	15.6	15.4	
	14.9	15.6	15.2	
	14.8	15.5	15.2	
	14.9	15.4	15.2	
	14.8	15.3	15.0	
	14.8	15.0	15.0	
	14.9	15.0	15.0	
	15.0	15.1	15.0	
	15.0	15.2	15.1	
	15.0	15.3	15.2	
	15.1	15.5	15.2	
	15.2	15.5	15.2	
	15.4	15.5	15.2	


170
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35
30
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15
10
5
Time in Minutes
4
6
8
10
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14
16
18
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22
24
26
M.V.
CONVENTIONAL DRUM
Torque - 2,000 lb.ft.
Speed - 100 RPM
Water - .41 gal/min.

TEMPERATURE RECORD FOR TEST ON CONVENTIONAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 2,000 lb-ft — Water Pressure - 0.28 gal/min
Drum Speed - 100 rpm — Water Outlet - 1/8" pipe

Run No. 1

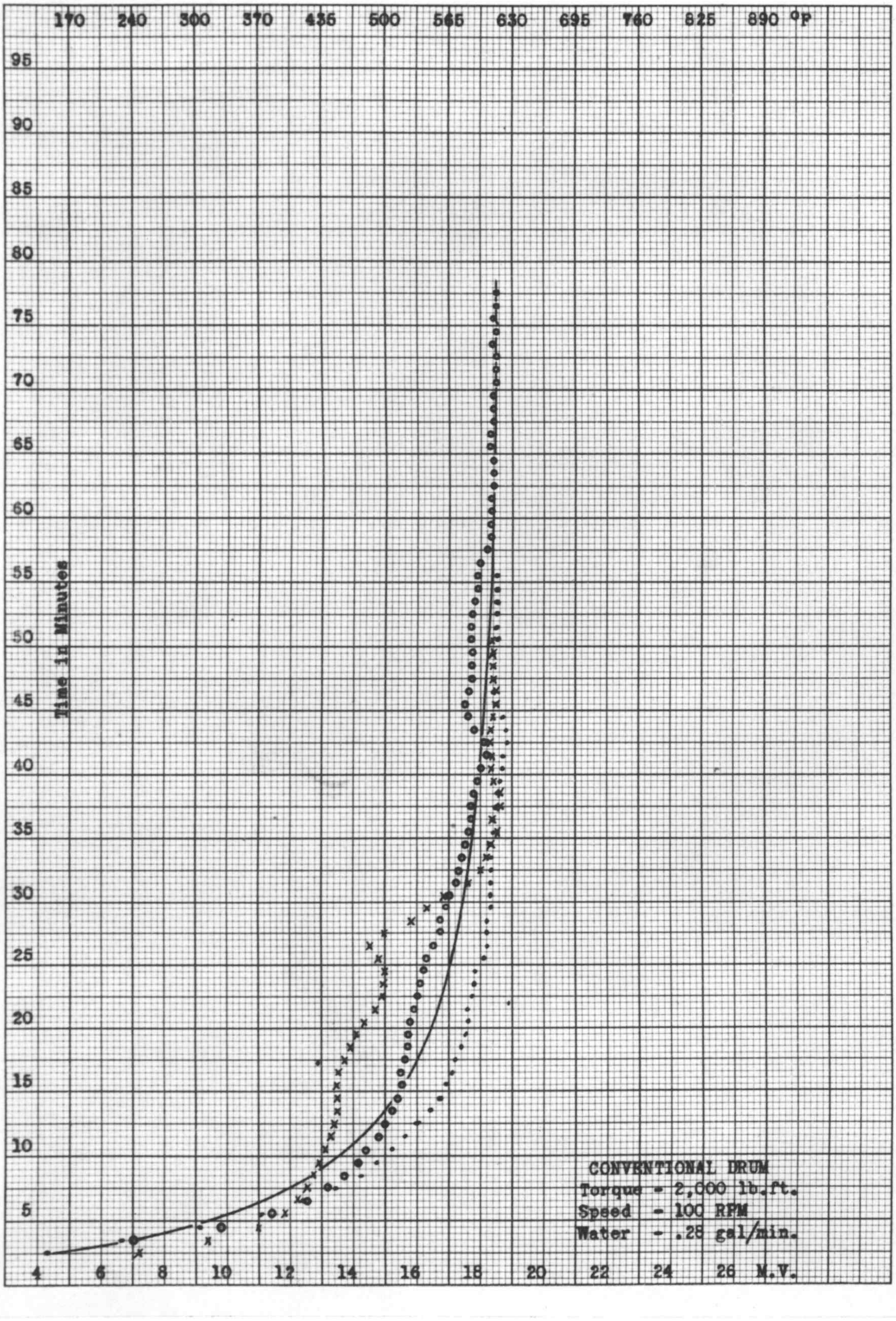
4.3	17.8	18.4
5.4	17.9	18.4
6.6	18.1	18.4
8.0	18.1	18.4
9.1	18.2	18.4
10.0	18.2	18.4
11.1	18.2	18.4
11.8	18.2	18.4
12.4	18.2	18.5
13.0	18.3	18.5
13.4	18.3	18.5
13.9	18.3	18.5
14.2	18.3	18.5
14.4	18.3	18.5
14.7	18.3	18.5
15.0	18.3	18.5
15.2	18.3	
15.4	18.3	
15.6	18.3	
15.9	18.3	
16.0	18.3	
16.2	18.4	
16.4	18.4	
16.5	18.4	
16.7	18.4	
16.8	18.5	
16.9	18.5	
17.0	18.5	
17.1	18.5	
17.2	18.5	
17.2	18.6	
17.4	18.6	
17.4	18.7	
17.4	18.7	
17.5	18.7	
17.5	18.8	
17.6	18.8	
17.6	18.8	
17.6	18.8	
17.7	18.8	
17.7	18.7	
17.7	18.6	
17.8	18.5	
17.8	18.4	

Run No. 2

4.3	16.3	17.6	18.4
5.6	16.3	17.7	18.5
7.0	16.4	17.7	18.5
8.4	16.5	17.7	18.5
9.8	16.7	17.7	18.5
10.7	16.7	17.7	18.5
11.4	16.7	17.7	18.4
11.9	16.7	17.7	18.4
12.5	16.8	17.7	18.4
12.8	16.9	17.7	18.5
13.2	16.9	17.7	18.5
13.4	17.0	17.8	18.4
13.7	17.2	17.8	18.5
13.9	17.2	17.9	18.5
14.1	17.2	17.9	18.5
14.3	17.3	17.9	18.5
14.4	17.3	17.9	
14.7	17.4	17.9	
14.8	17.5	18.0	
15.0	17.5	18.1	
15.0	17.5	18.2	
15.2	17.6	18.3	
15.2	17.6	18.3	
15.4	17.7	18.3	
15.4	17.7	18.3	
15.5	17.7	18.3	
15.5	17.8	18.3	
15.5	17.8	18.3	
15.6	17.8	18.3	
15.6	17.9	18.4	
15.6	17.9	18.4	
15.7	18.0	18.4	
15.7	18.2	18.4	
15.7	18.2	18.4	
15.7	18.2	18.4	
15.8	18.1	18.4	
15.8	17.9	18.3	
15.9	17.8	18.3	
15.9	17.7	18.3	
16.0	17.6	18.4	
16.0	17.5	18.4	
16.1	17.5	18.4	
16.1	17.5	18.4	
16.2	17.6	18.4	

Run No. 3

7.2	15.5
8.6	15.8
9.4	16.0
10.3	16.3
11.0	16.6
11.5	16.9
11.8	17.3
12.1	17.6
12.2	17.8
12.4	18.0
12.5	18.1
12.6	18.2
12.7	18.2
12.8	18.3
12.9	18.4
13.0	18.5
13.1	18.5
13.2	18.4
13.3	18.5
13.3	18.6
13.4	18.6
13.5	18.6
13.5	18.5
13.5	18.4
13.5	18.3
13.5	18.3
13.5	18.3
13.5	18.3
13.6	18.3
13.7	18.3
13.8	18.3
13.9	18.3
14.0	18.3
14.1	18.4
14.2	18.5
14.3	18.5
14.5	18.6
14.7	18.5
14.9	18.5
14.9	18.4
14.9	18.4
14.9	18.4
15.0	18.3
15.0	18.4
14.8	18.4
14.5	
14.5	
15.0	


170 240 300 370 435 500 565 630 695 760 825 890 °F
Time in Minutes
95
90
85
80
75
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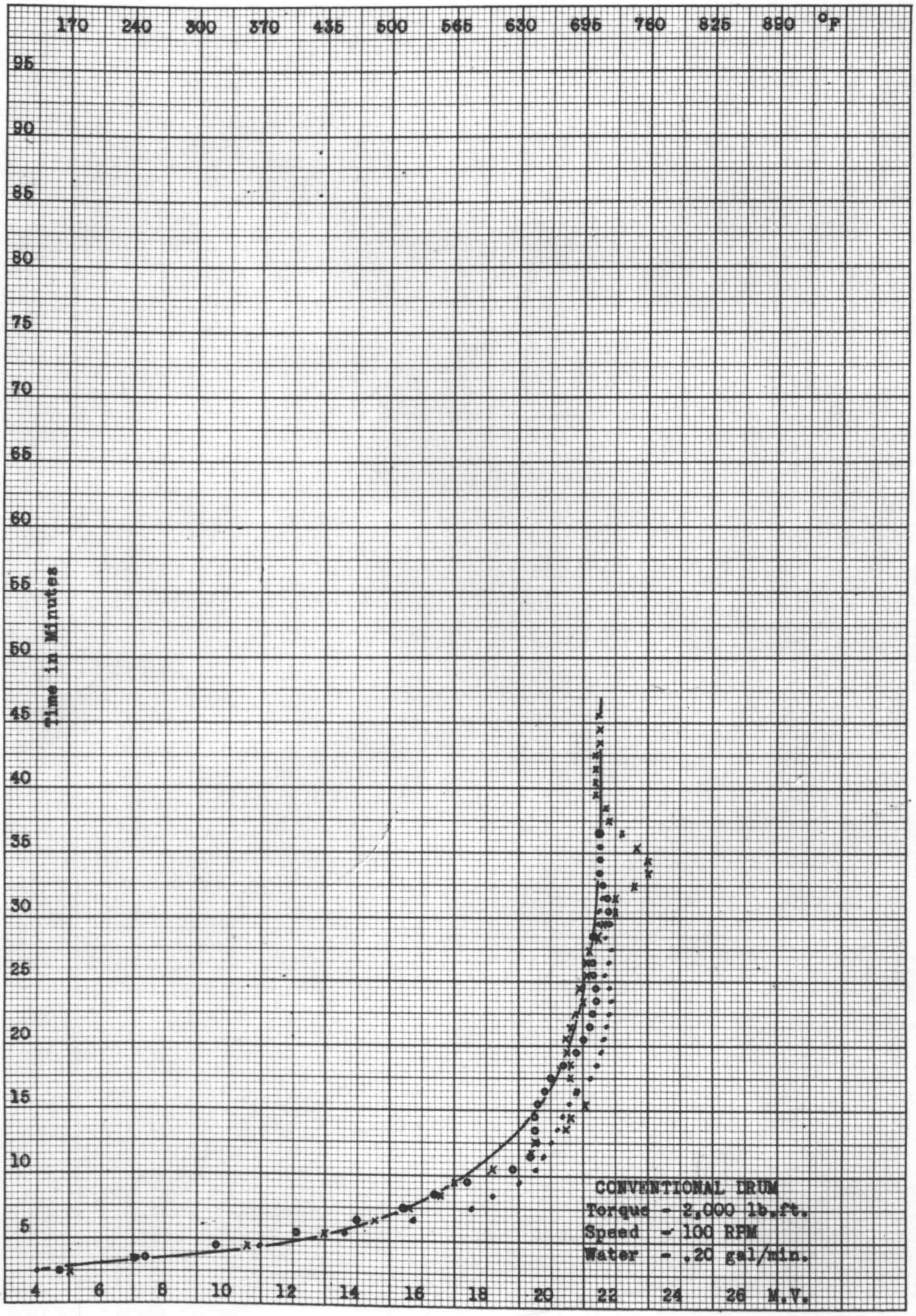
5
4 6 8 10 12 14 16 18 20 22 24 26 M.V.
CONVENTIONAL DRUM
Torque - 2,000 lb.ft.
Speed - 100 RPM
Water - .28 gal/min.

TEMPERATURE RECORD FOR TEST ON CONVENTIONAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 2,000 lb-ft — Water Pressure - 0.20 gal/min
Drum Speed - 100 rpm — Water Outlet - 1/8" pipe

Run No. 1		Run No. 2		Run No. 3	
4.0	21.8	4.7	21.4	5.0	20.9
5.4	21.8	5.7	21.3	6.0	21.1
7.0	21.7	7.4	21.3	7.0	21.1
9.1	21.7	8.6	21.2	8.9	21.1
11.0	21.8	9.6	21.3	10.6	21.1
12.2	21.8	11.0	21.3	11.6	21.2
13.6	21.9	12.1	21.2	13.0	21.2
14.8	21.8	13.0	21.2	13.7	21.3
15.7	21.7	14.0	21.3	14.6	21.4
16.7	21.6	14.9	21.5	14.8	21.5
17.5	21.6	15.4	21.8	15.6	21.6
17.7	21.6	16.1	21.8	16.1	21.7
18.2	21.5	16.4	21.8	16.6	22.0
18.6	21.5	16.7	21.8	16.8	22.0
19.0	21.6	17.4	21.7	17.0	22.0
19.3	21.6	18.3	21.6	17.5	22.5
19.5	21.6	18.8	21.6	18.2	22.6
19.6	21.5	19.2	21.5	19.2	22.8
19.8	21.5	19.4	21.5	19.3	23.0
19.9	21.5	19.5	21.5	19.3	23.0
20.0	21.5	19.5	21.5	19.5	23.0
20.1	21.5	19.6	21.5	20.0	22.8
20.2	21.5	19.5	21.5	20.5	22.7
20.4	21.5	19.5	21.5	20.6	22.4
20.4		19.5		20.6	22.2
20.6		19.6		21.0	22.0
20.6		19.6		21.1	21.8
20.7		19.6		20.0	21.8
20.8		19.8		20.8	21.7
21.1		19.9		20.6	21.6
21.2		20.0		20.6	21.4
21.3		20.1		20.6	21.4
21.4		20.4		20.6	21.4
21.4		20.7		20.5	21.4
21.5		20.8		20.5	21.4
21.6		20.8		20.5	21.4
21.6		21.0		20.5	21.4
21.7		21.0		20.5	21.5
21.7		21.2		20.6	21.5
21.8		21.2		20.7	21.5
21.8		21.3		20.8	21.5
21.8		21.4		20.9	21.5
21.9		21.4		21.0	21.5
21.9		21.4		20.9	


170 240 300 370 435 500 565 630 695 760 825 890 °F
Time in Minutes
95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
4 6 8 10 12 14 16 18 20 22 24 26 M.V.
CONVENTIONAL DRUM
Torque - 2,000 lb.ft.
Speed - 100 RPM
Water - .20 gal/min.

TEMPERATURE RECORD FOR TEST ON CONVENTIONAL DRUM

Readings in Millivolts	30 Second Intervals
Torque - 1,000 lb-ft	Water Pressure - 0.41 gal/min
Drum Speed - 164 rpm	Water Outlet - 1/8" pipe

Run No. 1

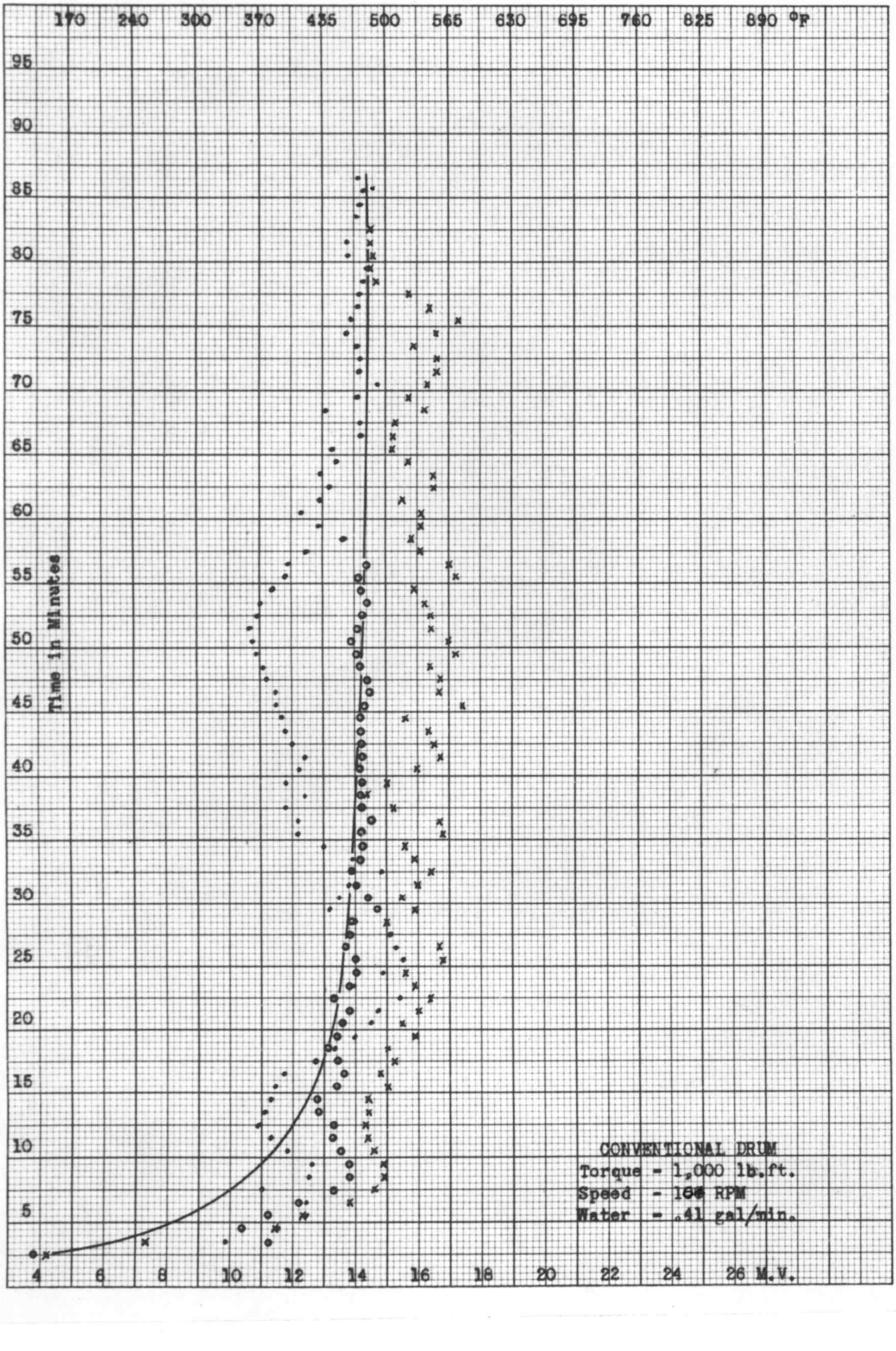
2.1	15.6	11.7	14.0
2.2	15.4	11.7	14.2
2.4	14.8	11.7	14.6
3.2	13.7	11.5	14.2
3.3	15.2	11.5	13.4
	14.9	11.5	13.1
	15.2	11.3	13.3
9.9	15.5	11.2	14.1
10.7	15.0	11.1	14.6
11.5	15.3	11.1	14.8
12.3	15.6	10.9	14.5
12.4	15.1	10.9	14.2
12.4	14.9	10.8	14.2
12.4	14.0	10.8	14.2
12.2	13.4	10.7	14.0
11.0	13.2	10.7	14.1
11.4	13.7	10.9	13.8
12.5	13.5	10.9	13.8
12.7	13.4	11.0	13.9
12.6	13.8	11.0	13.9
12.0	14.4	11.1	13.9
11.8	14.9	11.4	14.1
11.7	14.2	11.7	14.2
11.3	13.9	11.8	14.2
11.2	13.4	12.0	14.2
10.9	13.0	11.9	14.3
10.6	12.5	12.1	14.3
11.1	12.2	12.5	14.5
11.1	12.2	13.1	15.2
11.3	12.2	13.6	13.8
11.8	11.9	13.4	13.9
11.4	11.8	12.9	13.8
11.5	12.6	12.6	14.4
11.7	12.4	12.3	14.6
12.0	11.8	12.6	14.0
12.7	11.8	12.9	14.1
12.9	11.9	13.2	14.2
13.2	12.2	13.2	14.2
13.2	12.5	13.0	14.3
14.0	12.4	12.9	14.3
14.0	11.7	13.1	14.3
14.5	12.0	13.4	14.1
14.7	12.0	13.2	
14.7	11.8	13.3	

Run No. 2

4.8	14.0	14.5
10.2	14.2	14.6
11.2	14.0	14.4
10.8	14.0	14.2
10.4	13.7	14.2
10.2	13.6	14.1
11.2	13.8	14.1
11.8	13.7	14.1
12.2	13.9	13.9
12.8	14.5	14.1
13.3	14.7	14.1
13.6	14.5	14.3
13.8	14.4	14.3
13.9	14.1	14.3
13.8	14.0	14.4
13.8	13.9	14.3
13.5	13.9	14.2
13.3	14.0	14.1
13.3	14.1	14.1
13.3	14.3	14.3
13.3	14.2	14.4
13.1	14.2	
12.8	14.2	
12.7	14.3	
12.8	14.5	
13.2	14.6	
13.4	14.2	
13.4	14.1	
13.6	14.2	
13.6	14.2	
13.4	14.2	
13.2	14.1	
13.1	14.1	
13.4	14.2	
13.4	14.2	
13.5	14.1	
13.6	14.2	
13.7	14.2	
13.8	14.2	
13.4	14.2	
13.3	14.2	
13.6	14.2	
13.8	14.3	
13.8	14.5	

Run No. 3

4.2	16.7	16.1
6.4	15.9	15.7
7.3	15.2	15.5
10.2	14.6	16.0
11.4	14.4	16.5
11.6	14.6	16.7
12.3	15.0	16.5
13.1	15.3	16.3
13.8	16.0	15.7
14.3	16.7	15.3
14.6	16.7	15.2
14.7	16.7	15.2
14.9	16.5	15.2
14.9	16.4	15.2
14.9	16.3	15.3
14.8	15.8	15.5
14.6	15.6	16.2
14.3	16.5	16.0
14.4	17.4	15.7
14.4	17.3	15.9
14.3	16.7	16.3
14.4	16.7	16.4
14.4	16.7	16.6
14.4	16.4	16.8
14.4	16.4	16.6
14.9	16.9	16.1
15.0	17.2	15.9
14.9	17.2	16.2
14.8	17.0	16.6
14.9	16.7	17.0
15.2	16.4	17.3
15.1	16.2	16.8
15.0	16.4	16.4
15.5	16.5	15.9
15.9	16.2	15.7
15.7	16.2	15.0
15.5	15.9	14.7
15.6	16.8	14.5
16.0	17.2	14.5
16.2	17.2	14.5
16.4	17.0	14.6
16.3	16.4	14.2
15.9	16.1	15.4
15.3	15.8	14.5
15.6	15.8	14.5
16.2	16.0	
16.8	16.1	
16.6	16.2	


170
240
300
370
435
500
565
630
695
760
825
890 °F
95
90
85
80
75
70
65
60
55
50
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20
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10
5
Time in Minutes
CONVENTIONAL DRUM
Torque - 1,000 lb.ft.
Speed - 164 RPM
Water - .41 gal/min.
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6
8
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12
14
16
18
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22
24
26 M.V.

TEMPERATURE RECORD FOR TEST ON CONVENTIONAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 1,000 lb-ft — Water Pressure - 0.28 gal/min
Drum Speed - 164 rpm — Water Outlet - 1/8" pipe

Run No. 1

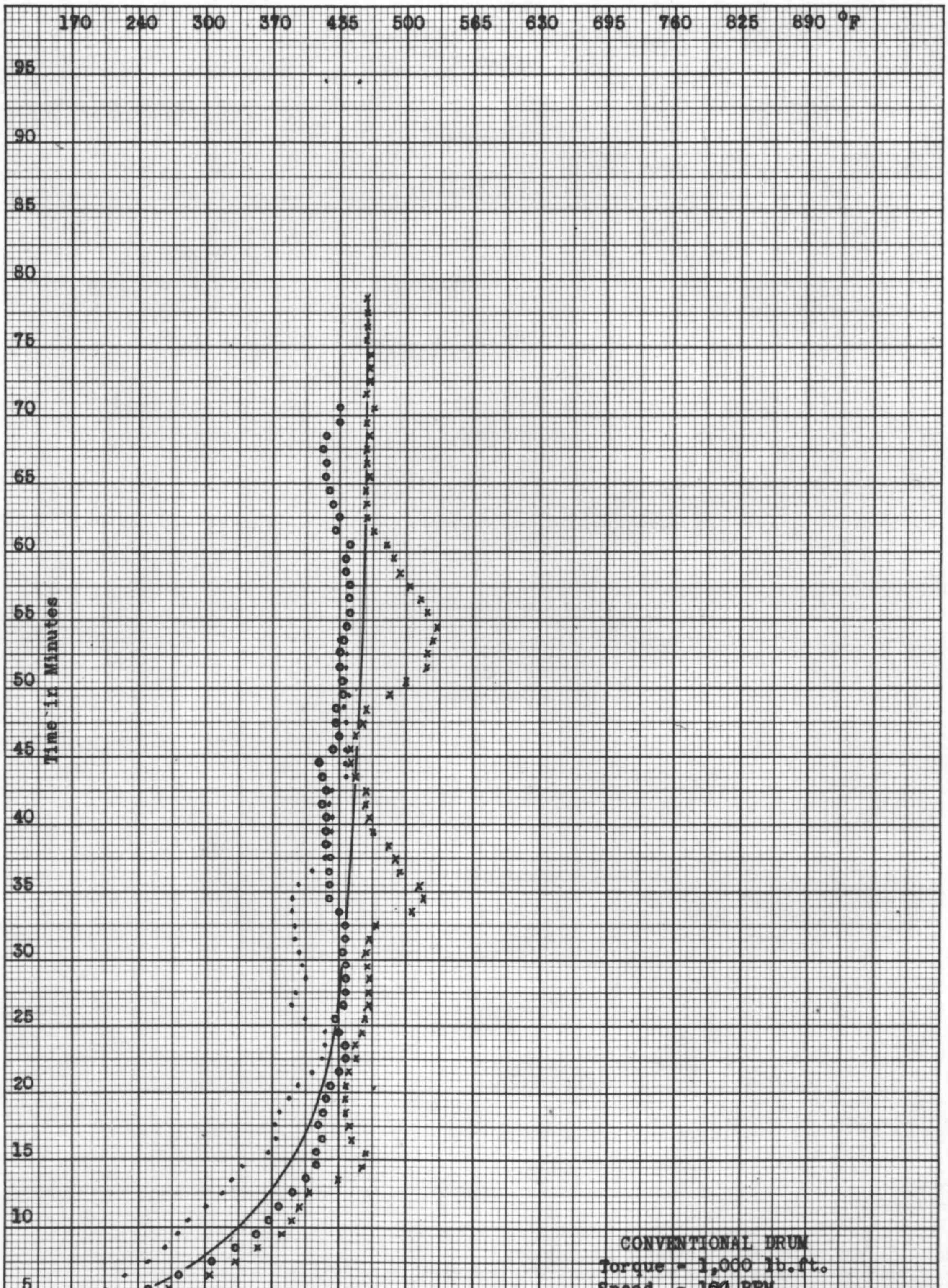
3.7	12.4	13.0
4.2	12.0	13.2
4.6	11.8	13.2
4.9	11.6	13.1
5.3	11.7	13.1
5.6	11.7	13.3
6.0	11.8	13.3
6.4	12.0	13.2
6.6	12.1	13.2
7.0	11.9	13.0
7.3	11.9	13.2
7.6	11.8	13.2
7.8	11.8	13.2
8.0	11.8	13.0
8.2	11.7	13.0
8.4	11.8	
8.8	11.7	
9.0	11.6	
9.3	11.6	
9.5	11.6	
9.7	11.6	
9.8	11.7	
9.9	11.8	
10.1	12.0	
10.6	12.2	
10.9	12.4	
11.0	12.6	
11.1	12.6	
11.0	12.7	
11.1	12.8	
11.2	12.8	
11.2	12.8	
11.4	12.8	
11.5	12.7	
11.7	12.7	
11.8	12.7	
12.0	12.8	
12.2	12.9	
12.5	13.2	
12.5	13.3	
12.5	13.2	
12.6	13.2	
12.6	13.2	
12.6	13.1	

Run No. 2

1.1	13.1	13.1	12.6
3.0	13.0	13.0	12.6
3.6	12.8	12.9	13.0
3.8	12.9	12.9	13.0
5.2	13.0	12.9	13.0
5.6	13.1	12.9	13.0
6.8	13.1	12.9	
7.3	13.2	13.1	
7.8	13.2	13.1	
8.2	13.2	13.1	
8.7	13.2	13.0	
9.2	13.2	13.0	
9.7	13.2	13.1	
9.8	13.1	13.0	
10.2	13.2	13.1	
10.5	13.2	13.1	
10.7	13.2	13.2	
10.9	13.2	13.2	
11.1	13.1	13.2	
11.2	13.0	13.3	
11.5	12.8	13.3	
11.6	12.7	13.3	
11.7	12.7	13.3	
12.0	12.7	13.3	
12.2	12.7	13.2	
12.3	12.7	13.2	
12.3	12.7	13.2	
12.3	12.7	13.2	
12.4	12.7	13.3	
12.5	12.6	13.3	
12.5	12.6	13.2	
12.4	12.6	12.9	
12.5	12.6	12.9	
12.5	12.6	13.0	
12.5	12.6	13.0	
12.6	12.5	12.8	
12.6	12.6	12.8	
12.7	12.6	12.7	
12.8	12.6	12.6	
13.0	12.5	12.6	
13.1	12.5	12.6	
13.2	12.4	12.6	
13.2	12.4	12.6	
13.2	12.8	12.5	

Run No. 3

3.0	13.8	14.8	13.9
3.9	13.9	15.0	13.9
5.0	13.9	15.3	13.8
6.2	13.9	15.6	13.8
6.9	13.9	15.6	13.9
7.5	13.9	15.6	13.8
7.8	14.0	15.7	13.8
7.9	13.8	15.8	13.8
8.7	13.8	15.8	13.8
9.1	13.8	15.9	13.8
9.4	13.8	15.8	13.8
9.9	13.9	15.6	
10.3	14.0	15.6	
10.6	14.1	15.4	
10.9	15.0	15.2	
11.3	15.2	15.1	
11.5	15.6	15.0	
11.6	15.5	14.8	
11.8	15.5	14.7	
11.8	15.4	14.6	
11.9	15.0	14.7	
12.1	14.8	14.4	
12.4	14.8	14.2	
13.0	14.7	14.0	
13.4	14.7	13.8	
13.7	14.5	13.8	
14.0	14.3	13.8	
13.8	14.0	13.8	
13.7	14.0	13.8	
13.4	13.9	13.8	
13.4	13.9	13.9	
13.3	13.8	13.9	
13.2	13.8	13.8	
13.2	13.7	13.9	
13.2	13.5	13.8	
13.2	13.3	13.8	
13.2	13.3	13.9	
13.2	13.3	13.9	
13.3	13.3	13.8	
13.4	13.5	13.9	
13.5	13.5	14.0	
13.4	13.6	13.9	
13.8	13.7	13.8	
13.6	13.8	13.8	
13.7	13.8	13.9	
13.7	14.3	13.9	
13.8	14.5	13.9	


170 240 300 370 435 500 565 630 695 760 825 890 °F
95
90
85
80
75
70
65
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55
50
45
40
35
30
25
20
15
10
5
Time in Minutes
4 6 8 10 12 14 16 18 20 22 24 26 M.V.
CONVENTIONAL DRUM
Torque - 1,000 lb.ft.
Speed - 164 RPM
Water - .28 gal/min.

TEMPERATURE RECORD FOR TEST ON CONVENTIONAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 1,000 lb-ft — Water - 0.20 gal/min
Drum Speed - 164 rpm — Water Outlet - 1/8" pipe

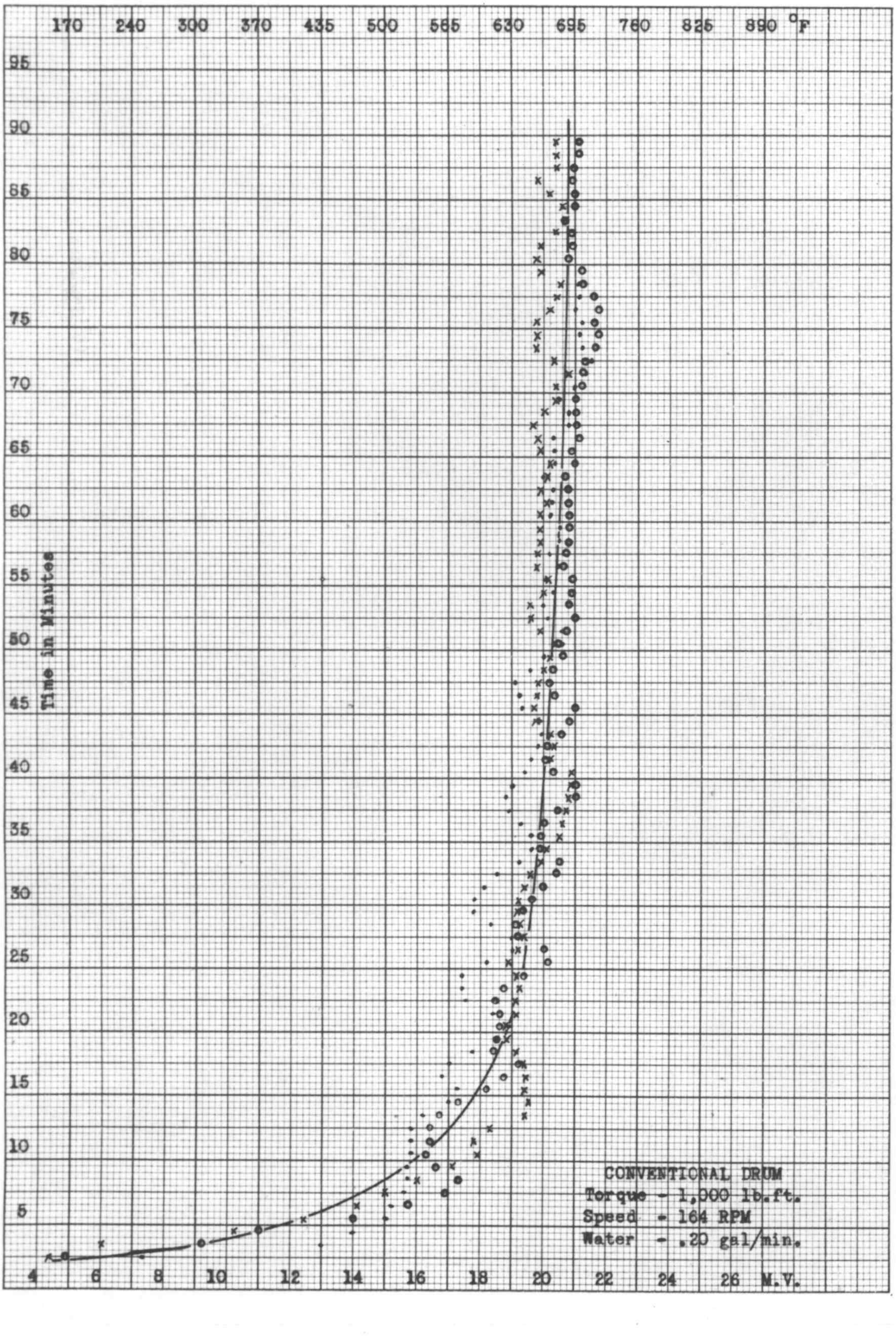
Run No. 1

7.3	17.4	19.2	20.8
8.0	17.7	19.1	20.4
13.0	18.2	19.1	20.5
13.5	18.6	19.5	21.0
14.0	19.0	19.6	21.0
14.6	19.1	19.7	21.0
15.0	19.0	20.0	21.3
15.3	18.5	20.5	21.5
15.2	18.3	20.6	21.5
15.5	18.0	20.6	21.3
15.6	17.8	20.6	21.3
15.7	17.8	20.4	21.1
15.7	17.8	20.1	21.1
15.7	18.0	19.8	21.1
15.7	18.1	20.0	21.2
15.8	18.3	20.3	21.0
15.8	18.5	20.3	21.0
15.8	18.7	20.4	21.0
15.8	19.2	20.6	21.1
15.8	19.4	20.6	21.1
15.8	19.6	20.5	21.1
15.8	19.8	20.3	
16.2	19.6	20.2	
16.5	19.4	20.3	
17.0	19.3	20.5	
17.2	19.0	20.3	
17.2	18.9	20.5	
17.0	18.9	20.2	
16.8	18.8	20.2	
16.7	19.0	20.4	
17.0	19.0	20.3	
17.4	19.3	20.3	
17.7	19.4	20.3	
18.5	19.4	20.1	
18.5	19.6	20.0	
18.7	19.7	20.1	
18.8	19.8	20.3	
18.6	19.9	20.2	
18.4	19.9	20.3	
17.9	19.9	20.1	
17.5	19.8	20.3	
17.5	19.5	20.6	
17.4	19.3	20.6	
17.4	19.3	20.6	

Run No. 2

2.8	19.2	20.6
4.9	19.4	20.3
8.0	19.9	20.2
9.2	20.1	20.2
10.2	20.2	20.3
11.0	20.0	20.3
12.2	19.5	20.3
14.0	19.2	20.6
14.6	19.3	20.6
15.7	19.1	20.5
16.2	19.1	20.7
16.9	19.3	20.7
17.2	19.4	21.0
17.3	19.6	21.0
16.8	19.7	20.8
16.6	20.0	20.8
16.4	20.2	20.8
16.3	20.4	20.9
16.3	20.7	20.9
16.4	20.5	20.9
16.4	20.1	20.6
16.4	19.9	20.6
16.5	19.8	20.6
16.7	19.9	20.7
17.0	19.9	20.8
17.3	20.0	20.8
17.8	20.2	20.8
18.2	20.5	20.8
18.5	20.6	20.7
18.7	21.0	20.8
19.0	21.1	20.8
19.2	21.0	20.8
18.7	20.5	20.8
18.4	20.3	20.8
18.3	20.3	20.9
18.5	20.1	20.7
18.9	20.0	20.9
18.6	20.1	21.0
18.6	20.2	21.0
18.6	20.6	20.9
18.6	20.8	20.9
18.5	20.8	21.1
18.7	21.0	21.0
18.7	21.0	21.0

Run No. 2 (Con't.)	Run No. 3			
21.0	4.4	19.0	20.2	20.3
21.0	5.3	19.2	20.3	20.2
21.1	6.0	19.2	20.4	19.8
21.0	8.2	19.4	20.2	19.8
21.2	10.2	19.3	19.9	19.8
21.2	11.7	19.2	19.6	19.8
21.2	12.4	19.3	19.6	19.8
21.3	13.3	19.2	19.6	19.9
21.3	14.1	19.3	19.6	20.2
21.3	14.6	19.2	19.8	20.2
21.5	15.0	19.4	20.0	20.4
21.6	15.6	19.4	20.2	20.4
21.7	16.0	19.5	20.1	20.5
21.7	16.5	19.6	20.1	20.2
21.6	17.1	19.8	19.8	19.9
21.6	17.6	19.9	19.8	19.7
21.7	17.9	20.1	19.8	19.8
21.7	17.9	20.1	19.8	19.8
21.7	17.8	20.3	19.9	19.9
21.6	17.9	20.5	19.9	20.0
21.3	18.3	20.6	19.9	20.4
21.2	18.8	20.6	19.9	20.7
21.2	19.4	20.7	19.9	20.7
21.2	19.5	20.7	20.0	20.8
21.0	19.5	20.8	20.1	20.6
20.8	19.4	20.8	20.0	20.3
20.9	19.4	20.9	19.9	20.2
20.9	19.4	20.9	19.9	19.9
20.9	19.5	20.9	20.1	19.8
20.9	19.4	20.9	20.1	20.2
20.8	19.3	20.6	20.2	20.4
20.7	19.3	20.2	20.1	20.4
20.9	19.1	20.2	19.9	20.4
21.0	18.9	20.3	20.0	20.6
21.0	18.8	20.3	19.8	20.4
21.0	18.8	20.2		
20.9	18.8	20.0	19.7	
20.9	18.9	19.8	19.7	
20.9	19.1	19.7	19.8	
21.0	19.1	19.7	20.0	
21.1	19.1	19.8	20.3	
21.1	19.2	19.8	20.4	
21.0	19.2	19.8	20.4	
21.1	19.1	19.8	20.4	
	19.1	19.9	20.5	
	18.9	20.0	20.8	
	18.9	20.2	20.6	



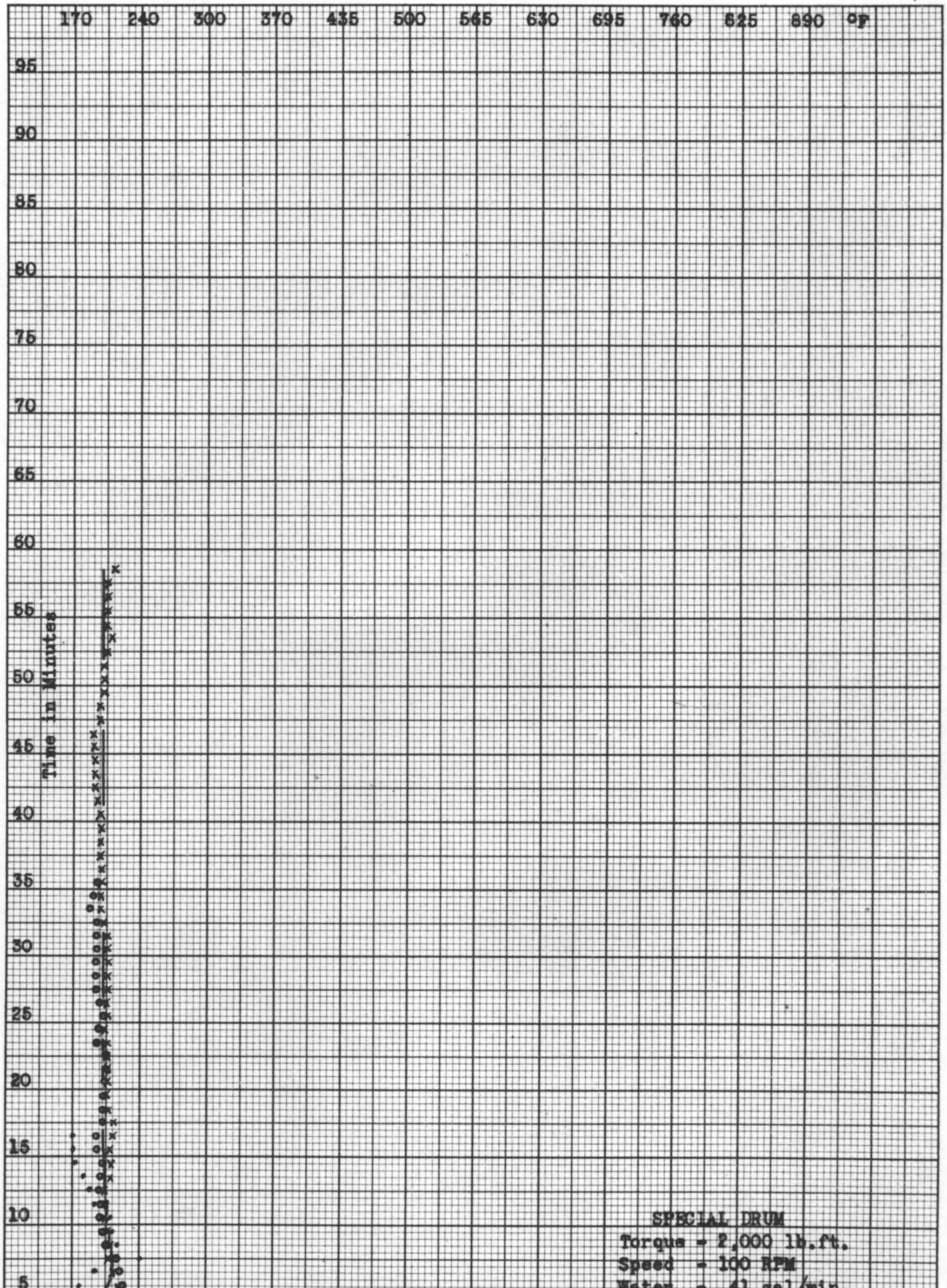
170 240 300 370 435 500 565 630 695 760 825 890 °F
95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
Time in Minutes
4 6 8 10 12 14 16 18 20 22 24 26 M.V.
CONVENTIONAL DRUM
Torque - 1,000 lb.ft.
Speed - 164 RPM
Water - .20 gal/min.

TEMPERATURE RECORD FOR TEST ON SPECIAL DRUM

Readings in Millivolts
Torque - 2,000 lb-ft
Drum Speed - 100 rpm

Water - 0.41 gal/min
30 Second Intervals
Water Outlet - Two 1/16" jets

Run No. 1	Run No. 2		Run No. 3		
3.5	3.7	5.8	4.2	6.0	5.7
4.7	5.3	5.8	4.8	6.0	5.8
5.2	6.4	5.9	6.0	6.0	5.8
5.5	6.7	5.9	6.4	6.0	5.8
5.7	6.7	5.8	6.4	6.0	5.9
4.5	6.6	5.7	6.5	6.0	5.9
4.0	6.5	5.7	6.4	6.0	5.9
5.2	6.5	5.6	6.3	6.0	5.9
5.6	6.4	5.7	6.2	6.0	5.9
6.1	6.3	5.7	6.2	6.0	5.9
7.0	6.3	5.7	6.1	6.0	5.9
7.0	6.1	5.7	6.1	6.0	6.0
6.3	6.0	5.7	6.1	6.0	6.1
5.9	5.9	5.7	6.1	6.0	6.1
6.1	5.9	5.7	6.1	6.0	6.1
6.1	5.8	5.7	6.0	5.0	6.0
6.1	5.8	5.7	6.0	5.8	6.0
6.1	5.8	5.5	6.0	5.8	6.0
5.7	5.8	5.5	6.0	5.8	6.0
5.7	5.9	5.6	6.0	5.8	6.0
5.5	5.8	5.7	6.0	5.8	6.0
5.4	5.8	5.7	6.1	5.8	6.0
5.3	5.8		6.1	5.8	6.1
5.2	5.8		6.1	5.8	6.2
5.1	5.9		6.1	5.8	
5.0	5.8		6.1	5.8	
5.0	5.7		6.1	5.8	
5.0	5.7		6.2	5.8	
	5.7		6.1	5.8	
	5.8		6.2	5.8	
	5.8		6.1	5.8	
	5.9		6.0	5.8	
	5.9		6.0	5.8	
	5.9		6.0	5.7	
	5.9		6.0	5.6	
	5.9		6.0	5.6	
	6.0		6.0	5.6	
	6.0		6.0	5.6	
	6.0		6.0	5.6	
	6.0		6.0	5.6	
	6.0		6.0	5.6	
	5.8		6.0	5.6	
	5.7		6.0	5.6	
	5.7		5.9	5.6	

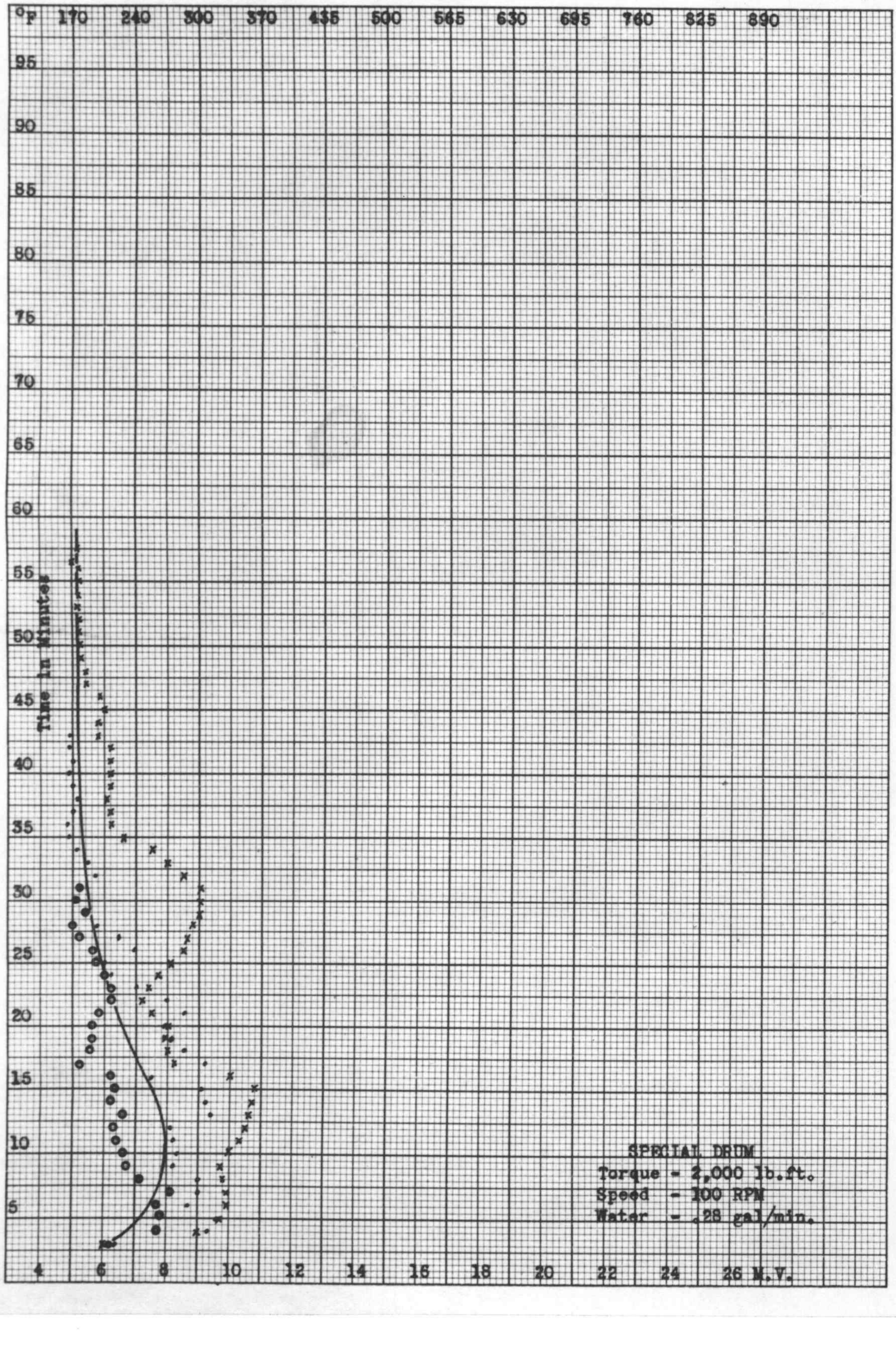


170 240 300 370 435 500 565 630 695 760 825 890 °F
95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
Time in Minutes
Temperature in Millivolts
4 6 8 10 12 14 16 18 20 22 24 26 28
SPECIAL DRUM
Torque - 2,000 lb.ft.
Speed - 100 RPM
Water - .41 gal/min.

TEMPERATURE RECORD FOR TEST ON SPECIAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 2,000 lb-ft — Water - 0.28 gal/min
Drum Speed - 100 rpm — Water Outlet - Two 1/16" jets

Run No. 1			Run No. 2		Run No. 3	
6.0	8.1	5.4	5.0	5.8	6.3	6.0
7.7	8.2	5.3	6.2	5.7	8.4	6.6
9.0	8.5	5.3	7.5	5.7	9.3	6.9
9.6	8.6	5.2	7.7	5.6	9.4	6.9
9.7	8.6	5.2	7.8	5.4	9.6	6.5
9.9	8.5	5.1	7.8	5.2	9.3	6.0
9.9	8.8	5.2	7.8	5.1	8.7	5.8
9.9	8.9	5.2	7.7	5.0	8.9	5.5
9.9	9.0	5.2	7.6	5.1	9.0	5.4
9.9	9.0	5.1	8.1	5.4	9.0	5.3
9.8	9.0	5.1	7.4	5.4	9.0	5.1
9.8	9.0	5.2	7.1	5.2	8.7	5.1
9.7	9.0	5.2	6.8	5.1	8.2	5.2
9.9	8.9	5.1	6.7	5.1	8.3	5.5
10.0	8.5	5.2	6.7		8.3	5.7
10.1	8.5	5.2	6.6		8.5	5.7
10.3	8.0	5.2	6.6		8.2	5.5
10.4	7.5	5.1	6.4		7.8	5.2
10.5	7.1	5.0	6.4		8.1	5.1
10.6	6.6	5.1	6.3		9.1	5.0
10.6	6.4	5.2	6.3		9.4	4.9
10.6	6.2	5.2	6.6		9.4	4.9
10.7	6.2		6.8		9.2	4.8
10.7	6.2		6.2		9.1	5.0
10.8	6.1		6.2		9.1	5.0
10.5	6.1		6.3		8.7	5.2
10.0	6.2		6.2		7.5	5.1
8.5	6.2		6.2		8.9	5.0
8.2	6.2		5.1		9.2	5.0
8.0	6.2		5.2		9.1	4.9
8.0	6.2		5.3		8.5	4.9
7.9	6.2		5.5		8.4	4.9
7.9	6.2		5.5		8.1	5.0
8.0	6.1		5.6		7.9	4.9
8.0	5.8		5.6		7.9	4.9
7.5	5.9		5.6		8.1	
7.5	5.8		5.6		8.5	
7.3	5.8		5.8		8.2	
7.2	6.0		6.2		8.0	
7.3	5.9		6.2		7.6	
7.4	5.9		6.2		7.0	
7.6	5.4		6.2		6.6	
7.7	5.4		6.0		6.2	
8.0	5.4				6.0	


°F
170
240
300
370
435
500
565
630
695
760
825
890
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Time in Minutes
4
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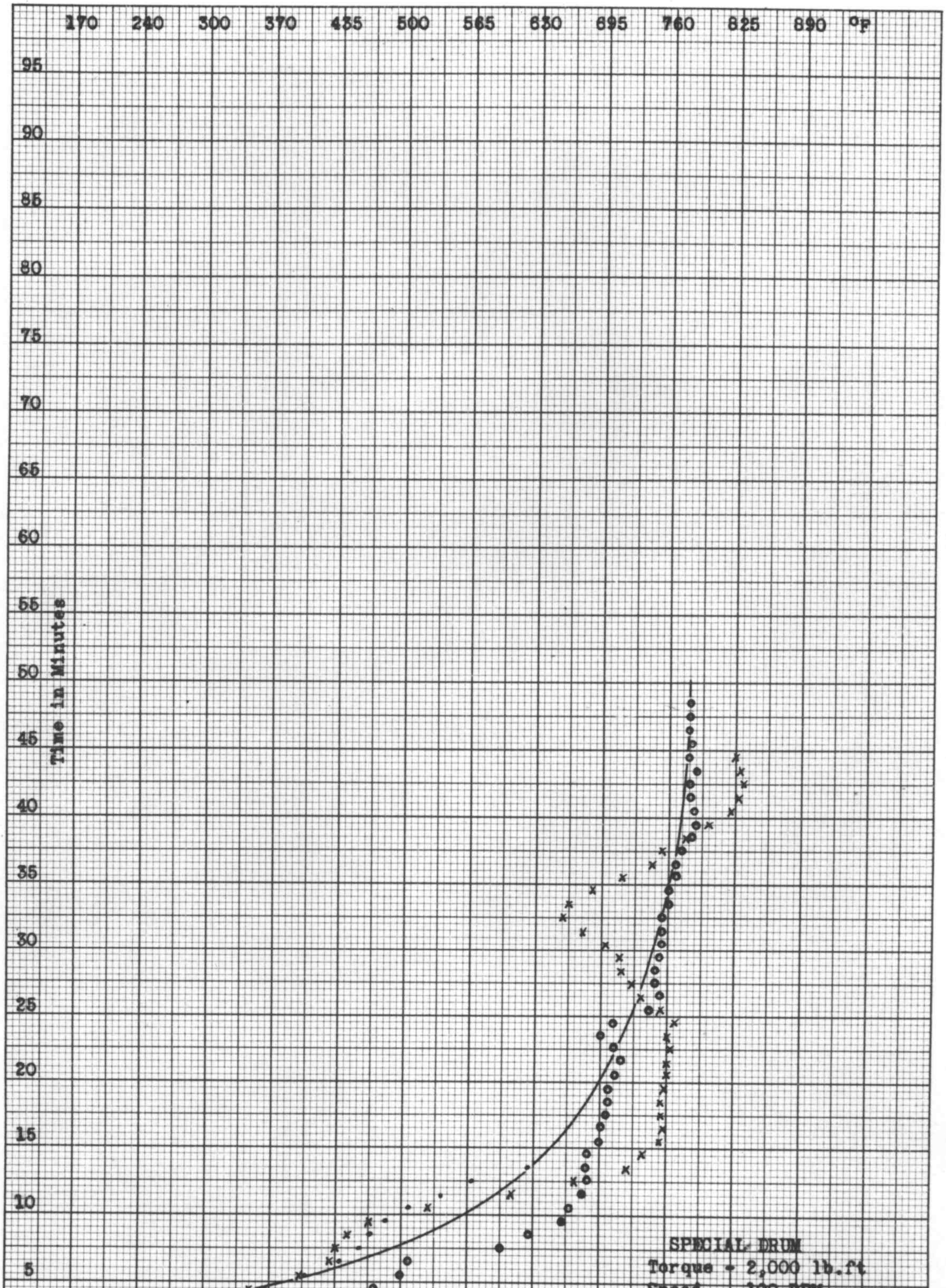
14
16
18
20
22
24
26 M.V.
SPECIAL DRUM
Torque - 2,000 lb.ft.
Speed - 100 RPM
Water - .28 gal/min.

TEMPERATURE RECORD FOR TEST ON SPECIAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 2,000 lb-ft — Water - 0.20 gal/min
Drum Speed - 100 rpm — Water Outlet - Two 1/16" jets

Run No. 1	Run No. 2		Run No. 3		
4.7	8.0	23.2	6.0	21.9	23.6
6.0	10.8	23.1	7.2	22.5	
7.2	12.0	22.8	9.4	22.6	
9.3	12.0	22.5	11.3	22.8	
10.8	10.4	22.2	14.2	22.6	
11.7	11.3	22.0	14.5	22.6	
12.0	11.9	21.9	15.0	22.7	
12.9	12.5	21.7	15.0	22.6	
13.1	12.8	21.6	15.2	22.6	
13.5	12.8	21.6	16.4	22.7	
13.7	13.0	21.5	18.0	22.7	
13.9	13.0	21.3	18.2	22.8	
14.0	13.3	21.1	18.8	22.7	
14.4	13.4	20.8	19.3	22.8	
14.5	14.0	20.4	19.8	22.9	
14.8	15.1	19.9	19.9	23.0	
15.2	15.8	19.8	20.1	23.1	
15.6	16.4	19.8	20.2	23.0	
16.2	18.3	20.0	20.5	23.0	
16.6	19.6	20.5	20.6	23.3	
17.1	20.2	20.7	20.7	23.2	
17.8	20.8	21.1	20.6	23.2	
18.8	21.8	21.6	20.6	23.2	
22.3	22.0	21.8	20.6	23.4	
	22.3	22.5	20.6	23.6	
	22.6	22.8	20.7	23.6	
	22.8	23.4	21.0	23.6	
	22.6	23.5	21.0	23.8	
	22.9	24.0	21.0	23.7	
	23.0	24.2	21.1	23.7	
	22.8	24.7	21.2	23.6	
	22.8	24.9	21.2	23.6	
	22.8	25.0	21.3	23.6	
	23.0	25.1	21.2	23.7	
	22.9	25.2	21.2	23.8	
	23.0	25.2	21.4	23.8	
	23.0	25.2	21.5	23.6	
	23.0	25.2	21.6	23.7	
	23.0	25.1	21.6	23.7	
	23.0	25.0	21.4	23.7	
	23.1		21.3	23.6	
	23.0		21.0	23.6	
	23.0		21.1	23.6	
	23.2		21.4	23.6	


170
240
300
370
435
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890
°F
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Time in Minutes
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26
M.V.
SPECIAL DRUM
Torque - 2,000 lb.ft
Speed - 100 RPM
Water - .20 gal/min

TEMPERATURE RECORD FOR TEST ON SPECIAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 1,000 lb-ft — Water - 0.41 gal/min
Drum Speed - 164 rpm — Water Outlet - Two 1/16" jets

Run No. 1		Run No. 2			Run No. 3	
3.9	6.3	3.1	5.9	5.9	2.8	7.0
4.9	6.3	6.2	6.0	6.2	4.3	6.8
5.7		7.5	5.9	6.1	5.7	6.8
6.3		7.8	6.0	6.2	6.5	6.7
6.6		7.5	6.0	6.2	6.9	6.7
6.5		7.5	6.0	6.2	7.0	6.7
6.5		7.5	6.1	6.2	6.9	6.7
6.3		7.4	6.0	6.2	6.8	6.7
6.3		7.3	5.9	6.3	6.8	6.7
6.4		7.3	5.9	6.2	6.7	6.6
7.2		7.2	5.9	6.2	6.7	6.5
6.5		7.2	5.9	6.1	6.7	6.4
6.6		7.2	5.9	6.1	6.6	6.4
6.6		7.0	5.9	6.0	6.6	6.3
6.5		7.0	5.9	5.9	6.6	6.3
6.5		7.0	5.9	5.9	6.5	6.3
6.4		7.0	5.9	5.9	6.5	6.3
6.3		6.9	5.9	5.9	6.5	6.2
6.3		6.9	5.9	5.9	6.5	6.1
6.2		6.8	5.8	5.8	6.4	6.0
6.2		6.8	5.8	5.8	6.4	5.9
6.2		6.8	5.8	5.8	6.4	5.9
6.2		6.6	5.8	5.8	6.4	5.7
6.2		6.6	5.8	5.8	6.3	5.7
6.2		6.5	5.8	5.8	6.0	5.8
6.3		6.4	5.8	5.8	5.9	5.7
6.3		6.4	5.7	5.8	5.8	5.7
6.4		6.3	5.8	5.8	5.8	5.7
6.3		6.3	5.8	5.8	5.8	5.7
6.3		6.3	5.8	5.8	5.8	5.5
6.3		6.4	5.8	5.8	5.8	5.4
6.3		6.3	5.9	5.8	5.7	5.5
6.3		6.3	5.8		5.7	5.4
6.3		6.2	5.8		5.7	5.4
6.3		6.0	5.8		5.7	5.4
6.3		6.1	5.8		5.7	5.3
6.3		6.1	5.8		5.6	5.3
6.3		6.3	5.7		5.7	5.3
6.3		6.1	5.7		5.7	5.3
6.3		6.1	5.7		5.6	5.3
6.2		6.0	5.7		5.5	5.2
6.3		5.9	5.7		5.4	5.2
6.2		5.9	5.7		5.6	5.2
6.3		5.9	5.7		7.2	5.2

Run No. 3 (Con't)

5.2
5.1
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5.0
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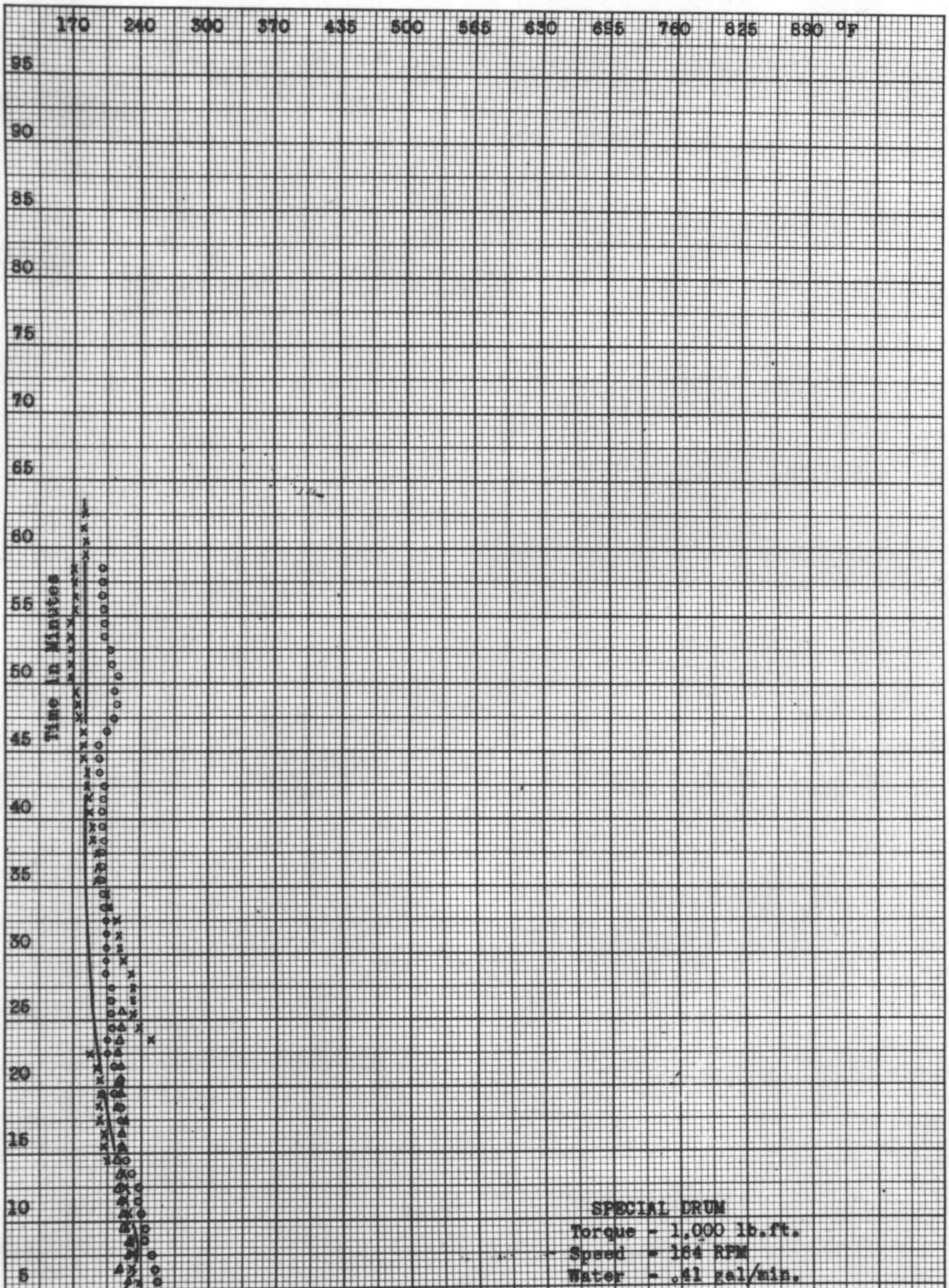
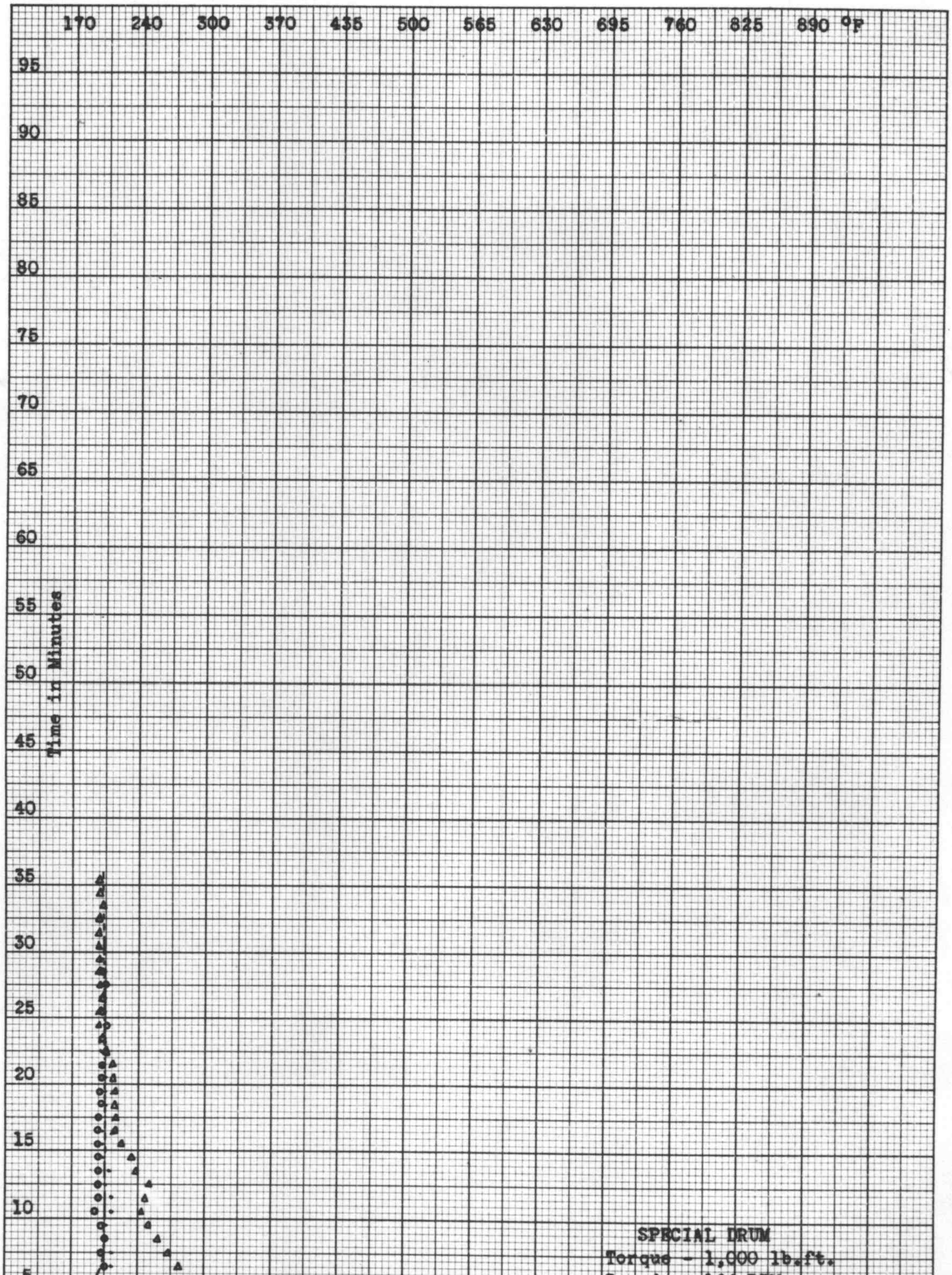


170 240 300 370 435 500 565 630 695 760 825 890 °F
95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
Time in Minutes
SPECIAL DRUM
Torque - 1,000 lb.ft.
Speed - 164 RPM
Water - .41 gal/min.
4 6 8 10 12 14 16 18 20 22 24 26 M.V.

TEMPERATURE RECORD FOR TEST ON SPECIAL DRUM

Readings in Millivolts 30 Second Intervals
Torque - 1,000 lb-ft Water - 0.28 gal/min
Drum Speed - 164 rpm Water Outlet - Two 1/16" jets

Run No. 1		Run No. 2		Run No. 3	
2.5	6.1	3.1	5.9	3.4	5.8
3.0	6.0	3.6	6.0	4.8	5.8
3.5	5.9	4.3	6.0	5.4	5.8
4.4	5.9	4.9	5.9	6.4	5.8
5.1	5.9	5.2	5.9	7.2	5.9
5.5	5.9	5.6	5.9	7.9	5.9
5.8	5.9	5.7	5.9	8.0	5.8
6.1	5.9	5.7	6.0	8.1	5.8
6.2	5.9	5.8	5.9	8.2	5.8
6.2	5.9	6.0	5.9	8.1	5.8
6.2	5.9	5.9	5.9	7.0	5.8
6.1		5.9		7.8	5.8
6.1		5.9		7.6	5.8
6.0		6.0		7.6	5.8
6.0		5.9		7.3	5.8
6.1		5.9		7.2	5.8
6.2		5.8		7.1	5.8
6.2		5.7		7.1	5.9
6.2		5.8		7.2	5.8
6.1		5.8		7.2	5.8
6.0		5.8		7.3	5.8
6.1		5.8		7.1	5.8
6.1		5.8		6.9	5.8
6.1		5.8		6.8	
5.9		5.8		6.8	
5.9		5.8		6.6	
5.9		5.8		6.5	
5.9		5.8		6.4	
5.9		5.8		6.3	
5.9		5.8		6.3	
6.0		5.8		6.3	
6.0		5.8		6.3	
6.0		5.8		6.3	
5.9		5.9		6.3	
6.0		5.8		6.3	
5.9		5.8		6.3	
5.9		5.8		6.2	
6.0		5.9		6.3	
5.9		5.9		6.2	
6.0		5.9		6.2	
6.0		5.9		6.0	
6.0		6.0		5.9	
6.0		6.0		5.9	
6.1		5.9		5.8	



170 240 300 370 435 500 565 630 695 760 825 890 °F
95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
Time in Minutes
SPECIAL DRUM
Torque - 1,000 lb.ft.
Speed - 164 RPM
Water - .28 gal/min.
4 6 8 10 12 14 16 18 20 22 24 26 M.V.

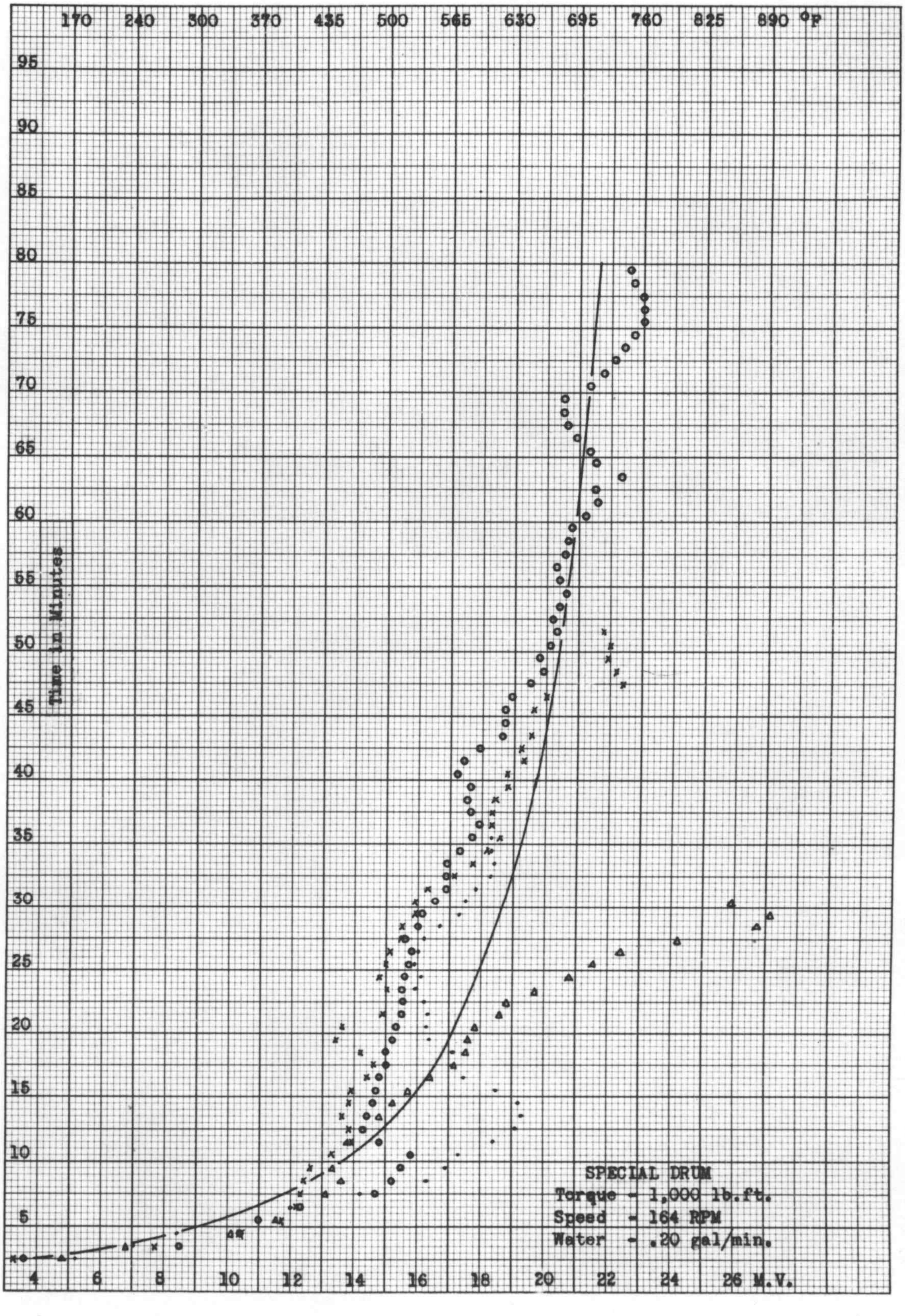
TEMPERATURE RECORD FOR TEST ON SPECIAL DRUM

Readings in Millivolts — 30 Second Intervals
Torque - 1,000 lb-ft — Water - 0.20 gal/min
Drum Speed - 164 rpm — Water Outlet - Two 1/16" jets

Run No. 1		Run No. 2			Run No. 3	
3.9	15.8	2.1	14.9	19.8	4.8	20.8
5.2	16.1	3.3	14.8	20.0	5.4	21.2
6.5	16.1	5.9	14.9	21.2	6.8	21.5
7.0	15.9	7.7	15.0	22.4	8.7	22.0
7.5	15.9	9.1	15.0	23.2	10.1	22.4
8.4	16.0	10.1	15.1	22.2	10.7	23.3
9.7	16.2	11.1	15.3	22.3	11.5	24.2
11.0	16.2	11.7	15.5	21.9	11.9	25.4
11.9	16.4	11.9	15.5	21.9	12.3	26.7
12.6	16.7	12.2	15.5	22.0	12.7	27.2
13.3	17.1	12.3	15.7	22.3	13.1	27.1
14.2	17.3	12.3	15.9	21.8	13.4	26.4
15.6	17.3	12.2	15.9	21.5	13.6	25.9
16.3	17.5	12.4	15.9		13.7	
16.7	17.6	12.4	16.1		13.3	
16.9	17.8	12.6	16.3		13.1	
17.1	18.0	12.9	16.7		13.3	
17.3	18.3	13.3	17.1		13.5	
17.7	18.3	13.7	17.5		13.8	
18.4	18.4	13.9	17.7		14.2	
18.7	18.3	13.9	17.9		14.3	
19.1	18.3	13.8	18.2		14.7	
19.2	18.4	13.8	18.6		14.8	
19.3	18.3	13.6	18.6		14.9	
19.2	18.3	13.5	18.7		15.2	
19.2	18.3	13.8	18.3		15.4	
18.9		13.9	18.5		15.7	
18.5		13.9	18.3		16.0	
18.2		14.2	18.1		16.4	
17.5		14.4	18.4		16.8	
17.3		14.5	19.2		17.1	
17.1		14.6	18.8		17.4	
16.8		14.6	19.4		17.5	
17.1		14.2	18.8		17.4	
16.7		13.8	19.1		17.6	
16.4		13.4	19.3		17.7	
16.3		13.3	19.3		17.8	
16.3		13.6	19.2		18.4	
16.3		14.4	19.5		18.6	
16.3		14.9	19.5		18.6	
16.2		15.2	19.0		18.8	
16.2		15.6	18.5		19.2	
16.1		15.4	19.1		19.7	
15.9		15.0	19.6		20.2	

Run No. 4

2.0	15.5	19.6	22.6
3.6	15.8	20.1	22.7
6.4	15.6	20.1	22.8
8.5	15.6	20.3	23.0
9.7	15.7	20.2	23.0
10.4	16.0	20.2	23.0
10.6	16.0	20.3	23.0
11.0	16.1	20.4	23.0
11.5	16.4	20.4	23.1
12.3	16.5	20.6	22.7
13.8	16.8	20.4	22.4
14.7	16.9	20.4	22.6
14.9	16.9	20.3	
15.2	16.9	20.3	
15.4	16.9	20.4	
15.5	16.9	20.6	
15.7	17.0	20.6	
15.8	17.3	20.7	
15.4	17.5	20.7	
14.8	17.7	20.8	
14.6	17.9	21.0	
14.3	17.9	21.2	
14.3	17.8	21.4	
14.4	17.6	21.6	
14.4	17.3	21.9	
14.6	17.5	21.5	
14.7	17.6	22.1	
14.7	17.6	22.3	
14.8	17.6	22.2	
14.8	17.2	21.5	
15.0	17.2	21.2	
15.0	17.4	21.3	
15.0	17.6	21.5	
15.0	17.9	20.9	
15.2	18.4	21.1	
15.2	18.6	20.6	
15.2	18.6	20.5	
15.3	18.7	20.5	
15.3	18.7	20.6	
15.5	18.7	20.5	
15.5	18.9	20.7	
15.5	18.9	21.3	
15.5	19.2	21.5	
15.5	19.5	21.7	
15.5	19.8	22.0	
15.6	19.9	22.1	
15.8	20.4	22.3	
15.7	19.8	22.4	



170
240
300
370
435
500
565
630
695
760
825
890
°F
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Time in Minutes
SPECIAL DRUM
Torque - 1,000 lb.ft.
Speed - 164 RPM
Water - .20 gal/min.
4
6
8
10
12
14
16
18
20
22
24
26
M.V.

TEMPERATURE RECORD FOR TEST ON CONVENTIONAL DRUM

Readings in Millivolts
Torque - 2,000 lb-ft 30 Second Intervals
Drum Speed - 100 rpm No Coolant Used

Run No. 1

4.5
5.7
6.4
7.3
8.4
9.3
11.0
12.5
14.2
16.2
18.0
19.8
21.1
22.4
23.5
24.4
25.2
25.4

(Brake released for adjustment)

25.3
26.4
27.3
27.9
28.5
29.3
30.1
30.6
31.2
31.6
32.1
32.4
32.8
32.9

This run was discontinued because outer rim of the drum became red hot.

TEMPERATURE RECORD FOR TEST ON SPECIAL DRUM

Readings in Millivolts	30 Second Intervals
Torque - 2,000 lb-ft	Coolant: Air, 120 psi
Drum Speed - 100 rpm	Run 1 - Two 1/16" jets
	Run 2 - One 1/8" pipe

Run No. 1	Run No. 2	
4.9	4.3	- 120 psi
6.6	5.8	
9.0	8.9	
11.3	11.9	
13.0	15.6	
14.6	17.2	- 70 psi
15.0	18.7	
15.6	20.2	
16.7	21.8	
18.1	23.7	- 50 psi
19.4	23.1	
21.5	23.1	
23.9	23.5	- 40 psi
26.8	23.7	
27.0	23.6	
26.4	23.8	- 30 psi
26.6	23.8	
27.8	24.3	
28.8	24.6	
	25.0	
	25.1	- 20 psi
	25.7	
	26.2	
	26.4	
	26.4	
	26.3	
	26.2	(Torque dropped to 1600 lb-ft)

CALIBRATION OF HYDRAULIC PRESSURE UNIT

Tinius Olsen 30,000 pound testing machine	Peacock Brothers steel tube gage
200	100
400	210
500	250
600	300
1000	500
1500	740
2000	1000
2500	1240
3000	1500
3500	1750
4000	2000
4500	2250
5000	2500
5500	2750
6000	3000
6500	3250
7000	3500
7500	3750
8000	4000
9000	4500